The Quaternary of Israel

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To my Mother,
in memory of my Father

Beaches are sometimes yearning for streams;
I saw a beach, deserted by a stream,
Left with broken heart of sand and gravel.

—N. JONATHAN

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Numbers in parentheses indicate the pages on which the authors' contributions begin.

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Preface

The Quaternary of Israel has, for a variety of reasons, attracted the attention of many scholars in recent decades. For one thing, Israel's unique geographic situation on the juxtaposition of three continents makes the region important for the study of problems of human evolution, distribution, and cultural development. The Levant also served as a crossroads for ancient African, European, and (most probably) Far Eastern cultures.

An almost complete sequence from the Early Acheulian onward is preserved within the Quaternary sediments of Israel and the Levant; this is cropping out richly thanks to active tectonics. The sediments vary in nature, origin, and environments of deposition: marine and coastal sediments, mainly influenced by the climatically controlled Mediterranean eustatic sea levels; aeolian sediments of the southern areas; lacustrine deposits of the Jordan Rift Valley, displaying an intricate interaction of climatic changes and tectonic activity; river and wadi terraces and gravel beds, formed under the influence of different climates and vegetations, with uplifting, downfaulting, and base-level changes; paleosols, cave and spring deposits—all bearing evidence of past environments, and many yielding artifacts and other signs of human activity. On the other hand, the different climates throughout the Quaternary resulted in places in weathering and in erosional processes, creating or demolishing suitable environments for plant communities, animal life, and human occupation. The richness of natural phenomena and evidence from the Quaternary of Israel resulted in a considerable body of data acquired in different fields, such as geology, geomorphology, climatology, animal paleontology, paleobotany, palynology, and archaeology.

Local type-sections and formations, established by various authors, have finally led to some confusion as to the use and meaning of stratigraphic, environmental, paleogeographic, and cultural terms. These are sorted out in the present work, using palynological and other new methods and concepts that have resulted in the establishment of a framework of climatically controlled, cross-correlated sequences. It is the aim of this book to represent the ensuing synthesis of the development of Israel during the Quaternary, with its implications in connection with paleoenvironments and human life. It is hoped that the present synthesis can be used as a basic background for defining geological, paleoclimatic, and evolutionary trends of plants, animals, and man that would enable us to deepen our knowledge of the interrelationships between these processes and the changing environments.

Israel occupies a crucial location for the study of the Quaternary period in general. This country has served as a bridge connecting Africa, Asia, and Europe since at least Miocene times. Israel is divided into three longitudinal belts: the coastal plain, the mountainous backbone, and the Jordan–Arava Rift Valley, running along the country from north to south. Different erosional and depositional processes prevail in each of these belts, responding in various ways to common causes, such as climate and sea levels. A steep environmental gradient along Israel—the north covered by Mediterranean forests, whereas the south is a bare desert—results from the location of the area in a border zone influenced by the Euro-Siberian, Mediterranean, Irano-Turanian, Saharan, and Sudanese environments. The combination of the environmental gradient and the longitudinal belts results in a great number of biotopes in which every minor change is recorded in more than a single way.

This pattern puts Israel in a very sensitive spot, and detailed paleoclimatic and sea-level records could be drawn for the entire Quaternary, also facilitated by the considerable number of boreholes, mainly drilled in the search for groundwater, and the availability of numerous outcrops due to the rather continuous tectonic activity and to the poor vegetation and soil cover. An important element in the understanding of Quaternary stratigraphy is the abundance of volcanic rocks, interbedded with sediments in the Jordan Valley. Postassium-argon datings of the basalts have helped to establish the absolute chronology.

The interconnection of climatically controlled sedimentary and erosive processes, eustatic sea-level changes, and radiogenic dating could be used to advantage in tying in the Quaternary sequence of Israel to Europe on the one hand, based on eustasy and paleoclimates, and to Africa on the other, based on the radiogenic datings. In fact, Israel is the key area for the connection of the African and European Quaternary sequences, which bear prime importance for the problems of human evolution, migration, and settlement.

This book is divided into three parts: The first describes the present-day environments, the pre-Quaternary geology, and the structural evolution of the region; the second summarizes the data; and the third brings discussions and interpretations concerning the paleogeographic, paleoclimatic, and environmental development of Israel in connection with human settlement. Chapters dealing with fauna and with anthropology were contributed by colleagues who specialize in these fields. Sometimes, when we could not agree on some issue, the questions were left open. This book does not aim to present a final solution for the problems of the Quaternary of Israel. On the contrary, it should be used as a background and a basis for further research and study.

Acknowledgments

The background of my interest in the Quaternary period, in its geology, fauna, flora, and human settlements, can be traced to several of my teachers, whose great devotion to the subject was quite contagious. L. Picard, M. A. Avnimelech, G. Haas, J. Lorch, and M. Stekelis of the Hebrew University, Jerusalem, have greatly influenced my direction, and I am indeed grateful for their guidance. My interest and practice in palynology came through T. van der Hammen, now at the University of Amsterdam, and his colleagues. Fruitful discussions with Mrs. M. Rossignol-Strick, who set the basis for polynological study in Israel, greatly helped me. However, it was not until 1975 that the practical conception of this book occurred, during a field trip to the caves of Lesotho with C. Garth Sampson of Southern Methodist University, Dallas. Garth took great pains to convince me of the need for a work like the present one, and, I daresay, without him this book would never have been written.

The tedious task of helping to collect all the published materials was done mainly with the help of Mrs. Varda Arad, Librarian of the Geological Survey of Israel. Many unpublished details were contributed by colleagues from the Geological Survey of Israel—A. Sneh, A. Ecker, E. Fleischer, U. Kafri, G. Gvirtzman, G. Almagor, S. Moshkovitz, and A. Ehrlich, to mention but a few. Dr. B. Derin of the Israel Institute for Petroleum, Dr. Z. Ben-Avraham of the Weizmann Institute for Science, and many of my students at the Institutes of Archaeology of Tel-Aviv University and of the Hebrew University of Jerusalem also contributed information.

This book would not be complete without the contributions of my colleagues, J. C. Vogel, M. Weinstein, E. Tchernov, Y. Rak, A. Ronen, O. Bar-Yosef, E. Mintz (who also helped to edit the entire chapter on anthropology), J. L. Phillips, and R. Gophna.

Some drawings and tables of already published material are reproduced in this book with the kind permission of the *Israel Journal of Earth Sciences*, the *Bulletin of the Geological Survey of Israel*, and *Pollen et Spores*.

All the line art was devotedly and skillfully done by Mrs. Ora Paran, who did not spare any effort to achieve the best possible results while working at the Drawing Department, Institute of Archaeology, Tel-Aviv University. At the same place, and with no less skill, Mrs. Rodica Penchas drew the artifacts. The scanning electron microphotographs were done at the Division of Paleontology, Geological Survey of Israel, by Mr. M. Dvorachek. The drafts of this book were typed by Miss Suzan Hamer (through Translators' Pool, Jerusalem), and the final manuscript by Mrs. Patty Sultan and Miss Hamer.

I would also like to thank the editors of *Notes et Memoirs sur le Moyen Orient* for their kind permission to use some of the figures from Rossignol's paper of 1969.

To my friends, who missed me at the 1976-1977 parties (and those who rather enjoyed my absence), those colleagues whom I forgot to mention, my wife Michal and my daughters Abigail and Pu'ah despite whose help this book was completed, and most of all my mother, who followed every step with interest and cooked such good food—I extend my gratitude.

1

Introduction

QUATERNARY STUDIES IN ISRAEL

Geological researches in the Near East began only during the second half of the nineteenth century. They were mainly conducted by various expeditions that visited the region for a short while and later published their impressions as thick volumes of "memoirs." These expeditions—German, British, American, and French—concentrated on geography, climate, ethnology, and "hard rock" geology and paid little attention to the Quaternary sediments, which were mostly referred to as "alluvial cover." An interesting exception was the French expedition (1869) headed by L. F. J. C. de Saulcy, with geologist Louis Lartet, who observed the Quaternary lacustrine deposits of the Lisan Formation around the Dead Sea and regarded them as sediments of an ancient Pleistocene lake that had existed in the area in times of greater precipitation (Lartet 1869). Toward the end of the nineteenth century, the geological study of the Near East became more and more progressive, mainly due to contributions of E. Hull (1886) and M. Blanckenhorn (1896). Both noted geological phenomena related to the Quaternary, and the latter continued his systematic geological studies of the area during a period of almost 50 years (Blanckenhorn 1898, 1905, 1910, 1912, 1921–1922, 1929). Another group of scientists who began surveying the area toward the end of the nineteenth century were anthropologists. Surveying was in the same style, with expeditions that came only for a short while, collected exclusively on the surface, and rarely excavated a site. The contribution of these expeditions, both those by geologists and those by anthropologists, to our knowledge of the Quaternary of the area is indeed negligible.

At the beginning of the twentieth century, and more toward the 1930s, interest grew concerning the prehistory of Israel. Systematic survey and excavation of sites began in the 1920s under the auspices of the British School of Archaeology in Jerusalem, which was headed by F. Turville-Petre (1923, 1927, 1932), who excavated the E-Zutiye Cave in Wadi Amud and found, besides a rich assemblage of artifacts, a considerable part of a human skull close to the Neanderthal type. During the later 1930s many more sites were excavated by foreign expeditions that came for relatively long periods. Notable among these are the expeditions of the American School of Prehistoric Research, headed by D. A. E. Garrod (e.g., 1928, 1937, 1942, 1962), who cooperated with the British, and the French expedition of the Institut de Paléontologie Humaine, Paris, headed by R. Neuville (e.g., 1929, 1934, 1951). Most of these expeditions included only anthropologists; occasionally, there were vertebrate paleontologists as well. Geologists were regarded as an unnecessary luxury, and, save for a site or two, no excavation report contained any information about geology, mineralogy, etc.

During this period interest in the Quaternary geology of Israel arose due to the work and dedication of L. Picard. He studied most of the sedimentary and volcanic formations attributed to the Quaternary age and placed the cornerstone for the study of this period, which had been generally neglected by geologists until then. Picard summarized his Quaternary studies in the last chapter of *Structure and Evolution of Palestine,* which appeared in 1943. Other studies by Picard (1928, 1931, 1932, 1937, 1952, 1963, 1965, etc.), Avnimelech (1937, 1950, 1952, 1962, etc.), Shalem (1924, 1937, 1950, etc.), Petrbok (1925, 1926, 1937, etc.), Loewengart (1928), Blake (1928, 1936), and others have outlined the framework for the understanding of the Quaternary development of the country.

Since 1948 almost all branches of scientific research have greatly developed, with some implications for Quaternary studies. These have developed in a number of directions. Anthropological research was mainly carried out through the institutes of archaeology of the Hebrew University of Jerusalem and later of Tel Aviv University by the late Professor M. Stekelis and his successors O. Bar Yosef, A. Ronen, and others. The Department of Antiquities also inclined somewhat toward prehistoric studies, and several foreign expeditions continue to excavate sites in Israel. Until the 1960s prehistoric and anthropologic research was carried out solely by archaeologists, and only rarely did scientists of other disciplines participate in the excavations. Vertebrate and human bones were mostly sent to their respective specialists, whereas a 1- or 2-day visit by a geologist seemed to satisfy everybody. This has changed in the last few years, and most expeditions, foreign and local, tend to include a multidisciplinary staff including geologists, palynologists, paleontologists, botanists, pedologists, etc. The institutes of archaeology at Tel Aviv and at Jerusalem now have geologists and palynologists on their permanent staffs.

Quaternary research has also advanced in the geological and pedological sciences; at the Hebrew University of Jerusalem, mainly at the Groundwater Research Center and at the Department of Pedology; at the Groundwater and the Oceanographic Divisions of the Geological Survey of Israel; and with smaller scale studies by other scientists in various institutions. Palynological studies of the Quaternary sequence were begun in Israel in the early 1960s by Mrs. M. Rossignol-Strick and were later continued by the present author and his students. Vertebrate paleontology is studied at the Department of Zoology, the Hebrew University of Jerusalem, by G. Haas and E. Tchernov and by their students. The main problem that arose throughout studies in these various disciplines was the lack of contact between investigators, which resulted from the great variety of the topics and the high level of necessary specialization. This problem was partly solved in 1970, when the Israel Quaternary Association (Horowitz 1970) was established; it now has almost 50 members.

CONCEPTS AND AIMS OF THE PRESENT SYNTHESIS

Natural processes throughout the Quaternary have been influenced by several main factors: tectonic and volcanic activity, which considerably changed the pattern of erosion base levels and their locations; climatic changes, which influenced plant and animal life, human settlement patterns, and erosional and depositional processes; and eustatic sea level changes, which superimposed their influence on all other processes.

During the Preglacial Pleistocene (see the following discussion for the use of terms) the Jordan–Arava Rift Valley did not form an internal drainage basin, and geological processes were influenced mainly by changing Mediterranean Sea levels and by extensive volcanic activity to the northeast of the country. A very restricted area around the Bay of Elat was controlled by the Red Sea levels. In general, the influence of sea-level changes on continental, erosional, and depositional processes can be summarized as follows: A climax of a regression resulted in erosional processes on the continent and in the formation of gullies and, sometimes, of rather deep canyons. A constant rise of the sea level during a transgression caused continental sedimentation, thus filling the preexisting relief. The first sediments deposited in this system were base conglomerates, and the deposition commenced at the river mouths. Further rising of the sea level resulted in an inland propagation of the conglomerates, whereas at the outlet areas the clastic sediments became finer and finer as the level rose. The maximum of transgression resulted in stagnation of the drainage system and deposition of chemical sediments of a brackish nature close to the sea, becoming freshwater-influenced toward the hinterland. If the maximum of transgression held for a long enough period, a peneplain would begin to be formed at the hinterland, extending more and more as the period grew longer. A consequent regression then resulted in an inverted process of deposition: Fine clastics, becoming coarser with the retreat of the sea, covered the chemical sediments until a veneer of top conglomerates covered the area. Near the sea, however, erosion began, propagating toward the hinterland, cutting and forming a new relief that incised into sediments of the preexisting system. It is clear, then, that most sedimentary units in this system are diachronous.

At the onset of the Glacial Pleistocene, when the great Syrian–African Rift Valley had been reactivated and formed the Jordan–Arava sector, three erosion base levels influenced the country: the Mediterranean, the internal Rift Valley, and the Bay of Elat. The Jordan Valley was occupied by a succession of lakes, their extension depending on the mutual relations of climate and of tectonic activity. The Mediterranean coastal plain was mainly influenced by the oscillating sea, the most common sediments during the ingressions being dune sands, whereas during regression erosional and pedogenic processes prevailed and marshes were formed.

The influence of changing climate on natural processes became crucial during the Glacial Pleistocene in Israel. It can be summarized as follows. During periods of interpluvial climate (corresponding more or less to present conditions), sea level was higher and dunes accumulated on the relatively narrow coastal plain. In the Jordan Valley, lakes covered only very restricted areas, sometimes degrading to marshes and peat bogs. Vegetation in the mountainous regions was poor and was restricted to the north of the country, and erosion through torrential floods created steep walled creeks and canyons. The Negev was generally wind-deflated. During periods of pluvial climate, in which the country resembled present-day northern Lebanon, the sea level was considerably lower than it is today. Dune ridges formed farther west; they are presently buried under the sea. The coastal plain was subject to erosional and pedogenic processes and was covered by rich vegetation and by many marshes. The Jordan Valley lakes extended considerably, leaving lacustrine sediments as evidence. Loess was deposited in the Negev, and the mountains were covered by rich vegetation that prevented torrential erosion and helped to create a rather gentle topography.

The correlations of Quaternary formations presented in this book are based on recognition of sea level and of climatically controlled processes of erosion and deposition. To help determine paleoclimates, palynological methods were extensively used in conjunction with geomorphological, paleontological, and other data. Sedimentary and erosive phenomena have been interpreted in their paleocimatic context, and sequences of such events in the various environments of the country could be compared and cross-correlated. Based on these correlations, a paleoenvironmental picture was obtained for the development of the country throughout the Quaternary. The dependence of human settlement, migration, and evolution on these factors is discussed.

TERMINOLOGY

The term *Quaternary* was first suggested in 1829 by a French geologist, Jules Desnoyers, to designate young sedimentary formations. It traditionally includes the Pleistocene Series, a name proposed by C. Lyell in 1839 for littoral rocks containing 70% or more of existing mollusk species, and the Holocene or Recent Series, proposed by Lyell for the postglacial deposits. The term *Pleistocene* was consequently used in Europe for the Great Ice Age and the term *Holocene* for the postglacial. Gignoux (1955) defined the Pleistocene by two developments: the appearance of man and of relics of his industry and the development of great glaciers covering large parts of Europe and North America.

Discoveries of earlier hominids in Africa and of earlier glacial periods in Europe, the Biber and the Donau, suggested lowering the limit of the Pleistocene to include the upper parts of what was previously assigned to the Pliocene. This had already been suggested by Haug in 1911 but was formally confirmed only in 1961, in the VI INQUA Congress at Warsaw. Later, R. G. West (1968) suggested the division of the Quaternary into the Preglacial Pleistocene (the time preceding the four major glacial phases in the Alps) and the Glacial Pleistocene that followed. West also suggested dropping the use of the terms *Holocene* and *Postglacial,* since the Holocene practically represents another interglacial, with no indication for termination of the Ice Age.

In view of these and of many other different opinions, it seems that a more natural definition should be sought for the Quaternary, one that could be based on a worldwide correlatable phenomenon. Definitions that have been accepted for the boundaries of the Pliocene (Colalongo *et al.* 1972) at the Mediterranean Basin seem to serve well for the lower boundary of the Quaternary. The Pliocene is regarded as the time of the Tabianian and Piacenzian Transgressions and is terminated at the maximum regressive phase separating the Piacenzian from the succeeding Calabrian Transgression. Analysis of the Mediterranean Sea level changes from the beginning of the Calabrian until the present (Figure 1.1) shows that the Quaternary is a natural geologic division; namely, a division based on a single marine transgressive cycle, with superimposed eustatic oscillations. The radiometric age suggested for the beginning of the Calabrian is in the range of 2.6–2.9 MY (million years), based on K–Ar analysis of basalts from Israel that overlie Piacenzian sediments (Siedner and Horowitz 1974). This age correlates well with the first phase of severe cooling of the oceans (Beard 1969) and with the disappearance horizon of *Globoquadrina altispira* in the Gulf of Mexico.

The Mediterranean marine Quaternary begins, according to many authors, with the first appearances of cold water fauna, among which *Hyalinea balthica* is the most common constituent. The radiometric age assigned for this horizon is mostly around 1.8 MY. The reason for this discrepancy of a million years lies in the method of dating. The cover basalt of Preglacial Pleistocene age was dated (Siedner and Horowitz 1974) directly from outcrops, yielding the 2.6–2.9 MY range for the beginning of that period. The Mediterranean deep sea cores have been indirectly dated on the basis of paleomagnetic reversals, and the first appearance of *Hyalinea* lies at a transition from a normal to a reversed event. The normal event is generally recognized as the Olduvai, and the overlying reversed, as the second sector of Matuyama. The Olduvai normal phase is a very short one, and it seems quite possible that it may not always be readily recognized. It is suggested that the normal event, at the end of which the Quaternary begins, is instead the Gauss, which is followed by the Matuyama (Reversed Epoch) at about 2.4 MY. This suggestion, if accepted, would place the beginning of the Mediterranean Quaternary somewhat below this transition, thereby accounting for the million year discrepancy. The term *Quaternary* is therefore used in the present context as defined by the last global marine transgression, accompanied by pronounced cold periods and eustatic sea level changes.

According to the radiometric and paleomagnetic data, the Quaternary began somewhat before the Gauss-Matuyama Transition, and the concept of a Long Pleistocene (Cooke 1973) record is here accepted. The term, as accepted, also correlates with the definition given for the Quaternary in the Netherlands by Zagwijn (1974), who suggests beginning this period with the onset of the Pre-Tiglian Glaciation. Six major glacial phases are known from the Netherlands for the Quaternary; these most probably correspond to the six major Alpine phases. The first two, the Pre-Tiglian and the Eburonian (apparently corresponding to the Biber and the Donau), are somewhat less pronounced than are the following four. This may be a natural phenomenon, be due to the masking of previous glacial activity by succeeding glacials, or be a combination of both. This was, however, the reason to divide the Quaternary (West 1968) into the Preglacial and the Glacial Pleistocene, a nomenclature that has only a chronostratigraphic, not a paleoclimatic, implica-

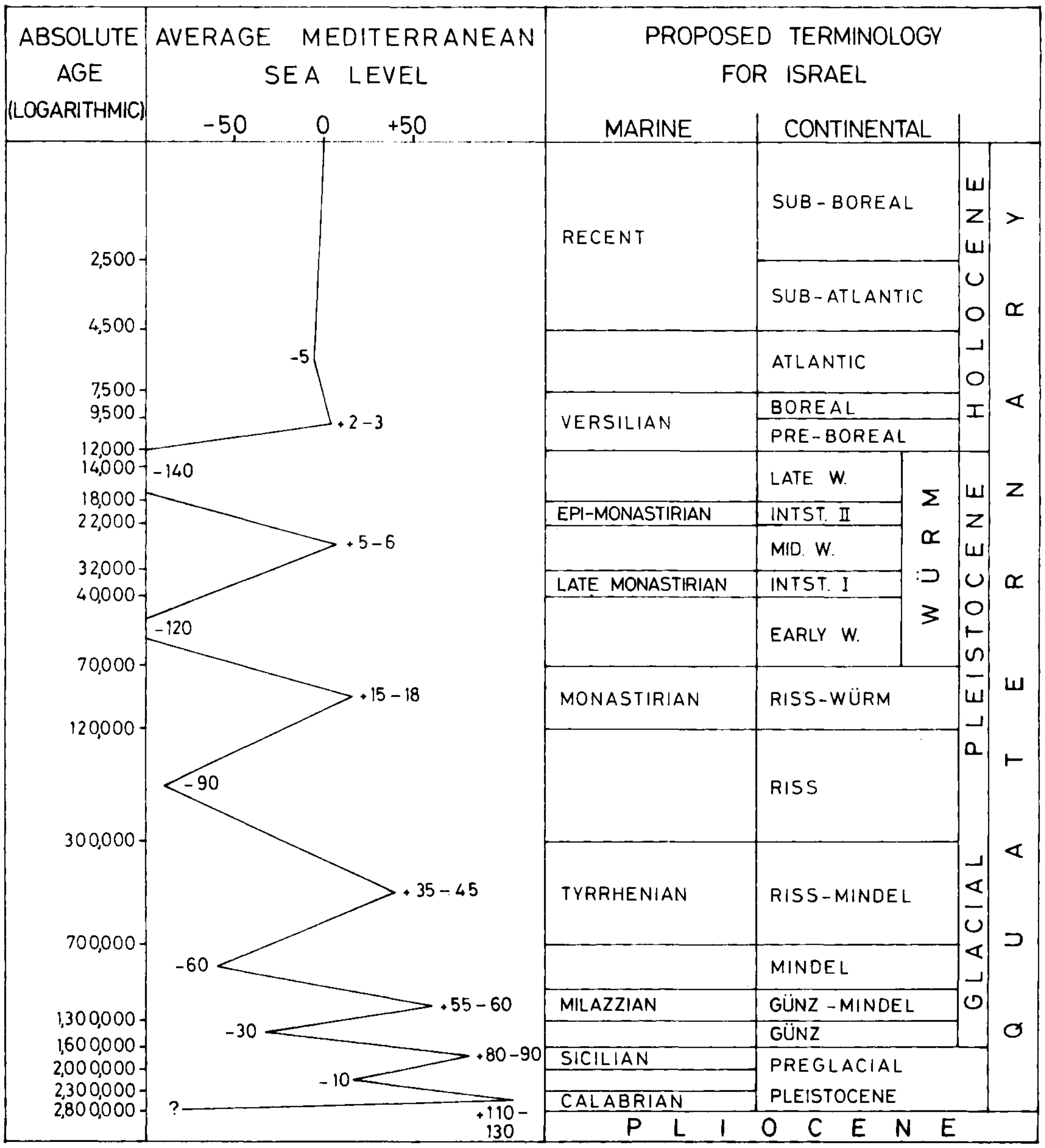


FIGURE 1.1. *Absolute chronology, eustatic sea levels, and proposed terminology for the Quaternary in Israel.*

tion. As a matter of convenience, I shall keep the use of the nomenclature suggested by West, instead of inventing and adding a new name to the overcrowded Quaternary terminology. The radiometric age suggested for the transition from the Preglacial to the Glacial Pleistocene is about 1.6 MY (Siedner and Horowitz 1974).

The Preglacial Pleistocene sediments and volcanics are overlain in various parts of Israel by a sequence representing four major pluvial phases. The correlation of pluvial phases with the Alpine and European glacials had been previously established (Horowitz 1971, 1973, 1975, 1976), and it was therefore suggested to retain in use the Alpine terminology, replacing glacial with pluvial in order to relate the phases better to the local climate in these periods. Correlation had also been established between the climatic phases and the Mediterranean Sea level changes. Pluvial climates are accompanied by regressions, whereas interpluvials are characterized by conspicuous sea level rises. The eustatic ingressions in the Near East have been compared with the classical sequence described by Dépèret (1918) from the French–Italian Rivieta (Horowitz 1974) and seem to be parallel in terms of sequence. It was therefore also suggested to retain the names proposed by Dépèret for the Mediterranean Quaternary eustatic ingressions (Figure 1.2).

The use of Dépèret's sequence to define stratigraphic

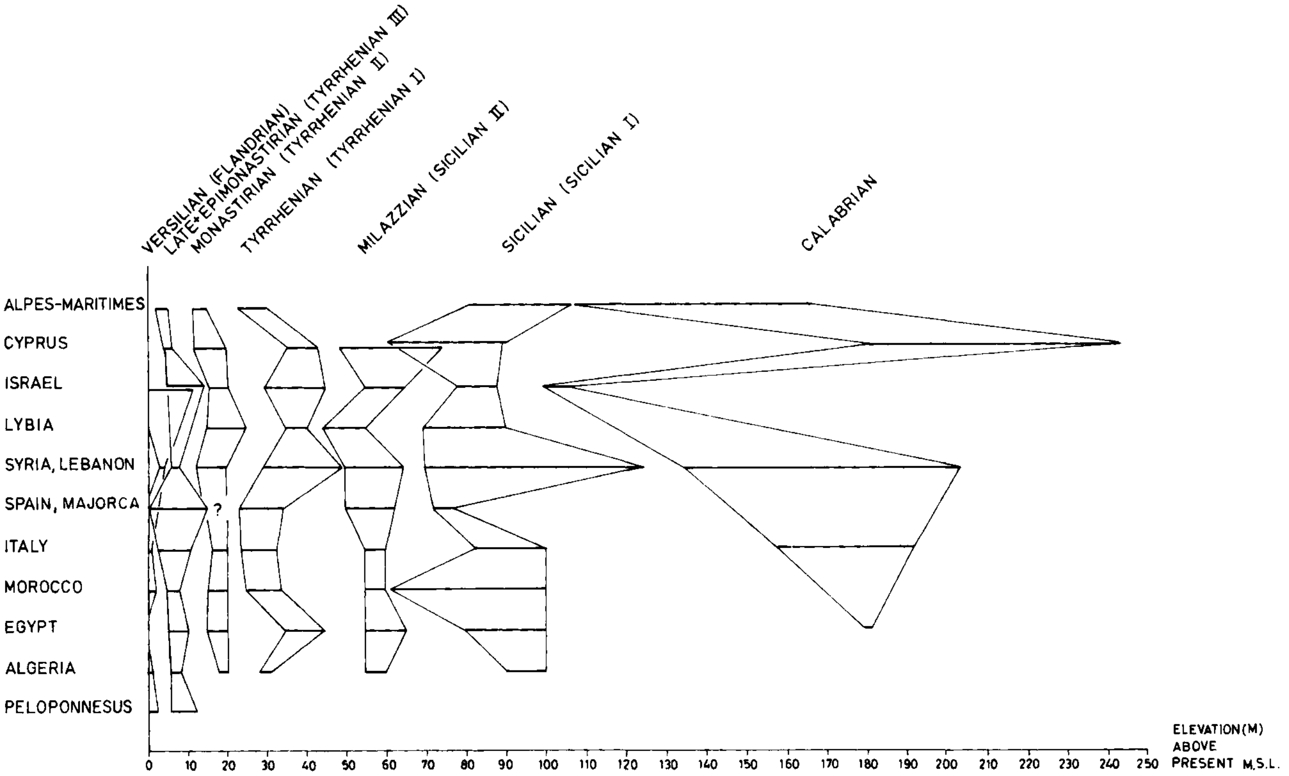


FIGURE 1.2. *Variability of elevations of Quaternary sea levels around the Mediterranean. (Data compiled by M. Lamdan, Haifa Museum of Antiquities.)*

units within the coastal Quaternary, especially around the Mediterranean, is now widely accepted. However, several complications in method have developed since the original proposal. Two of these are most important and, unfortunately, are in rather common use. First, when an incomplete sequence crops out somewhere and it is impossible to relate it to the type-section in terms of a succession of events, it is quite customary to try to determine its correlation only on an altimetric basis. We are now aware of tectonic movements that offset blocks around the Mediterranean, sometimes in the order of hundreds of meters; so, altimetry alone is of no use. Another problem is the paleontologic characteristics of various marine ingressions in the Mediterranean area. The Calabrian faunal assemblage is quite well-defined (see Moshkovitz 1968) and poses no problems, provided the analyzed spectrum is rich enough. The Sicilian assemblage differs somewhat from the Calabrian, but the Milazzian is very similar to the Sicilian, which resulted in the invention of the term *Neo-Sicilian* (Nir 1970; Valentin 1952). As long as the two ingressions are represented in a sequence, there seems to be no problem; but, if only one of them appears, the term *Sicilian,* if based only on the "typical" cold water fauna, might be misleading.

A similar problem appears with the Tyrrhenian and with later ingressions. During the long Mindel–Riss Interglacial, warm-water fauna penetrated the Mediterranean, and their first appearance characterizes the "classic" Tyrrhenian. However, these elements remained in the Mediterranean, especially in its eastern part during the succeeding ingressions. Hence the use of terms such as *Paleo, Neo, Early, Middle,* and *Late Tyrrhenian,* T1, T2, T3, etc. The altimetric nomenclature is, therefore, used here only in its original sense. Use of the terms *Early, Middle,* and *Late Pleistocene* (or *Lower, Middle,* and *Upper*) has also led to great confusion. Agreement had never been achieved concerning two main issues: how to divide the Pleistocene into these three substages and whether the Preglacial Pleistocene is or is not included in this subdivision. It seems that almost every author developed a personal preference as to the use of these terms, and these are generally avoided in the present work. Discussions of the stratigraphic meaning of the local use of these terms by various authors is given in Chapter 5.

The local stratigraphic sequences, both those of the coastal plain and those of the Jordan Valley, have acquired various nomenclatures due to the growing number of investigators. As far as possible, I have tried not to apply new stratigraphic names or terms, and, in the case of synonyms, I have tried to retain the one that, to the best of my knowledge, has priority. Much more detailed discussion of the local nomenclature will be given in Chapter 5.

Geographical and location names are given here in two forms: Names that are known and are common are given in their English form (Jerusalem, not Yerushalayim, and Dead Sea, not Yam HaMelah, etc.); names that are known only in Hebrew or Arabic and those for which English use is rather rare are given in their original phonetic transcript, according to the latest English edition of the official map of Israel (1:250,000), printed by the Survey of Israel, 1976. Two or three of the more common names need explanation, and the rest, if of any interest or importance, will be explained in the text. *Nahal* means "stream" and stands for both perennial and intermittent. The latter is sometimes referred to as *wadi*, an Arabic term that defines mostly (but not exclusively) the intermittent type. The term *har* (or *jebel*, in Arabic) means "mountain." Whenever possible, the English form will be used. The same holds for *emeq*, which means "valley."

2

Present-Day Configuration

MORPHOLOGY

The Levant is longitudinally divided into several strips, generally running in a north–south direction, depending on the major structural units. These are, from the west eastward: the continental shelf, the coastal plain, the western hilly or mountainous region, the rift valley, and the eastern plateau and eastern lowlands that grade eastward into the Euphrates Valley and the Persian Gulf (Figure 2.1). Israel contains parts of only four of these regions: the continental shelf, the coastal plain, the mountainous backbone, and the Jordan–Arava Rift Valley. The structure and tectonic development of these regions is discussed in Chapter 3, and the pre-Quaternary geology in Chapter 4. The subdivision and extent of each of the morphologic units is shown in Figure 2.2, and a satellite photograph, Figure 2.3, presents their overall appearance.

The continental shelf is wider (up to 20 km) to the south, opposite Gaza; it tapers to some 10 km in width in the north, opposite Rosh HaNiqra. Comparing this shelf to widths of continental shelves around the world, the Israeli shelf is very narrow, about a third of the average. The width of the continental shelf decreases still more northward and at some places opposite the Lebanese coast does not exceed 3–5 km, with a shelf break at about 90 m water depth (Nir 1973). The Israeli shelf has been subdivided by Nir into three morphologic units: the near-

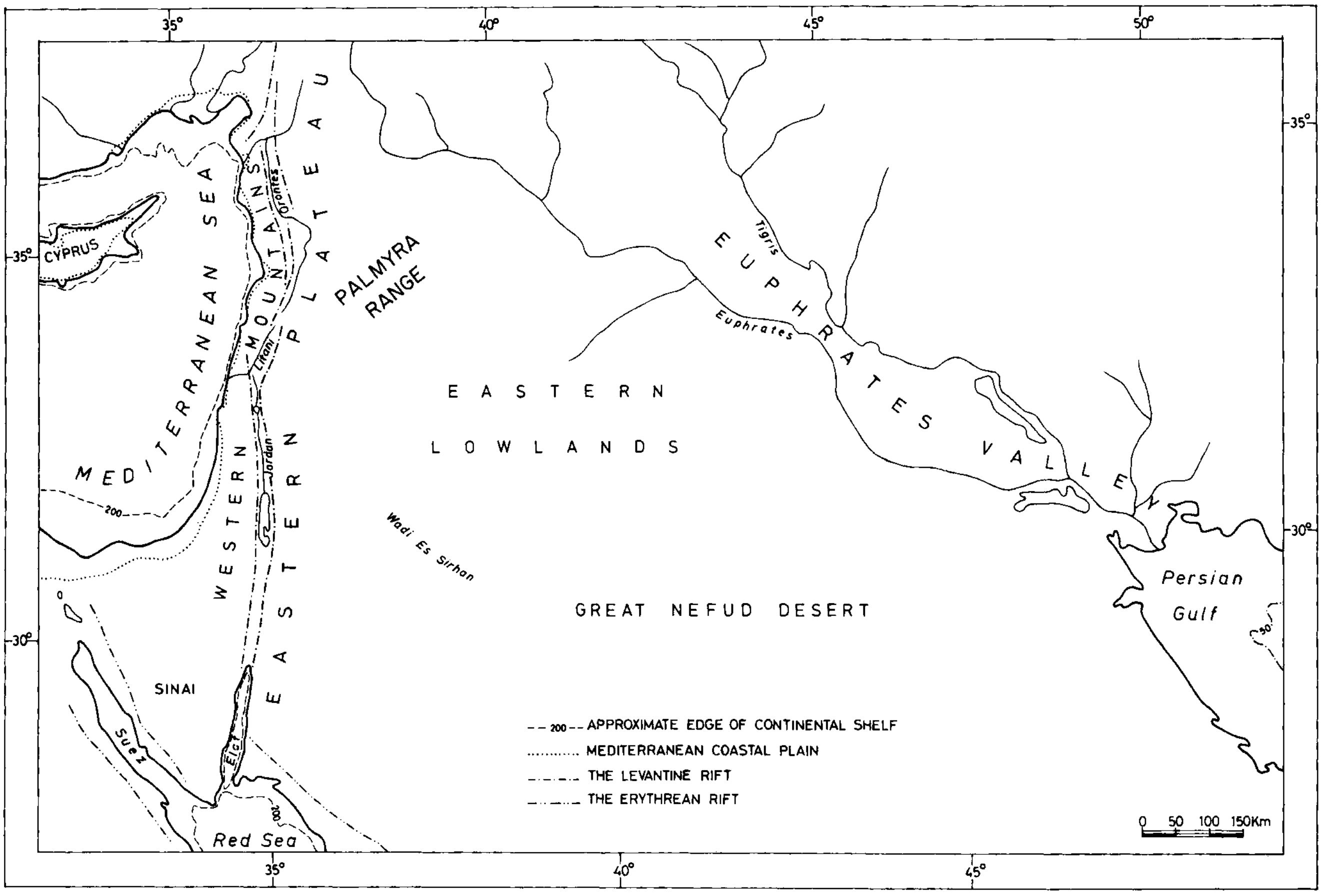


FIGURE 2.1. *The main morphologic units of the Middle East.*

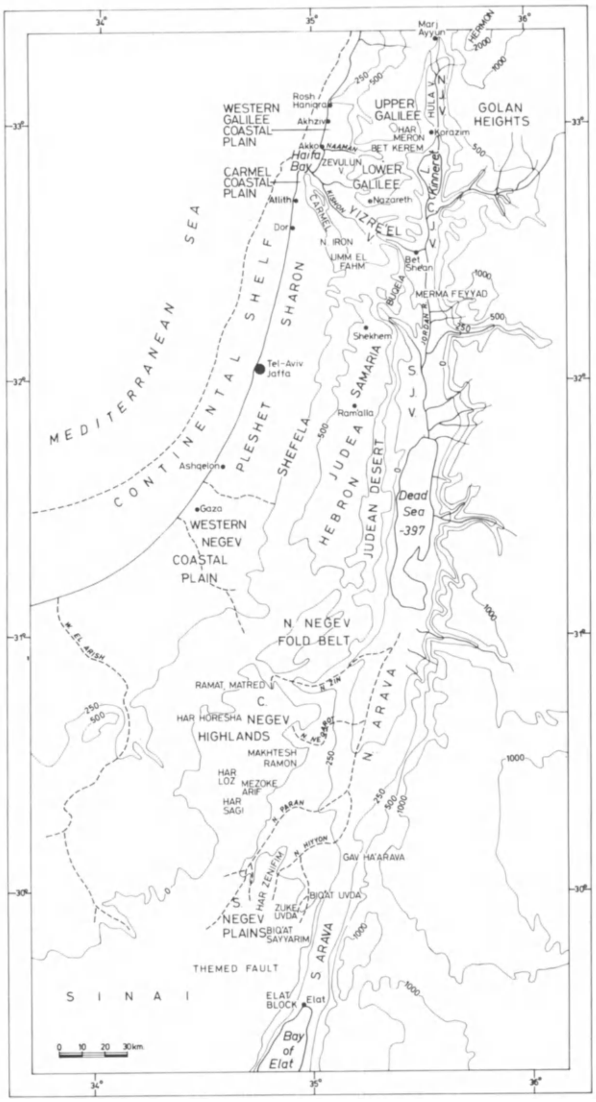


FIGURE 2.2. *The morphologic units of Israel.*

shore belt, extending from the shoreline down to 25–30 m, with a relatively steep slope (30′–1°); the middle belt, a wide, flat area, extending down to about 80 m depth, gently dipping (10–20′); the shelf edge belt, where the downslope commences toward the deep sea, with slopes of about 2° to the south, grading up to 8°30′ to the north. The Israeli shelf is generally flat, bearing occasional shallow landslide scars, but is cut at the north by two submarine canyons, off Haifa Bay and off Akhziv. The continental slope extends from water depths of 90–100 m down to the continental rise, with dips similar to those of the shelf edge belt.

The Israeli Mediterranean shoreline bends at the south of the country from its east-west direction (which swings down the northern coast of Africa) in a gentle arch curving more and more to the north. The shoreline is straight along almost the entire length of Israel, becoming much richer in bays as one approaches Lebanon. Bays are rare in the Israeli part, and the only conspicuous one is Haifa Bay, an extension of the Zevulun Rift Valley. Only a very restricted number of very small, shallow bays, such as those at Jaffa, Dor, and Atlit, break the straight shoreline and can be used as small ports. The coastal plain of Israel is a natural continuation of the coastal plain of Sinai. It is very wide—up to 50 km—to the south, tapering northward up to the southern tip of Haifa Bay, where Mount Carmel touches the Mediterranean waters. It is once again somewhat wider at Haifa Bay, about 8–10 km, becoming a rather narrow strip west of the Galilee. At the northern frontier of Israel, Rosh HaNiqra, the Galilee mountains touch the Mediterranean. The coastal plain extends westward to the eastern boundary of the foothills and is divided into six main morphologic and geographic units differing from each other in many respects.

The southernmost sector is the Western Negev Coastal Plain. It extends from Sinai up to about Ashqelon, encompasses mainly sand and sand dunes, and is the widest sector of the Israeli coastal plain. The area is dissected by several large wadis that drain the hinterland,

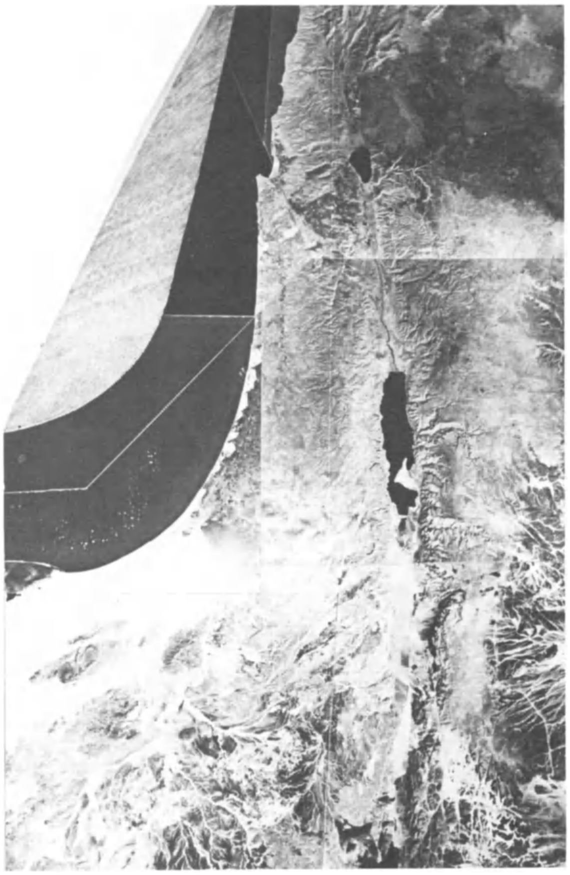


FIGURE 2.3. *Satellite imagery of Israel. (Courtesy of NASA, EROS Program.)*

and, except for some localities where the groundwater table is high, is practically a sand desert or a steppe (Figure 2.4). The eastern parts are covered by loess, which erodes and forms typical badlands (Figure 2.58). North of the Western Negev Coastal Plain, about 20-30 km wide, lies the area presently known as Pleshet, or Philistea. A number of small streams, some of them perennial, cross the area, which comprises an alternation of low sandstone ridges and wide, rather fertile plains covered by red soils and, occasionally, by seasonal marshes. The western parts of Pleshet are covered by Recent sand dunes, and some of the area, especially to the south, is covered by loess (Figure 2.5). The region extends northward to Tel Aviv. From Tel Aviv, where the coastal plain is about 20 km wide, it extends northward to the southern tip of Mount Carmel. This area is known as the Sharon (Figure 2.6), an ancient name that probably means a plain. The region is composed of sandstone ridges separated by wide plains in the same style as Pleshet but is richer in water, which gives it a unique character. The westernmost part of the Sharon is covered by Recent sand dunes, but the elongated valleys were mostly occupied by marshes until the beginning of Jewish settlement during the early years of the twentieth century. Five perennial streams and a relatively high groundwater table throughout the year have turned the Sharon into a fertile country, already known as such from the Bible. The areas that were not covered by marshes consist of a typical red soil (locally known as *hamra*) partly covered by oak forests.

North of the Sharon, between Mount Carmel and the Mediterranean, lies the Carmel Coastal Plain (Figure 2.7). This part of the coastal plain is rather narrow, about 3.5 km wide at its southern part, gradually diminishing to the north, up to the point where the hills touch the sea. The Carmel Coastal Plain has more or less the same characteristics as the Sharon but is much narrower. In fact, some geographers tend to include this sector within the Sharon. In view of its importance and somewhat different nature throughout the Quaternary, it seems preferable to treat the two separately. The Zevulun Valley lies north of the Carmel "nose." It is about 15 km long and 5-8 km wide and is bordered by two rivers, the Kishon to the south and the Na'aman to the north. The Zevulun Valley (Figure 2.8) is built of sand dunes to the west, which are the northernmost well-developed sand dunes of the Levantine coast, and from alluvial deposits of the two


FIGURE 2.4. *The Western Negev Coastal Plain.*


FIGURE 2.5. *The Pleshet (Philistea) Coastal Plain.*


FIGURE 2.6. *The Sharon Coastal Plain.*


FIGURE 2.7. *The Carmel Coastal Plain.*

FIGURE 2.8. *The Zevulun Valley and Nahal Kishon.*

FIGURE 2.9. *The Western Galilee Coastal Plain.*

rivers to the east. Marshes and *sebkhas* (inland or coastal, saline shallow depressions) were part of this valley before the Jewish settlement, and it was mainly covered by hydrophil and halophil vegetation. The northernmost sector of the Israeli coastal plain is the Western Galilee Coastal Plain (Figure 2.9). This sector extends from Akko (Acre) in the south up to Rosh HaNiqra in the north, about 18 km. The average width is 2–4 km. The characteristic lack of any sand dunes along the shore prevented the formation of marshes. Sandstone ridges are very limited in distribution and altitude, and the area is mostly built of rich alluvial soils. The Western Galilee Coastal Plain is dissected by several small, perennial streams.

The mountainous backbone runs along the entire length of the country, extending south of the Lebanese mountains, which lie to the north, down to the Sinai Peninsula highlands in the south. It comprises several different structural and geomorphic units, separated in Israel by two transversal valleys, Yizre'el Valley at the north and Be'er Sheva Basin at the south, into three main blocks: the Negev highlands to the south, Judea and Samaria, which constitute the central part, and the Galilee to the north. The mountains are mostly carbonate rocks, limestones, dolomites, and chalk, except for the southernmost sector of Elat, which consists of magmatic and metamorphic formations. Generally, they are characterized by a rather rugged landscape; lapies (extensively furrowed, hillocky, karstific limestone countryside) are quite common, and the bedrock is exposed at the surface, rarely covered by soil. The mountainous block generally dips gently toward the coastal plain, in one or two tectonically controlled steps that form the foothills, except at the Carmel "nose" and at Rosh HaNiqra, where mountains face the sea directly. To the east, the pattern is different. In most cases, the contact between the mountains and the Jordan Valley is along steep fault scarps that form conspicuous morphologic escarpments. Only at the Central Arava and the southern part of the Central Jordan Valley do the mountainous formations gently dip below the Jordan-Arava Valley floor, in which places the Valley is a syncline rather than a true taphrogenic rift.

The Negev Highlands are subdivided into four sectors: the Elat, mainly magmatic and metamorphic block, the Southern Negev Plains, the Central Negev Highlands, and the Northern Negev Fold Belt, each a separate morphotectonic domain. The Elat Block (Figure 2.10) is chiefly built of Precambrian Basement Complex rocks transected by several systems of faults and dikes. The proximity to the Bay of Elat and the extremely dry climate has produced a very rugged surface, with no soil cover whatsoever, breached by steep walled canyons. The mountains dip straight into the sea, and only rarely does a very narrow strip of beach occur. The same landscape is to be found along almost the entire Sinai coast down to the junction of the Bay of Elat (or the Bay of Aqaba) with the Red Sea. Sedimentary rocks occur at this area in only a restricted number of small grabens, which are subordinate in their influence on the morphology. The average elevations of the Elat Block are on the order of 600–700 m. The Elat Block is bordered to the north by the Themed Fault, which separates it from the Southern Negev Plains. These comprise mainly the vast floodplains of Nahal Hiyyon and Nahal Paran and their tributaries, which flow to the Arava (Figure 2.11) and are sometimes separated by small elevated structures, such as Zuqe Uvda and Har Zenifim. The floodplains are mainly built of pebble *hammadas* (wind-denuded desertic plateaus); vegetation is poor and is restricted to the wadi beds, and the elevation grades from about 600 m to the west down to about 300 m to the east, near the Arava. Several tectonically controlled valleys, such as Biq'at Uvda and Biq'at Sayyarim, border the southeast corner of the Southern Negev Plains from the Elat Block.

The Central Negev Highlands (Figure 2.12) is probably the oldest elevated structure within the Israeli borders. It had been formed as a plateau by Middle to Late Eocene times (Garfunkel and Horowitz 1966) and has since then eroded. Parts of the area still maintain the original flatland morphology of Late Eocene times, like the Ramat Matred, Har Horesha, Har Loz, Har Sagi, and their environments, but the central part of this region is deeply breached, exposing the huge buried anticlinorial structure

FIGURE 2.10. *The Elat Block. (Photograph by D. Darom, courtesy of I. Paperna, H. Steinitz Marine Biology Station, Elat.)*

FIGURE 2.11. *The Southern Negev Plains.*

FIGURE 2.12. *The Central Negev Highlands.*

FIGURE 2.13. *The Northern Negev Fold Belt.*

of Ramon in the form of an enormous erosion cirque. The elevation of the Central Negev Highlands exceeds 1000 m, slowly dipping northward until it reaches about 600 m at the cliffs of Nahal Zin, its northern border. The almost vertical cliffs of the erosion cirque, Makhtesh Ramon, are approximately 300 m high, and the cirque is drained to the Arava by a single canyon, Nahal Neqarot. The Highlands also dip eastward toward the Arava, generally with gently dipping strata and no faults. To the south, the Central Negev Highlands are separated from the Southern Negev Plains by an intermediate block that extends from Nahal Paran north to Mezoqe Arif. Elevations of this block are in the order of 500–600 m. It contains mainly pebble hammadas and bare limestone flats and is incised by several rather deep canyons flowing eastward, to the Arava.

Further north, separated from the Central Negev by Nahal Zin, lies the Northern Negev Fold Belt. This is a typical anticline and syncline region. The anticlines form hilly ridges attaining up to 700 m in elevation and mainly composed of bare limestones. Some of them are deeply breached, forming erosion cirques (Figure 2.13), whereas others are cut by antecedent valleys. All the anticlines are asymmetric, dipping gently toward the northwest and steeply to the southeast, which is clearly expressed in their morphology. The synclines are filled with soft sediments, mainly chalk and conglomerates, forming wide, elongated, flat-bottomed valleys. The entire region dips gently toward the Be'er Sheva Basin and the Western Negev Coastal Plain to the northwest, grades into the Ramat Matred Plateau in the south, from which it is partly separated by Nahal Zin, and approaches the Dead Sea Rift Valley, eastward, in a complicated fault pattern that forms an escarpment cut by several steep-walled canyons. Be'er Sheva Basin is a large synclinorial structure, narrow to the east and widening westward. It is filled with soft sediments that form a flat-to-rolling landscape (Figure 2.14) mostly covered by windblown loess. Elevations are up to 400 m in the east, grading very gently to about 150 m westward. No perennial rivers flow in the Basin, but its structure enables collection of large quantities of groundwater that maintain some vegetation in the area.

Judea and Samaria, which extend north of the Be'er Sheva Basin up to the Yizre'el Valley, form a mountainous block that had quite recently been upwarped (Horowitz 1974). The block is obliquely divided into several anticlinal ridges and synclinal basins. The most conspicuous of these are the Hebron, Judea, Ramallah, and Buqei'a anticlines, attaining up to 800–900 m in elevation, which comprise a rather rugged landscape of lapies only slightly covered by terra rossa soil (Figure 2.15). Three large synclinorial complexes are part of the Judea–Samaria region: the Shefela (Figure 2.16), forming the western foothills of rolling landscape and considerably rich vegetation; the Judean Desert in the east, also comprising a rolling landscape due to the chalky bedrock but, being an orographic desert, almost devoid of vegetation except for the wadi beds (Figure 2.17); and the Shekhem (Nablus) synclinorium, the landscape of which is somewhat softer but not much different from the anticlines. The main morphologic difference between Judea (Yehuda) and Samaria (Shomeron) is occasioned by the occurrence of a considerable number of intermontane valleys in the latter region (compare Figures 2.15 and 2.18). Almost no perennial streams occur in the Judea–Samaria mountains, probably due to the great abundance of karst phenomena, which favor a subterranean drainage. The Judean Desert meets the Dead Sea Rift Valley in a complicated pattern of faults and escarpments breached by some canyons, whereas the Buqei'a structure dips eastward toward the Central Jordan Valley with almost no faulting and a gentler morphology. Westward, both grade rather gently to the coastal plain through the foothills. To the northwest, the mountainous region is connected through the Umm el Fahm anticline and the Nahal Iron (Wadi Ara) syncline to the Carmel elevated block (Figure 2.19), the landscape of which is almost the same as that of Judea except that it is richer in water and vegetation and includes a number of gentle valleys developed on volcanic ashes and tuffs of Cenomanian age.

FIGURE 2.14. *The Be'er Sheva Basin.*

FIGURE 2.15. *The Judean Hills.*

FIGURE 2.16. *The Shefela Foothills.*

FIGURE 2.17. *The Judean Desert.*

FIGURE 2.18. *The Samaria (Shomeron) Mountains, with a typical intermontane valley.*

FIGURE 2.19. *The seaward-facing cliff of Mount Carmel.*

FIGURE 2.20. *The Yizre'el Valley.*

FIGURE 2.21. *The Lower Galilee Hills.*

FIGURE 2.22. *The Upper Galilee.*

The Yizre'el Valley (Figure 2.20) cuts the entire country obliquely, from the Central Jordan Valley to Haifa Bay. Its elevation is about 100 m in the center, grading to sea level to the west and down to 200 m below sea level to the east, where it approaches the Jordan Valley rather gently. The Yizre'el Valley is a graben formed in Early Pliocene times. The southwest and northeast escarpments are rather eroded in comparison with those bordering the younger Dead Sea Rift but still form sometimes quite steep cliffs, such as those of the Carmel and Nazareth mountains. The Valley is filled with very dark, heavy soils, which form a flat morphology. It was partly covered by marshes before the Jewish settlement. North of the Yizre'el Valley the hills of the Galilee ascend up to the center of its mountainous block, Har Meron, 1208 m above sea level—the highest point in Israel. The region is naturally divided into the Lower (Figure 2.21) and the Upper (Figure 2.22) Galilee. The Lower Galilee is characterized by a series of subparallel tilted blocks that create a typical basin and range morphology. The central and western sectors are mostly composed of limestone, dolomite, and chalk, the first two forming rugged surfaces, the surfaces being somewhat more gentle when chalk is the bedrock. The prevailing element in the morphology, however, is the faultlines. At the eastern sector the bedrock is mostly basalt and the tilted blocks form flat, slightly tilted plains separated by rather steep escarpments. The Lower Galilee dips gently into the Zevulun Plain to the west and approaches the Kinneret Lake to the east, 210 m below sea level, by a series of steps.

The great escarpment of the Bet Kerem Fault System separates the Lower Galilee, with elevations in the order of 400–600 m, from the Upper Galilee to the north, with elevations of 800–1200 m. The morphology of the Upper Galilee is also mainly controlled by its complicated fault pattern. Limestones and dolomites comprise most of the area, except for the easternmost part, which is built of chalk and basalt. The Upper Galilee is highly dissected by karstic landforms that catch the runoff waters into a subterranean drainage system. Only a limited number of small perennial streams occur, both at the Lower and Upper Galilee. The Galilee block continues northward into Lebanon, ascending further until reaching the highest elevations, more than 3000 m, opposite Tripoli.

The Jordan–Arava Rift Valley runs along the entire country, from the Bay of Elat (Aqaba) up to the foothills of the Hermon Range. The Valley is divided into four sectors separated by thresholds higher than the average Valley floor but considerably lower than the surrounding mountains. The Southern Arava runs from the Bay of Elat up to Gav Ha'Arava, near Jebel el Khureij, where an elevation of more than 200 m is reached. The area is bordered (Figure 2.23) by steep escarpments cut by canyons from which huge alluvial fans emerge. The Valley floor is flat, gradually descending towards the Bay of Elat, but almost no drainage system has developed, due to the scarcity of water; only several sebkhas are scattered along the Valley. The groundwater table is rather high, which results in a relatively rich vegetation and in the existence of some springs.

The Dead Sea Basin is the largest sector of the Jordan–Arava Rift. It comprises three morphological subunits: the Northern Arava (Figure 2.24), the Dead Sea proper (Figure 2.25), and the Southern Jordan Valley (Figure 2.26). The Northern Arava is mainly a synclinal valley bordered by gently dipping strata to the west and by considerably tilted strata to the east, sometimes breached by deep canyons. The valley floor is flat to the south and is cut by several gorges to the north, approaching the Dead Sea. The valley gently descends from more than 200 m at Gav Ha'Arava to 400 m below sea level at the Dead Sea. The Dead Sea occupies a graben bordered east and west by steep fault escarpments that extend some 20–25 km north of the Lake and fall straight to the water with almost no coast, except in places where the escarpment is breached by canyons that give place to alluvial fans. The Dead Sea water level is at 398 m below sea level, and the basin comprises a southern sector in which the water depth is only 2–3 m and a northern basin in which the water depth is 350–400 m below the lake's surface.

The Southern Jordan Valley extends about 50 km north of the Dead Sea, up to the breached threshold opposite Merma Feyyad. The mountains on both sides gradually dip into the Jordan Valley at this sector, which, like the Northern Arava, is a synclinal valley. The bottom is flattened by sediments of the Würmian Lisan Formation that form a morphologic unit called the *ghor* (Arabic), in which the Jordan River and its tributaries flow to the Dead Sea. The Jordan floodplain, 2–4 km wide, forms a lower flatland, the *zor*. The Southern Jordan Valley gently descends from about 200 m below sea level in the north toward the Dead Sea, 400 m below sea level. The Lisan Formation sediments form badlands due to erosion by the Jordan and its tributaries.

The Central Jordan Valley (Figure 2.27) is flat, at an elevation of approximately 200 m below sea level, extending to the northern shore of Lake Kinneret (the Sea of Galilee). It is bordered by a steep fault escarpment to the

FIGURE 2.23. *The Southern Arava.*

FIGURE 2.24. *The Northern Arava.*

FIGURE 2.25. *The Dead Sea.*

FIGURE 2.26. *The Southern Jordan Valley.*

FIGURE 2.27. *The Central Jordan Valley.*

FIGURE 2.28. *The Hula Valley. Photograph taken from the elevated Gadot-Korazim Block to the northeast toward the Golan Plateau and the Hermon Range. The lighter area in the center of the valley was occupied by Lake Hula until reclaimed in 1955.*

east and by a complicated fault pattern to the west. The bottom is cut by the Jordan and by some other gorges, and the northern part is occupied by Lake Kinneret, 212 m below sea level. The Northern Jordan Valley, the smallest sector, includes the basaltic elevated block of Korazim (Figure 2.28) at its southern part, breached by the Jordan River, which runs from the Hula Basin, about 70 m above sea level, to the Kinneret through a basaltic gorge. The Northern Jordan Valley occupies a deep graben bordered by fault escarpments. The Korazim block is mostly covered with basaltic soils, its morphology depending on two fault systems, one running north–south and the other north–northwest and south–southeast. The Hula Basin is a flat-bottomed valley, rising somewhat northward until bordered by the Marj Ayyun elevated block system. The southern sector was occupied by the shallow Hula Lake until 1955, and the central sector was covered by peat bogs. The northern sector is crossed by a number of perennial streams that supply water to the entire Jordan Valley. Many springs occur around the Hula Basin, draining the karstic mountainous aquifers.

DRAINAGE PATTERN

The present drainage system of Israel (Figure 2.29) depends on the morphotectonic pattern of the country. Three final base levels into which the area is drained exist: the Bay of Elat, connected to the Red Sea; the Mediterranean; and the Dead Sea, which is an inland basin. The catchment area leading to the Bay of Elat is rather restricted, including only the Southern Arava and part of the Elat Block. No perennial streams occur in the entire region, and the rare, strong rains result only in short torrential flooding of the wadis. The floods coming from the Elat Block occasionally reach the sea, while those flowing to the Southern Arava disappear under the surface gravel, enriching the groundwater or forming seasonal playas.

The Southern Negev Plains are drained to the Dead Sea through the long paths of Nahal Hiyyon and Nahal Paran, leading to the Northern Arava. Most of the Central Negev is also connected with this system and is drained to the Dead Sea through Nahal Ha'Arava. Only a minor sector at the western part of the Central Negev is drained west to the Mediterranean via northeastern Sinai and Wadi el Arish. The Northern Negev drainage is divided between the Dead Sea and the Mediterranean. The southeastern sector belongs to the Nahal Zin catchment area and flows to the Dead Sea, whereas the northwest sector is drained through the catchment area of Nahal Besor, which reaches the sea somewhat south of Gaza. The wadis of the Negev do not maintain perennial flow but are instead subject to strong, seasonal torrential floods. Several springs occur in the Negev (including the Elat Block); all of them are stratigraphic and are mostly seasonal, active only during the winter. The outputs, however, are always low.

The western part of the mountainous backbone of the country is drained to the Mediterranean through several small perennial streams, the catchment of which depends on the extent of the karstic aquifer. The eastern sector is drained to the Jordan Valley by dry, intermittent wadis to the south and by perennial streams to the north. The Jordan gets its water mainly from the north, from three main tributaries: Nahal Hermon, Nahal Dan, and Nahal Iyyon, which flow into the Hula Valley. Springs and small streams from both the western and the eastern highlands add somewhat to its water, but considerable amounts are added by rivers coming from the Transjordan Plateau, mainly the Yarmouk and the Yaboq (Wadi Zarqa). The Jordan drainage system has two intermediate lakes, the Hula (artificially reclaimed after 1955) and the Kinneret, and has its final base level at the Dead Sea, which loses water by extensive evaporation and is, therefore, highly hypersaline.

CLIMATE

Israel occupies a transition zone between the rainy, almost subtropical Mediterranean climate to the north and the dry, subtropical desert to the south. The region is characterized by a short, rainy winter and a long, dry summer. During the winter, the country is subject to the influence of cyclones that develop in the Eastern Mediterranean, generally over Cyprus (Figure 2.30) and the Aegean Sea. The climate of northern and central Israel is therefore considerably influenced by cyclones, whereas the south is only marginally influenced, or sometimes even totally out of the cyclones, clouds, and rains.

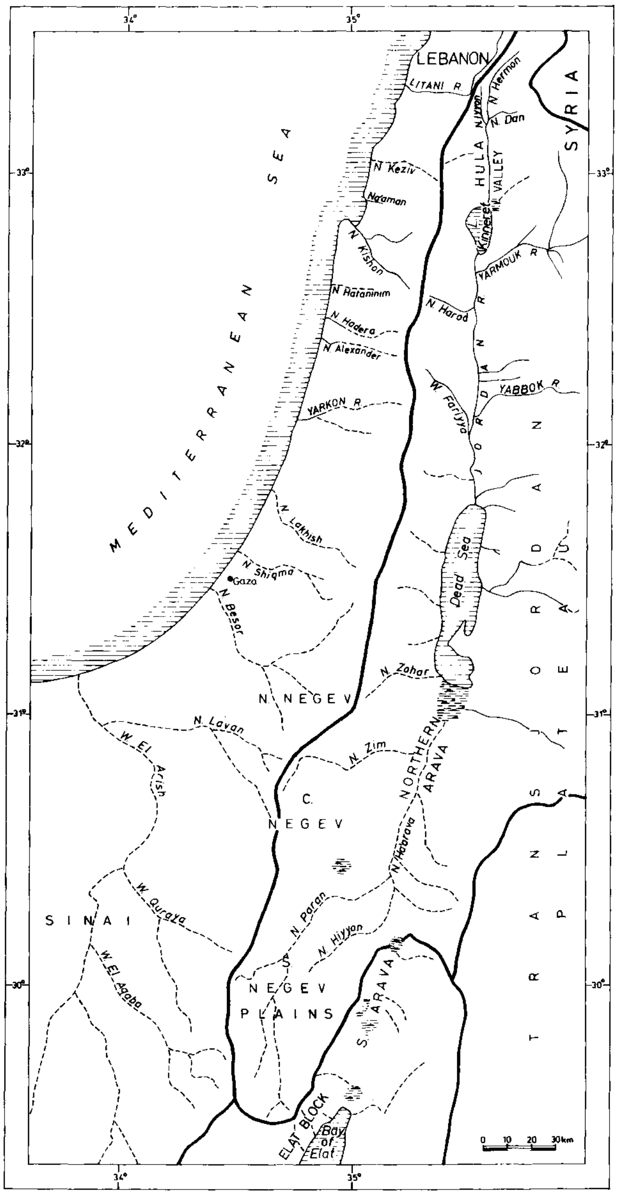


FIGURE 2.29. *The drainage pattern of Israel.*

Barometric lows reach Israel from the west by two main paths. The most important is that coming from northern Italy via the Adriatic Sea, Greece, and the Aegean Sea, where it parts into two heads, one toward the Black Sea and the other toward Syria and northern Israel. This path is the most important for the winter rains. The other, which is much less common, heads from southern Italy over the central Mediterranean toward the southeast corner of the sea, in the direction of Israel. Very rarely do the two other paths occur: One comes along the northern coast of Africa, Egypt, and Israel, and the rarest is a barometric low coming from the Red Sea, causing enormous floods in Sinai, the Negev, Arava, and the southern Jordan Valley. The Mediterranean lows are frequent in the 8 months from October until the beginning of June. Cold air comes to the area from Eastern Europe through the Balkans, and its influence is very important, dictating the amount of rain.

The barometric pressure is generally higher over Israel in the winter than in the summer and is lower only on stormy days. This permits the phenomenon of very clear, sunny, cold winter days in which visibility can exceed 100 km. The lower barometric pressure during the summer, about 5 milibars as an average, is caused by the influence of the great barometric lows connected with the Indian monsoons. During the summer, Israel is in the outermost belt of the South Asian System. This barometric low causes an almost constant flow of humid air from the Mediterranean in the form of western and northwestern winds, which are responsible for considerable amounts of dew. Only at the beginning and at the end of the summer, when the South Asian low is not well-developed and when low pressures develop over the Mediterranean, is Israel subject to strong, very hot, dry eastern winds. These eastern winds cause special weather, locally named *Hamsin,* during which temperatures may rise to 35–40° C; temperatures as high as 54° C have even been recorded.

The described pattern of barometric pressures through the year is also responsible for cloudiness, which is much more conspicuous during the winter. Summer clouds, although quite common, never cause rain in Israel, due to the lack of any cold air masses. They very frequently form morning fog, which later rises.

The total number of cloudy days does not exceed half the number of winter days, and they occur mainly from November through the beginning of March. During the summer more than 90% of the days are clear. This results in great amounts of radiation: A square meter of flat land gets an annual average of half a million calories per day. The average amount of light, consequently, is also considerable.

Rains (Figure 2.31) generally begin in November, attain their maximum during the second half of December,

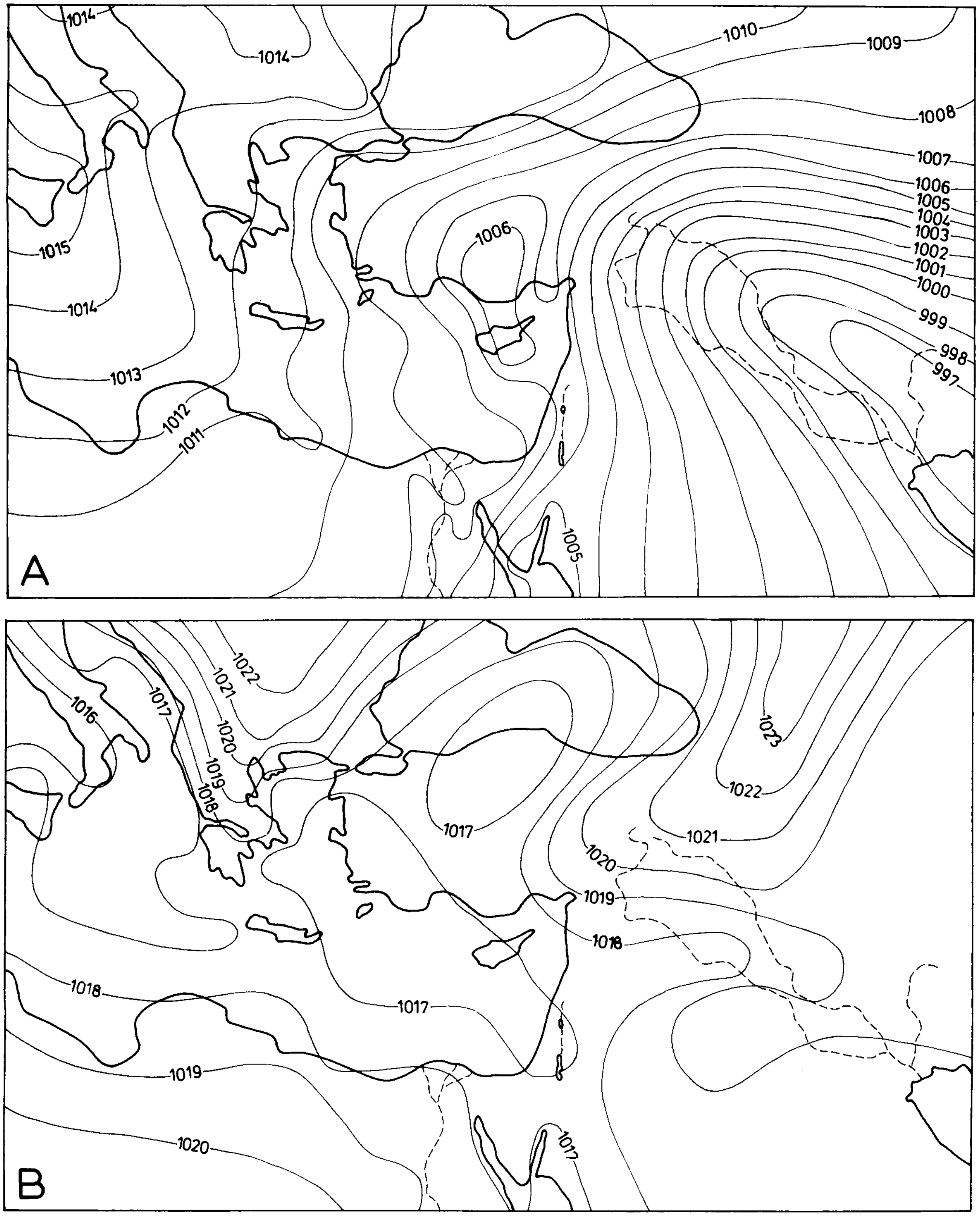


FIGURE 2.30. *Synoptic map of the Levant: A, winter; B, summer.*

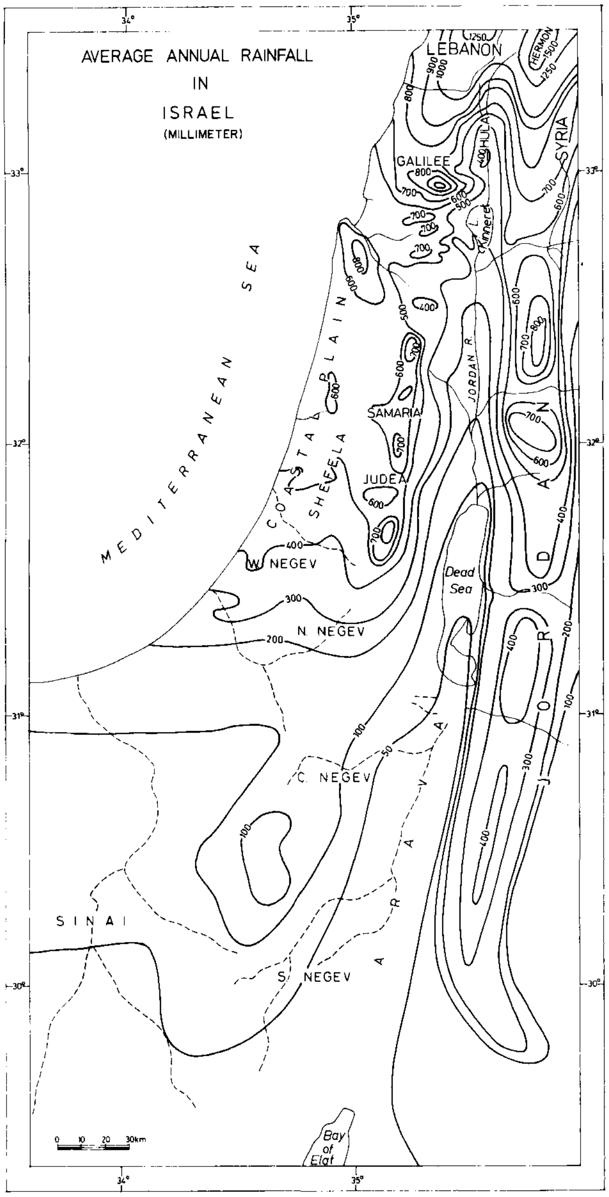


FIGURE 2.31. *The rainfall pattern of Israel.*

January, and the first half of February, when about 72% of the annual quantity falls, and decrease in quantity later. Rains during April and May are rather rare. Differences in amount of rain over the country are remarkable: The southern Negev and Arava get an annual fall of about 30 mm; the Northern Negev and the Dead Sea get 50–75 to 150–200 mm; the Western Negev, the Shefela, and parts of the coastal plain get 300–600 mm; Judea and Samaria receive 500–800 mm, and the Upper Galilee up to 1100 mm. The amount of rain generally increases northward. The average number of rainy days is 40–60, decreasing in proportion to the amount of rain over various parts of the country. Most rains are rather strong and fall over short periods. These factors have always been a problem for agriculture, because a lot of water is lost in short, torrential floods. This phenomenon is more acute in the southern parts of the country, where there is no vegetation cover to prevent the floods. To the north, where the vegetation cover is better developed, floods are rare.

Snow falls over the mountainous areas of Israel almost every year and holds for several days, usually sometime in December or January. It is a common phenomenon in the Galilee, Samaria, and Judea, but also occurs in the Central Negev Highlands. The snow on the Hermon Range northeast of the Hula Basin holds almost all the year round (the elevation attaining up to 3000 m) and serves as one of the important water supplies for the Jordan River.

Average temperatures in Israel depend on elevation and distance from the Mediterranean. Temperatures on the mountains are lower than at the coastal plain and are higher to the south than to the north. The warmest region is the Jordan Valley, especially the Dead Sea area and the Arava. The main cause for temperature differences is the adiabatic cooling of the frequent western and northwestern winds while ascending the mountains and the warming while descending to the deep Jordan–Arava Valley. The average annual temperature is somewhat more than 20° C, but this figure is misleading due to the considerable differences at various regions. Diurnal differences are hardly pronounced on the coastal plain, are rather pronounced at the mountainous regions, and are extreme in the Negev, especially in its central highlands. Relative humidity is highest at the coastal plain, diminishing eastward and southward. Generally, areas of similar elevation to the north enjoy higher humidity than do those to the south. Extremely low values are recorded at the Arava, especially at its southern sector and around the Bay of Elat. This is probably a result of the descending winds (*chinook*), which become considerably warmer and drier.

The most frequent winds over Israel are western and northwestern, except when a cyclone approaches and during a *hamsin*, discussed earlier. When the cyclone is still over the Mediterranean, it causes an eastern wind, which veers into southern and, consequently, into western, bringing rains. The final stage is a northern wind that clears the sky. The western and northwestern winds prevail over the mountains of the entire country, down to the Negev. They are generally stronger during the summer, weak in the morning, becoming strongest during the late afternoon hours. These are regional winds. Local winds are very rare in the mountains. The coastal plain is subject to typical coastal breezes almost the year round, namely, a western wind during the day and an eastern at night. These winds are never strong. A very important local wind blows along the Jordan and Arava Valleys. During the summer days, the air is still until early afternoon hours. At about two o'clock a very strong northern wind begins to blow along the entire valley, down to the Bay of Elat. In the winter, this wind begins much earlier and can sometimes blow for weeks.

SOILS

Given its small geographical area, Israel is extremely diverse in soil types (Figure 2.32). This great variety depends on three main causes: the climate, parent rocks, and relief. The climate, grading from Mediterranean type to the north to an extreme desert climate to the south, the varied parent rocks, of which the most abundant are limestones and dolomites, marls, sandstones, and basalts, and the wide variety of relief, from broad valleys to steep escarpments—the combination of all of these contribute to the formation of many types of soils and to their restricted areal distribution in Israel. Pedogenic processes under the Mediterranean climate create four main soil types in Isreal: *terra rossa,* a red, shallow clayey soil that forms on limestones and dolomites; *rendzina,* a gray, somewhat deeper soil that forms on chalk and marl; deep brown soils that develop on basalts; and light brown and reddish soils that develop on the sandstones of the coastal plain. The semiarid areas of the country are characterized by gray soils, mostly developed on loess and lacustrine deposits of the Jordan Valley, whereas the desert areas are typified by hammada and sebkha soils, whitish or grayish in color.

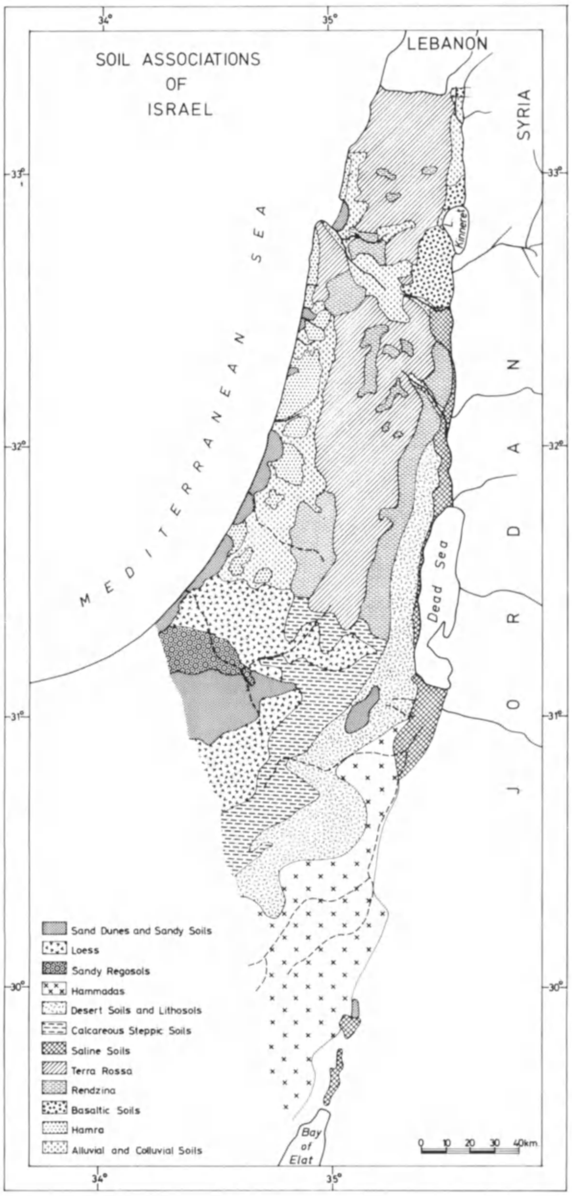


FIGURE 2.32. *Soil map of Israel.*

Mature soils with a well-developed profile are rare in Israel, mainly due to the extensive erosional processes that quickly remove whatever soil is formed on the mountains and bury alluvial soils in the valleys. In the more arid parts of the country, aeolian soils are easily wind-deflated or buried due to the poverty of the vegetation cover, which prevents the formation and development of proper profiles in these regions. Regarding evolutionary processes, five main soil types can be discerned in Israel:

1. mountainous soils, shallow, with almost no profile development
2. alluvial soils of the greater valleys, where the profile changes laterally rather quickly
3. aeolian soils, such as sands, sandy soils, and loess soils
4. immature desert soils, such as hammadas
5. hydromorphic soils formed due to an excess of water, such as marshy soils in which there is no concentration of salts, or saline sebkha soils

Many systems of soil classification have been proposed for Israel, of which the more important are by Yaalon (1959), who first suggested physical properties as a guide, by Ravikovitch (1969), whose classification is based mainly on climatic factors, and by Dan (1968), whose system is based on physical properties of soils and is accompanied by a map by Dan and Raz (1970). The first systematic survey accompanied by a map and that dealt with soils in Palestine was presented by Strahorn (1929). The system on which this discussion is based was suggested by Zohary (1959), who based his classification on ecologic principles, taking into consideration mainly soil properties directly associated with requirements of the vegetation. Zohary states that any attempt to classify soils exclusively by their physical properties, namely, degree of development and type of profile, or by climatic regions is arbitrary, since it does not take into consideration the natural factors as a whole. According to the ecological properties of the soils of Israel, six main groups are discerned:

1. calcareous soils
2. basaltic soils
3. sandy and calcareous–sandy soils

4. loess soils
5. alluvial soils
6. saline soils

Five of these types occur both at the Mediterranean and in desert areas and could, thus, be subdivided, since the ecology of each of the variants is considerably different. The reasons for adopting this system of soil classification mainly concern methods of determining Quaternary stratigraphy and paleogeography when most of the evidence is gathered from paleoecologic data. These data are principally pollen spectra, which represent vegetation directly related to the six soil types.

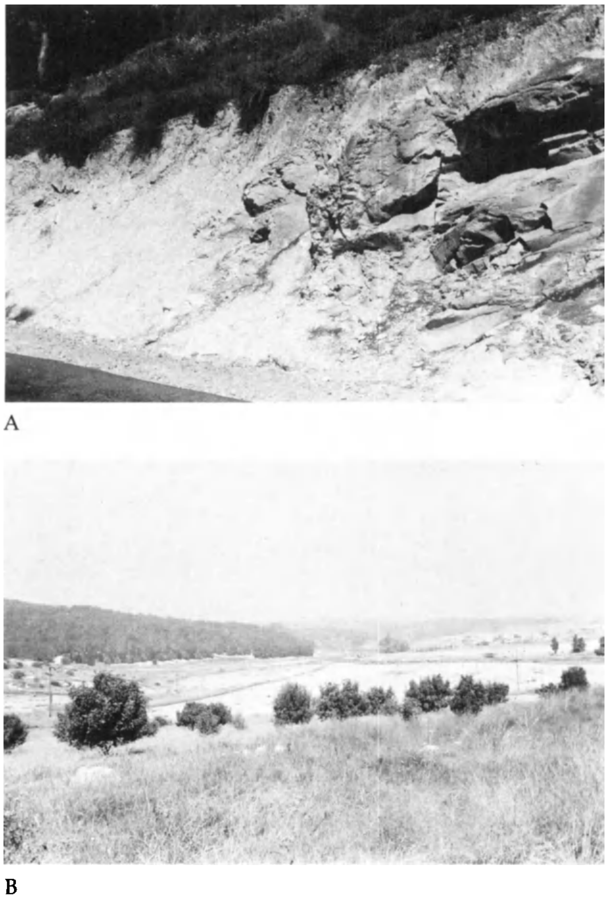
MEDITERRANEAN SOILS

Calcareous Soils

This group of soils includes several variants formed from calcareous rocks, all rather rich in lime.

Terra Rossa. This is the most common soil in the circum-Mediterranean area, mainly associated with hilly or mountainous regions (Figure 2.33). It is typically red to light brown (hence the name, meaning "red soil"), contains very little humus, and is mostly clayey and relatively poor in lime. The profile is very poorly developed, of the (A)C type. Terra rossa appears both as mountainous soil, generally several centimeters to half a meter thick, and as an alluvial soil, generally occupying the intermontane valleys, where it may be rather thick. It is generally suggested that formation of terra rossa requires hard carbonate rocks, limestone and dolomite, which are thoroughly leached to form the soil (see, for example, Zohary 1959). This is in contrast to soft rocks, such as marl and chalk, which form another type of soil, rendzina, discussed later. It seems, though, that the connection of terra rossa with hard carbonate rocks is due to their total leaching, but the remaining interbedded clay horizons form the soil, with some addition of aeolian dust. Most of the hard carbonate rocks in Israel were deposited in a shallow marine environment and are quite frequently interbedded with clays, whereas chalks were deposited in much deeper basins (Flexer 1964) with only rare clayey intercalations, therefore decomposing into gray, lime-rich soils. The terra rossa soils maintain typical Mediterranean vegetation of maquis, batha, and garigue.

FIGURE 2.33. *Terra rossa soil, developed on hard limestone in the Judean Hills.*



A

B

FIGURE 2.34. *Rendzina soil: A, developed on chalky rocks; B, alluvial, accumulated in the Shefela Foothills.*

Rendzina. This type of soil is rather abundant in the same areas as is terra rossa, but it differs considerably from the latter (Figure 2.34). It is gray, contains 30–80% lime, and is relatively better-developed and somewhat thicker than terra rossa. Where rendzina soil is well developed, it comprises an upper, A layer, rich in humus, a median B layer, which is typically gray and rich in lime, and a C layer, grading to the chalky or marly bedrock. In many regions of the country, this soil was destroyed due to human activities, mainly deforestation, which removed the protective vegetation cover and led to severe erosion. In areas that have been inhabited through the last several millennia, only the C layer now remains. Rendzina, according to M. Zohary, maintains forests of *Quercus ithaburensis*. A variant of rendzina is *white rendzina,* typically developed over Senonian chalk in Israel, which apparently maintained pine forests. This variant is made up almost exclusively of lime, with very little clayey and organic materials. It might well represent an immature stage in the formation of a true rendzina.

Basaltic Soils

These soils (Figure 2.35) occupy considerable areas in the northeast of the country. In contrast to the calcareous soils, basaltic soils cover the terrain with almost no protruding rocks or lapies. The soil is heavy and clayey and has considerable water content. It is brown or chocolate in color and rather poor in lime, the profile is poorly developed, and the soil depth rarely exceeds a meter. In Israel, there is almost no place in which natural vegetation still covers areas of basaltic soils. An exception is the Golan Heights, where this soil maintains an oak forest (Weinstein 1976).

Sandy Soils

This complex of soils originated from dunes and is typical of the Israeli coastal plain. Some restricted inclusions of sandy soils are known also from the Negev, where they developed over Nubian sandstones or Neogene river beds. Ecologically, they form three main types: sands, calcareous sandstones, and red soils.

Sands. The sands are composed almost entirely of quartz grains brought down the length of the Nile and deposited along the Israeli coastal plain, where they drift and are spread by winds. They are rather thick (Figure 2.36), up to 50 m, and, besides quartz, contain lesser amounts of heavy minerals, clays, and carbonate. The latter is mainly aragonite, derived from the breaking-up of sea shells, and sometimes comprises up to 10% of the sands. Only to the north of the country, on the Western Galilee Coastal Plain, where the influence of the Nile is less marked, are the sands, rare in that locale, composed almost entirely of limestone grains.

Calcareous Sandstones. These are solidified dunes (Figure 2.37), secondarily enriched in lime (Gavish and Friedman 1969), which form elongated ridges along the coastal plain. Like the sands, they apparently did not suffer any pedogenic processes and, although ecologically significant, do not represent a true soil.

FIGURE 2.35. *Basaltic soil from eastern Galilee.*

FIGURE 2.36. *Sandy "soil" of stabilized dunes in the Sharon.*

FIGURE 2.37. *Calcareous sandstone "soil" on kurkar, Sharon.*

FIGURE 2.38. *Hamra soil of the Sharon developing a calcareous B horizon.*

Red Soils. Red soils, locally known as *hamra* (Figure 2.38), from "red" in Arabic, are very abundant along the coastal plain, generally filling the low depressions between calcareous limestone ridges. The main constituent of these soils is quartz grains, typically coated with iron oxide, which gives them red coloration. Lesser amounts of clay are almost always present, whereas lime is rather rare. These soils are very poor in organic material and seem to have been very well-washed. For a long time, these were thought to be weathering products of the dunes, brought about under recent conditions. It is now believed, however (Horowitz 1975), that all the hamra red soils are really paleosols, whereas soils recently forming on the coastal plain are gray. This gray soil is quite rare due to the great extension of paleosols and marshes on the coastal plain. This point will be discussed in much more detail in Chapter 5. The B layer of hamra soil is sometimes quite well-developed and contains concretions, either of lime or of clays. In the latter case, the soil (locally called *nazaz*) is rather poor for agriculture because roots cannot penetrate the hard clayey layer.

Alluvial Soils

This group comprises genuine alluvial, partly hydromorphic soils and colluvial soils, which fill river valleys and border alluvial areas.

Colluvial Soils. These are soils (Figure 2.39) that fill river valleys and frame mountainous regions. They are heavy, clayey, and sometimes intermingled with gravel; in color, they are grayish-brown or, sometimes, reddish or gray. Lime comprises only a minor part of these soils, 5–25%. The composition of colluvial soils depends to some extent on their provenance, being terra rossa in the intermontane valleys of Samaria, basaltic soils in the Galilee valleys, and rendzina in the Shefela. These soils were suitable for agriculture in the early days because they needed no special treatment; therefore, very little of their original vegetation was preserved.

Alluvial Soils. These soils are mainly concentrated in the Yizre'el Valley, the eastern coastal plain, and the Jordan Valley. Sometimes they also accumulate in oases of the Negev. Alluvial soils form in areas that are sometimes occupied by marshes, at least during winter time. On the western coastal plain, they accumulate where the coastal dunes block the seaward outlet of small streams, whereas at the Jordan Valley they accompany the rivers and wadis. These soils (Figure 2.40) are very rich in organic materials and are generally black. Due to the occasional excess of water, they are sometimes hydromorphic or halo-hydromorphic. In some extreme cases, like the northern Hula Valley or Nahal Poleg at the coastal plain, they become genuine peat soils.

Desert and Steppe Soils

This group comprises four main soil types, all characteristic of the desert and semidesert areas of Israel: the gray desert soils, the loess soils, the hammadas, and the sebkhas. All of them are characterized by a shallow, hardly developed profile and considerable amounts of lime or gypsum. Their clayey fraction, mostly of aeolian provenance, coagulates easily when wet, causing rainwater to flow on the surface rather than to infiltrate down to the subsoil. This phenomenon is the main cause of torrential floods in Negev and Judean Desert wadis.

Gray Desert Soils. These do not comprise soils in the pedogenic sense. They include only a thin C layer, which is mostly merely the weathering surface of chalky rocks (Figure 2.41) under desert conditions. The "soils" are very rich in lime, with only minor amounts of clay, apparently aeolian in origin. In the desert valley, this soil is somewhat thicker but is, at any rate, devoid of organic material that might characterize an A layer. They can thus be regarded as of (A)C or C profile. In some areas, especially in lowlands, this soil is also very rich in gypsum, which appears either as crust or, occasionally, as a subordinate B layer, in the form of concretions or of "gypsum sole."

FIGURE 2.39. *Colluvial "patchy" soils of the Shefela Foothills.*

FIGURE 2.40. *Alluvial soil of the Yizre'el Valley.*

Loess Soils. Loess soils (Figure 2.42) cover wide areas of the northern and northwestern Negev. As with the previous type, this is not a soil in the pedogenic sense, because no profile is developed. It should, rather, be regarded as an alluvial soil of aeolian origin or sometimes, whenever it is washed and redeposited, of a fluviatile origin. The loess soils comprise mainly silt, more quartz-rich to the west, more carbonatic to the east. They are almost devoid of organic material. In the past, under more humid climatic conditions, the loess underwent pedogenic processes that can presently be discerned as buried paleosols. Occasionally, a kind of B layer containing carbonate concretions is observed within the loess.

Hammada Soils. These, once more, are not proper soils. They comprise a mixture of pebbles, predominantly flint (Figure 2.43), interbedded with silt or silty clay. This kind of substrate is typical for the wide plains of the southern Negev and mainly forms on bedrock made up of conglomerates of ancient river floodplains in these regions. Most of the hamadas are saline or gypsiferous to some extent and, at present, maintain almost no vegetation, except rarely in the wadi beds.

Sebkha Soils. Sebkha soils are developed in the arid and semiarid areas of the southern Jordan Valley, the Arava, and the Negev, as well as in small internal drainage basins where evaporation is higher than is water influx. They are fine-grained, with a rather well-developed A layer, rich in organic material, sometimes even black (Figure 2.44). B layer, containing concretions, is also sometimes developed, the concretions comprising lime, gypsum, or sometimes rocksalt. The southern variants of sebkha soils are poorer in organic material, and, at the extreme south of the country, they are covered by crusts, mostly composed of gypsum, that allow only a very restricted vegetation. Other variants of sebkhas are the coastal type of Haifa Bay and some that are formed due to the groundwater level's being very near the surface, which results in a concentration of salts when solutions coming up by capillary movement in the subsoil evaporate.

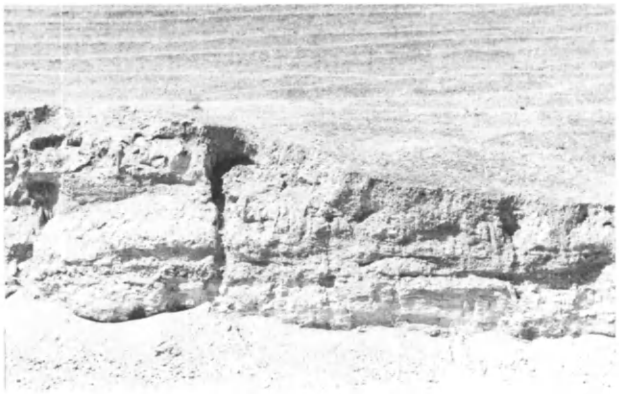


FIGURE 2.41. *Gray desert soil, Judean Desert.*

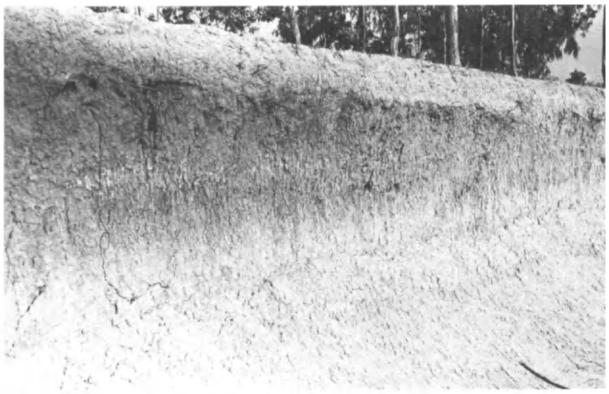


FIGURE 2.42. *Loess soil of the Western Negev.*

FIGURE 2.43. *Hammada soil, Central Negev.*

FIGURE 2.44. *Sebkha soil, south of the Dead Sea.*

ENVIRONMENTS, FAUNA, AND FLORA

Israel lies at the junction point for three continents—Europe, Asia and Africa—and, at least from Miocene times onward (Horowitz 1974), served as a continental bridge that allowed migrations of plants and animals from one continent to another. The country is bordered by three major environmental belts, the Mediterranean, the Irano-Turanian, and the Saharo-Sindian, which meet within the limited area of Israel (Figure 2.45). Two other major environmental belts are represented in Israel: the tropical Sudano-Deccanian, in some of the desert oases, and the Palaearctic, represented only by several plants and animals that have succeeded in finding suitable ecologic niches in the present, after having inhabited the country in earlier days under somewhat different climates. The global climatic and environmental belts are generally latitudinal, whereas the main morphologic units of Israel are longitudinal, so that the ensuing environmental pattern of Israel looks rather like a chessboard.

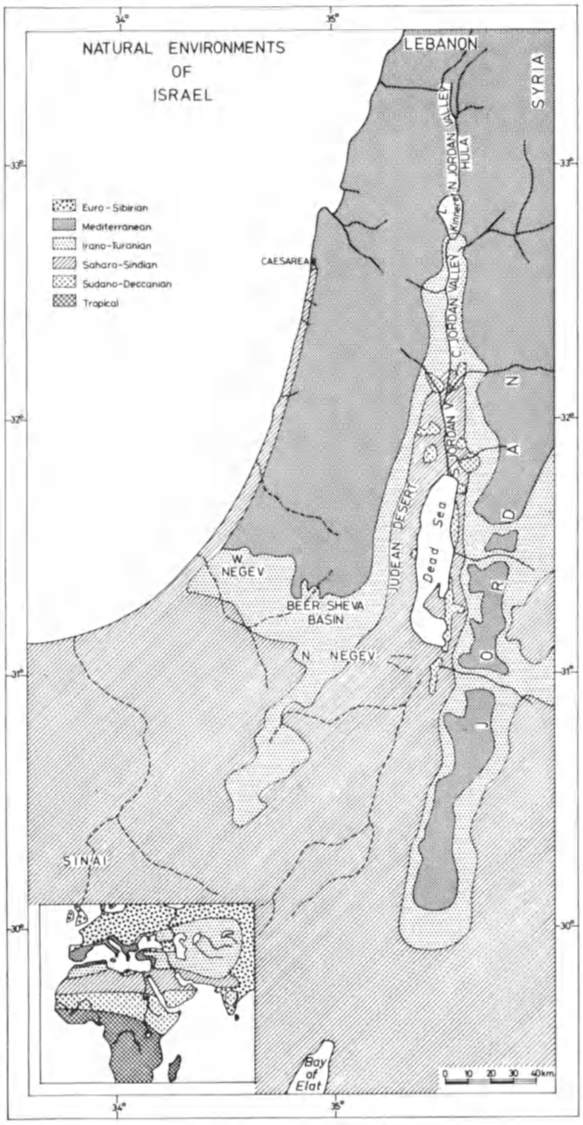


FIGURE 2.45. *The natural environments of Israel.*

The variety of natural environments caused the development and concentration of faunal and floral elements in a number and variety of species rarely found on such a restricted geographical area elsewhere, except for tropical regions. About 2500 plant species are known in Israel. (Compare this to 1700 in Great Britain, 1800 in Iraq, and 1500 in Egypt—all *much* larger in area) About 100 species of mammals are known, as are almost 500 species of birds, of which more than 200 are resident in the country, and so on. For details, one is referred to the treatises on flora by Zohary (e.g., 1959, 1962 and others) and on fauna by Bodenheimer (1935). It is quite interesting to compare the major groups of plants and animals (Table 2.1) as to their environmental provenances.

MEDITERRANEAN ENVIRONMENT

The Mediterranean environment surrounds the Mediterranean Sea in a rather narrow belt no more than a couple of hundred kilometers wide, except for the southeastern coast, where the Sahara Desert extends northward up to the coast. It is characterized by a rather short, mild, and rainy winter and a long, warm, and dry summer. Rainfall averages from 400 to 1200 mm/year, mostly concentrated in short, strong showers. The fauna and flora are rich and varied in number of genera and species. A considerable part—about 50%—of the plant species is endemic to the circum-Mediterranean (Zohary 1959). The climax vegetation comprises evergreen forests and maquis (Figure 2.46) in which typical trees are *Pinus halepensis, P. pinea, Laurus nobilis, Ceratonia siliqua, Pistacia lentiscus, P. saportae, Phillyrea media, Olea europaea, Viburnum tinus, Myrtus communis, Rhamnus alaternus, Juniperus oxycedrus,* and *J. phoenicea.* More restricted to the eastern Mediterranean are trees like *Cedrus libani, Quercus calliprinos, Q. infectoria, Q. ithaburensis, Q. aegilops, Q. libani, Arbutus andrachne, Pistacia palaestina, Abies cilicica, Cupressus sempervirens, Crataegus azarolus, Cercis siliquastrum, Styrax officinalis,* and so on, some of which are winter deciduous.

Two other vegetational formations are typical and widespread within the Mediterranean environments, the batha and the garigue. The batha (Figure 2.47) covers large areas that have been deforested or marginal areas in which the climate can no longer maintain the maquis. It consists of low shrubs and herbs, many of them aromatic, of which the most typical is *Poterium spinosum.* The

TABLE 2.1
Percentages of Plant and Animal Species of Israel, Regarding Their Environmental Provenance

Group	Environment				
	Mediterranean	Irano-Turanian	Saharo-Sindian	Tropical	Euro-Siberian
Plants	57	20	20	3	1
Mammals	25	14	36	12	14
Birds (res.)	26	28	22	8	14
Reptiles	39	18	37	4	—
Freshwater fish	45	20	7	27	—
Terrestrial mollusks	68	9	15	1	6
Animals—total	52	15	15	5	13

Note: Among the plants, only those that show definite environmental connection (about 60% of all the plant species of Israel) are treated in this table, and this sample is taken as 100%.

A

B

C

FIGURE 2.46. *Mediterranean maquis: A, typical, well-developed variant of the uppermost Galilee; B, degenerated, due to less precipitation and pasturing, characteristic for most of the Mediterranean region of Israel; C, the coastal variant of* Ceratonia siliqua *and* Pistacia lentiscus.

garigue is kind of a bush (Figure 2.48) that consists mainly of woody shrubs sometimes regarded as a transition stage between the batha and the maquis or as a subclimax vegetation. Typical soils of the Mediterranean environment are the terra rossa, rendzina, and sandy soils of the coastal plain.

The Mediterranean environment occupies about half of Israel (Figure 2.45): the mountainous areas down to the Be'er Sheva Basin, except for the east-facing slopes, which suffer from rain shadow; the Northern Jordan Valley down to the southern shore of Lake Kinneret; and the coastal plain down to the Western Negev Coastal Plain, which is included only in part, except for the coastal dunes from Caesarea southward. To the north and on the higher mountains, rainfall is in the range of 800–1000 mm/year, whereas to the south and in the lowlands it gradually decreases down to 400 mm/year. Soils are mainly terra rossa and rendzina on the mountains, hamra on the coastal plain, and alluvial or colluvial soils in the valleys. The Mediterranean vegetation of Israel comprises several variants (according to Eig, 1946). The sub-Mediterranean group comprises species that are not confined only to the Mediterranean region proper but also appear in neighboring environments. About 160 species of these are known in the country; most of them also appear in the Irano-Turanian steppes. Of interest is a small group of plants found in Israel that otherwise appear only in the Atlantic sector of the Euro-Sibiric domain. Examples of these are *Crithmum*

FIGURE 2.47. *Batha, in the Judean Hills.*

FIGURE 2.48. *Garigue, in the Judean Hills.*

maritimum, Euphorbia paralias, Inula crithmoides, Glaucium flavum, Pancratium maritimum, and *Adonis autumnalis.* No trees are known for this subgroup.

The circum-Mediterranean group includes plants known practically all around the Mediterranean. About 150 species of these grow in Israel, including important trees such as *Pinus halepensis, Pistacia lentiscus, Ceratonia siliqua, Rhamnus alaternus, Viburnum tinus,* and others, all constituents of the Mediterranean maquis. It should be noted that no deciduous trees occur among the circum-Mediterranean group. This group also includes several of the more important constituents of the batha and garigue, such as *Calycotome villosa, Cistus villosus, Lavandula stoechas, Thymus capitatus,* and others. The eastern Mediterranean group is the most conspicuous of the Israeli vegetation, including more than 500 species. The most important maquis, batha, and garigue constituents are trees such as *Quercus calliprinos, Q. infectoria, Q. ithaburensis, Pistacia palaestina, Arbutus andrachne, Acer syriacum, Cercis siliquastrum,* and *Platanus orientalis* and shrubs such as *Poterium spinosum, Salvia triloba, Phlomis viscosa, Teucrium divaricatum, Majorana syriaca,* and many more. The eastern Mediterranean group is relatively rich in geophytic plants—about 12% of the total. Most of the endemic plants of Israel belong to this subgroup. It is interesting to note that some of the trees that belong to this group are winter decidous, like *Quercus ithaburensis.* The two other groups, the western Mediterranean and the northern Mediterranean, are represented in the Israeli flora by only a minor number of species that are indeed subordinate today. They are, however, of great interest for the evolution of Israeli flora, which will be discussed later.

The Mediterranean vegetation of the mountainous areas includes several communities, of which the most important are the *Pinus halepensis–Hypericum serpyllifolium* community, which grows mainly on calcareous soils (rendzina) and is accompanied by *Quercus calliprinos, Pistacia palaestina, P. lentiscus, Ceratonia siliqua, Phillyrea media,* and other trees and shrubs; the *Quercus ithaburensis* community, in which this tree is the main constituent and is sometimes accompanied by *Q. calliprinos, Pistacia palaestina, P. atlantica* or *Styrax officinalis;* the forest and maquis of *Quercus calliprinos* and *Pistacia palaestina,* which occupy considerable areas in Israel and are accompanied by trees such as *Pistacia lentiscus, Crataegus azarolus,* and *Ceratonia siliqua* among others. Whenever humidity and water availability are somewhat above average, this forest is also accompanied by trees such as *Laurus nobilis* and *Cercis siliquastrum* among other northern elements. An interesting community is that of the *Ceratonia siliqua* and *Pistacia lentiscus,* which grows not only on the foothills but also on the coastal dunes of the central coastal plain. Transition areas between the Mediterranean and the Irano-Turanian belts are sometimes occupied by a maquis made up mainly of *Amygdalus communis* and *Crataegus azarolus.* The typical Garigue communities are dominated by *Salvia triloba, Phlomis viscosa, Calycotome villosa,* and *Cistus salvifolius,* and the typical batha plants are *Poterium spinosum* and *Thymus capitatus,* among many other herbs. The Mediterranean sector of the coastal plain is an independent vegetational unit characterized by palnts such as *Ammophila arenaria, Artemisia monosperma,* and *Retama roetam,* which can resist movements of the dunes.

The Mediterranean fauna of Israel includes mammals such as *Rhinolophus blasii, Microtus guentherii, Lepus syriacus,* and *Lynx pardina* among others, which totally amount only to some 25% of the 95 mammal species of Israel. The reason for this is probably the considerable influx of Saharo-Sindian elements from the Sahara, through the North African coastal plain. Mediterranean resident birds also form only 26% of the resident avifauna. Typical are *Sylvia melanocephala,* and *Alectoris graeca,* for example. Mediterranean reptiles such as *Agama stellio* and *Coluber jugularis,* among others, form about 40% of the reptilian fauna of Israel, which includes a total of some 80 species. Freshwater fishes, of which *Blennius fluviatilis* and *Discognathus rufus* are typical Mediterranean representatives, share 45% of the 35 species known. Most groups of Mediterranean insects or other invertebrates comprise more than 50–60% of the total.

IRANO-TURANIAN ENVIRONMENT

The Irano-Turanian region extends from the Danube to the west to the Gobi Desert to the east. It is characterized by rather low rainfall, mostly not exceeding 350 mm/year, and by extreme temperatures: a very cold winter, a mild spring, and a hot summer. The plant activities are generally restricted only to the spring and early summer, being limited by the cold winter and the hot summer. The most common vegetational formation is the steppe (Figure 2.49), which is rather rich in number and variety of species. It grades to deserts where precipitation is lower and to forests mostly confined to the mountainous areas, where local rainfall is heavier.

Irano-Turanian environments in Israel form a strip separating the Mediterranean from the Saharo-Sindian region. The more conspicuous areas are the Central Jordan Valley, the Judean Desert, and the Northern and part of the Western Negev, including the Be'er Sheva Basin. The Irano-Turanian flora makes up only about 13% of the plant species of Israel and forms steppes. Trees and shrubs occasionally accompany the steppes, of which some of the more important are *Zizyphus lotus, Pistacia atlantica, Artemisia herba-alba, Noea mucronata, Haloxylon articulatum,* and *Rhus tripartita.* The first two trees, *Zizyphus* and *Pistacia,* sometimes form a kind of savannah where they grow quite sparsely, separated by areas of grasses and other small herbs. Irano-Turanian animals comprise about 15% of the total fauna of Israel. Typical mammals are *Dryomys pictus, Vormela peregusna,* and *Lepus judeae;* birds, *Oenanthe nomacha* and *Lanius nubicus;* reptiles, *Ophisops elegans,* and *Leptotyphlops phillipsi;* and freshwater fish, *Cyprinodon* and *Nemachilus.*

FIGURE 2.49. *Irano-Turanian steppe of the Western Negev.*

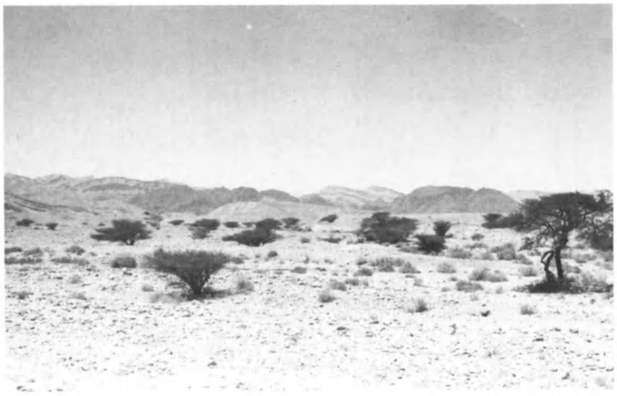


FIGURE 2.50. *Saharo-Sindian desert vegetation of the Southern Negev, with strong Sudanian influence of acacias.*

SAHARO-SINDIAN ENVIRONMENT

The Saharo-Sindian domain extends along Northern Africa, the Sinai, Arabia, the southern parts of Iraq and Iran, Baluchistan, and the Sind Desert of western India. It is characterized by very low precipitation, which never exceeds 200 mm/year and is usually much less. The rare rains occur only very irregularly during the mild winter, and quite frequently the entire annual amount pours down in a couple of hours. Rates of evaporation are frequently a hundred times the average precipitation. The summer is very long, hot, and dry. The diurnal temperature differences are considerable; this keeps the yearly average close to constant. The typical soils are of an immature profile, such as hammadas, sands, and sebkhas. In marginal areas, loess is sometimes deposited. Both plants and animals, of which the total number of species is rather restricted, show adaptation to these desert conditions. The annual plants have a very quick growth, and during the short rainy season they are able to produce seeds. The seeds can resist drought several years and germinate only when water is available. Some of the plants have developed succulent organs and have reduced considerably their evapo-transpiration processes. The greater part of the shrubs and the rare trees do not carry leaves throughout most of the year, except for the short rainy season, when all growth processes take place rapidly. The animals are mostly nocturnal, live underground, or stay in rock shelters during the daytime. They do not normally drink water—they absorb enough from their food—do not sweat, and have various physiological adaptations to keep their blood osmotic pressure constant (M. Horowitz 1971).

The Saharo-Sindian environment extends in Israel over almost the entire Negev, with northward intrusions to the Dead Sea Basin, the Southern Jordan Valley, and the coastal dunes up to about Caesarea. The hammadas are sparsely covered by vegetation (Figure 2.50), and in many areas, especially to the south, they maintain vegetation only on the wide floodplains of the wadis. The most abundant plants are *Zygophyllum dumosum, Anabasis articulata,* and some others. In gypsiferous soils, which are especially abundant near the Dead Sea, plants such as *Suaeda asphaltica* and *Chenolea arabica* are common. Sand deserts maintain vegetation that is somewhat richer than

FIGURE 2.51. *Hydromorphic vegetation of the southern Dead Sea area, comprising* Tamarix, Phoenix, *and other plants supported by the high groundwater table.*

FIGURE 2.52. *Sudano-Deccanian enclave of En Gedi, connected with the running water.*

that of the hammadas, and the most common plants are *Zilla spinosa, Noea mucronata, Haloxylon persicum, H. salicornicum, Retama roetam, Artemisia monosperma,* and *Aristida scoparia.* The sebkhas, which form a unique environment of the Saharo-Sindian domain, are inhabited by several species of *Tamarix* (Figure 2.51), which occasionally cover the area so densely as to become dense groves, and by other plants, of which the most abundant are *Suaeda monoica, Statice pruinosa, Alhagi maurorum,* and various species of *Atriples.* The Saharo-Sindian elements of the Israeli flora comprise only about 13% of the total number of species, although the area occupied by those elements is approximately half of the country. In comparison, the Mediterranean elements comprise about 50% of the Israeli species and grow on a somewhat smaller area than that occupied by the Saharo-Sindian.

Saharo-Sindian animals, if we take into consideration veterbrates and invertebrates together, comprise about 15% of the fauna (Bodenheimer 1935). Surprisingly high figures, though, are for mammals and reptiles—almost 40% of the total representatives of each group in Israel. Examples are the many desert mice, like *Acomys cahirinus, Meriones crassus,* and *Gerbillus allenbyi;* some gazelles; and reptiles such as *Agama sinaita, Varanus griseus, Psammophis schokarii,* and *Naja haje.* Saharo-Sindian birds are also quite common in Israel, comprising about 22% of the avifauna, with species such as *Ammomanes deserti* and *Pterocles senegallus.*

Springs and wadi beds of the Saharo-Sindian region of Israel, in which water is available throughout the entire year, maintain a microenvironment that resembles the dry tropical regions of Africa in which savannahs are the main vegetational formation. These microenvironments are sometimes referred to as Sudano-Deccanian enclaves (Figure 2.52), but it seems that they are just niches and should not be treated as a unique phytogeographic domain, since they also contain some elements typical of other environments. About 40 species of tropical plants are known from these niches, many of them trees. Such are various species of *Acacia, Zizyphus spina-christi, Balanites aegyptiaca, Moringa aptera,* and *Salvadora persica.* They are most abundant along the Arava and Jordan Valley, but some varieties of *Acacia albida* are also known from the western slopes of Judea and from the Central Jordan Valley, and *Zizyphus* is quite common on the coastal plain.

OTHER ENVIRONMENTS

Tropical elements form about 5% of the Israeli fauna, but among them two groups connected with freshwater bodies are conspicuous: freshwater fish (27%), of which the most abundant are cichlids and *Clarias,* and dragonflies (38%). Tropical mammals, such as *Caracal caracal* and *Mellivora ratel,* are rare, and some of the typical tropical mammals, such as lions and cheetahs, known in Israel until the nineteenth century, are now extinct due to hunting. The same fate was shared by the ostrich, whereas some other tropical birds seem to do quite well in the presence of man: birds like *Pycnonotus capensis, Cynyris oseae* and *Streptopelia senegalensis,* known only as rarities in the nineteenth century, are now common and abundant all over the country.

Euro-Siberian elements, both of fauna and flora, appear in Israel in small numbers. Most of them are scattered among the Mediterranean environments, but some appear in niches of the desert as well. Such species are bats like *Pipistrellus,* some soricidae, and at least two of the larger mammals (which are now extinct due to overhunting during the nineteenth and the early years of the twentieth centuries), the buck *Capreolus capreolus* and the bear *Ursus syriacus.* Euro-Siberian elements within the vegetation number about 15 species, including *Scutellaria galericulata, Bellis perennis,* and *Dryopteris thelypteris;* these share only a subordinate part of the flora.

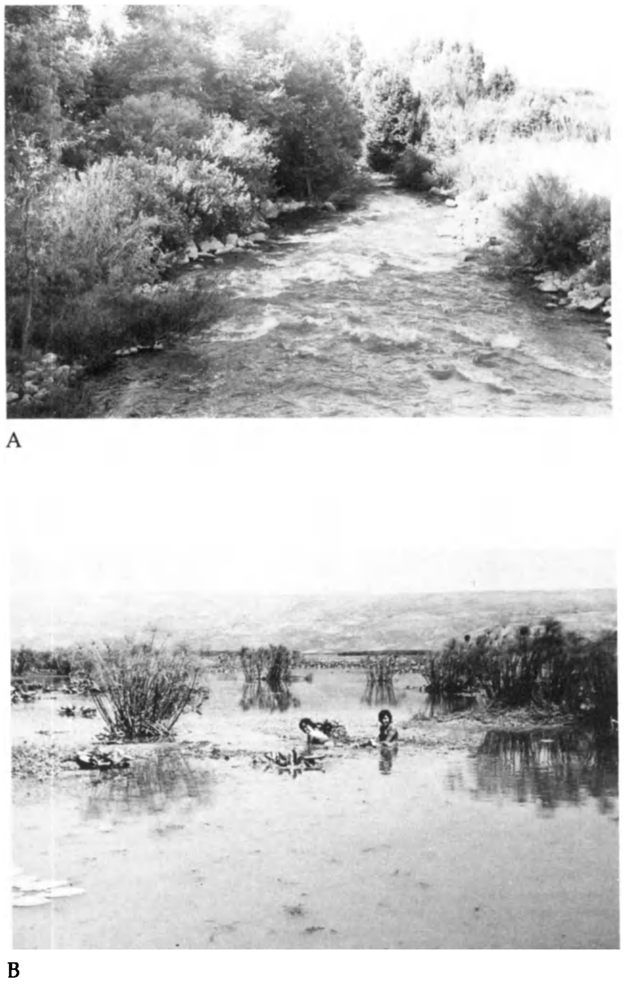


FIGURE 2.53. *A, hydrophil bank vegetation of the northern Hula Valley; B, hydrophil marsh vegetation of the Hula swamps.*

About 40% of the plant species of Israel grow in two or three of the previously mentioned environmental domains and do not characterize one in particular. They are either found in the entire country or, as is the case quite frequently, belong to the special *hydrophil environment.* The main necessity of plants confined to this environment is the availability of water throughout the year, and they are less dependent on factors such as rainfall, temperature, and so on. The hydrophil environments (Figure 2.53) maintain, therefore, a mixture of almost everything; a good example would be the Hula Basin, in which Euro-Siberian elements such as *Dryopteris thelypteris* and *Fraxinus syriaca* grow side by side with tropical plants like *Tamarix* or *Cyperus papyrus.* The same is true for the animals that inhabit these water bodies. The distribution of the more important plant communities in Israel is shown in Figure 2.54.

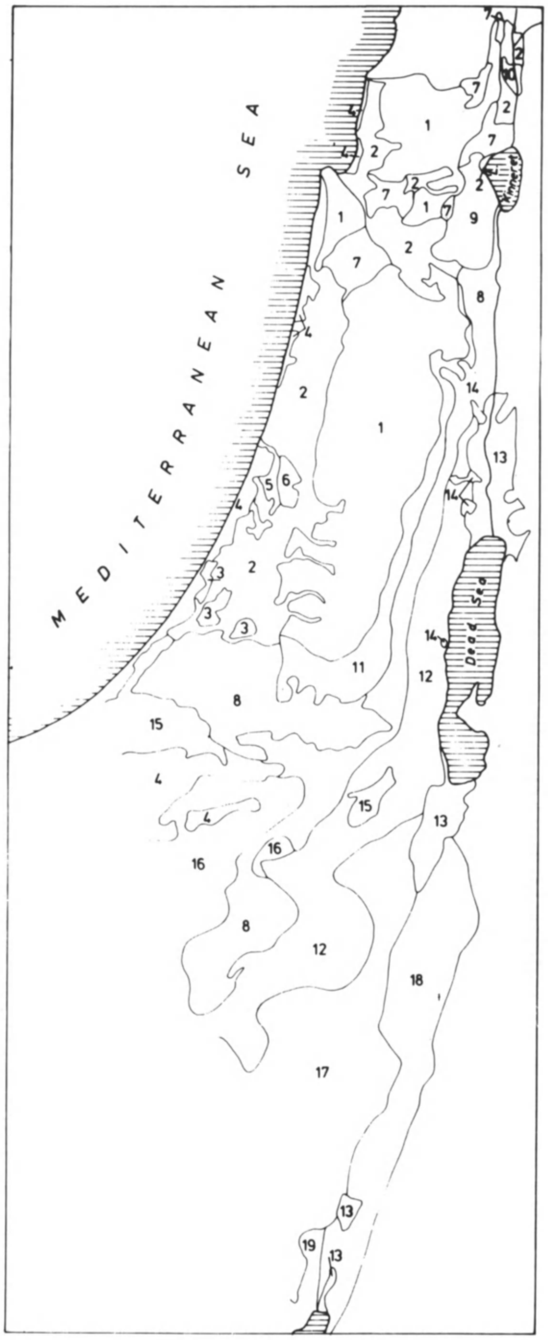


FIGURE 2.54. *Distribution of the main vegetation groups in Israel: 1, Mediterranean maquis; 2, cultivated alluvial plains, natural vegetation unknown; 3, batha and garigue; 4,* Retama roetam *community of sand dunes; 5, sandy-clay soil vegetation, mixed with batha; 6, sandy-clay soil vegetation; 7, Mediterranean herbaceous batha; 8, Irano-Turanian steppes; 9, semi-steppe batha with* Zyziphus; *10, hydrophil vegetation of the Hula; 11, semi-steppe batha; 12, Saharo-Sindian desert vegetation; 13, halophil vegetation; 14, sudanian oases; 15, psammophil vegetation; 16, stony and loess desert vegetation; 17, hammada vegetation, mainly in wadi beds; 18, sandy and rocky desert vegetation; 19, pseudo-savannah with* Acacia.

RECENT EROSIONAL AND DEPOSITIONAL PROCESSES

Most of the elevated areas of Israel are presently subject to quite severe and extensive erosion resulting from the rather steep, tectonically young morphology, the pattern of rains, which pour down strongly during short times, and the lack, in many places, of a vegetation cover, which might have prevented to some extent the consequences (Figure 2.55) of these floods. The mode of erosion varies with the area under consideration, being more gentle to the north (Figure 2.56) and becoming more and more steep and torrential south and eastward. Some other factors play a role in the mode of erosion, such as properties of the bedrock, the existence and the directions of joints, etc.

Leopold *et al.* (1964) tried to calculate rates of erosion under different amounts of runoff, given in tons per square mile of eroded debris. They have shown that the quantities of debris increase very quickly from a condition of no rain up to about 250–300 mm/year rainfall, then drop considerably as rainfall approaches 750–800 mm/year, at which point an annual amount of about 250–300 tons per square mile of debris is removed, regardless of increasing runoff. Most of the Mediterranean areas of Israel fall at the top of the curve, with maximal rates of erosion of approximately 500–800 tons of debris removed from each square mile annually. Runoff is the main cause of erosion in the Mediterranean areas, combined with some soil creeping and landslide processes. The combination of natural conditions that influence erosion—average runoff, poor vegetation, concentration of strong rains over short periods, and tectonic innovation of the relief—cause the formation of quite steeply incised valleys (Figure 2.57). With decreasing runoff southward, badlands are formed in soft sediments (Figure 2.58), whereas harder, more resistant rocks form cliffs, which are typical for almost the entire Negev (Figure 2.59) and for the Judean Desert.

Exact figures for amounts of material removed during erosion are rare, mainly due to the impossibility of follow-

FIGURE 2.55. *This "building" is the inside lining of a Byzantine well, now protruding some 6 m above Nahal Gerar thalweg, Western Negev.*

FIGURE 2.56. *Gently dipping erosive surfaces in the Galilee.*

FIGURE 2.57. *Flood activity in the Dead Sea area. The boulders, some of which are more than 0.5 m across, covered the road to a depth of almost a meter during a single flood on January 4, 1978 of Nahal Hever.*

FIGURE 2.58. *Badlands in loess, Western Negev.*

ing such processes over a controlled period long enough to factor out random variables. A minimum figure was obtained for northeastern Israel and seems rather considerable (Horowitz 1975a). A swarm of clastic dikes was found to cut the Eocene rocks of the Yir'on–Bar'am Plateau, west of the Hula Valley. The dikes consist of Rissian paleosols containing Acheulian artifacts and have been downsifted into tensional fissures formed following some tectonic deepening of the Hula Graben. The dikes are presently exposed on both sides of a tributary of Nahal Dishon (Figure 2.60) leading to the Hula. The locality where the dikes presently cut the wadi must have been part of the Plateau, since otherwise the paleosols would not have been downsifted into the fissures but would rather have been carried away by the wadi. The dikes cut the wadi perpendicularly, and a minimum figure for the amount removed by the single wadi during the last 100,000 years of its incision in the hard Eocene limestone is about one-third of a cubic kilometer.

In the desert areas, where throughout most of the year there is no vegetation cover at all, wind deflation also becomes a major erosive force. It is impossible, at the present state of knowledge, to assess annual quantities removed by the wind per unit area, but, looking at the amounts of dust brought northward during dust storms and sometimes covering Jerusalem with a 5-mm-thick layer overnight, the wind deflation action is considerable in the deserts. In the southern Negev, where winds are the main and almost sole erosion agent, they produce stone deserts in which the bedrock is exposed over large areas (Figure 2.61).

The fine dust that is lifted by winds in the Negev and the Sinai is deposited at every other locality of the country where there is enough vegetation to trap it. In the desert itself, dust is trapped in playas and sebkhas. The area most influenced by dust deposition is the northernmost and the Western Negev. In these areas, vegetation cover is sufficient to cause dust trapping, and loess accumulates (Figure 2.62). Some reworking of the loess by local wadis results in what is locally called *fluviatile loess*, a term that is basically wrong, since it is applied to sediments that are, in fact, fluviatile silts. Dust carried by winds further

FIGURE 2.59. *The post-Mousterian canyon of Avedat, cut into Eocene limestones and Paleocene shales.*

FIGURE 2.60. *Clastic dikes in the northeastern Galilee. The predominant rock of the countryside is Eocene limestone. The dikes comprise fissure sifting of Rissian paleosols containing Middle Acheulian flakes.*

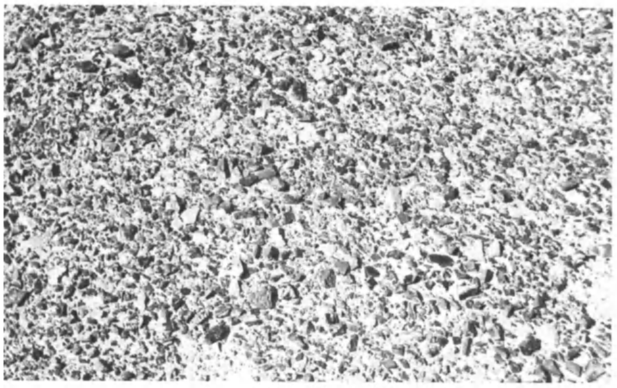


FIGURE 2.61. *Wind-deflated surface (hammada) of the southern Negev.*

FIGURE 2.62. *The northwestern Negev, an area of present-day loess deposition.*

north mixes with the locally formed weathering products, somewhat increasing their silty and clayey fraction. This dust is apparently the source of clay minerals for the coastal plain and other soils (Yaalon and Dan 1967). The share of aeolian dust in the sediments decreases northward, and at the Galilee it is hardly noticeable. The prevailing western winds in Israel also carry some dust from the sea inland, in the form of minute halite crystals. These crystallize from the waves' spray and are carried quite far inland, and according to some investigators (Loewengart 1961) are the main cause for salinity of groundwater in Israel.

Sand dunes are deposited in two regions of the country, the coastal plain and some parts of the Negev and the Arava (Figure 2.63). In the coastal plain, the dune sands are carried by winds eastward from the shoreline, where they are pushed and accumulated by wave action. The major part of coastal dunes is made up of quartz grains, with some carbonate shell debris and minor amounts of heavy minerals. The heavy mineral assemblage (Nachmias 1969) points to the Nile as the main source area for sand. The geographic distribution of sand along the coast also seems to corroborate this finding: Sand dunes are much wider on the Western Negev Coastal Plain and are also carried far into the Western Negev, whereas the sand dune strip narrows northward to Haifa Bay, which is the final locality at which these dunes are encountered on the Levantine coast. Some littoral sands, but not actual dunes, that accumulate north of Akko (Acre) do not contain quartz grains and consist instead of carbonate shell debris. Dunes also accumulate in the Negev, where older sandstones are subject to erosion, mainly near outcrops of Paleozoic, Early Cretaceous, and Miocene rocks, such as those at the Makhteshim erosion cirques and in the Rotem Plain. Some more extensive dunes accumulate at the southern Arava, where wadis drain the eastern rift escarpment and the northern winds catch the sand and cause the formation of elongated seif dunes.

Alluvial and colluvial deposits are presently being accumulated in many areas of the country, in the intermontane valleys and on the shoulders of wadis' floodplains, as a result of the strong weathering that takes place on the surrounding elevated areas. The colluvium is mainly silty and red to brown, depending on the source materials, and at some localities may accumulate rather quickly to form sequences of tens of meters in thickness. Colluvial deposits are especially common in the large valleys and plains, such as the Yizre'el Valley and the Shefela foothills (see Figures 2.39 and 2.40).

Alluvial sediments are restricted to the wadis and their outlets. The strong erosion prevents almost any sediments from accumulating in the wadi floors as long as they flow within mountainous terrain; on the contrary, wadis seem to erode previous alluvial sediments in their course (Figure 2.57). Otherwise, many of the wadis in Israel flow directly on bedrock, intermittently carrying with them and depositing some gravel that is then carried away by the next flood. This phenomenon is typical for the entire mountainous region of Israel, from the Galilee down to the Elat area, and in almost no place are alluvial sediments found to fill the present-day wadi floors. Most of the alluvial sedimentation occurs at the wadi outlets, where, at some localities, such as the Arava or the Dead Sea, considerable alluvial fans are formed (Figure 2.64). Most of these fans are fossil today and are subject to erosion and incision, whereas the fans formed now are farther downstream and are considerably smaller. Floodplain deposition is at present quite rare in Israel, occurring only following some considerable seasonal flooding of the wadis and, sometimes, on the shoulders of the Jordan River, especially in its southern reaches (Figure 2.65).

No proper deltas are formed by any of the perennial streams that flow to the Mediterranean, and their sediments are spread along the shore by the longshore current of the eastern Mediterranean. Streams flowing to the Mediterranean are sometimes blocked by dunes, forming seasonal or sometimes even all-year-round marshes in which organic sediments accumulate (Figure 2.66). These sediments are clays and silts rich in organic material for the most part. Some of the mineral fraction is aeolian, and the rest comes from admixture with the subsoil. At one

FIGURE 2.63. *Sand dunes of the Southern Arava.*

FIGURE 2.64. *Alluvial fan of a wadi flowing to the Dead Sea.*

FIGURE 2.65. *Floodplain deposits of the Jordan River, Central Jordan Valley.*

FIGURE 2.66. *The coastal plain marshes, connected with the floodplain of Nahal Alexander.*

locality on the coastal plain, the marshes connected with Nahal Poleg, peat was deposited until the area was artificially drained.

The Mediterranean sediments off the shore of Israel are mainly influenced by the Nile (Nir 1973). They are presently arranged in strips subparallel to the shoreline. At the shoreline itself,.beachrock is formed in many localities as a very narrow strip made up of beach gravels, coarse sand, and many mollusks (Figure 2.67). The beachrock grades to carbonate cemented quartz sandstone seaward, also containing some mollusk debris. Farther seaward extends a strip of medium-grained quartz sand, several kilometers wide at the southern shelf and tapering northward. Farther west extends a strip of silt, also tapering northward, that grades to fine clays. It is quite interesting to note that at present the Nile does not carry to the Mediterranean sediments coarser than lutite, and the sand that is deposited along the Israeli shore and the upper shelf was probably brought to the area during times of a somewhat different regime of the Nile and at present is only reworked. This was noted by Butrimowitz (1971) when he measured sand movements along the coast; it was found that sand moves mainly southward.

Rates of deposition offshore in the eastern Mediterranean are considerable. A palynological study of seabottom cores off Haifa Bay (Horowitz 1974d) enabled correlation of the sequences with continental radiocarbon-dated sections. It was calculated that sediments accumulate near the shore (under 44 m of sea water) at a rate of 1500 years/meter, whereas sediments accumulate under 1116 m of sea water at a rate of 3000 years/meter. Further south, at the area of Palmahim, cores have been collected under 500 m of sea water, and their foraminiferal content has been analyzed (Reiss *et al.* 1971). By comparing the paleoecology of fossils with the paleoclimates, the cores could be dated, and a rate of deposition of 1000–1200 years/meter ensues.

Lacustrine sediments are presently laid down in three subbasins of the Jordan–Arava Rift Valley, the Hula, Lake Kinneret, and the Dead Sea. The processes described for the Hula are valid only up to 1955, when the lake was artificially drained. Three types of sediments accumulated in the Hula Basin, interfingering with each other. Alluvial fans line the Basin, consisting mainly of conglomerates and colluvial sediments. Lacustrine marl containing quite a variety of fossils of freshwater mollusks (Figure 2.68) was deposited in Hula Lake proper at a depth of 3–4 m. This lacustrine marl contains high amounts of carbonates and, in some localities, turns to chalk. At places where the lake was shallower, the amount of organic material within the marl becomes considerable. North of Hula Lake there existed an area, occupied by marshes throughout the year, in which peat, composed mainly of roots and stems of *Cyperus papyrus* (Figure 2.69), was deposited. Rates of deposition for the Hula sediments are very high (Horowitz 1971), in the order of 400 years/meter, according to radiocarbon-dated cores.

FIGURE 2.67. *Recent beachrock of the Mediterranean, near Nahariyya, Western Galilee.*

The northern end of the Central Jordan Valley is presently occupied by Lake Kinneret, which is much deeper than the Hula. The shores slope down considerably toward the center of the lake, which is more than 40 m deep. The salinity of Lake Kinneret is much higher than that of the Hula, up to 20 times as great, because of the influx of

FIGURE 2.68. *Recent lacustrine marls of Lake Hula, rich in* Corbicula *and* Unio *shells.*

FIGURE 2.69. *Peat bogs of the Hula Valley, with* Cyperus papyrus *as the main peat-producing plant.*

FIGURE 2.70. *Recent lakeshore sediments of the Kinneret.*

FIGURE 2.71. *Recent salt and gypsum crust, forming on the Dead Sea shore.*

saline solutions from a series of springs on the lake's shores and bottom. The sediments are made up mainly of silts that are gray-brown, poor in organic material, and relatively poor in carbonates (Nir 1963). The shores are lined with beach gravels and with some alluvial conglomerates carried down from the encircling hills, which are sometimes rather rich in *Melanopsis* shells (Figure 2.70). Only on part of the eastern shore, where outcrops of Miocene sandstones face the lake, are the beaches sandy. The rate of deposition of lacustrine sediments in Lake Kinneret is approximately 2000 years/meter.

The Dead Sea, which is the final base level of the Jordan drainage system, is a hypersaline lake, in which salinity exceeds 32%. The most important anion (Neev and Emery 1967) is chlorine, followed by small amounts of bromine, sulphate, and bicarbonate. The principal cations are magnesium and sodium, followed by some calcium and potassium. Most of the sediments deposited in the Dead Sea, except for some clastics that line the shores, are chemical precipitates—rocksalt, gypsum (Figure 2.71), aragonite, and calcite. The Dead Sea sometimes displays annual cyclic sedimentation, although probably not repeating every year. The hot summer causes precipitation of a white gypsum–aragonite mixture, whereas a dark aragonite–calcite blend is typical for the winter. In addition, winter sediments contain some fine clastics, chiefly clays like kaolinite, illite, and others. Halite is not deposited extensively at present in the Dead Sea, except in some marginal lagoons. Spring deposits, in the form of travertines, are known from many localities of the country where springs are active (Figure 2.72). These springs are especially common around the Jordan–Arava Valley, and the travertines are composed mainly of carbonates, mostly aragonite. In some locations, the carbonates envelop vegetal remains and rare freshwater snails and thus contain organic material.

The Bay of Elat (Aqaba), at the southernmost tip of the country, differs considerably from any other depositional environment in Israel. It has no connection with the Mediterranean and is a tropical enclave, probably the northernmost tropical environment on earth. No streams presently flow to the Bay, and except for rare wadi floods the only source for clastic material is the wind. The shoreline is framed by beachrocks of coarse, polymyctic conglomerates (Figure 2.73) opposite the wadi outlets, and coarse-to-medium sandstones at the interfluves.

FIGURE 2.72. *Recent travertine, forming at En Mashaq, near Hazeva.*

FIGURE 2.74. *The fringing coral reefs at the Bay of Elat. (Photograph by D. Darom, courtesy of I. Paperna, H. Steinitz Marine Biology Station, Elat.)*

Several meters seaward, deposition is controlled by the development of coral reefs (Figure 2.74). These are magnificently developed, including a variety of species and colors that yield all types of sediments typical of reef environments—backreef lagoons with pelletal limestones, reef cores, forereef talus, etc. The rate of growth of these reefs is apparently very slow, but no figures for this area are available.

The deeps are covered with ooze, sometimes "deep ocean" pteropod ooze, made up mainly of pelagic fossils, with only small amounts of clastic materials, such as kaolinite. The rate of deposition is extremely slow, which one can conclude from the very high absolute abundance of pollen grains in the sediments (Horowitz 1966). Pollen comprises a considerable part of the sediments, and, since it is carried into the Bay from distant areas, it seems that a long time is necessary for its concentration. Distribution of the main erosive and sedimentary terrains in Israel is shown in Figure 2.75.

FIGURE 2.73. *Recent beachrock, Bay of Elat.*

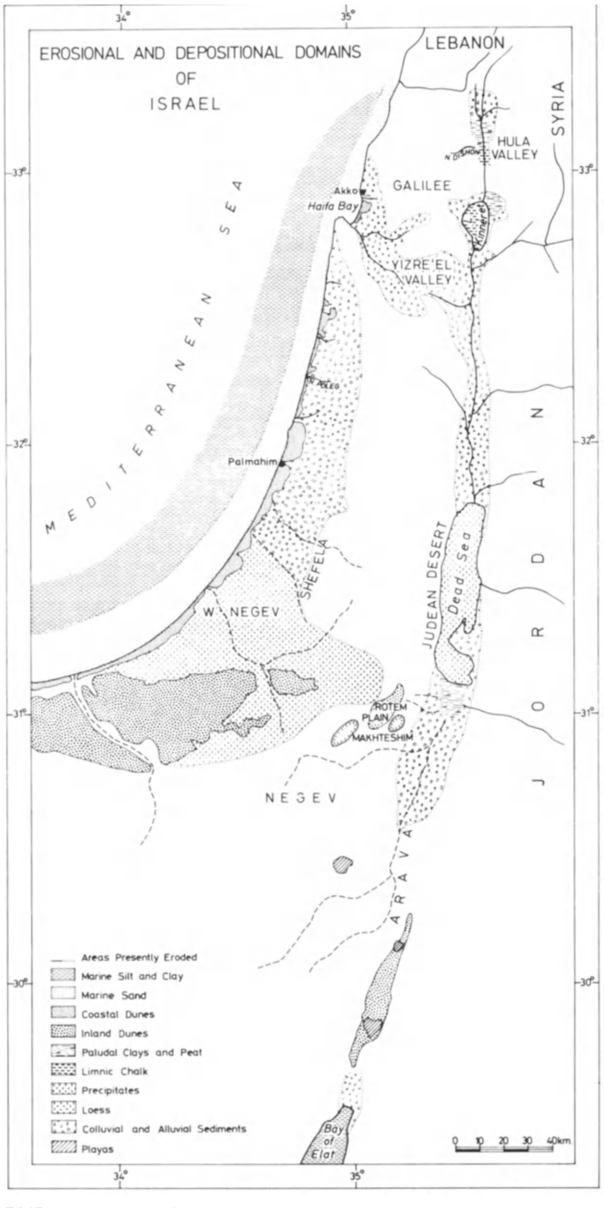


FIGURE 2.75. *Erosional and depositional domains of Israel.*

SEISMICITY AND RECENT TECTONIC ACTIVITY

The seismicity of Israel has been studied by several investigators who have compiled maps and catalogs, such as Amiran (1951), Shalem (1951, 1954), and Arieh (1967). Generally, the present-day earthquakes are rather weak, not exceeding 5.2 on the Richter Scale. Some stronger ones (although not exceeding 6.2) have been noted during the last 60 years. According to the geographical distribution of epicenters in Israel and in the rest of the Near East during the last 60–100 years, several theories have been developed as to the possible connection of seismicity and local tectonics. Sieberg (1932) postulated that a belt of earthquakes crosses the country from the Galilee down to Gaza (NE–SW), whereas Shalem (1954) insisted that the seismic belt should run in a NW–SE direction, which he preferred to call "the Erythrean System." Arieh (1967), objecting to both interpretations, found a connection between the seismic activity of the Levant and the N–S lineament of the Jordan Rift Valley. It seems clear that the various opinions are due to the scarcity of data. Prior to 1954, no instrumental observations were made, and the data have been collected mainly from witnesses who did not necessarily live right on the epicenters but always claimed that the locality where they were was the center of activity. Also, it seems that observers without instruments tend to exaggerate the strength of activity.

Stronger seismic activity has been observed (Figure 2.76) in the eastern Mediterranean, between Cyprus and the Syrian–Lebanese coast. Once again, this is subjective; the weak quakes were never recorded in the sea, since most of them were not felt on land. Still further north, Turkey is subject to strong seismic activity. Although no tremors weaker than 5.2 are reported from the Mediterranean, a survey of historic documents shows quite a number of reports on what apparently were *tsunamis* that have affected the eastern Mediterranean coast (Shalem 1956). A survey of historic documents for earthquakes during the last 2000 years in the eastern Mediterranean (Ambraseys 1975) shows that throughout this span several tremors have been recorded, some of which, according to descriptions, had a considerable intensity. Once again, it is rather difficult to assess the intensity on any scale, since most of the descriptions are highly exaggerated. The frequency of medium-to-strong earthquakes in this region, however, is one every 100–200 years, and at least some of them are connected with eruptions of the Santorini Volcano, the only active volcano in the eastern Mediterranean Basin. Arieh (1967) has suggested that earthquakes recorded during recent decades in Israel are connected with movements along the Jordan–Arava Rift Valley, whereas those recorded from the vicinity of Cyprus are connected with the Alpine chain. Looking at the map (Figure 2.76), it does not seem so definitely clear. Many of the epicenters in Israel are outside the Rift area, and it is much more so in Lebanon. It might well be that most earthquakes are connected with activity along faults in Israel, but it seems that much more information must be gathered before firm conclusions can be drawn. Neev *et al.* (1976) claim that earthquakes in the Mediterranean are connected with the tilting of the shelf.

Recent tectonic activity is presently a subject of great debate in Israel. Previous authors, such as Picard (1943) and Itzhaki (1955), claimed that at least some faults are still active in Israel, especially in the Galilee (Figure 2.77) and in the coastal plain (Figure 2.78). However, measurements are not available, and the only evidence is the "fresh" appearance of fault planes and the fact that some planes are practically uneroded. Zak and Freund (1966) brought forward the best documented (possibly Recent) faulting in Israel at the southern Arava, opposite the copper mines of Timna (Figure 2.79). Looking eastward, a series of low hills with quite steep, west-facing escarpments can be seen. But when observed from the air, or on aerial photographs, it can be seen that some of the more recent alluvial fans are offset in a combined strike-slip–dip-slip movement, forming small rhomb-shaped grabens. The amount of strike-slip movement is about

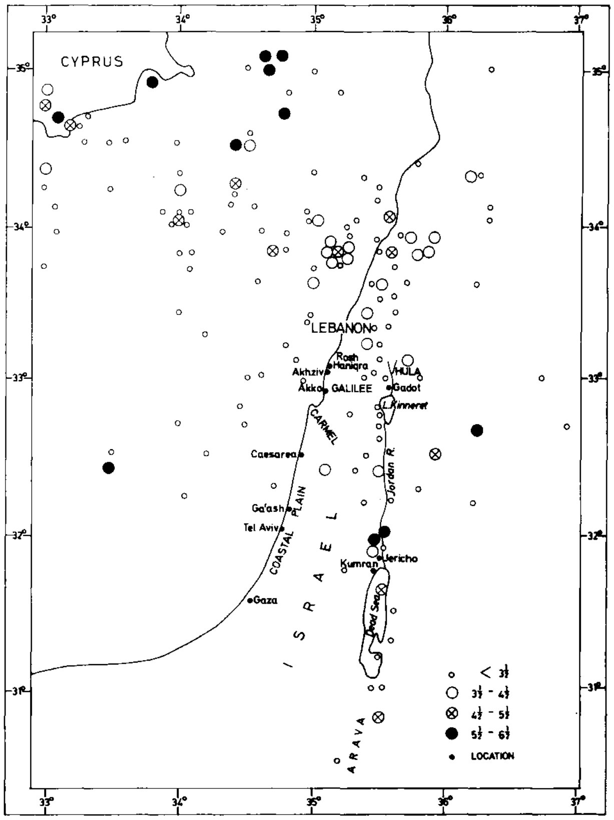


FIGURE 2.76. *Earthquake epicenters in the Levant. (From Arieh, 1967.)*

FIGURE 2.77. *Fault scarp of the active Bet Kerem Fault, which separates the Lower from the Upper Galilee and extends west to the northern boundary of the Zevulun Valley Rift.*

FIGURE 2.79. *Faults of the Southern Arava, opposite Timna, which laterally offset the alluvial fan of the Garof System.*

FIGURE 2.78. *The coastal cliff south of Netanya (due to faulting?).*

FIGURE 2.80. *The "Staircase Fault" at Kumran, south of Jericho. (Courtesy of U. Kafri, Geological Survey of Israel.)*

150 m, and the eastern block has moved north. The amount of dip-slip cannot be calculated and is estimated at several tens of meters, the western being the downthrown block. Age of the faulting is given as Recent because the faults offset the alluvial fans. However, it should be stressed that in the Arava this indication is only broadly significant. Not all the alluvial fans are active sedimentary bodies, and, therefore, the age of the faults' activity should be regarded in a geological sense, and might as well be of Holocene or even Pleistocene age.

Some other Late Holocene or Recent tectonic movements are reported for the Jordan Valley. Ambraseys (1975) reported that a staircase leading to the cave in which some of the Dead Sea Scrolls were found, in Kumran near Jericho, is normally faulted, with an offset of 10–15 cm (Figure 2.80). It is clear that this movement took place some time during the last 2000 years, but Karcz and Kafri (1976) doubt its tectonic origin. Lacustrine sediments of the Hula Lake, radiocarbon dated (Horowitz 1973) at approximately 4500 years B.P., are presently situated on the elevated block of Gadot, at least some 60 m above similar sediments at the Hula Basin. Some of this difference must be attributed to initial dips at the time of deposition, but the faulting seems quite clear, and the fault line can be seen in the area as a steep escarpment developed on the soft lacustrine sediments (Figure 2.81).

Late Pleistocene tectonic movements of a considerable magnitude are reported for the Dead Sea environs (Neev and Emery 1967) and for Lake Kinneret (Golani 1962; Horowitz 1968, 1968a; Neev and Emery 1967), but, since most of the movement along these faults took place during the Late Pleistocene and can be accurately dated,

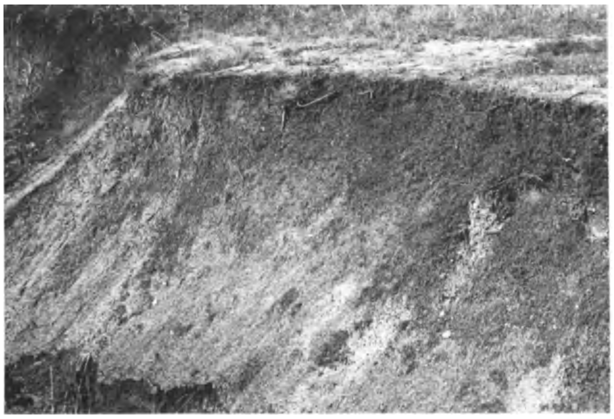


FIGURE 2.81. *Fault scarp developed on Middle Holocene sediments near Gadot, just south of the Hula Valley.*

they are not treated here but instead in Chapter 3, which deals with the tectonic and structural development of the country.

The coastal plain was subject to quite detailed study of Recent movements by Neev *et al.* (1973), by Horowitz (1974a), and by a team, headed by N. C. Flemming, at Haifa University. Dating of these movements has been facilitated by a wealth of archaeological information, both on land and under the sea. Neev *et al.* (1973) produced evidence as to Recent faulting along the Mediterranean coast of Israel based on several observations. At various localities along the coastal plain, horizons of marine shells are found at elevations of 3–40 m above sea level, on top of the coastal cliff, sometimes as far as several hundred meters east of the present shoreline. The shells, mainly *Glycymeris violacescens,* are sometimes interbedded with sand dunes and at some localities cover Roman or Crusader sites. Radiocarbon dates of these shells are in the range of 2100–3800 years B.P., which is in discrepancy with their stratigraphic setting, overlying sites as young as 700 years B.P. The age discrepancy is explained by Neev *et al.* as a result of the time span needed for the shells to get deposited on the beach after they die. Recently deposited *Glycymeris* yielded ages in the range of 1150–1500 years B.P., and, since these shells are known to live only in deep waters (only one living specimen of this shell has ever been found on the Israeli beach), the age discrepancy is not so surprising.

Dunes, presently stabilized and inactive, cover various sites along the Israeli coast. The most conspicuous is a Byzantine settlement situated just on top of the coastal cliff near Ga'ash, some 15 m east of the shoreline, at an elevation of 41 m above sea level (Figure 2.82). It is quite clear that dunes cannot be formed at this locality under present conditions, because the 40-m-high cliff blocks sand coming from the beach. It was, therefore, suggested that at least the major part of the elevation is of a post-Byzantine age, due to tectonics (Neev, *et al.* 1973).

Another argument brought up by Neev *et al.* has to do with the ancient port at Caesarea. The rocky patches of the sea floor between Tel Aviv and Mount Carmel terminate rather abruptly westward, in an almost straight line. Part of the Herodian port of Caesarea, built about 10 B.C., is west of this line (Figure 2.83), submerged under some 10–15 m of sea water. Some of the masonry, now under 10 m of water, is found *in situ* with lead joints to strengthen connections between the stones. These lead joints could not have been cast under water, hence a subsidence of about 10 m from Roman times on is suggested for the westward continuation of the site. Mazor (1974) presented a strong objection to the facts brought forward by Neev *et al.* (1973), pointing out that if the shells were accumulated by human activity and wave action, the dunes could indeed have reached elevations as high as 40 m as close as they are to the shoreline, since the Roman port of Caesarea was originally built under water, with the lead cast made on land and the stones dipped later into the sea. Neev, in a reply (1974), stressed once more the natural deposition of the shells and the rest of the facts. A detailed survey of many archaeological sites located on the Mediterranean coast of Israel, which included exact land and underwater study and meas-

FIGURE 2.82. *Byzantine site on the coastal cliff near Ga'ash, south of Netanya, covered by the upper part of the Hadera Dune Bed.*

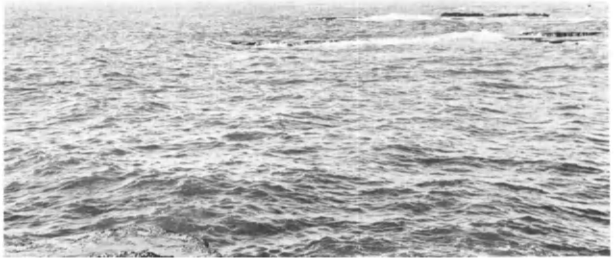


FIGURE 2.83. *The Mediterranean, looking north from Caesarea. The rock platforms stop abruptly on a straight north–south line that might be a post-Roman fault.*

urements, was organized by the Department of Studies of Ancient Marine Civilizations of Haifa University, headed by N. C. Flemming and E. Linder. In a symposium organized by the team in 1976, they claimed that most of the archaeologic sites along the coast are presently in similar locations as regards the shoreline to those when they were erected.

Horowitz (1974a) brought some more evidence in favor of the differential block movement along the Israeli coast, based on observations on some sites that were not discussed in Neev *et al.* (1973). The most important are sites in the Western Galilee Coastal Plain. Dips observed in Roman quarries and quarries submerged under 5 m of sea water near Rosh HaNiqra and Akhziv (Figure 2.84) suggest some postquarrying tilting of the area, and the submerged Tower of Flies in Haifa Bay near Akko (Acre) also suggests some later sea-level rise, more than the suggested eustatic rise for this period. Neev *et al.* suggested that, during the last 700 years, the coast was first submerged and then uplifted, thus accounting for the covering of sites by coastal sediments. Horowitz (1974a) suggested a simpler mechanism and attributed the deposition of shells and dunes to the post-Roman eustatic sea-level rise, known also from the Carmel Coast (Michelson 1970), followed by a later tectonic uplift to the present position. Detailed geodetic measurements of the Israeli coastal plain (Kafri and Karcz 1975; Karcz and Kafri 1971, 1973, 1975) and of the mountainous backbone of the country (Karcz and Kafri 1973) seem to corroborate Neev's and Horowitz's postulates. They show a pronounced tilting of the Israeli coastal plain eastward, at an average rate of 2.5 cm/year. The elevated areas of the mountainous backbone are presently slowly subsiding, whereas the basins are now in a process of uplift. Karcz and Kafri do not try to assess whether these are constant movements or whether the direction of movement up or down depends on the momentary situation of an oscillating system. It is quite clear, however, that tectonic movements affect Israel at the present, and, although they do not cause strong disturbances on the average, they must be taken into consideration when regarding the tectonic instability of the country.

FIGURE 2.84. *Roman quarries at Rosh HaNiqra, looking south. The quarrying walls show tilting to the west, and some quarries are also covered by the sea in this area. About 1.5 km seaward, quarries are also known on some small islets that now have no sign of buildings.*

3

Structure and Tectonic Development of Israel

STRUCTURE

Israel, as part of the levant, occupies the junction of the African Craton to the south, the Alpine Orogenic Belt to the north, the eastern Mediterranean Basin to the west, and the Arabian Plate to the east. Relative movements of these plates influenced the Levant in a rather complex way, producing a variety of structural patterns connected with folding, upwarping, and rifting. It is important to follow these processes in time, since they are the basis for the present-day configuration of the country and considerably influenced Quaternary erosional and depositional processes. The present chapter deals with the entire Levant; otherwise, the overall pattern of the tectonic framework would be lost in unnecessary details.

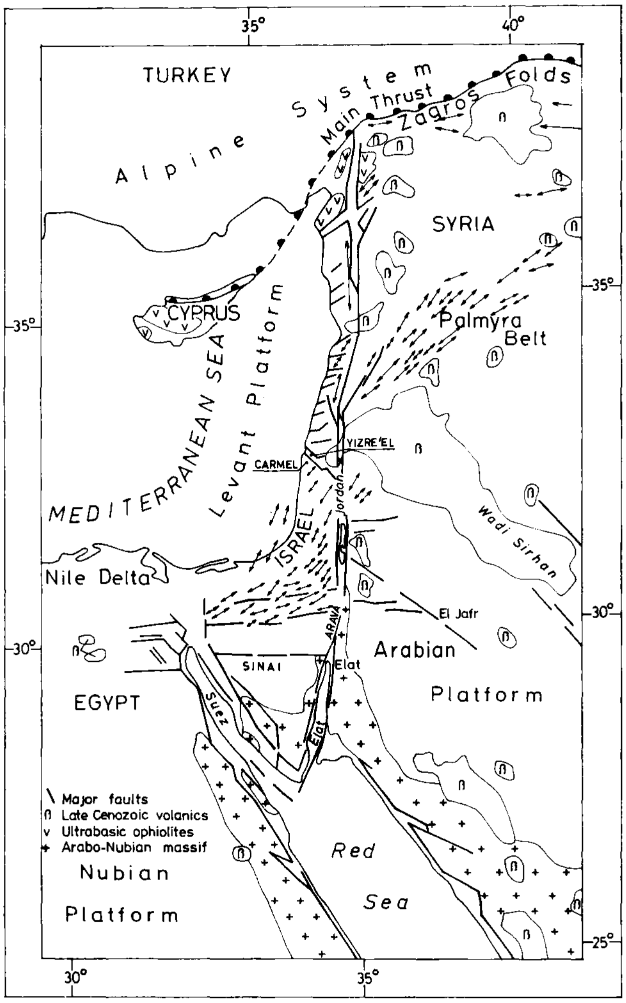


FIGURE 3.1. *Structural pattern of the Levant.*

The Arabo-Nubian Massif, which constitutes the northeasternmost corner of the African Craton, is exposed only at the southernmost part of Israel in the Elat area. It extends south to Sinai (Figure 3.1), but, to the east of the Arava, in Transjordan, it extends as far north as the Dead Sea. The Arabo-Nubian Massif was peneplained in Late Precambrian times and is encircled by younger, platform sediments, mostly deposited in fluviatile or shallow marine environments. In the Israeli sector, the sedimentary cover becomes thicker to the northwest, and, although at the southern sector of the country a considerable part of the sequence is continental, the north and west are covered by shelf deposits, mainly fossiliferous limestones and similar rocks. The picture changes, however, further west. The western coastal plain and the shelf areas are covered by deep-sea sediments, made up mostly of marls and clays. This is observable only from the Triassic onward, since no information is available on the deep-buried Paleozoic of the western and northern sectors of Israel.

The Levant is folded by a series of anticlines and synclines that form an S-shaped fold belt that bends westward in the Negev and the Sinai and eastward in Lebanon and Syria. Most of these structures are asymmetric, the steeper flank facing southeast, but some are conspicuously asymmetric the other way. Three superimposed folding phases, all of them quite simple and almost along the same lineaments (but not necessarily along the same axes), have been hitherto discerned: a probable pre-Jurassic system (Freund *et al.* 1975), a Late Mesozoic through Early Cenozoic system (Bentor and Vroman 1951), and a Late Eocene–Oligocene folding phase (Gvirtzman 1970). Some of the folding continued through the Miocene (Garfunkel and Horowitz 1966), sometimes affecting only parts of the previously folded structures (Freund and Zak 1973). The central parts of Israel are upwarped in a north–south direction, superimposed on the fold structures, along the entire country (Horowitz 1974). This upwarping took place in Quaternary times. The same north–south lineament prevails along the downthrown region of the coastal plain (Neev 1975). The area east of the Jordan–Arava Rift Valley is also upwarped, in the same direction.

The fault pattern of the Levant is rather complex. The north–south running Jordan-Arava Rift Valley borders Israel to the east and is connected in the south with the Gulf of Elat and the Red Sea system. This fault system is connected northward to a fault system that runs through Lebanon and Syria, to the south of Turkey. The main fault zone connected with the Rift Valley is north–south lineated, but many small-scale faults diverge in different directions, compensating for volume problems of approaching structures. Another important fault system runs in a general northwest–southeast direction. This fault system is responsible for the Yizre'el Valley, the Mount Carmel elevated block, and other structures. This lineament, called by Shalem (1954) "the Erythrean System," is apparently older than the Jordan-Arava fault system and dates to the Earliest Pliocene (Horowitz 1974). A great number of relatively minor faults run in an east–west direction, crossing the folded and the upwarped structures. Almost all of them are small-scale gravity faults, compensating for the uplifting of these regions. These faults are more and more conspicuous toward the north of the country. In the Negev structures, they are relatively rare, whereas at the Galilee they form the most prominent feature of the landscape, attaining sometimes considerable length and throw. Some of these faults are rather young, of Quaternary age, and sometimes even active today, but many faults of this nature have been observed among the high structures of the Negev and Samaria, ranging in age from Triassic onward (Freund *et al.* 1975; Mimran 1972). All the hitherto described systems are made up almost exclusively of normal faults and, in my opinion, represent gravity faulting. No compressional features are associated with these systems.

An interesting fault system appears only in the Negev, but its continuation is known from Transjordan (Bartov 1974) and the Sinai, extending far into Egypt, where it underlies the Nile Delta (Said 1975). The direction is generally east–west, and the dextral strike-slip faults are associated both with normal faulting and with compressional features, mainly displayed as a series of equidimensional domes. The shear along the faults is in the order of several kilometers, and they are clearly of post-Miocene, apparently Earliest Pliocene, age. The coastal plain fault-system is rather problematic. No definite faults are observed, and, if they exist, they are covered by younger sediments. The coastal plain structure could be explained solely as the result of folding and channeling, with no faulting at all.

EASTERN MEDITERRANEAN

The easternmost sector of the Mediterranean, defined in Neev (1975) as the Levantine Basin, extends west of an ancient structural hinge line that has been almost continuously active at least since pre-Jurassic times (Gvirtzman and Klang 1972). This hinge line (Figure 3.2) extends in a general north–south direction, underlying the Israeli shoreline at the central sector of the coastal plain, running somewhat east of the shoreline at the southern sector, and bending west toward the coastal plain of Sinai. It runs to the south and northwest at the northern coastal plain, opposite Haifa Bay, then follows the Carmel "nose" as it extends seaward, and finally becomes, to the north, once more parallel to the Lebanese-Syrian coast.

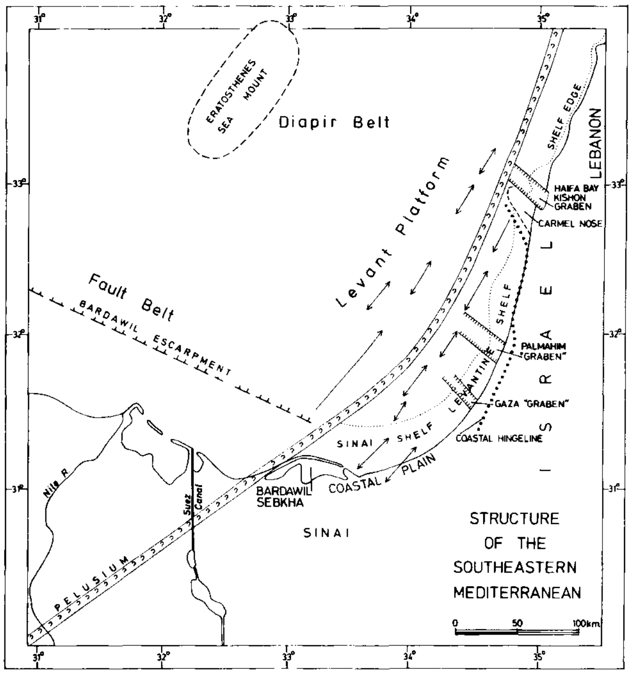


FIGURE 3.2. *Structural pattern of the Levantine Basin.*

Detailed geophysical studies of the Levantine Basin have led to interpretations of its configurations and its geological and structural development; these are summed up in Neev (1975), Ginzburg *et al.* (1975), and Neev *et al.* (1976). Ginzburg *et al.* mainly discuss the development of the Israeli shelf, and Neev *et al.* deal with the southern Levantine Basin, which forms a rough rectangle bordered by the Sinai to the south, Israel to the east, and Cyprus to the northwest. The area is physiographically divided into several units: the Sinai Shelf, bordered to the north by the Bardawil Escarpment; the Levantine Shelf, bordered to the west by a series of parallel fold structures approaching the "Pelusium Line" (discussed later); and the deep-sea Levant Platform, extending west to the Eratosthenes Seamount and to Cyprus. The Platform is divided into two facies belts: the southern, "Belt of no M," in which the typical Late Miocene evaporitic beds are not recorded geophysically; and a "Diapir Belt" to the north, in which those evaporites form conspicuous diapiric structures.

The main structural units are arranged in two directions, almost perpendicular to one another, parallel either to the Levantine or to the North African coasts. Fold structures extend west of the Levantine coast as broad synclinoria and anticlinoria, as much as 150 km offshore. They are arranged in an *en échelon* pattern, their amplitudes up to several tens of kilometers. About 50–60 km offshore lies the "Pelusium Line" (named after the Roman settlement of Pelusion, situated on the offshore bar of the Bardawil Sebkha), suggested by Neev (1975) to be a compressional zone separating the "Central Plate" of the Levant and Arabia from the Mediterranean Plate. The tectonic elements parallel to the North African coast are mainly fault zones, of which the most conspicuous is the Bardawil Escarpment (Figure 3.2). The vertical throw of this fault zone is on the order of 1000 m. Another phenomenon parallel to the Bardawil Escarpment is the facies differentiation between the "Belt of no M" and the Diapir Belt. This facies difference is most probably tectonically controlled. To the north, the Levantine Basin grades into the foldbelt of Turkey, Crete, and Greece through Cyprus, which might represent an elevated part of the ancient Tethys midocean ridge. The crust comprising the Levant Platform is defined by Neev (1975) as "oceanic to semioceanic," but practical information concerning its nature is not available at the moment.

Apparently, the most important problem concerning the structure of the Levantine Basin is the age of its tectonic activity. Most of the information was obtained from geophysical data, of which the major part was collected by oil companies and, therefore, is practically unavailable. More information was gathered from boreholes drilled on the Israeli coastal plain; this information is summed up in Gvirtzman (1970). It seems that the main fold structures have been intermittently active at least since pre-Jurassic times. The facies of the sediments has been controlled by these activities at least since then (Ginzburg *et al.* 1975). Gvirtzman (1970) suggested, based only on geophysical and isopach data, a series of north–south, *en échelon* major faults as underlying the entire Israeli coastal plain. Itzhaki (1955) suggested that the east–west facies changes depend mainly on the folding pattern and that the coastal plain comprises a wide synclinorium rather than a step-fault system. Horowitz (1974) showed that some of Gvirtzman's findings are based on misidentification of Miocene and Pliocene beds and concluded that any step faults that might occur at the coastal plain subsurface should be regarded as of Late Miocene to Early Pliocene age. This hypothesis is further supported by the conspicuous faulting of the "M Reflector" horizon (the Late Miocene evaporites) in the Mediterranean (Neev 1975; and others), in the Red Sea (Ross and Schlee 1973), and in the Gulf of Suez (Said 1962, and many others). This (Earliest Pliocene) is apparently also the age for the formation of the Bardawil Escarpment.

It seems, therefore, that the tectonic activity of the Levantine Basin underwent two phases: folding, mainly along north–south lineaments, which commenced at least in the early Mesozoic and was active in pulses until the Early Tertiary, and faulting, mainly along northeast–southwest and east–west lineaments, which commenced at the beginning of the Pliocene and has been, apparently, slightly active up to the present day.

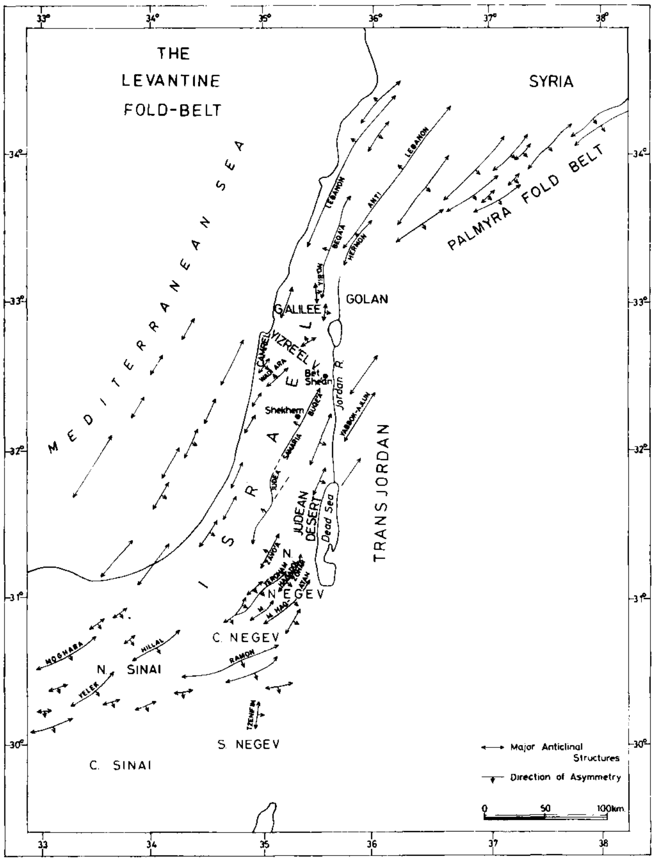


FIGURE 3.3. *The Levantine Fold Belt.*

LEVANTINE FOLD BELT

The Levantine folds, called by Krenkel (1924) "the Syrian Arc," are arranged in an S-shaped belt (Figure 3.3) comprising three sectors. The southwestern sector, that of northern Sinai and of the Central and Northern Negev, is lineated east–west and bends northward and the Northern Negev and the Judean Desert. The central sector, of central and northern Israel and western Transjordan, is lineated N30E and occupies the entire length of Israel up to its northern border. The Lebanon, Hermon, Anti-Lebanon, and Palmyra ranges constitute a fan-shaped belt lineated generally in a northeast direction until plunging below the Euphrates Valley. The fold belt, and especially its southern and central sectors, is parallel to the boundary of the Arabo-Nubian Massif to the south, separated by a series of gently-dipping northwest-oriented strata, which form the typical cuesta country of central Sinai, southern Israel, and Transjordan and go far south into Saudi Arabia.

The southwestern sector, that of the northern Sinai and of the Central and the Northern Negev, comprises several major anticlinal and synclinal structures. The most conspicuous anticlines of the Sinai are Jebel Moghara, Jebel Yelek, and Jebel Hillal; at the Central Negev, the anticlinorial range of Ramon; and at the Northern Negev, a number of smaller anticlines comprising the Makhtesh HaGadol, Makhtesh HaQatan, Har Tsavo'a, and some others. The oldest strata exposed at the cores of these anticlines are rocks of Jurassic age, except for a small outcrop of Triassic rocks at Makhtesh Ramon, which are exposed mainly due to later faulting. The structures comprising this sector are asymmetric, dipping much more steeply to the southeast and rather gently to the northwest. The steepest dips in some places may reach up to 70–80°, and the gentle dips are in the order of 5–15°. The synclines are mostly filled with younger sediments, either Eocene chalk or Neogene conglomerates, that were laid down in an ancient drainage system.

The fold belt of the northern Sinai plunges westward below the Suez Canal area and the Western Desert, which are generally covered by flat-lying sediments of Eocene age. Some buried structures are known from the Western Desert; these are probably the continuation of the northern Sinai fold-belt. The central sector, comprising the main hilly ranges of Israel and Transjordan, bends northward towards the N30E direction and comprises a number of anticlines and synclines that were later elevated by an epeirogenic process, to be described below. These structures, and especially Judea and Samaria, are also asymmetric, but to the other side; the steeper dips toward the west–northwest. Most likely, the Carmel is also part of these structures. The anticlines are separated by several synclines, of which the most conspicuous are the Shekhem and the Wadi Ara synclines, which are filled with Eocene sediments.

The most ancient rocks exposed on the elevated structures are of Early Cretaceous and Jurassic age, but they are mostly built of Cenomanian and Turonian limestones and dolomites. In western Transjordan, the most conspicuous elevated structures are the Al-Qarak-Amman and the Wadi Yaboq-Ajlun anticlinoria. These are much wider structures than those in Israel, and they do not show conspicuous asymmetry. Further north, separated in Israel by the Yizre'el Valley and in western Transjordan by the Golan basaltic plateau, comes the third sector of the Middle East Fold Belt, which is conspicuously fan-shaped. The center of the fan lies in the Galilee and is an approximately north–south lineated elevated structure continuing far north to comprise the Lebanon range, which runs along the Near East coast north up to Hattai. The Galilee–Lebanon range dips steeply toward the Mediterranean coast and more gently toward the east, to the Yir'on and the Beqa'a synclines. The Yir'on syncline is filled with Eocene sediments, whereas the Beqa'a syncline is filled with Eocene through Pliocene beds, separating the Lebanon range from the Anti-Lebanon and the Hermon ranges. The Anit-Lebanon dips quite steeply towards the Beqa'a and extends eastward gently toward the Palmyra Fold Belt, which is asymmetric, dipping quite steeply toward the southeast.

Jurassic limestones and marls are exosed in the Lebanon and in the Anti-Lebanon ranges, whereas the Palmyra Range is built mainly of Late Cretaceous rocks and its synclines are filled with Eocene and Miocene limestones and conglomerates. The Palmyra Belt plunges gently under the Euphrates Valley. The Northern Sinai and the Israeli sectors of the Levantine Fold Belt extend to the northwest and are known from the subsurface of the coastal plains of Israel and of the Sinai, extending to the shelf and to the continental slope of the southeastern Mediterranean. The Sinai sector is bordered to the north by the Bardawil Escarpment; the Israeli and Lebanese sectors are bordered to the west by the steep continental slope that leads down to the Levantine Deep Sea Platform.

The age of folding of the Levantine Fold Belt is somewhat problematic. Said (1962) and Bartov (1974) indicate that the main phases of folding in the northern Sinai terminated before the Eocene. Some slight post-Miocene movements or tilting of the strata was observed by Horowitz (1975b), but this is most probably due to movements on the transversal, E–W faults. The Central and Northern Negev folds have been active at least since the post-Turonian, chiefly during Senonian, Maastrichtian, and Paleocene times. In some localities, like Makhtesh Ramon, the folded structure is almost covered by flat-lying Eocene strata, and in other structures the Eocene is folded as well. It is even more problematic in Judea and Samaria, since the Tertiary sediments are preserved only in the synclines, and little indication is given for the age of folding. Eocene conglomerates exposed at the Shekhem syncline (Cook *et al.* 1973) indicate that most of the folding apparently took place before this period. Garfunkel and Horowitz (1966) observed some post-Miocene folding or accentuation of the Northern Negev anticlines, and Schulman and Rosenthal (1968) observed some post-Miocene folding in the Jordan Valley, south of the Bet She'an Valley. Miocene conglomerates are also somewhat folded in the Palmira Range, the Galilee, and Lebanon. It seems that the main folding movements of the Levant took place at the end of the Mesozoic and at the beginning of the Cenozoic; only some minor accentuation phases took place during the Late Cenozoic. In no place, however, are sediments of Pliocene age or younger folded. Gvirtzman (1970) determined two phases of conspicuous folding in the subsurface of the coastal plain of Israel: a pre-Senonian, which produced wide, shallow, north–south running structures, and an Oligocene, which produced much narrower, superimposed structures following approximately the same lineament. The Oligocene folding grouped the pre-Senonian structures into a series of anticlinoria and synclinoria. Sufficient data for comparison are not available for the subsurface of the northernmost Sinai and Lebanon.

Some fold structures in the Negev and in the Sinai are generally east–west lineated short anticlines connected with strike-slip movement along the transversal faults of this area. These will be treated separately. Only one anticlinal structure, rather limited in area, differs from the scheme given for the Levantine folding. This is the

Zenifim anticline of the Southern Negev, which is north–south elongated. It is also asymmetric and dips much more steeply to the east than to the west. No indications as to the age of folding are given for this anticline, and it seems that it might connect with the Bay of Elat block fault-system rather than with the Levantine Fold Belt. According to Vroman (1973), the folding of the Palmyra Belt is younger than the rest and is of Neogene age.

Most of the folded structures are also faulted. The most conspicuous system comprises faults that run approximately perpendicular to the folding axes. All of these are normal faults, mostly confined to short distances and to a general throw of not more than tens of meters. However, in the Galilee and in Lebanon they become rather major faults and seem to have stretched the central Galilee by as far as 7 km (Freund 1970), even more in Lebanon. The reason for the conspicuousness of the faults in the Galilee and Lebanon will be discussed below. Another system of deep-seated faults was suggested by de Sitter (1962) for the Levantine fold structures. These should be reverse faults, affecting mainly the Precambrian basement rocks and possibly also some Paleozoic and Early Mesozoic formations. Such faults were discovered at the Zohar anticline, where a sequence of about 100 m of Jurassic rocks repeats itself in the borehole, and at some other anticlines of the Northern Negev, such as Yeroham and Har Tsavo'a. The Ramon Anticlinorium, in which the entire Jurassic and part of the Triassic sequences are exposed, does not show any faulting of the type suggested by de Sitter. The same is the case with the Yaboq anticline on the eastern side of the Jordan River.

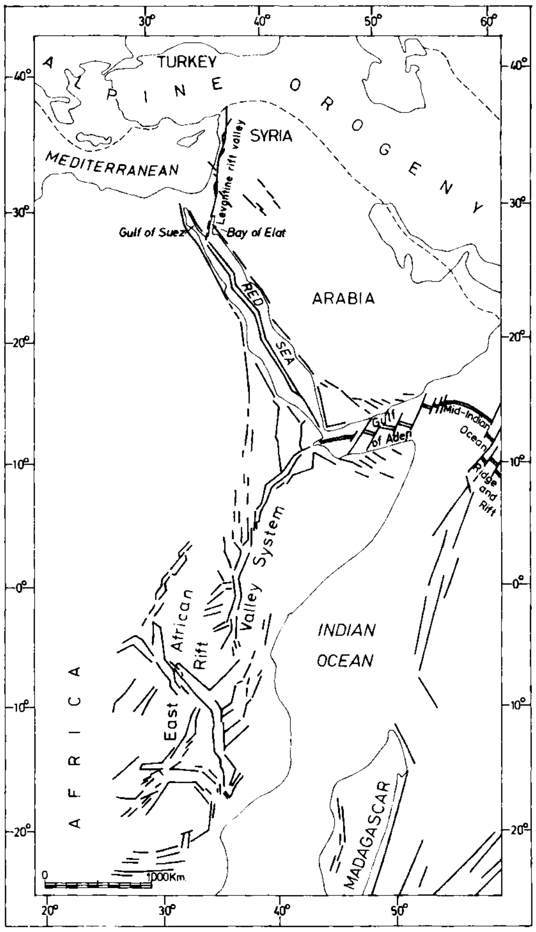


FIGURE 3.4. *The Syrian–African Rift System.*

RIFT VALLEY

The Levantine Rift Valley is the northward elongation of the Red Sea Rift System and forms the northernmost sector of the Great Syrian–African Rift Valley (Figure 3.4). The central part of this system is the Red Sea Rift, which is bifurcate to the south and connected to the Mid-Indian Ocean Ridge by the almost perpendicular Gulf of Aden, and its other branch continues down southward into the continent of Africa to form a quite complicated system of rift valleys and horsts that is generally known as the East African Rift Valley System. To the north, the system continues to the Levant and is also bifurcate. The Sinai peninsula separates the northern sector of the Syrian–African Rift Valley into two: the Gulf of Suez sector, which is a geographical continuation of the Red Sea in the same lineation and is presently a rather shallow bay with a maximum depth of 40 m below sea level, bordered by a complicated system of block faults; and the eastern sector, which breaks up the Levant and goes north up to southern Turkey, diverging from the Red Sea through the Bay of Elat (Aqaba), which is very deep, down to 1800 m below sea level.

The Bay of Elat is bordered by a system of very long (up to several tens of kilometers) north–south running faults. They are younger than the Pliocene; some of them offset the Eilot Conglomerate of that age. It is still not clear, however, whether some movement on these faults began before the Pliocene. Miocene sediments of the Raham, Haimur, and Hazeva formations are much more affected by faulting than are the Pliocene conglomerates (Garfunkel 1970), but this might have been under the influence of earlier, diagonal faulting. The youngest age for movement on these faults has been designated by Zak and Freund (1966) as post-Lisan, which puts it in the range of the last 20,000 years, but this seems somewhat doubtful. It seems that the alluvial fans offset by these faults are part of the Pliocene Eilot Conglomerate. Most of these longitudinal faults bordering the Bay of Elat show a strike-slip component in their movement. Garfunkel (1969, personal communication) claimed a lateral offset of several kilometers, which seems to us quite inconceivable, whereas Zak and Freund (1966) could not measure more than 150 m on one of the longest faults. It should be noted that the only phenomena that might point to wrenching on these faults are several minor rhomb-shaped grabens. No compressional features were observed, and the appearance is mostly of a set of normal, gravity faults. The Bay of Elat is also affected by diagonal faults, but these are much more conspicuous on the sea-bottom charts than on the rift shoulders, probably due to some masking of the consequent strong north–south faulting.

The Israeli–Jordanian sector of the rift valley is divided into several subsectors. The Southern Arava, which drains to the Bay of Elat, is bordered by a complicated system of step faults. The Northern Arava is at places bordered by a system of step faults on the eastern side, whereas on the western side it is bordered by gently dipping Eocene strata that form a monoclinal structure in this part of the rift valley. This sector goes north to about 20 km south of the Dead Sea, at which point faulting on both sides becomes conspicuous again. The Dead Sea itself occupies the deepest part of the rift valley of the Levant, and a sequence of graben filling sediments 7–10 km thick has been estimated by gravimetric survey of the area. North of the Dead Sea, the main fault systems diverge from the generally north–south direction and enter diagonally the mountainous blocks on either side. These were called by Picard (1943) "crescent" faults. The faults run some 20–30 km on each side. At the Southern Jordan Valley, the area is not a rift valley. Mesozoic and Cenozoic strata on both sides dip gently into the valley and cross it as a rather shallow syncline. Rift valley fill is not encountered in this sector of the Jordan Valley, and, except for about 10–15 m of Late Pleistocene Lisan Formation lake sediments, Miocene formations are exposed across the entire valley. This syncline separates the Buqei'a structure to the west from the Yaboq–Ajlun structure to the east.

Up to the north end of Lake Kinneret, the Central Jordan Valley is once more fault-bordered. The Rift Valley of Yizre'el, which diagonally crosses the hilly backbone of the country, connects the Central Jordan Valley with the Mediterranean. The fault that runs east of Lake Kinneret enters the Golan Heights at the northeast corner of the Lake and forms another very conspicuous crescent fault. Several crescent faults on the western side of Lake Kinneret form a series of tilted blocks that are typical for the landscape of this area. The Northern Jordan Valley is connected to the Central Jordan Valley by a single fault along which the Jordan River made its path from Lake Hula to Lake Kinneret. The Hula is a true graben, bordered by faults both to the east and to the west, and a gravimetric survey (Yuval 1967) estimated its filling thickness as 1700 m. A borehole that was drilled later at the center of the Hula Basin (Horowitz 1973) penetrated about 450 m of lacustrine, paludine, and fluviatile sediments of Mindel-Riss Interpluvial through Recent age, which seemed to verify the gravimetric survey's conclusions. Several diagonal faults running in a N30W direction border some of the subbasins of the Jordan Valley. The most conspicuous are the faults running south of and at the center of the Dead Sea (Neev and Emery 1967) and a fault system (Horowitz 1973) that runs along the southern edge of the Hula Valley. The northern side of the Hula Valley is downfaulted by a complicated fault system, and the Hula Valley is bordered to the north by the elevated block system of Metulla–Marj Ayyun.

North of the Hula Valley, in the area near Lebanon, the rift valley proper disappears and the structure continues as an array of faults. The most important are the Roum Fault, which points in the direction of Beirut, the Rakhaya and Serraya Faults, parallel to the Anti-Lebanon, and the Yamoune Fault, which is apparently the main one, separating the Anti-Lebanon from the Lebanon mountains and continuing north into Syria (Dubertret 1962). The Yamoune Fault runs in a general north–northeast direction for about 150 km and then turns back to the north. It runs due north about 100 km and only then opens to form the Ghab Rift Valley of western Syria, later disappearing at the south of Turkey. It should be noted that the Yamoune Fault and its bending is approximately parallel to the Mediterranean coast of this area. The bending of the Yamoune Fault along the Lebanon, which separates the two north–south lineated rift valley sectors, the Jordan–Arava–Bay of Elat to the south and the Rhab to the north, occurs at the area where the Erythrean Lineament ceases to play a role. Instead, the Alexandretta Lineament, bearing northeast–southwest, takes place. This change of direction is somewhat gradual, and the east–west Galilee faults turn more to the northeast when approaching the Lebanon, until, at the northern tip of the rift valley to the south of Turkey, the Alexandretta Lineament is fully developed.

At least four successive, superimposed fault-systems were discerned (Horowitz 1974) in the Jordan–Arava Rift Valley. The earliest has a conspicuous N30W direction, parallel to the Red Sea, called by Shalem (1954) the Erythrean Lineament (Figure 3.5). It is of Early Pliocene or Latest Miocene age, affecting in many areas the Late Miocene rocks. This phase created the graben of the Yizre'el Valley, through which the Pliocene sea entered the Jordan Valley. The Jordan Valley itself was mildly downfaulted except for the Dead Sea area, in which 5–6 km of Pliocene evaporites were later accumulated (Zak 1967). It should be noted that most of the faulting of the Gulf of Suez also occurred at this stage. This is also the first stage of opening of the Red Sea proper (Ross and Schlee 1973). The Late Miocene evaporites of the Red Sea were laid down under very shallow conditions of a drying sea that most probably connected the Red Sea with the Mediterranean that also dried up during those times, called the Messinian salinity crisis (Hsü 1972). These evaporites formed the M-Reflector both in the Mediterranean and in the Red Sea subsurface sediments. The rifting of the Red Sea, which affected these evaporites, began, therefore, only in the Latest Miocene or in the Earliest Pliocene. At least two rift valleys in Transjordan were formed in the Earliest Pliocene, the Wadi Sirhan (Bender 1968; Wetzel and Morton 1959) and the El-Jafr. Another that is Earliest Pliocene in age, directed N30W, is

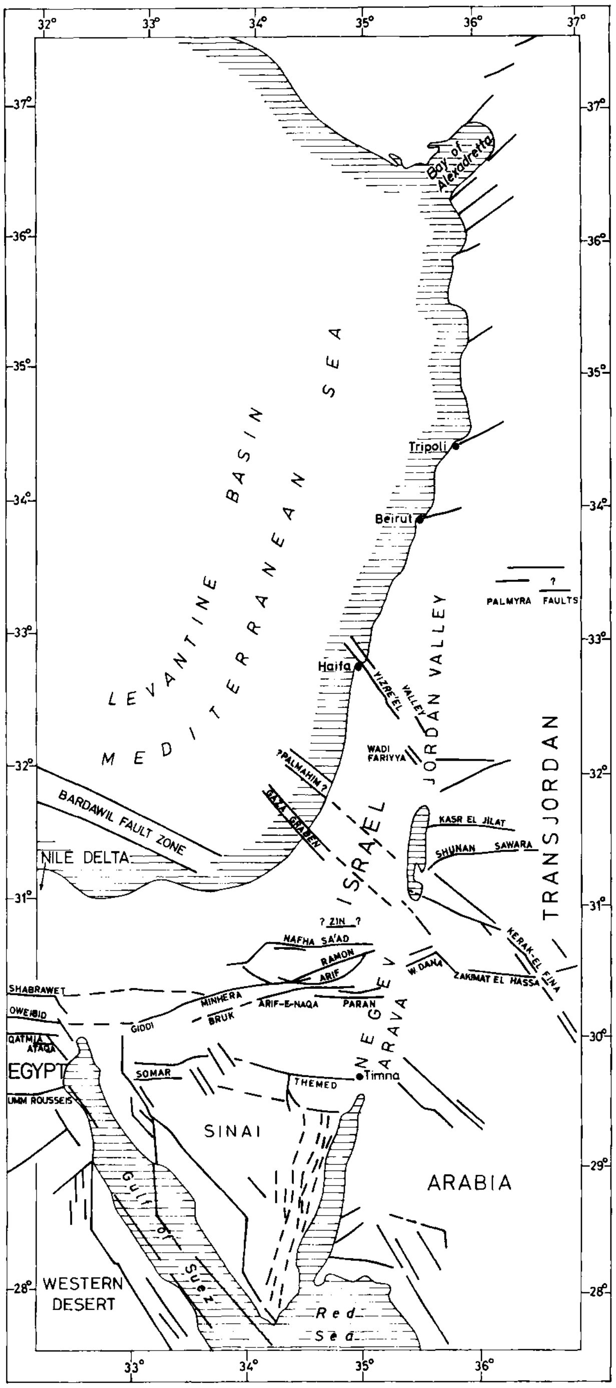


FIGURE 3.5. *The Erythrean Fault System.*

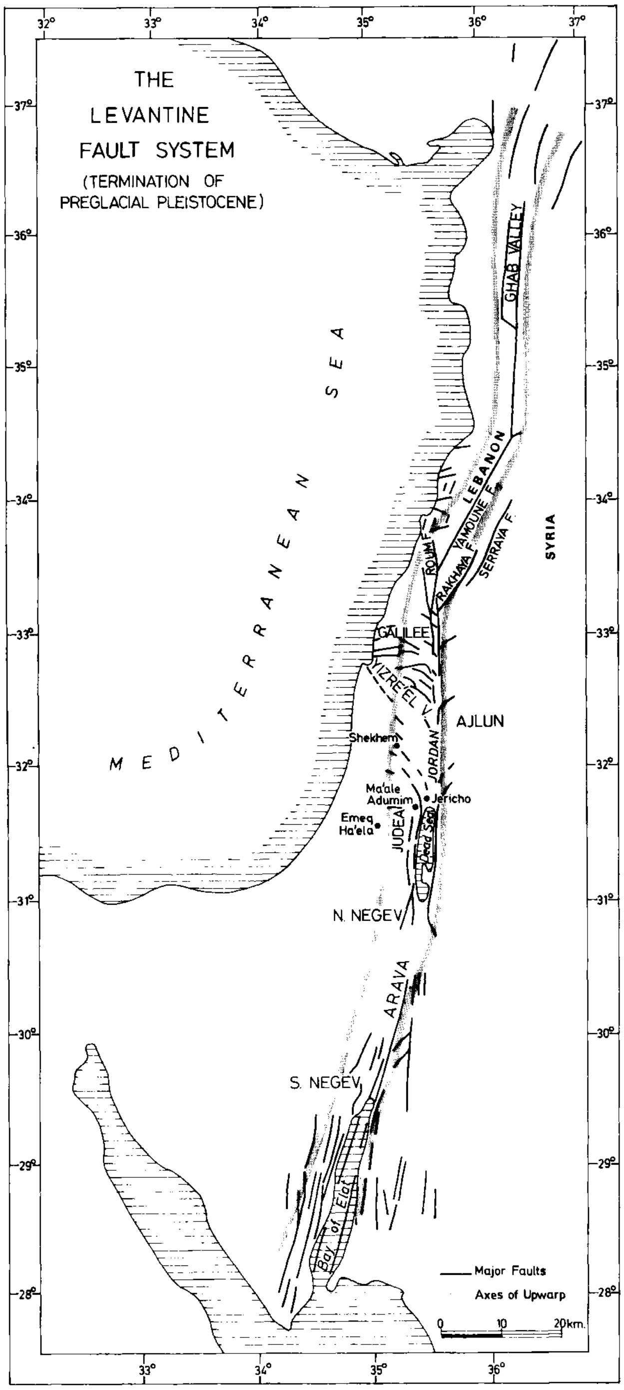


FIGURE 3.6. *The Levantine faulting and upwarping system.*

the Wadi Fariyya graben, in which extensive sequences of Miocene conglomerates were preserved from consequent erosion by the downfaulting. The Erythrean faulting system is also quite conspicuous on the eastern side of the Arava, in southern Transjordan, where it forms major faults sometimes extending hundreds of kilometers, like the Kerak-El Fina Fault and others.

The second faulting phase, which occurred at the transition of the Preglacial to the Glacial Pleistocene (Horowitz 1974), is more restricted to the Levantine system per se. This faulting phase (Figure 3.6) opened up the Bay of Elat and caused deepening of the Jordan-Arava Rift Valley with the Dead Sea Basin as its center, so that it became an internal drainage system with no connection to the Mediterranean. On its northern side, the valley was blocked by the Marj Ayyun-Metulla elevated block system, which separated the Jordan–Arava from the Lebanese and western Syrian drainage systems, which flowed to the south in Pliocene times. This faulting phase was mainly active along north–south lines, but the aforementioned crescentic faults also belong to it. The crescentic faults apparently compensated for volume problems of approaching structures, such as the Northern Negev Fold Belt and the Ajlun, Judea, and Galilee anticlinorial ridges.

The third phase, that of post-Mindel-pre-Riss times, is conspicuous in the Central and to some extent also in the Northern Jordan Valley. This faulting phase, which was called by Picard "intragraben faulting movements" or "rift-in-rift faulting," caused only local phenomena and did not have any regional bearings. The fourth, apparently a rather mild faulting phase, created the present morphology of the Jordan Valley and occurred only some 18,000 years ago (Horowitz 1968a; Neev and Emery 1967). This phase encompasses a system of diagonal faults that delineated the northern and southern basins of the Dead Sea, created the Lake of Kinneret, ended the existence of the Late Pleistocene Lisan Lake, and considerably deepened the Hula Valley.

TRANSVERSAL FAULTS

A system of transversal, east–west running faults is quite conspicuous in southern Israel and in the Sinai (Bartov 1974) but is also observed in Egypt, crossing the Western Desert and underlying the Nile Delta (Said 1975), and in the southern part of Transjordan. These faults are associated with compressional features, such as domes, and with tensional features, mainly some small grabens. According to Bartov (1974), these are dextral strike-slip faults in which the southern sector moved westward. Garfunkel (1964) has also established the strike-slip movement along the Ramon Fault in the Negev. The youngest rock formations that are offset are the Late Miocene top conglomerates of the Hazeva Formation. Pliocene sediments of the Nile Delta (Said 1975, and personal communication 1973) overlie these faults and are not offset. At Nahal Paran, in southern Israel, one of these faults offsets Late Miocene conglomerates and is covered by unfaulted Pliocene gravel. It seems that the Latest Miocene–Earliest Pliocene age of these faults is quite well-established.

The most conspicuous of these faults are the Themed Fault, which runs across the entire Sinai from somewhat north of Elat to the Suez Bay and crosses near Jebel Umm-Rousseis to the Western Desert, the Nahal Paran–Jebel Arif E-Naqa–Bruk Fault, which crosses the Negev and about half of Sinai, and the Ramon–Jebel Minshera–Jebel Giddi Fault, which crosses the Negev and the entire Sinai and continues on the other side of Suez Bay as the Jebel Qatmia Fault, which reaches as far as Cairo. The most conspicuous faults east of the Jordan–Arava Rift Valley are the Wadi Dana–Zakimat el Hassa Fault, the Jebel Shinan–Jebel El-Sawara Fault, and the Qasr El Jilat Fault. Faults associated with the Palmyra and the Lebanese Ranges are considered by Vroman (1973) to be of the same system. It seems also that the Bardawil Escarpment is part of this fault system, since the Late Miocene M-Reflector appears to be faulted in this region. It is quite interesting to note that most of these faults do not offset elevated structures of the Levantine Fold Belt. To the south, they are concentrated in the tablelands of Sinai and in the Western Desert; east of the Arava and the Dead Sea, they are concentrated on the elevated plateau of Transjordan. The only possible exception is the northern part, where they apparently offset some of the structures connected with the Palmyra Fold Belt and with the Lebanon mountains, if these faults are indeed part of the system (which I still doubt).

The faulting along the transversal system and, especially, the formation of the Bardawil Escarpment is responsible for the beginning of the influence of the Nile in the eastern Mediterranean. The Nile did not exist as a large river (Horowitz 1974b; Said 1975) before the beginning of the Pliocene, and the transversal system is responsible both for the formation of the Nile as a regional, large scale river and for the separation of the Red Sea from the Mediterranean, to which it was connected until the end of the Miocene (Horowitz 1974). The Bab-el-Mandeb Straits (Picard 1970) were also opened at this time, and the Red Sea, in its present configuration, has existed only from the beginning of the Pliocene, approximately 5.5 million years ago (Hsü 1972; Ross and Schlee 1973). Another influence of this fault system is the deepening of the Mediterranean to its present configuration and the formation of its subbasins, especially the Levantine Basin. Until Late Miocene times, the Mediterranean was a rather shallow sea, as is proved by the existence of widespread Late Miocene evaporites. These in fact prove (Hsü 1972) that the entire Mediterranean Sea, including its Red Sea tributary and the northern Persian Gulf area, dried up.

Other ideas, for instance, that the Miocene Mediterranean Basin was very deep and as such dried up, are not confirmed by the facts (Gvirtzman and Buchbinder 1977).

MOUNTAINOUS BACKBONE OF ISRAEL

The mountainous backbone of Israel, which forms the watershed between the Mediterranean to the west and the Dead Sea and Bay of Elat to the east, runs in a north–south direction along the entire country, from Lebanon down to the Sinai. The upwarping along this line affects all the preceding tectonic structures, anticlines, synclines, and even rift valleys. It seems to be one of the most important morphostructural units of Israel, apparently continuing north to Lebanon and possibly also to western Syria. It has, however, been neglected by most students of tectonics of the Near East. The line of upwarping is parallel or approximately parallel to the north–south elongated Jordan–Arava Rift Valley, and it is the reason that the internal drainage system of the Dead Sea is disconnected from the Mediterranean. It is quite clear now that the uplifting of the mountainous region should be described as a lineated upwarping along a north–south line and not as just a mere epeirogenesis that affected the entire region. More details of the upwarping of the Galilee are given in Schulman (1959, 1962), who observed the upwarped Preglacial Pleistocene Cover Basalt. Horowitz (1974) observed the same upwarping in the Judea elevated structure, where river sediments of Preglacial Pleistocene age form in places a morphologic plateau on top of the Judean hills, at an elevation of approximately 800 m above mean sea level. Similar conglomerates, which could be correlated with those appearing on top of the mountains, have been recorded at Ma'ale Adumim, which is on the road to Jericho and lies at an elevation of approximately 100 m above sea level, on the eastern side of the watershed. On the western side of the watershed, near Bar Giora and west of it, at Emeq Ha'Elah, the conglomerates occur at elevations down to 400 m above sea level.

Another suggestion as to the Glacial Pleistocene upwarping came from a study of terraces on the Judean hills (Horowitz 1974, 1975). The Günzian terraces proved to be rather high in topography, cut directly into the Preglacial Pleistocene conglomerates. the Mindelian ones were somewhat lower, the Rissian still lower, and the Würmian terraces form a bench that is occasionally some tens of meters above the present-day wadi levels. In the southern Negev, Garfunkel and Horowitz (1966) have observed what they call HaMeshar Conglomerate of Preglacial Pleistocene age, which was tilted postdepositionally toward the east. The same Conglomerate west of the watershed is tilted to the west. It was concluded that the present-day watershed is of a Glacial Pleistocene age. The Yizre'el Valley, in which no Preglacial Pleistocene sediments were encountered, shows the same phenomenon for the Pliocene sediments, being tilted to the west and east of the present-day watershed. Synclines situated on the same line of upwarping, of which the most conspicuous example is the Shekhem Syncline, are upwarped. The central and eastern parts of the Be'er Sheva Basin are also tilted to the east, the tilting clearly postdating the deposition of Pliocene sediments in this Basin. It should be noted that the age of this uplifting and upwarping is synchronous with the age of major downfaulting of the Jordan–Arava Rift Valley and with the opening of the Bay of Elat. It seems, therefore, that these two lineaments acted simultaneously but in opposite directions.

Farther to the west, the continental shelf and slope of Israel are warped, according to Neev (1975), in a westward direction. Neev suggests a Pleistocene age for this warping. Data for the warping of the Israeli shelf and slope are quite scarce, but correlation of activity along the three N–S lineaments, the downfaulted Jordan Valley, the upwarped mountainous backbone, and the warped shelf and continental slope, seem to better corroborate a Pleistocene dating.

ANCIENT STRUCTURES

Very little is known in the Levant about pre-Late Mesozoic activity, and, at any rate, this is quite out of the scope of this book. It is only interesting and worthwhile mentioning that Early and Middle Mesozoic tectonic movements took place in the region but were rather mild in their influence. Information as to these movements is gathered mainly from boreholes. Naturally, these can only give an outline of the picture. It seems that a series of north–south elongated, quite wide and shallow basins developed in Early Mesozoic times; these later migrated perpendicular to their axes. It is quite conspicuous that many of the anticlinal ridges of the country, and especially the northern Negev anticlines, are situated on top of Jurassic and Triassic basins rather than swells. Some indication of Jurassic and Triassic faulting can be seen in the Ramon escarpment (Garfunkel 1964) and in the Wadi Malih area (Mimran 1972). A study by Freund *et al.* (1975) brings forth data and conclusions related to these earlier tectonic movements, including quite conspicuous faulting and volcanic activity as well, which they regard as indicative of northward migration of the African plate and the occurrence, below our area, in Early Mesozoic times, of a Benioff zone that later migrated (Ninkovich and Hays 1972) to comprise the present-day Mediterranean island arcs.

VOLCANIC ACTIVITY

Volcanic activity is known from the Mesozoic and from the Late Cenozoic of Israel. Triassic volcanics are known from the Negev and the Sinai, where they interfinger with continental and shallow marine rocks. Jurassic volcanics appear in similar country rocks all over Israel and crop out on almost any of the larger structures, such as Buqei'a, the Hermon, and Makhtesh Ramon. They are also known from several boreholes, such as those drilled in the Haifa Bay area. Early Cretaceous volcanics are very abundant in Israel, some cropping out, but most are known from numerous boreholes. Cenomanian tuffs and basalts are known only from the Carmel–Umm el Fahm area. Two characteristics are typical for the Mesozoic volcanics: They are potash-rich, and their distribution is confined to the continent or to the shallow shelf. Many boreholes that penetrated the deep-marine facies of the Mesozoic of Israel have never encountered any volcanic rocks.

Late Cenozoic volcanic activity in Israel began to influence considerable parts of the country only in mid-Miocene times. Some earlier, rather restricted activity is known to have affected the Sinai about 20 million years ago (G. Siedner, personal communication, 1975; G. Steinitz, personal communication, 1977), in the form of several dikes. The Negev was little affected by Late Cenozoic activity, and only two volcanic phenomena are known, a plug in Nahal Ashosh and a dike near En Yahav, both of Middle Miocene or later age. Middle Miocene lava flows of considerable extent interfinger with marine sediments in the subsurface of the coastal plain of Israel. They have been named the National Park Volcanics (Grader and Gvirtzman 1961), and they interfinger with Middle Miocene sediments of the Ziqim Formation. These lavas partly solidified under the sea but, apparently, under rather shallow water. Volcanic activity of Middle Miocene age (Siedner and Horowitz 1974) is also known from the eastern Galilee and from the Yizre'el Valley, comprising the Lower Basalt (Schulman 1959).

Middle Pliocene volcanics are known from the Central and Northern Jordan Valley, where they interfinger with Pliocene sediments in a series of volcanic tuffs and flows of limited extension. The most conspicuous Late Cenozoic volcanic activity resulted in the Cover Basalt. It forms the Golan Plateau and extends west toward Israel and eastward to the Wadi Sirhan area. It covers an average area of around 80,000 km^2 and was poured out through a system of fissures from about 2.8 to 1.7 million years ago, during the entire Preglacial Pleistocene period (Siedner and Horowitz 1974). Some restricted volcanic activity is also known from the Quaternary of the Central and Northern Jordan Valley and the Golan Plateau (Horowitz 1973, 1974; Mor 1973); this will be discussed later in more detail. Freund *et al.* (1975) tend to see the Mesozoic high potash-rich vulcanism as a result of the African plate's being pushed northward over a Benoiff zone that plunged below the Middle East in Mesozoic times.

The Miocene National Park Volcanics are considered by Gvirtzman (1970) to have been erupted through fissures resulting from an Early Miocene faulting of the coastal plain. Horowitz (1974) doubts the existence of this fault system and sees no direct connection between volcanism and faulting for the Middle Miocene in Israel. It was also quite clear from evidence from northeastern Galilee (Schulman 1962) that no direct connection could be established for any of the volcanic formations or for the tephrogenic phases that have been encountered in this area.

STRUCTURAL EVOLUTION OF THE LEVANT

Many theories have been proposed during the last 100 years to explain the Late Mesozoic—Cenozoic structural development of the Levant. Lartet (1869) was apparently the first to suggest an explanation for the opening of the Bay of Elat and the Dead Sea Rift as a result of a left lateral movement along this line. Bogolepov (1930), von Seidlitz (1931), and Dubertret (1932) suggested that a 160-km sinistral shear along the Dead Sea Rift, associated with a 6° rotation between Arabia and Africa, could explain the structural features and relations in the Levant. Picard (1943) and later Dubertret (1947) rejected this theory and regarded the Dead Sea Rift as a "normal" type of rift valley, corresponding in style to the Rhine Graben. Picard (1943, 1967, 1970) distinguished between the folding that resulted from lateral compression and the opening of the Dead Sea Rift, which resulted from tension caused by opening and widening the crust, both of which had developed as a "décollement" over the rigid basement. Quennel (1958) and Freund (1965) advocated a rather complex shear movement along the Dead Sea Rift, one that both opened the rift and created the fold structures as lateral offshoots of the shear movement.

Vroman (1967, 1973) distinguished between the folding the Levantine Fold Belt and faulting along the Dead Sea Rift and tried to relate both to block movements within the rigid basement. He denies both Picard's "décollement" and Freund's strike-slip hypotheses and attributes the Levantine folds to a complex two-directional wrench movement of the Precambrian Basement. As for the Rift Valley, Vroman suggests that the tension was northeast–southwest lineated, creating a diagonal opening with some strike-slip component for the Jordan–Arava and Rhab sectors, while the main wrench movement occurred only in the diagonal Yamoune sector. Attempts to describe the Jordan–Dead Sea Rift as a compressional ramp valley (Willis 1938) did not find support in the field evidence and were, consequently, rejected. Picard's and Vroman's theories are primarily based on the distinction in age of the Levantine Fold Belt and the Rift Valley, as well as on many laboratory experiments, such as those by Cloos (1955) and others. The shear theory is presently much more accepted, chiefly because of its elegance and because it attempts to explain all the tectonic phenomena as due to a single process. It will be treated here in more detail, to show its invalidity upon close examination of the field data. A modification of Vroman's ideas is suggested at the end of this chapter; it, in my opinion, seems to answer most of the doubtful points more adequately.

Freund *et al.* (1970) based their assumption of a 107-km shear along the Dead Sea Rift on the following points: Precambrian quartz-porphyry bodies associated with conglomerates occur in the vicinity of Elat in southern Israel, as well as from Gharandal to Fenan in Transjordan; a very thick sequence of arkoses, the Zenifim Formation, which underlies the Cambrian sediments in Sinaf 1 borehole in southern Israel and the Permo-Carboniferous in other boreholes in the Central and Northern Negev is most probably of Precambrian or Infracambrian age. These arkoses are suggested to be identical to the arkosic cement of the Saramuj Conglomerate exposed on the southeast side of the Dead Sea, beneath the Cambrian. Cambrian sediments are exposed on the east side of the Dead Sea, where their thickness exceeds 300 m, in Zerka-Ma'in. On the west side of the Dead Sea, Cambrian sediments are probably absent, and the Late Paleozoic sediments overlie unconformably the Precambrian or Infracambrian arkoses. Cambrian copper- and manganese-bearing sandstones and shales occur between Fenan and Abu Husheiba in Transjordan and in Timna in Israel. Late Paleozoic sediments about 750 m thick, representing the Carboniferous and Permian, are known from boreholes on the western side of the rift, at the Ramon structure. On the east, they are totally absent and only appear about 100 km north, in Safra 1 borehole.

The Triassic, Jurassic, and Cretaceous sediments behave in almost the same way. It is much more difficult to follow the younger sediments, although Senonian phosphorites exposed in the Northern Negev are known in Transjordan only in the vicinity of Amman. Eocene sediments are much more confined by the preceding fold structures and are, therefore, meaningless in paleogeographic reconstruction of any movements along the rift. Freund *et al.* (1968) presented another set of data considered to be valid in dating the strike-slip movement along the Dead Sea Rift. They correlate what are presumably Miocene, Pliocene, and Early Pleistocene phenomena, such as ancient river courses and basalts on both sides of the rift, and come to the conclusion that about 65 km of the movement along the rift is pre-Miocene, whereas the rest, about 40 km, is Miocene and post-Miocene in age. Structurally, Freund (1965) and Freund *et al.* (1968, 1970) defined the Dead Sea, Lake Kinneret, and the Hula Valley as rhomb-shaped grabens, postulating that these are the typical products of a strike-slip movement. The crucial point is, however, the problem of excess material on the eastern side of the rift, due to the northward movement of the Arabian block. This is solved by Freund *et al.* (1970) and by Freund (1970) in a very complicated way. They claim that some of this material is packed within the Anti-Lebanon and the Palmyra ranges east of the Yamoune fault, whereas the rest is said to splay west by the Roum Fault, compensated by a set of strike-slip faults that cross the Lebanese mountain range east to west.

Many objections arose to the shear theory, and some of the more important points will be mentioned here. The Precambrian rocks, which are exposed on the Israeli side only at Elat and Timna, are exposed on the eastern side of the Dead Sea, more than 200 km north of Elat. The copper- and manganese-bearing rocks (Bender, in Freund *et al.* 1970) are found at many localities along the rift edge in Transjordan, and not only at Fenan. The same holds for the quartz-porphyry and conglomerate bodies. As for the rest of the changes in facies along the two sides of the rift, Bentor and Vroman (1960) suggested that these might have resulted from configuration of the coastline in ancient times, which apparently was more or less parallel to the present coastline. This, in fact, could easily be checked. Isopach maps of many formations, from the Cambrian onward, have been made in much detail for the west side of the rift, and one could check to see if they display the bend, direction, and perpendicular thickening of the layers parallel to the present coastline or if they conform to an east-west coastline, as is postulated by supporters of the strike-slip theory.

Cambrian sandstones of the Timna area were analyzed by Karcz and Key (1966) for their paleocurrent structures. The direction of flow of the rivers depositing these sandstones was determined as coming from the east westward, and not northward, as should have been the case to support the shear theory. Weissbrod (1969) dealt with the Paleozoic of southern Israel, and his maps show quite clearly that the thickening (Figure 3.7) of the strata is to the northwest and not in a northerly direction, which proves that on the west side, which is not masked by rifting, the Paleozoic coastline ran approximately parallel to the present-day coastline. The same holds true for the Triassic (Druckman 1974) and for the Jurassic (Goldberg and Friedman 1974). The Early Cretaceous coastline is even clearer. Early Cretaceous sandstones are known from both the Negev and Qiryat Shemonah in the Upper Galilee. Marls are known from the central Galilee, Judea, and the Northern Negev, whereas more to the northwest only limestones and deeper sea sediments are encountered. The same holds also for the Cenomanian and Turonian rocks (Dimant, 1972). Although the Turonian strata show some superimposing of structures that are not definitely parallel to the present-day structures, the same direction of bending persists. An analysis of the Lower Cretaceous fluviatites of the Levant (Karcz 1965) clearly shows that the main river courses flowed from the east westward. The pre-Senonian structures of the country (Flexer 1971) are more or less parallel to the present-day fold structures, although not on the same axes. This phenomenon of parallel wandering of axes has also been shown by Freund *et al.* (1975) to exist in much more ancient structures.

As for the data presented by Freund *et al.* (1968), much more serious consideration should be given to points presented by these authors as final conclusions. Unfortunately, they tried to correlate river courses of different ages, and Miocene river courses on the west side are correlated with Glacial Pleistocene river courses to the east (Horowitz 1974). The same holds for their treatment

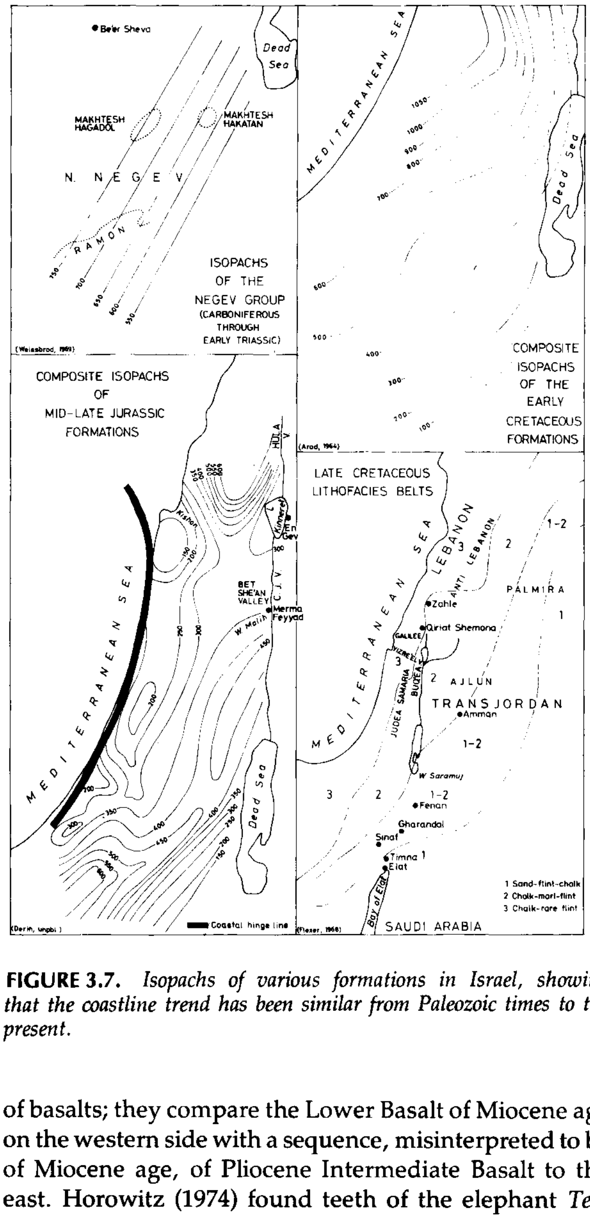


FIGURE 3.7. *Isopachs of various formations in Israel, showing that the coastline trend has been similar from Paleozoic times to the present.*

of basalts; they compare the Lower Basalt of Miocene age on the western side with a sequence, misinterpreted to be of Miocene age, of Pliocene Intermediate Basalt to the east. Horowitz (1974) found teeth of the elephant *Tetralophodon,* which is clearly a Pliocene fossil, in sediments interfingering with these basalts. Miocene conglomerates and sandstones of the Herod Formation, cropping out at the Wadi Malih outlet, are said by Freund *et al.* to be missing on the opposite side of the rift, occurring only at the En Gev area, about 40 km to the north. On examination of the opposite side of the Valley, these sediments can be seen to crop out almost continously from the area opposite Merma Feyyad (Schulman and Rosenthal 1968), and, in fact, the outcrop can be followed continually from the outlet of Wadi Malih to the other side of the Jordan and to the ascending flank of the Ajlun Anticline. The nature of the Herod Formation sediments, being red and rich in conglomerates on the one hand, or comprising alternations of white and red sandstones and chalk on the other, is thought by Freund *et al.* to represent two separate domains, but Michelson (1972) found both to be sediments of a single channel: The center comprises alternations of red and white, whereas red sandstones and conglomerates have been deposited on the rims. Michelson showed the transition between the two facies at the En Gev area.

Pliocene sediments of the Kefar Gil'adi Group, known from the northern Hula Valley and appearing also at the Zahle area in Lebanon, are regarded by Freund *et al.* as of Miocene age. Horowitz (1973) showed that they are of Pliocene age, since *Hipparion* was found (Kansou 1961) at the base of this sequence in the Lebanon. Moreover, the postulated distance of 40 km between the mentioned outcrops cannot stand any critical check of the Lebanese geological maps because otucrops (although small) of these conglomerates occur along the entire way from Zahle to the Hula Valley and down from there to Lake Kinneret, where they interfinger with the Pliocene Bira and Gesher formations (e.g., Schulman 1959). On the other hand, similar conglomerates were also discovered on the east side of the Hula Valley, just at the foothills of Mount Hermon (Horowitz 1973). It is, therefore, inconceivable to base any movement at all on such data, definitely not to give rates of a sinistral strike-slip faulting along the Dead Sea Rift, for which proof seems indeed doubtful.

From the structural point of view, one can or cannot accept the idea of the Dead Sea, Lake Kinneret, and the Hula Valley as rhomb-shaped grabens, but, if several rhomb-shaped grabens are developed along a single strike-slip system, they should be of approximately the same age and size. The Dead Sea and the Hula Valley (Horowitz 1974) are both of Glacial Pleistocene age, but they differ in size by about an order of magnitude. The Lake Kinneret Basin is somewhere intermediate in size between the two but is much younger, apparently only about 18 thousand years old (Horowitz 1968a; Neev and Emery 1967). The problem of excess material on the eastern side of the rift is even much more complicated, as noted by Vroman (1973). The Palmyra range, including the Hermon and the splay of faults in the Lebanese mountains, cannot account for more than about 20 km of shortening. It is notable that on the eastern side of the rift valley, from the southwestern tip of Saudi Arabia up to Turkey, there is no single large compressional feature. On the contrary, there are quite a number of tensional features on this side, like the grabens and the normal faults of Transjordan, Wadi Sirhan Graben, and the Plio-Pleistocene extensive effusions of basaltic lavas in the Hauran, the Golan, and the western parts of Syria.

The Palmyra and Anti-Lebanon ranges might be considered as compressional features, but they predate the major movements along the rift valley by quite a number of millions of years. As to the age of movement along the rift valley, Freund postulates a movement, of around 60 km, that predates the Miocene. Picard (1967) and Horowitz (1974) showed that no pre-Miocene faults are exposed along the entire Jordan–Arava Rift Valley and that the first major faulting is confined to the transition of the Miocene to the Pliocene. It is inconceivable to think that such a major fault movement as postulated by Freund *et al.* (1970) for the pre-Miocene strata, of 60 km lateral offset, would not be displayed in the area by a single fault. On the other hand, the Jordan Valley seems to be traversed by at least one major structure that is not interrupted by any fault. This is a post-Miocene syncline that can easily be seen from Merma Feyyad, at the southern Bet She'an Valley (Schulman and Rosenthal 1968). The Buqei'a anticline of Eastern Samaria dips quite steeply toward the southern Bet She'an sector of the Central Jordan Valley, and Miocene and Eocene strata can be seen traversing the valley, where they are only partly covered by several meters of Late Pleistocene Lisan Formation lake deposits. These strata climb once more on the other side to join the Ajlun Anticline. About 20 km north of Jericho, the same phenomenon was noted earlier by Hull (1886), who defined this area as a "great syncline." The syncline at the Merma Feyyad area is paved with fluviatile Miocene sediments, whereas the one north of Jericho is paved with lacustrine and fluviatile sediments of Pliocene age. In both areas, no Pleistocene rift fill deposits can be seen, except for several meters of the Lisan Formation. This, of course, is an extreme case, because, if a strike-slip movement had occurred along the Jordan Valley, in no place could a continuous structure run from west to east without being interrupted. The idea that the strata are interrupted but that the faults cannot be seen seems inconceivable.

An attempt by Bartov (1974) to date the shear along the Dead Sea Rift as post-Miocene in age is yet another extreme. Bartov, who mapped the transversal faults of the Sinai and the Negev, also mapped a number of such faults on the Transjordan Plateau. He tried to place the Transjordanian faults farther southward and to show correlation of these to the Negev and Sinai faults and, therefore, to postulate that the 100 km shear along the rift took place in post-Miocene times, namely, during the last five million years. A rate of movement of such magnitude seems unacceptable, especially with regard to the fact that the Miocene sediments of the southern Bet She'an Valley are not faulted at all. Horowitz (1973, 1974) showed that faulting along the Dead Sea Rift has taken place recurrently since post-Miocene times. On the other hand, folding of the Levantine Fold Belt had almost terminated in Oligocene times, except for some slight accentuation in places. The time lapse between the two tectonic phases, the folding and the faulting, should be regarded as at least 30 million years; therefore, no association, as suggested by Freund (1965), can be sought for these two phenomena.

According to Freund (1974), the Bay of Elat–Dead Sea–Lebanese-Syrian sector of the Syrian-African Rift Valley should be regarded as a transform fault inclined at an angle of 30° to the opening of the Red Sea. The opening of the Red Sea, which is generally accepted as an offshoot of the mid-Indian Ocean Ridge and Rift System, is regarded by Freund as taking place across its entire width, about 200 km, therefore provoking the idea of a 6° rotation of the Arabian Plate in comparison to the African. It seems that the real opening of the Red Sea should be regarded as only somewhat more than the width of the deep sea trench running through its central sector, which rarely exceeds 30 km and in which oceanic crust is intruded. The shoulders of this deep trench should be regarded as gravitationally spread toward the deeper part (as was suggested by Horowitz, 1967, 1968c, for the formation of the Dancalian block and of the triangle of Afar, in Ethiopia).

Vroman's findings (1973) are much more conceivable concerning the movements along the fault system of the Near East sector of the rift. However, one point still requires explanation. The Yamoune Fault, which runs for several tens of kilometers in a N30E direction, later bends northward and proceeds due north toward the Rift Valley of El Ghab. If the Yamoune was a strike-slip fault, as suggested by Vroman, then north of it, when the faultline bends northward, we should expect a rift valley or a graben to have been formed at the turning point of the fault. This is not the case, and a graben is developed only at the Valley of El Ghab, about 100 km north of the expected point. Picard's concept of the formation of the Jordan Valley as a tensional rift valley of the Rhine Graben type is also, in a way, untenable because, as shown by Vroman (1973; based on experiments by Cloos), such a rift valley should have been much wider than the Jordan Rift Valley, which, in fact, in several places is not really a rift but a syncline. Picard maintained (1939, 1943) that the folding of the Levant resulted from a megagravitational spreading from the uplifting Arabo-Nubian Massif toward the Tethys to the northwest, forming in this way a great *décollement* with the basement. This is not conceivable, as can be seen from studies by Folkman and Yuval (1971), Domzalsky (1967), Mimran (1976), and Weissbrod and Klang (1974), who showed that the Precambrian basement rocks act in the process of folding in a style of definite fault-bordered blocks being subjected to tilting movements. de Sitter (1962) suggested that some of these blocks were tilted and thrust on one another by compressional forces, by which mechanism asymmetric anticlines should have developed over reverse faults in depth. In fact, such reverse faults were found in the Jurassic (Goldberg 1970) of some structures penetrated by boreholes of the Northern Negev.

Up to now, most of the discussion has touched on the problem of the Jordan–Arava Rift Valley, which is to be expected, since most of the geological, stratigraphic, and tectonic elements along this valley are cropping out. The coastal plain, on the other hand, is much more difficult to analyze, since most of the information is obtained from drilling and from geophysical studies. Gvirtzman (1970), who carried out, mainly based on boreholes and geophysical research, the most detailed compiled study of the coastal plain of Israel, suggested two systems of pre- and post-Miocene faults along the coastal plain: one running approximately parallel to the present coastline and the other parallel to the Erythrean System. As for the longitudinal faults, it seems that the information brought forward by Gvirtzman (see also Horowitz 1974) is not sufficient to justify placement of so many faults along the coastal plain. I tend, therefore, to accept Itzhaki's hypothesis (1955) of the folding and downwarping (see also Neev 1975) of the coastal plain, not Gvirtman's suggestion of various faults running here and there.

Considering the Erythrean System's features, the most prominent in the coastal plain is the Kishon Graben, which is the northwestward continuation of the Yizre'el Valley into the sea and can easily be seen on bathymetric maps of the Mediterranean. Another is the so-called Palmahim Graben, which runs in the same direction and is known from geophysical research (Ginzburg *et al.* 1975), from bathymetric work (Neev 1975), and from the study of Late Cenozoic stratigraphy (Derin and Gerry 1971). The Middle Miocene National Park Volcanics, which Gvirtzman sees as one of the outbursts through the Miocene fault system, cannot be taken as indicative of faulting, as has been noted in the Galilee by Schulman (1962), who, after a detailed study of basalts and tectonics, came to the conclusion that there is no definite connection between volcanic and taphrogenic phases.

CONCLUSION

The following "credo" regarding the structural evolution of the Levant in Late Mesozoic through Cenozoic times is based on the previously presented data and assumptions. Basically, Picard's (1967) distinction of three tectonic phases is of prime importance. These are as follows:

1. formation of the Levantine Fault Belt, which took place in Late Mesozoic through Oligocene times.
2. formation of the Erythrean Fault System of the southern Levant, which gives place to the Alexandretta System to the north. This faulting phase was accompanied by a system of transversal wrench faults, forming taphrogenic inland basins and shaping the Eastern Mediterranean Basin. These systems were active during the transition between the Miocene and Pliocene periods.
3. formation of the Levantine Rift System along a north–south lineament, accompanied by parallel uplifting of the mountainous backbone west of the rift and of the plateau east of it. This phase commenced during the transition of the Preglacial to the Glacial Pleistocene, and is still active.

Naturally, each of the succeeding phases affected the preceding ones, mostly as accentuation or rejuvenation of previous activity, whether it was folding or faulting, which occurred at localities where the systes intercepted.

The Levantine Fold Belt

Processes involved in the formation of the Levantine Fold Belt are somewhat outside the scope of this book but will be treated in some detail due to the considerable influence of this folding phase on present-day morphology. The folding, as has been shown previously, is connected with fault-bordered blocks of the Precambrian Basement. The age of folding of the system, from Late Mesozoic through Oligocene, compares rather well with the uplifting of the Alpine chain due to the closing of the Tethys. Indeed, it could be proposed (Horowitz 1972) that in Late Paleozoic times the Levant occupied the equatorial region of the globe.

The northward movement of the African Plate, of which Arabia was a part at the time, in Mesozoic through Early Cenozoic times was the main cause for the closing of the Tethys. Freund *et al.* (1975) suggested that Israel lay above a Benioff Zone in this period; this resulted in potash-rich lava effusions interbedded within the Mesozoic sediments of the country. The edge of this plate was most affected by the northward movement, breaking into a system of blocks arranged parallel to the plate's margins. The epicontinental sediments covering this marginal area have been shaped into the series of asymmetric or even monoclinal folds comprising the Levantine Belt. The contour of the plate's margins at the Levant was parallel to the present coastline (Bein and Gvirtzman 1977), as can be seen from the configuration of the coastal Hinge Line (Gvirtzman and Klang 1972), which is known to have been active from at least Jurassic times onward. The shape of the African Plate's margins dictated the distribution of facies belts of epicontinental and continental deposits from the Early Paleozoic onward, which is quite clear when looking at these phenomena in areas not affected by later rifting (Figure 3.7).

It should be noted that the fold structures of the Levantine Belt, at least in the southeastern Mediterranean sector, extend far westward under the Late Tertiary cover of the coastal plain and offshore. They are even known northwest of the Pelusium Line, thought by Neev *et al.* (1976) to represent a compressional feature bordering the Levantine Plate. It seems that the extension of fold structures beyond this line casts doubt on its validity as a division between continental and oceanic crusts. The Benioff Zone has since migrated northward, as can presently be seen (Ninkovich and Hays 1972) by the potash-rich Greek volcanic arc. The folding of the Levantine Belt was also accompanied by some faulting, mostly perpendicular to the fold axes. These faults, all of them of the gravity type, rather short and of no great vertical throw, can be seen on the geological map. Some of them have later been rejuvenated by the succeeding tectonic phases.

The Erythrean System

This was defined (Shalem 1954) as a faulting phase of a preferred northwest–southeast lineament. Based on contemporaneity, I would like to include within the Erythrean System two other lineaments: the Alexandretta, of a preferred northeast–southwest bearing, which affected the northern Levant; and the Transversal, which faulted the Levant latitudinally. Most of the faults associated with this System are of the gravity type, but strike-slip components are quite common, with lateral offsets in the order of a few kilometers. This is conspicuous in the Transversal System.

The age of this phase is the transition from the Miocene to the Pliocene, and its most important products are a series of elongated, wide, rather shallow rifts of the Rhine Graben type, of which the most conspicuous is the Red Sea–Gulf of Suez System. Faulting along parallel lines affected mainly the southern sector of the Levant, creating a series of inland basins that were consequently occupied either by the transgressing Pliocene sea or by lakes and larger rivers. The ultimate configuration of these basins resulted from the combination of the Erythrean faulting and the residual Late Miocene topography, which, to some extent, had still been influenced by the Levantine Fold structures. Moreover, in places where faults of the Erythrean System crossed structures of the Levantine Belt, some accentuation of the latter could be seen. To the north, the Erythrean System changed direction to comprise the Alexandretta lineament, most probably to conform to the main tectonic lineaments of the southern Turkish Alpine System. The Transversal System, of a dextral wrench type, seems to us to be of a compensating nature for volume problems and is developed much better at localities where this problem is more acute; namely, where the continental masses are of a considerable size, such as the Sinai. The System continues also on both sides of the Sinai and on the sides of the bordering rifts, in Transjordan and Egypt, but fades away at some distance from the major rifts. An important creation of the Erythrean System is the Eastern Mediterranean Basin in its present configuration. We do not have sufficient information as to the northern sector of this basin. The southern is bordered by the Bardawil Escarpment to the south, which faults the Late Miocene evaporites, and by a downwarping of the Israeli shelf and continental slope, which has also affected the Miocene evaporites. It should be noted that, although most authors tend to draw a considerable number of faults running both parallel and perpendicular to the coastline in the coastal plain's subsurface (see, for example, Gvirtzman 1970), these have never been positively detected, except for some seaward continuation of the Carmel Fault (Horowitz 1974).

The main reason for development of the Erythrean System seems to be the clockwise rotation of the African Plate in post-Miocene times, as summed up in Girdler and Darracot (1972). This rotation commenced following change in the direction of movement of the African Plate, which released the compression on the Alpine Belt. Indeed, many tensional features of Pliocene age are known from the Alpine Belt (see, for example, Gignoux 1955). The cause for this change in movement direction is most probably the extension of the mid-Indian Ocean Ridge and Rift System toward the area of the present-day Red Sea. This event also disconnected the latter area from the Mediterranean and opened the other end, through the Bab el-Mandeb Straits to the Indian Ocean. It should be noted though, that the actual opening of the Red Sea is much smaller than the actual width of the water body and should be regarded in the order of 20–30 km, or about an order of magnitude less than the width of the actual rift, which is so much wider due to gravitational spreading perpendicularly to the Pa'ar. This suggestion allows for some clockwise rotation of the African Plate but disregards the northward migration of the Arabian side; this seems to us inconceivable (as was discussed earlier).

The Levantine Rift System

This is basically a north–south lineated system that has affected the area since the transition of the Preglacial to the Glacial Pleistocene and is still active at the present day. The main features of the Levantine Rift System are the formation of an elongated, relatively narrow depression, which is sometimes a true rift, sometimes a monoclinal rift bordered by only a single fault, and sometimes a syncline. The depression is accompanied by elevated belts on both sides; these have been upwarped synchronously with its downfaulting, creating the western mountainous backbone and the eastern plateau. Once more, previous tectonic features, mainly those of the Erythrean System, have been rejuvenated.

It seems to us that the Levantine Rift was formed and, in fact, is still in the process of formation due to a completely different pattern of forces than those responsible for the Erythrean System. The only mechanism that might have created the Levantine System and might answer for the three main structural features—the upwarped margins, the downwarped depression, and its relative narrowness—is a parallel of a mid-ocean ridge, with its median rift and elevated shoulders. It is therefore suggested that the Levantine System is the Pleistocene offshoot of the Red Sea Pa'ar rather than a transform fault of this system, as suggested by Freund (1974). The opening along the Levantine System is no more than 2–3 km and, at many localities, is much less. This goes well with its young age—no more than 1–1.5 million years. The Gulf of Elat (Aqaba) is the embryonic stage of the ocean-to-come. Indeed, in some places its depth exceeds 1800 meters and resembles an oceanic floor much more than the Gulf of Suez, which does not exceed 40–50 m depth.

North of the Yizre'el Valley, at the Galilee and Lebanon, the Levantine System bends, apparently to conform with the approaching structures of the Turkish area. In earlier, Erythrean times, this involved a change of direction to the Alexandretta System. In Levantine times, the change involved shear in these areas, displayed and compensated by a great number of meridional faults, many of which have pronounced dextral strike-slip components. Neev *et al.*'s (1976) idea of the downwarping of the Eastern Mediterranean slope in Quaternary times must be rejected, based on the data presented in their work. Quaternary eolianite ridges are mapped down to a maximal depth of 150 m and are not recorded any deeper. This conforms quite well with the depth indicated for the maximum regression during Würmian times and could not be taken as indicating any tectonic activity. We tend to think that the Eastern Mediterranean was shaped by the Erythrean rather than by the Levantine System.

4

Pre-Quaternary Geology of Israel

The pre-Quaternary geological history of Israel (Figure 4.1), as well as that of Near East in general, can be divided into three major phases. The first is the Precambrian phase, in which orogenic processes, metamorphism, and intrusion of rather large-scale granites take place. This phase is terminated at the end of the Precambrian by a large-scale outpouring of volcanic rocks intermingled with conglomerates and flattened by a regional peneplain. The second phase comprises deposition by the oscilating sea of marine and continental strata of platform type; this spread generally from the northwest, over the Precambrian peneplain. The type and facies of these sediments depend on the sea level and later, especially in late Mesozoic through early Cenozoic times, also on the gentle folding of the Levantine Fold Belt. The third phase begins at the transition of the Miocene to the Pliocene and is connected with the faulting of the Erythrean and Levantine Rifts.

Rock units comprising the second and third phases were divided in the Negev by Ball and Ball (1953) into three major units: the Lower Clastic Division, of Cambrian through Early Cretaceous age, which comprises mainly sandstones and conglomerates; the Middle Calcareous Division, of Cenomanian through Eocene age, comprising mainly limestones, dolomites and some chalk, clays, chert, and marls; and the Upper Clastic Division, of Oligocene through Recent, comprising mainly conglomerates, with some sandstones and shales. At the northwest of the country, where marine processes influenced the sedimentation much more than to the south, this threefold division is not so clear. Paleozoic sediments never penetrated this area, and the nature of these sediments is uncertain. The Jurassic and Early Cretaceous sediments are much more marine than to the south, whereas the Upper Clastic Division maintains its clastic character in the northeastern parts of the country too. In the western parts of the country the main influence is marine, and, in areas such as the coastal plain, marine deposition continues until the present day.

PRECAMBRIAN BASEMENT COMPLEX

Precambrian rocks, which form the Arabo-Nubian Massif crop out in Israel only in a restricted area around Elat, in a number of tectonically elevated blocks bordered by faults connected with the Levantine Rift. On the other side of the Rift Valley they occur far north almost continuously, reaching the eastern side of the Dead Sea. The petrography of the Precambrian rocks in the vicinity of Elat was studied in detail by several investigators and is summed up in Bentor (1961). The sequence is divided into three major petrographic units, the earliest, Metamorphic Complex, the Intrusive or Granitic Complex, and the youngest, Volcano-Conglomeratic Complex. Several peneplains separate subunits within the Precambrian complex, which was finally flattened by a regional peneplain, exposed in the entire area of southern and eastern Sinai, the area of Elat, and the eastern side of the Rift Valley up to the Dead Sea.

The Metamorphic Complex at Elat and Sinai was studied in detail by Shimron (1972), who discerned several phases of metamorphism and orogenesis within the sequence. The first and second phases of folding, F1 and F2, are widespread and are responsible for the high-grade regional metamorphism of the area. The first phase produced an axial plane slaty cleavage with associated micro- and mesoscopic intrafolial folds. The second phase produced mainly macroscopic east–west trending flexural slip folds, by folding of the F1 cleavage planes. Tight, steeply plunging north–south crossfolds form the third phase, F3. The fourth generation, F4, of folding, which comprises meso- and macroscopic recumbent folds and associated crenulations, culminated in a major low angle thrust and in the production of the Zefahot Thrust Sheet, above a conspicuous zone of *décollement*. Recrystallization accompanied deformation but was mostly completed before the beginning of the fourth phase, which is indicated by deformed polygonal arcs of micas, partial recrystallization, and locally brittle fractures. Garnet and staurolite porphyroblasts began to grow during the interkinematic between the first and second phases. The growth of staurolite ended after the end of the second phase, with garnet continuing to grow until after the third phase.

Andalusite and cordierite began to grow toward the end of the second phase and continued to grow until the third. Fibrolite sillimanite is postkinematic with regard to F2, and most of its growth can be attributed to late granitic intrusions. Plagioclase and potassium felspar porphyroblasts occur mainly in narrow contact aureoles, where they

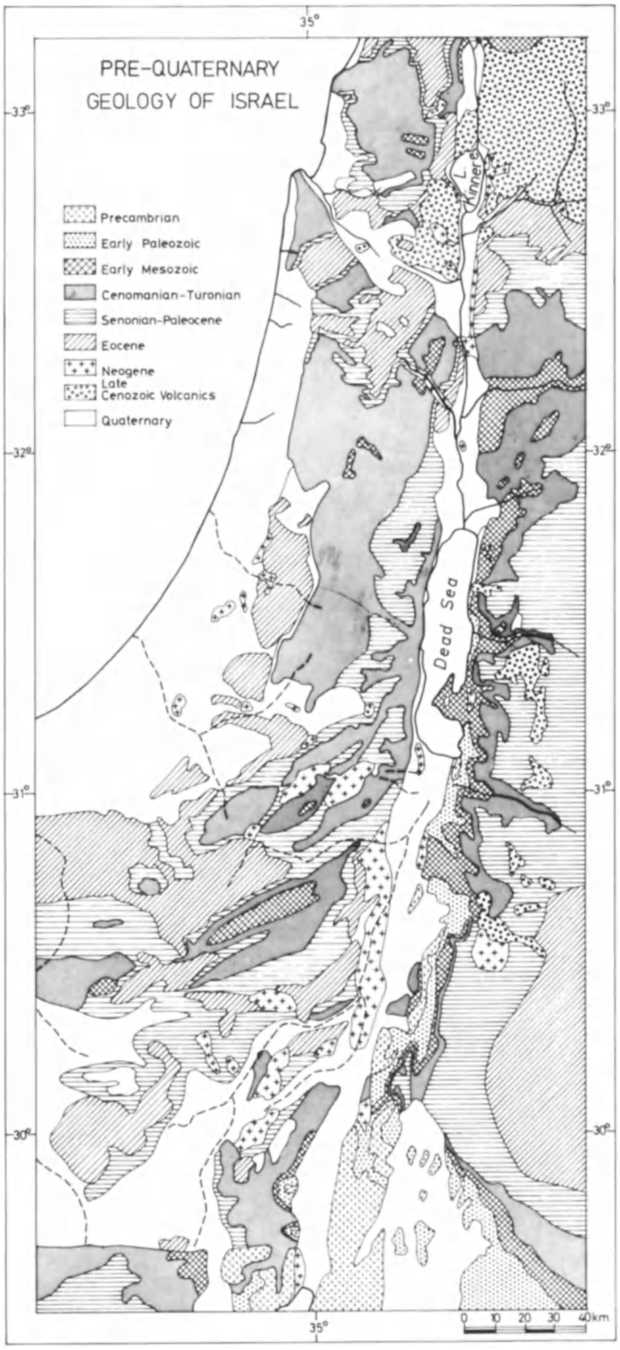


FIGURE 4.1. *The pre-Quaternary geology of Israel.*

are related to the emplacement of the synkinematic Elat Gneiss. Metabasites were emplaced during F1 and IK1. They are present now as actinolite–biotite, tremolite–biotite, and tremolite–calc–chlorite amphibolites, which have been affected by retrograde metamorphism in postkinematic shear zones. Mafic dike sheets were emplaced preferentially into axial planar zones of F2 folds and are synkinematic with this phase. Subsequent deformation, Late F2, took place along synkinematic shear belts confined to the mobile dike sheets. The extreme deformation and metamorphism produced amphibolite–biotite–plagioclase schists from the mafic dikes, as well as flaser granulitic gneisses from border-zone porphyroblastic and augen-gneisses. The Elat Granite was injected preferentially into what were probably reactivated cores of macroscopic F2 folds during and after the third interkinematic phase. It has locally participated in the fourth phase folding movements and in the related para- or postcrystalline deformation.

The polyphase deformation and plurifacial metamorphism in the Elat area and Sinai Peninsula is of the low-pressure amphibolite facies series type, closely resembling that of the Hercynians in the Pyrenees and throughout Europe. The Metamorphic sequence in the Elat area includes a number of migmatitic bodies, granitoidic in texture. Most of the metamorphic rocks are metasediments and comprise at least four orogenic cycles that were active in the area during middle and late Precambrian times. These orogenic phases are separated by peneplains. The migmatitic complex gradually changes to quartz diorite, which seems to be a hybrid rock as a result of partial melting. Some porphyritic gneisses are also associated in this border complex. The synkinematic Elat Granite appears in several intrusions that are concordant with the general structure. It differs from the granitic gneiss by not showing any metamorphism, and it does not include schist dikes. When the granite intrudes the schists, which are metasediments, it is generally surrounded by a migmatitic zone and a zone of hybridic rocks and granitic dikes. These rocks are very heterogenous in their composition and frequently include relics of metamorphic rocks, into which they have intruded. It seems, according to Garfunkel (1970), that the granite was intruded into the bodies of the metamorphic rocks toward the end of the kinematic process. Several alkaline and calc-alkaline granitic bodies are definitely postkinematic and belong to the Volcano Conglomeratic Complex. These rocks do not show any sign of metamorphism, and they are not connected in their appearance with the structure of metamorphic bodies. Some of them are cataclastic in places. Some of these young post kinematic granites are definitely of different ages, and the petrographic similarity between them does not indicate any genetic relations.

Dikes of different compositions are very abundant in the Elat Complex and penetrated most of the metamorphic and plutonic rock bodies in the area. Some of them are earlier than some of the postkinematic intrusions. Most of the dikes predate the sediments and volcanic rocks that comprise the Volcano-Conglomeratic Complex. The Elat Conglomerate and the volcanic rocks associated with it are intruded only by two kinds of dikes, red quartz porphyry and green diabase. The dikes are more frequent in granite, gneiss, and quartz diorite bodies and less frequent in schists. The Volcano-

Conglomeratic Complex is built of several units of sedimentary and volcanic, nonmetamorphic rocks, and also of several intrusions that are typically alkaline. This series of supracrustal rocks was divided by Garfunkel (1970) into three main complexes. The first complex comprises alternations of polymyctic coarse conglomerates that are badly sorted, named Elat Conglomerate, and volcanic and pyroclastic flows. The volcanic rocks differ in petrography and composition but are mostly acid, sometimes even containing free quartz. The second group of the Volcano-Conglomeratic Complex is represented by the quartz porphyries of the Yotam Plain. South of the plain a volcanic crater is exposed associated with a large ignimbritic body. The rocks are dacitic and include plagioclase as phenocrysts. Occasionally conglomerate beds interfinger with them. The third group comprises the quartz porphyry of the Amram Block and the Neshef Mountains. These are rhyolitic and include quite high potash felspar as phenocrysts and matrix. The large bodies of these rocks are not crossed by dikes.

The Late Precambrian peneplain phase affected all the rock bodies in the area of Elat and apparently also in Transjordan and Sinai. Only in some rare cases, such as in the block of Timna (Karcz and Key 1966), a Late Precambrian relief of sandstone-filled canyons can be seen. The Saramuj Conglomerate of Transjordan and the Hammamat Conglomerate of Egypt were correlated by Picard (1943) with the Volcano-Conglomeratic Complex of Elat. A thick sequence of volcanic rocks and arkoses, which is up to 2.5 km in thickness in the Ramon 1 borehole, was penetrated by several boreholes in the Negev. It was designated by Weissbrod (1969) the Zenifim Formation and correlated with the other Volcano-Conglomeratic sequences.

LOWER CLASTIC DIVISION

The Lower Clastic Division, traditionally known as Nubian Sandstone, is best exposed at the Timna erosion cirque. It was divided by early workers (Shaw 1947) into five units, later given formation names by Weissbrod (1970). The lowermost horizon of sandstones and conglomerates was named Paleozoic Nubian Sandstone, or the Amudei Shelomo Formation. This sandstone is overlain by a thin transgressive sheet of Cambrian marine sediments (Parnes 1971) comprising dolomites and shales, the Timna Formation. The Paleozoic Nubian Sandstone, representing channels flowing from east westward (Karcz and Key 1966), comprises mainly dark red to brown sandstones, in places conglomerates, locally very coarse ones, such as those in the outcrop near Amudei Shelomo at Timna. This formation represents an erosion system cutting into and covering the late Precambrian peneplain. The Cambrian sediments, which comprise the Hakhlil, Nimra, Nekhushtan, and Mikhrot members of the Timna Formation, occur in the area of Timna and in southern Transjordan up to the Dead Sea. The sequence was penetrated also by the Sinaf 1 borehole but is absent in boreholes drilled in the Northern and the Central Negev, where Carboniferous sediments directly overlie the Precambrian Zenifim Formation. Copper and manganese ores are locally concentrated in these formations and were exploited by the Timna Copper Mines and by ancient miners. The marine sequence is covered by the Lower Variegated Nubian Sandstone, which was most probably deposited in a fluviatile system. The sandstones are rather rich in felspar.

The earlier mentioned formations belong to the Yam Suf Group, tentatively assigned a Cambrian age (Weissbrod 1969). The Middle White Sandstone, later designated (Weissbrod 1970) as the Amir Formation, belongs to the Kurnub Group, of Early Cretaceous age, which overlies the Yam Suf Group in the Timna area over a considerable hiatus.

The late Paleozoic sediments of the Negev Group, which are known from boreholes in the Central and Northern Negev, truncate sediments of the Yam Suf Group and overlie the Zenifim Formation. The early Paleozoic is represented only by Cambrian sediments in Israel and in eastern Transjordan, but in southern Transjordan and Arabia these are much better preserved, and Ordovician, Silurian, and Devonian marine rocks occur (Bender 1965; Hellal 1965). These are totally truncated in southern Israel and in eastern Transjordan (Weissbrod 1969). In the Northern Negev, the Negev Group comprises four formations: the Sa'ad, Arqov, Zafir, and Yamin formations, of late Paleozoic age (Horowitz 1974c). The Sa'ad Formation is of Late Carboniferous age, and the Arqov, Zafir, and Yamin formations, penetrated by most of the Northern Negev boreholes, are of Late Permian age and represent a shallow sea, sometimes intercalated by fluviatile sediments. These formations are not known from any outcrops in the area of Israel.

Triassic rocks of the Ramon Group crop out only in southern Israel and eastern Transjordan and were studied in detail by Zak (1963), Picard and Flexer (1974), and Druckman (1974). The most complete outcrops occur at the Makhtesh Ramon breached anticline, and the sequence was divided by Zak into three formations: the Gevanim, Saharonim, and Mohilla. Later, Druckman (1974) added, mainly from subsurface information, the lowermost, Ra'af Formation. The Ra'af Formation, of Early to Middle Triassic age (Horowitz 1974c), consists mainly of fossil-bearing limestones. The Gevanim Formation, of Middle Triassic age, consists of sandstones, shales, and some horizons of fossil-bearing limestones. The Saharonim Formation, of Middle to Late Triassic age, consists of fossiliferous limestones, dolomites, shales, and some horizons of gypsum or anhydrite. The Mohilla Formation, of the uppermost Triassic comprises mainly anhydrite or gypsum and dolomite. All the units have been deposited in a shallow marine environment, sometimes lagunar, sometimes with a marked fluviatile influence. Analysis of subsurface occurrences of Triassic sediments known from boreholes all over the Northern and Western Negev indicates that most of the Triassic sediments were deposited in a series of basins, the most conspicuous being those of Ramon, Kurnub, Kana'im, and Ramallah, separated by restricted dolomitic sequences of the higher areas of Nafkha, Sherif, and Lot.

The different lithologies of Triassic sequences are the first indication of the early Mesozoic fold movements that affected the Levant, although, due to lack of detailed data, the exact nature of these movements cannot be accurately determined (Freund *et al.* 1975). The Triassic sequence is also truncated in southern Israel, but toward the northwest, as revealed from a number of boreholes that penetrated the sequence, it becomes more and more marine in nature, sometimes even represented by deep-sea sediments in the coastal plain, such as black shales and clays. Several bone-bearing strata known from the Triassic outcrop of Makhtesh Ramon revealed a variety of early reptiles and amphibians (Brotzen 1955). A major regression took place at the end of the Triassic, and most of the Israeli area, at least from Judea southeastward, was exposed to the surface. Lateritic paleosols separate the Triassic Ramon Group from the overlying Jurassic Arad Group. Jurassic sediments of the Arad Group (Goldberg and Friedman 1974) are known from the three major breached anticlines of the Central and Northern Negev, Makhtesh Ramon, Makhtesh HaGadol, and Makhtesh HaQatan, and are also known from a great number of boreholes almost all over the country. The style of sedimentation seems to be almost the same as during the Triassic. A number of basins and elevated areas have controlled the sedimentation, but in general the sea was rather shallow and rivers from the southeast brought terrigenous clastic materials that frequently intercalcate with the Jurassic sediments of the Negev.

The Jurassic sediments of Makhtesh Ramon, the southernmost Jurassic outcrop in Israel, comprise mainly fluviatile sandstones and clays, with some lagunal and marsh deposits intercalated occasionally, but quite rarely, by marine limestones. The Jurassic sequence in Makhtesh HaGadol and Makhtesh HaQatan is much more marine, although shallow, and contains quite a lot of fossil corals and coral reefs. The Jurassic sequences become, toward the northwest, much more of a deep marine environment and, at the coastal plain, comprise almost entirely black clays and shales. The Jurassic sequence is also known from Wadi Malih in Samaria and from the Hermon Range to the north of Israel, where it resembles the Negev sequence. Late Jurassic sediments are not known from the outcrops of southern Israel and were probably removed by the succeeding erosion phase, which took place following the great regional regression at the end of the Jurassic and the onset of the Cretaceous. This regional regression is also accompanied in many places by outpouring of volcanic rocks.

The Early Cretaceous unconformity is known almost throughout the Middle East, except for some areas to the northwest where deep marine sediments overlie conformably deep marine sediments of the Jurassic. This unconformity has truncated most of the Paleozoic and early Mesozoic sediments of the Negev, and the Early Cretaceous Middle White Sandstone overlies, over a great unconformity, the Cambrian deposits at the Timna area. The Early Cretaceous sediments, designated as the Kurnub Group in southern Israel, comprise mainly fluviatile and paludine sandstones and clays to the south and east of the Levant. Sandstones are known even from the coastal plain in the area of Heletz and from the Lebanon around Beirut. The general flow direction of the Early Cretaceous drainage system, in which these sandstones were deposited (Karcz 1966), is from the east westward. The marine influence becomes greater to the northwest. At the Timna area, which is the southernmost outcrop of Early Cretaceous sediments in Israel, the entire sequence is fluviatile, whereas in Makhtesh Ramon it is intercalated by a single marine transgression and in the Makhtesh HaGadol three such marine transgressions are represented. The sandstones are known as far north as Qiryat Shemona in Israel, on the western side of the rift, and it seems that the coastline ran almost parallel to that of the present day. The marine sequence is much better represented in Judea, Samaria, and the Galilee, comprising mainly marls and some limestone horizons. In the coastal plain, west of the structural hinge line, the Early Cretaceous sediments comprise mainly gray to black marls and shales of rather deep marine origin.

MIDDLE CALCAREOUS DIVISION

The Middle Calcareous Division is divided into the Judea Group, of Cenomania–Turonian age, the Mount Scopus Group, of Senonian–Maastrichtian–Paleocene age, and the Avedat Group, of Eocene age. To the west of the country, the Shefela Group, of late Eocene through Recent (Gvirtzman 1970), is the marine correlative of the Upper Clastic Division of the Negev and the Galilee. The Cenomanian transgression submerged almost the entire Middle East, depositing the lower part of the Judea Group sediments. These comprise mainly limestones, marls, and dolomites, all of them deposited in a shallow marine environment over a vast platform. The Cenomanian transgression reached the Negev area (Bartov *et al.* 1972) later than the northern and western parts of the country, in which the Judea Group sequence is much thicker, attaining almost a kilometer in thickness. Towards the Turonian, influence of the Levantine Fold Belt began to be felt in Israel, and the Turonian and Coniacian sediments were controlled by the structural pattern, which resulted in thicker sediments in synclines and thinner sediments, mostly dolomitic, on anticlines. This folding phase was felt much more in the Negev than in the Galilee during this period.

During the Senonian, the sea became much deeper and the entire Middle East, including Northern Africa, was covered by a sea 300–400 m deep (Flexer 1971). The sea was much shallower in the Southern Negev and Sinai (Bartov *et al.* 1972), and the thick sequence of chalks occurring in the north was much reduced in thickness to the south, containing conspicuous chert and some quartzite and sandstone horizons. In the Central and Northern Negev and in the area of Amman in Transjordan, synclines of the Levantine Fold Belt were filled by phosphorites, which at present are exploited economically. The relations between the sea and the Arabo-Nubian Massif remained more or less the same until the end of the Eocene, and shales and chalks were deposited over the whole area throughout the entire period. Only in some rare locales, around the Ramon Anticlines for example, are terrigenous sediments and paleosols known to interfinger with the Senonian and Eocene sediments, apparently because the Ramon anticlinorial structure was an island at this time. Eocene conglomerates are also known from Samaria (Cook *et al.* 1973), which indicates that most of the folding took place before the Eocene. In fact, in most places the Eocene strata lie horizontally and unconformably over the previous structures. Only in some rare cases, such as those connected with the Levantine Rift System, the eastern flank of the Wadi Fariyya structure, for example, do the Eocene sediments take part in the folding.

During Oligocene times, most of the country was uplifted high above sea level, and a drainage system was developed towards the Mediterranean. Marine sediments of Oligocene age are known only from the coastal plain of Israel, from a restricted number of outcrops, but mainly from boreholes. These comprise the lower part of the Shefela Group (Gvirtzman 1970). Although an Oligocene drainage system is known to have developed quite significantly at this time (Garfunkel and Horowitz 1966; Neev 1960) and the system later filled by Miocene sediments (Gvirtzman 1970), no distinct Oligocene fluviatile sediments are known from Israel. Apparently, the only exception is a sequence of conglomerates described by Shahar (1973) from the Ef'e Syncline of the Northern Negev, which underlies the lower Miocene base conglomerates of the Hazeva Formation. No age indication except for the position of these sediments, which also contain Eocene pebbles, is known. Another outcrop of marine Oligocene sediments is known (Michelson 1972) from the Golan Plateau, east of the En Gev area, which is a large synclinal embayment separating the Ajlun Anticline from the Hermon and Palmyra ranges and is apparently connected (Horowitz 1974) with the Persian Gulf system, through the Damascus Basin. The marine Oligocene sediments of the En Gev area differ considerably from those known from the western coastal plain of Israel.

UPPER CLASTIC DIVISION

The Neogene geological processes, being the base on which the Quaternary is superimposed and developed, will be discussed in greater detail under this heading. We shall discuss together the upper part of the Shefela Group, of Miocene and Pliocene age, and the Upper Clastic Division, the continental correlatives of the marine transgressions, which are mutually connected.

MIOCENE

The Marine Miocene (Figure 4.2) of the coastal plain of Israel is known from a large number of boreholes and comprises the Ziqim-Mavqi'im formations suite, which represents (Horowitz 1974) a transgressive cycle of the Mediterranean. It begins with a base conglomerate, which is covered by the shaley, marly 300–400-m thick Ziqim Formation overlain conformably by the Mavqi'im evaporitic sequence. The foraminifera of this sequence (Derin and Reiss 1971) indicate a Miocene age. The Ziqim Formation sediments are interfingered by the National Park Volcanics, which bear the same chemical characteristics as the Lower Basalt of the Yizre'el and the Central Jordan Valleys. In several boreholes at the coastal plain, reefoidal limestones were found in the upper part of the Ziqim Formation, underlying the Maviqi'im evaporites. These are correlated by Derin and Reiss (1971) on the presence of *Borelis melo,* with the Ziqlag Formation, which occurs at the Be'er Sheva and Shefela regions. The heavy minerals association of the Ziqim Formation (Nachmias 1969) indicate that the main source of clastics is the Early Cretaceous Nubian Sandstones of the Negev. The maximal thickness of the Ziqim Formation, several hundred meters, is known from the southern coastal plain, where it fills the preexisting erosion channels. The thickness decreases on the interfluves, and gradually northward.

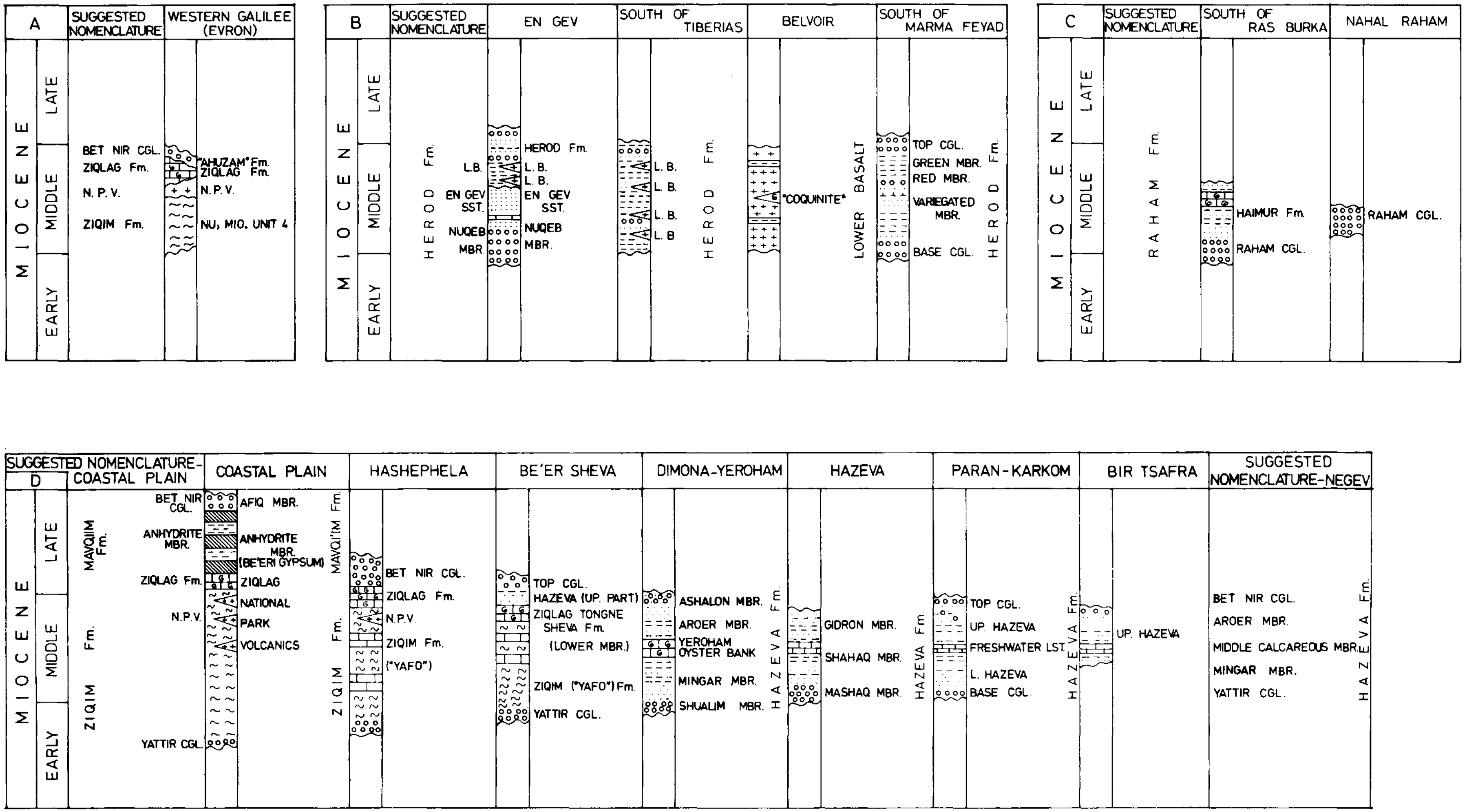


FIGURE 4.2. *Miocene rock units of Israel and their suggested correlations: A, The Western Galilee system; B, the Eastern Galilee system, leading to the Persian Bay; C, the Elat system, leading to the Red Sea; D, the southern coastal plain and Negev system.*

In the coastal plain of the Western Galilee (Bar Josef 1967) the thickness of the Ziqim is only several tens of meters. The sediments overlie an erosional relief, and the top is always truncated. Pollen spectra of the Ziqim Formation (Horowitz 1974b) comprise mainly pollen derived from xerophytic and halophytic plants, such as *Chenopodiaceae, Gramineae,* and *Cyperaceae,* and some arboreal pollen, mainly derived from pines. Littoral sediments of the Miocene are represented along the coastal plain of Israel in the Shefela and Be'er Sheva regions by the Ziqlag Formation, comprising reefs and reefoidal limestones. The Ziqlag Formation in the Be'er Sheva region is replaced westward by the Lower Member of the Sheva Formation. Further eastward in the Be'er Sheva region, in the Yeroham and Dimona area, the Ziqlag Formation becomes an oyster bank, the Yeroham Oyster Bank (Harash 1967). An almost similar oyster bank is reported from the Ras Burka area south of Elat (Garfunkel 1970; Hildebrand *et al.* 1974), interfingering with the Haimur Formation that overlies the Raham Conglomerate. Both are thought to be of Miocene age. Littoral Miocene sediments are also known in northwestern Israel, from the Western Galilee Coastal Plain, where some poorly developed outcrops and subcrops of Ziqlag-type sediments are reported by Issar and Kafri (1972). They interfinger westward with marine Miocene marls of the Ziqim Formation and also with basalts, apparently of the National Park Volcanics.

A middle Miocene marine intercalation is reported within the continental sands and conglomerates of the Herod Formation (Michelson 1972) in the area east of En Gev, in northeastern Israel. The marine intercalation comprises some limestone horizons rich in sandstones, which are also thought to have been deposited under marine conditions—the En Gev Sandstone (Golani 1962). The rocks contain an assemblage of mollusks and foraminifera of which the most interesting is *Austrotrillina,* very abundant in the Persian Gulf area and thought by Michelson (1972) to indicate a marine transgression that came from the east, rather than from the Mediterranean. The continental Miocene of Israel comprises three sedimentary suites: the Raham Conglomerate and Haimur Formation of the Gulf of Elat area; the Hazeva Formation at the Negev; and the Herod–En Gev suite of northeastern Israel. The Raham Conglomerate occurs at several localities along the Gulf of Elat and the Arava and is correlated by Garfunkel (1970) with similar conglomerates occurring at Jebel el Khureij in the eastern part of the Arava (Bender 1968). It comprises coarse clastics at the base, always overlying an erosional relief. The clastics become finer towards the upper part of the exposed sequence, where they may include yellow and red fine clastics, mainly siltstones. The pebbles are mainly derived from limestones, dolomites, sandstones, and some subordinate magmatic rocks, most of them of types that are not exposed presently in the Elat area. The Raham Conglomerate is strongly folded and faulted. The Haimur Formation overlies the Raham Conglomerate and consists of about 40 m of alternating sandstones, siltstones, and some conglomerate horizons, overlain by a 3-m-thick oyster bank, which is, in turn, overlain by about two meters of sandstone.

The top of the Haimur Formation is always eroded and unconformably covered by a conglomerate layer, possibly the Pliocene Eilot Conglomerate. The clastic components of the Haimur Formation, same as the Raham Formation, are derived from Early Cretaceous through Eocene sedimentary rocks, although presently most of the outcrops in the close vicinity are of Precambrian rocks. The oyster bank comprises mainly oyster shells, among which the large *Ostrea crasissima* is found, together with some benthonic foraminifera indicating a Neogene age. The flow direction of the drainage system in which the Raham-Haimur were deposited is discussed by Garfunkel (1970) and is shown to be toward a proto-Elat bay, in a general southward direction. The Hazeva Formation is known from the entire Negev down to about 100 km south of Elat. It was described by Bentor and Vroman (1957) from the Hazeva area in the northern Arava and discussed in detail by Garfunkel and Horowitz (1966), Garfunkel (1970), and Horowitz (1974). The Hazeva sediments fill a river system, draining the Negev, northeastern Sinai, and southwestern Transjordan toward the Mediterranean, over a pre-existing relief. In most cases, the Hazeva sediments fill synclinal basins connected by narrow passages cutting through the pre-existing anticlines. The Hazeva sequence overlies a coarse base conglomerate, always covering an erosional relief. The base conglomerate is overlain by sandstones and clays, mostly reddish or yellow, which become finer upward, where lagunal or freshwater limestones and marls occur. Above come, once more, fine clastics, clays, and sandstone, becoming coarser upward with more and more flint pebbles until they constitute a top conglomerate that covers the entire area and is preserved in places where it was sheltered from subsequent erosion.

In the Yeroham–Dimona Basin of the Northern Negev, the middle part of the Hazeva sequence is intercalated by the Yeroham Oyster Bank, whereas in the Be'er Sheva area the Hazeva Formation sediments interfinger with the Ziqlag Formation or with the Lower Sheva Formation (Gvirtzman and Buchbinder 1969). The remains of typical Miocene mammals, such as *Mastodon angustidens* and *Deinotherium bavaricum* (Savage and Tchernov 1968), were found in the middle member of the Hazeva Formation at the Yeroham–Dimona Basin. The base conglomerate of the Hazeva Formation was designated as the Yattir Conglomerate by Aharoni and Aizin (1966) from the eastern Shefela, and the top conglomerate was designated by Gvirtzman and Buchbinder (1969) as the Bet Nir Conglomerate. The Bet Nir Conglomerate presently forms most of the hilltops in the Shefela foothills region. Almost no continental deposits of Miocene age are known from the western parts of northern Israel, except for some very poorly developed conglomerates that may correspond to the Bet Nir (Gvirtzman 1970) and some conglomerates that interfinger or overlie the marine Miocene described from the subsurface by Bar Josef (1967).

The continental Miocene formations of northeastern Israel have been mentioned and described by many investigators, especially by Schulman (1959, 1962) and Michelson (1972). The most prominent are the Herod Formation, the Lower Basalt, and part of the En Gev Group. The Herod Formation, cropping out at the area around Tiberias, comprises more than 400 m of clastic sediments, mainly sandstones and siltstones, with some conglomerate horizons, sometimes interfingering with lateral tongues of the Lower Basalt. The base is only rarely exposed, and the formation always overlies an erosional relief. The top of the Formation is almost always truncated and unconformably overlain by Pliocene sediments and basalts. The southernmost outcrops of the Herod Formation are known from Wadi Fariyya, where they overlie a base conglomerate and continue throughout the Central Jordan Valley on both its western and eastern rims. They have been designated there as the Beida Formation (Daniel 1963). In the southern part of the Central Jordan Valley, the Herod Formation sediments are folded and comprise the floor of the syncline separating the Fariyya and the Ajlun Anticlines. The En Gev Group (Golani 1962) on the eastern side of Lake Kinneret comprises mainly sandstones and conglomerates, interfingers with littoral Miocene sediments, and is correlated with the Herod Formation (Horowitz 1974). The Lower Basalt (Blake 1928) appears both as a massive, continuous basalt sequence, as in Belvoir, where it attains more than 500 m (Schulman 1959), and as basaltic tongues interfingering with the Herod Formation near Poriyya and En Gev. The Lower Basalt is known approximately from the same areas as the Herod Formation but is somewhat more restricted to the valleys. It is also known from large areas in the eastern Yizre'el Valley, mainly from boreholes. Radiometric dating of the Lower Basalt (Siedner and Horowitz 1974) yielded ages of 12–15 million years.

The geological processes and the paleogeography of Israel in Miocene times can be summed up as follows (Figure 4.3): The Raham, Hazeva, and Herod Formations fill river systems leading toward different base levels, the proto-Elat Bay, the Mediterranean, and the Persian Gulf. However, these base levels have undergone basically the same processes, which indicates that they were essentially interconnected. The Raham Formation fills a river system that led in the direction of the present Red Sea. Garfunkel (1970) proved that the marine intercalation within the Raham came from the south and could not have been connected with the marine intercalation known from the Hazeva Formation, north and west of the Miocene watershed in the Elat area, which was rather close to the present Gulf of Elat. The pebbles that comprise the Raham have been mainly derived from Eocene formations, indicating that these formations built most of the area in Miocene times. Relics of Late Eocene rocks are still preserved in the Elat area, showing that this region was a syncline during the Miocene. This syncline continued further north, as can be seen from the nature of the Senonian rocks north of Gerofit. Actually, the end of this syncline was not affected by the consequent severe faulting that had affected the Elat area, and it can still be observed about 50–60 km north of Elat. A pre-Miocene erosion channel in the Elat area was developed along this syncline, whereas the anticlinal ridge that terminated the syncline to the north, at the Jebel el Khureij area, was, apparently, eroded down to its Precambrian core, which supplied minor amounts of magmatic and metamorphic pebbles to the Raham, together with somewhat larger amounts of pebbles derived from Early Cretaceous and Cenomanian rocks. The marine transgression in Raham times traveled along the same route northward and arrived at the area of Jebel el Khureij, depositing the oyster bank of the Haimur Formation on its way.

The Hazeva sediments are widespread in southern Israel and fill a river system that led to the Mediterranean. The flow directions of the main rivers of this system and the provenance of the clastics are discussed in detail by Garfunkel and Horowitz (1966) and by Horowitz (1974). The southern extension of the Hazeva Formation sediments is discussed by Garfunkel (1970). Sediments belonging to the Hazeva System are found down to more than 100 km south of Elat, about 30–40 km west of the present gulf, in Bir Tsafra and Sheikh Atiyya. Most of the Hazeva System was drained to the Mediterranean through the Be'er Sheva area (see also Neev 1960). Some areas of the Western Negev were drained by the Wadi el Arish system, as well as most of Sinai (Horowitz 1975b), but most of these are outside the scope of this discussion. The Hazeva System is developed south of the Judea-Hebron anticlinorium, and most of the deposition in this area was confined to the synclines. Some of the channels have cut through the anticlines and have formed superimposed valleys. The most prominent are those cutting the system of the Northern Negev anticlines. Some poorly developed outcrops were preserved on the anticlines' flanks, like those in the Yattir and Mount Tsavo'a area, with angular and erosional unconformities within the sequence.

Several rather small Miocene rivers led to the Mediterranean through the present coastal plain, up to the Western Galilee. Their courses are drawn by Gvirtzman (1970), Bar Josef (1967), and Issar and Kafri (1972). These were rather steep, short rivers draining the mountainous block of Judea, Samaria, the Carmel, and the Western Galilee. Generally, those channels are less conspicuous when going northward, which corresponds also to the diminution in thickness of the marine Miocene sediments from hundreds of meters to the south to tens of meters to the north. It should be noted that there is no evidence for a marine ingression through the area of Haifa Bay toward the present Yizre'el Valley, and no conspicuous channel

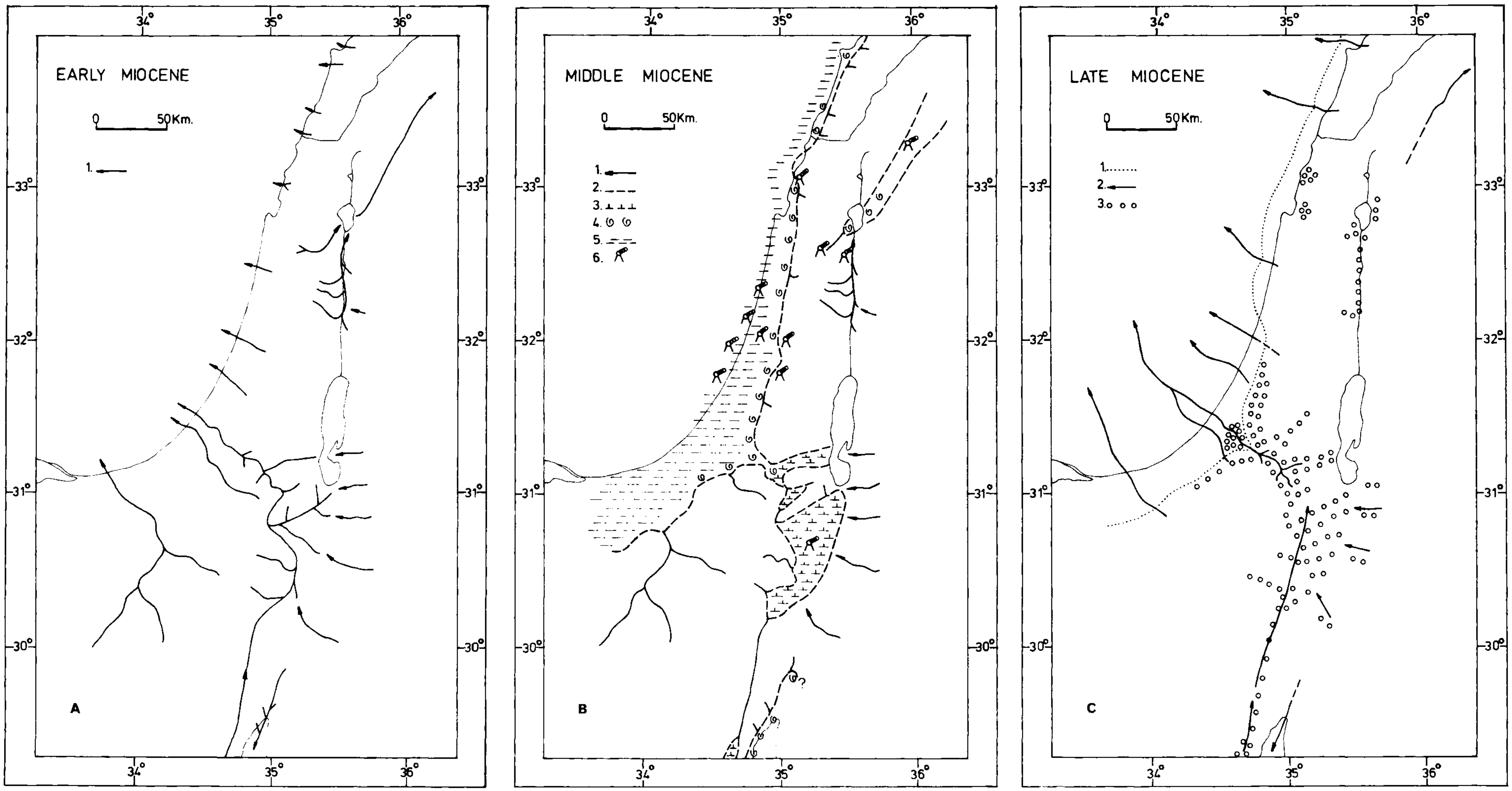


FIGURE 4.3. *Miocene paleogeography of Israel. A (1) direction of main river courses; B (1) rivers, (2) maximum extension of marine transgression and inland lakes and lagoons, (3) lakes, (4) shallow sea and coastal lagoons, (5) deep sea, (6) volcanoes; C (1) maximum extension of coastal lagoons, (2) rivers, (3) floodplains.*

led westward from the Yizre'el Valley area in Miocene times. The Herod Formation system led to the Persian Gulf basin. The canyons in which the Herod Formation was deposited occupy a large synclinal area that has a general northeast trend, leading from the eastern Lower Galilee to the direction of Damascus. This basin already existed in Senonian and Oligocene times (Flexer 1968) and controlled the facies and deposition of marine formations of these times. Folding movements continued somewhat also through the Miocene and afterward in this area, as can be seen from the angular unconformities within the successive Miocene units (Michelson 1972) and the later folding of the entire Herod complex in the same trend as the rest of the older rocks in the southern sector of the Bet She'an Valley.

Westward and southwestward, in the areas of the Central and Western Yizre'el Valley and on the flanks of the Fariyya structure in Samaria, the pre-Herod erosion had cut down to the Early Cretaceous or even Jurassic rocks (Gerry 1965). The Early Cretaceous rocks, which cropped out at the Western Yizre'el and the Fariyya structures, comprise mainly sandstones and are regarded as the source for large quantities of quartz grains occurring within the Herod Formation, especially in the lower members, at the En Gev area. The Fariyya has remained as high structure and topography until the present day, although obliquely cut by a fault system in late Miocene times, which in the Wadi Fariyya area served to preserve the Miocene sediments. The western Yizre'el Valley had a high structure and topography in Miocene times, and the Kishon Graben, which presently separates the Carmel from the Western and Upper Galilee Block, formed only at the end of the Miocene. It seems, therefore, that the Herod Formation presently fills a river system that led from northern and northeastern Israel, from the Central Jordan Valley, and from the eastern slopes of the Fariyya structure in the direction of the Persian Gulf basin. Sediments that seem to be the continuation of the Herod Formation crop out at the valley of the Barada River near Damascus (Dubertret 1966). Further northeast these sediments intercalate with marine middle Miocene sediments, which are connected with the Persian Gulf basin.

The resemblance of the Raham, Hazeva, and Herod Formations points to a mutual and similar influence of their subsequent erosion base levels. The Hazeva deposition was controlled by the Miocene Mediterranean, the Raham by the proto-Red Sea, and the Herod by the Persian Gulf. The history of the Mediterranean and the Red Sea in Miocene times seem to have been similar, as concluded from the Red Sea sediments of this time (Ross and Schlee 1973). It seems that both basins were connected through the Suez Bay area, which was a wide syncline in these times, whereas the proto-Red Sea area was not connected to the Indian Ocean at the Bab el-Mandeb area, which was still closed in Miocene times. The Miocene history and sediments of the Suez Bay also resemble those of the Mediterranean (Said 1962). The Persian Gulf basin had a much larger areal distribution in Miocene times as compared to the present day. It was connected to the Mediterranean through the northern part of Syria (Dubertret 1966) in the mid-Miocene. These connections explain the similarities and characteristics of the three systems, which were controlled by the Miocene transgression. Horowitz (1974) tends to think that the influence of this transgression and the ensuing changes of sea level were the main agents that dictated the pre- and post-Miocene erosion and the Miocene sedimentation in Israel and, apparently, in the entire Middle East as well, rather than proposed tectonic movements, which should have caused deposition of "syntectonic conglomerates" (Bender 1968; Garfunkel 1970; Gvirtzman 1970; Schulman 1959).

It seems that the wide distribution and similarity of erosive and depositional phenomena call for a general, regional, common cause. The lack of earliest Miocene sediments from the continental plate almost everywhere in the Middle East (Dubertret 1966; Picard 1943) is the result of the regional regression in late Oligocene–earliest Miocene, which is known from the entire Mediterranean, Red Sea, and Persian Gulf areas. This regression is also the reason for the conspicuous channeling of the country in these times. The transgression, which came to a maximum in the middle Miocene, caused marine and continental sedimentation on a large scale, which is the reason for the great areal distribution of these sediments. Volcanic activity in Israel, the Suez Bay, and Syria is known from this period. The late Miocene regression was so pronounced as to cause an almost complete drying up of the Mediterranean, the proto-Red Sea, and the Persian Gulf, so that only anhydrite and rock-salt deposits are known for this time (Hsü 1972). This was the main reason for the end of sedimentation and the beginning of erosion of the Raham, Hazeva, and Herod systems.

The general scheme for the deposition of the Raham–Haimur, Hazeva, and En Gev–Herod complexes is proposed as follows. During the late Oligocene, the sea regressed, causing erosion and formation of deep channels, until, in the late Oligocene–early Miocene transition time, the sea was at its lowest position. The early Miocene rising of sea level resulted in lower erosive energy, which initiated deposition of base conglomerates. Further rising of sea level decreased this energy until only fine clastics could have been carried and deposited by the rivers. The maximum transgression, in middle Miocene, caused stagnation of the river systems in which lagunal and freshwater sediments were accumulated. Large areas of the former river system were occupied by shallow marine estuaries, depositing littoral sediments, like the oyster banks. At the same time, further seaward, reefs were developed, which constitute the Ziqlag Formation. The nonreefoidal facies of this time is represented by the Lower Sheva Formation, and in the deeper part of the sea the Ziqim Formation marls were deposited. In the hinterland, a morphological plateau was developed, relics of which can still be seen in southern Israel and, especially, in Sinai (Horowitz 1975b). The late Miocene regression inverted the process. When sea level lowered, clastic sedimentation began again, becoming coarser toward the upper part, until terminated with top conglomerates, which in some cases developed as a sheetwash over large areas. Further regression resulted in erosion that first removed parts of the top conglomerates and later incised into the lower members.

Conglomerate deposition continued only in the lower reaches of the rivers, covering evaporites formed in the drying sea. The Mavqi'im Formation evaporites represent the drying Miocene Mediterranean, and similar formations are known from the Red Sea and the Persian Gulf. The relief over which the evaporites were deposited is probably the result of some oscillations during the last phases of regression, which are noted within the Mavqi'im Formation when comparing sections penetrated in areas of former rivers and interfluves. In the canyons the anhydrite alternates with clays, whereas on the shallower interfluves the anhydrite is massive and was deposited there only when the sea level was higher, which caused deposition of clays in the channels.

PLIOCENE

The marine Pliocene is represented in the subsurface (Figure 4.4) of western Israel by the Yafo Formation, which comprises black to gray marls, attaining more than a kilometer in thickness in the southern coastal plain, gradually diminishing northward and attaining only some tens of meters at the Nahariyya-Keziv area. The Yafo Formation overlies the Mavqi'im Formation unconformably, over an erosional relief that led to the retreating late Miocene Mediterranean. Almost no outcrops of the Yafo Formation are known, except for the one assigned by Picard (1943) to the "Yagur Facies," at the northern slope of Mount Carmel. The sporomorph assemblage of Yafo Formation indicates a two-fold source of the material: About 20% of the sporomorphs came with the Nile and were deposited in the eastern Mediterranean Basin, and the rest are pollen grains of the local vegetation that were carried by the winds and streams to the sea. Those represent a cool Mediterranean vegetation, which is in contrast to the dry-tropical vegetation represented by the Miocene pollen spectra (Horowitz 1974b). Littoral sediments of the Mediterranean, of Pliocene age, are known from the north of the country at the Kishon Graben and the Western Galilee Coastal Plain, as the Kurdane Formation, and at the southern part of the country, as the Pleshet Formation. The Kurdane and the Pleshet comprise mainly calcareous sandstones, rich in the mollusks *Glycymeris* and *Cardium,* attaining 30–60 m in thickness. The Kurdane Formation interfingers eastward with conglomerate horizons and southward, in the Kishon area, with the Yafo Formation sediments. According to the faunal assemblages, the Kurdane Formation represents a very shallow sea and overlies an erosional relief almost everywhere. It is overlain by the Ahuzam Conglomerate and by Quaternary sediments. The middle part of the Kurdane Formation is conglomeratic and also contains some pebbles of the Miocene Ziqlag Formation, containing the typical *Borelis* fauna. The lower and upper parts of the Kurdane have been deposited in a deeper sea than has the middle part. The Pleshet Formation is known from the Lower Shefela and the western Be'er Sheva Basin. It overlies an erosional relief, over a base conglomerate, that in places is developed over the Lower Sheva or the Ziqim formations. It is mostly covered by soils and, in the western coastal plain, by conglomerates of the Ga'ash Formation or the Gaza Formation sandstones or paleosols, both of Quaternary age. The Pleshet Formation comprises calcareous sandstones, with a conglomeratic middle horizon, in places rich in marls, bearing Pliocene fauna (Moshkovitz 1968).

Littoral sediments of Pliocene age are described by Picard (1928) and Blake (1937) from the Yizre'el Valley as calcareous sandstones, rich in mollusk fauna. Brackish lagunar sediments of Pliocene age are known from the area of Elat—the Eilot Conglomerate—where they comprise the lower and upper parts of the sequence. Garfunkel (1970) regards them as a filling of the northernmost part of a drainage system leading to the proto-Elat Bay. The sediments comprise mainly calcareous sandstones, clays, and marls. A conglomerate horizon is conspicuous in the middle part of the sequence (Perath 1966). Lagunar sediments of Pliocene age are known from the Yizre'el Valley and from the Central Jordan Valley, where they are designated as the Bira Formation (Schulman 1959). This Formation comprises a sequence of white or grayish chalks overlying the Umm Sabune Conglomerate in the Central Jordan Valley and overlain by the freshwater sediments of the Gesher Formation.

Several basalt intercalations, the Intermediate Basalt, are known within the Bira Formation sediments and have been potassium–argon dated, yielding an age of 4.7–5 million years (Siedner and Horowitz 1974). The Bira Formation is very widely distributed in the internal valleys of Israel and is known from the Yizre'el Valley, the Central Jordan Valley, the Kinneret area, the Bet She'an Valley, and, south of it, in Merma Feyyad, the Dead Sea area, and southward down to the entrance of the Makhtesh HaQatan (Shahar *et al.* 1966). The Bira Formation always overlies an erosional relief and, in some cases, over a well-developed base conglomerate as well, such as the Umm Sabune Conglomerate of the Central Jordan Valley or the Giv'at Oz Conglomerate in the Yizre'el Valley. The Bira Formation is unconformably overlain by the Gesher Formation over a conglomerate, over a thin horizon of feruginous sandstone, or over evaporites, called the Menahemya Gypsum, which belong to the upper part of the Bira Formation (Schulman 1959). The thickness of the Bira Formation is approximately 400 m in

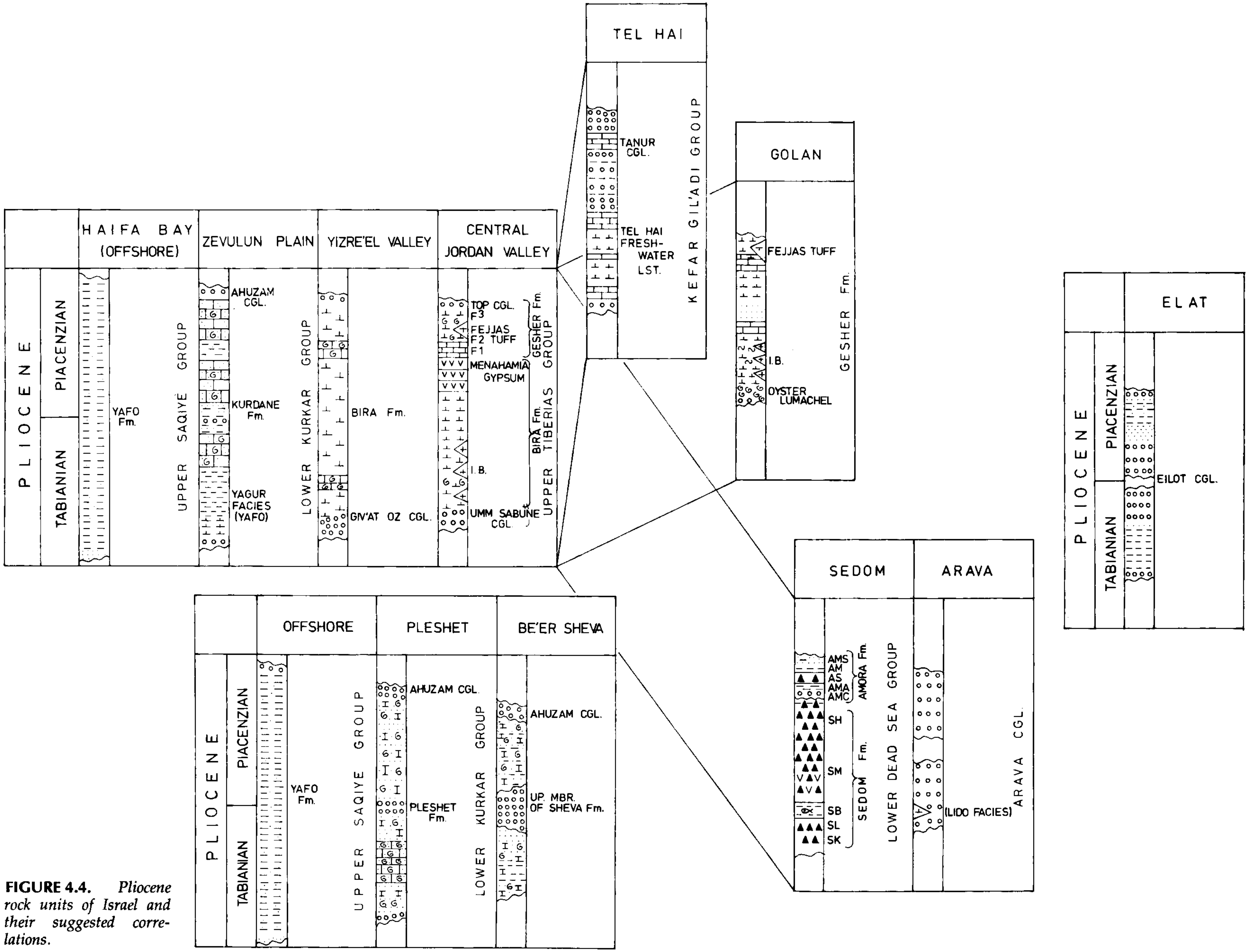


FIGURE 4.4. *Pliocene rock units of Israel and their suggested correlations.*

the Yizre'el Valley, 200 m in the Central Jordan Valley, diminishing southward until in the Dead Sea area it is only several meters thick. The Bira Formation was mostly deposited in hyposaline, brackish, lagunal conditions.

Lacustrine sediments of Pliocene age are known from the Central Jordan Valley, designated as the Gesher Formation; from the Northern Jordan Valley, the Tel Hai Freshwater Limestone; and from the Dead Sea Basin, the Amora Formation. The Gesher Formation comprises 20–50 m of white lagunal and lacustrine limestones, clays, and marls. It overlies unconformably the Bira Formation and is overlain in places by a top conglomerate. It is almost everywhere unconformably overlain, over an erosional relief, by the Preglacial Pleistocene Cover Basalt. The Gesher Formation occurs in the Central Jordan Valley down to the southern Bet She'an Valley at the area of Merma Feyyad, which is the southernmost outcrop known of this formation. Eastward it is known to underlie the Cover Basalt in the western escarpment of the Golan Plateau (Michelson 1972), and northward it extends into the Hula Valley and is known from several boreholes in the Korazim–Gadot block (Fleischer 1968). Further northward, the Gesher Formation interfingers with the Tel Hai Freshwater Limestone and the Tanur Conglomerate (Horowitz 1973). The fauna of the Gesher Formation comprises mainly freshwater mollusks, of which the most typical is *Hydrobia fraasi*, together with several others, such as *Melanopsis*, *Melania*, and *Dreissena*.

The Tel Hai Freshwater Limestone comprises about 400 m of limestones, chalks, and some clays, overlying a base conglomerate in the Tel Hai-Kefar Gil'adi area, overlain in turn by the Tanur Conglomerate. Both formations comprise the Kefar Gil'adi Group (Glickson 1966). The Tel Hai Freshwater Limestone yielded malacological assemblage similar to the Gesher Formation, and the two are, therefore, correlated (Horowitz 1973). Dubertret (1966) describes a suite of sediments from the Beqa'a in Lebanon that seems to be the northern extension of the Kefar Gil'adi Group. Bones of *Hipparion* (Kansou 1961) were discovered at the basal parts of these sediments in the Lebanon. Volcanic rocks of the Fejjas Tuff interfinger with the Gesher Formation sediments in the Central and Northern Jordan Valley. The Amora Formation (Zak 1967) comprises a suite of sediments about 400 m thick, consisting of conglomerates, shales, dolomite, and rock salt. Some of the shales were deposited in freshwater lakes, as can be seen from the floral remains, mostly *Valisneria*. The Amora represents alternating environmental conditions in which the lacustrine and fluviatile prevail, with the exception of the middle "As" rock-salt horizon, which is probably of a hypersaline, lagunar origin.

Sediments of Pliocene age, which were deposited in hypersaline lagoons, are known from the Southern and Central Jordan Valley. At the Southern Jordan Valley and the Dead Sea area, the Sedom Formation comprises a very thick sequence of rock salt, anhydrite, and some shale horizons. This sequence crops out at Mount Sedom, at the Southern Dead Sea area, and is known to pave the Dead Sea floor (Neev and Hall 1976). The base of the Sedom Formation is nowhere exposed. It underlies the Amora Formation, and the transition zone is rich in conglomerates. Pollen analysis of the Sedom Formation rock salt (Horowitz and Zak 1968) yielded palynological assemblages similar to those obtained from the Yafo and Bira Formations. The Sedom Formation sediments show geochemical characteristics that indicate connection of the basin of deposition with the open sea, most probably through the Central Jordan and Yizre'el Valleys (Horowitz and Zak 1968). A sequence of gypsum and anhydrite, intruded by a number of basaltic sills, is described by Schulman (1959) from the vicinity of Menahemya-Gesher in the Central Jordan Valley. The sequence comprises about 14 m, interfingering with the upper part of the Bira Formation and overlain by the Gesher Formation. It seems that these evaporites were deposited in a hypersaline lagoon in this area, following desiccation at the end of deposition of the Bira Formation.

Fluviatile sediments of Pliocene age, mainly conglomerates, are known from various parts of the country. The Umm Sabune Conglomerate crops out at the Belvoir area of the Central Jordan Valley. The sequence comprises coarse conglomerates overlying the Lower Basalt over an erosional and taphrogenic relief, attaining up to 200 m in thickness. The clasts become finer toward the upper part. The Umm Sabune Conglomerate is conformably overlain by the Bira Formation sediments and is known from the Central Jordan Valley, the Southern Bet She'an Valley, and the Yizre'el Valley, where it is called the Giv'at Oz Conglomerate. Schulman (1962) assumes that the Umm Sabune is a syntectonic conglomerate marking the downfaulting of the Yizre'el and Jordan Valleys. Another conglomerate cropping out at the Central Jordan Valley, of fluviatile origin, overlies in some localities the Gesher Formation. The thickness of this conglomerate never exceeds a couple of meters, and in most cases the upper parts of the Gesher are eroded and truncated by the Preglacial Pleistocene Cover Gasalt. The Kefar Gil'adi Group of the Hula Valley is very rich in conglomerate horizons. Two conglomerates seem to be the main ones: The first is the base conglomerate of the Tel Hai Freshwater Limestone, which is poorly sorted, overlies an erosional relief, and is of local origin. The more conspicuous is the Tanur Conglomerate (Glickson 1966), attaining up to 400 m in thickness, which is composed of well-rounded pebbles, mostly cemented by very hard carbonate cement that sometimes breaks with the pebbles. The Tanur Conglomerate is known from various localities around the Hula Valley, such as Tel el Ahmar at the Hermon foothills, along the western margins of the Hula Valley, down to Rosh Pinna and the Kinneret, and in the Hukok area, where the conglomerates interfinger with the Bira Formation. Some other conglomerates of Pliocene age are known from the wadis draining the Fariyya structure, especially the Wadi Malih Gompholites (Picard 1943), and, in the Dead Sea area, the Samra Formation conglomerates (Picard 1931).

Further south, the Arava Conglomerate comprises a sequence of well-rounded conglomerates known from the Arava and the Southern Negev and is discussed in detail by Garfunkel and Horowitz (1966). These conglomerates are typically rich in pebbles derived from magmatic rocks. The flow directions of the rivers in which these conglomerates were deposited is generally from the Elat area northward, reaching the Dead Sea area. The conglomerates overlie unconformably the Hazeva Formation at the Arava and are overlain by the Preglacial Pleistocene HaMeshar Conglomerate. The Arava Conglomerate interfingers in the Mount Sedom area with lower horizons of the Amora formation where the typical assemblage of magmatic pebbles is discerned (Zak 1967). Pliocene fluviatile sediments designated as the Eilot Conglomerate are exposed at the Elat area. The suite is mainly fluviatile, but at its lower and upper parts lagunal-brackish sediments occur. It overlies unconformably the Raham Formation sediments of Miocene age. It is overlain, also unconformably, by the Preglacial Pleistocene Garof Conglomerate. Various conglomerates were designated by Issar (1961) at the southern coastal plain and the northwestern Negev as the Ahuzam Conglomerate. The name was later amended by Horowitz (1974) to include only those conglomerates that form the top conglomerate of the Pleshet Formation, of Late Pliocene age.

Erosive plateaux connected with the Pliocene sediments have been discerned by various authors. At the Elat area, Garfunkel (1970) discerned the "High Erosive Plateau" that is connected with the maximum of the transgression that deposited the Eilot Conglomerate. East of the Dead Sea, Picard (1943) discerned an erosive plateau that can easily be seen at present from Jerusalem, developed at the present sea level elevation and still very well preserved. The western escarpment of the Golan Plateau, east of the Kinneret and somewhat south of it, below the Cover Basalt, represents the Pliocene erosive plateau connected with the maximum of transgression that caused deposition of sediments of the Gesher Formation in these areas. It seems also that the Galilee, Samaria, and Judea Blocks were part of these erosive plateaux, which were later upwarped. In the Shefela area, the Pliocene plateau is preserved as the series of hilltops at an approximate elevation of 200 m above sea level (Avnimelech 1936), on which littoral Pliocene sediments of the Pleshet Formation and the Ahuzam Conglomerate are preserved.

The paleogeography and geological history of Israel during the Pliocene are summed up as follows (Figure 4.5). The Miocene period ended with major regression that caused redeepening of erosion channels, and the Erythrean faulting phase, discussed in Chapter 3, changed the country during the Mio-Pliocene transition time. The faulting affected mainly the areas of the Yizre'el and Jordan Valleys, which were downfaulted, and a connection of the Jordan Valley area via the Yizre'el Valley to the Mediterranean was established. The uplifting of the eastern sector of the Rift Valley margins, in the area of Transjordan, ended the connection of the previous Miocene drainage system with the Persian Gulf. The southern part of the country was much less affected by faulting, but step faulting and downwarping of the coastal plain is, apparently, one of the subsurface features that should be taken into consideration. The Elat area was much more severely influenced by faulting. The Pliocene Transgression, for which two phases are known, the Tabianian and Piacenzian, separated by a slight regression, flooded the coastal plain, depositing the Yafo Formation throughout the entire Pliocene period in a rather deep sea. The sea penetrated Israel in three localities: the Elat area, which was connected with the proto-Elat Bay; the Be'er Sheva embayment; and the Yizre'el Valley, through which the sea reached the Jordan Valley, sometimes extending as far south as the present Dead Sea and somewhat south of it. The Tabianian Transgression deposited the lower parts of the Pleshet and the Kurdane Formations in the littoral Mediterranean domain. The lower part of the Eilot Conglomerate was deposited in the lagunal domain of the proto-Elat Bay.

In the Be'er Sheva, Shefela, Western Galilee, and Elat regions, the littoral sediments interfinger with conglomerates brought forward by rivers. In the Yizre'el Valley, the Tabianian Sea caused deposition of the lower part of the Bira Formation, and the peak of the transgression is marked by deposition of a lumachel bank. The lagunal nature of most of the sequence is the result of mixing of seawater from the west and freshwater influx from the direction of the Jordan Valley. The transgression caused deposition of base conglomerates at the beginning, the Giv'at Oz Conglomerate, which propagated eastward with the sea, becoming the Umm Sabune Conglomerate of the Central Jordan Valley. The maximum of Tabianian marine influence at the Central Jordan Valley caused deposition of the Bira Formation in the lagoons that developed, whereas further north and east lakes were formed in which freshwater influence was strong enough to enable deposition of the Tel Hai Freshwater Limestone, also over a base conglomerate, and the Gesher Formation sediments of the Golan Plateau. To the south, the climate was more arid, and hypersaline lagoons were developed in which the Sedom Formation evaporites were deposited. A river system leading to the southern extension of the Sedom Bay had been previously developed, and the Arava Conglomerate filled it during the maximum of the Tabianian. This maximum caused deposition of Bira Formation sediments down to the area of the present Makhtesh HaQatan.

The Middle Pliocene Regression is marked by clastic horizons in all of the littoral formations; by erosion of the Arava Conglomerate and propagation of its pebbles into the lower part of the Amora Formation; by drying up of the Bira Lagoon of the Central Jordan Valley and deposi-

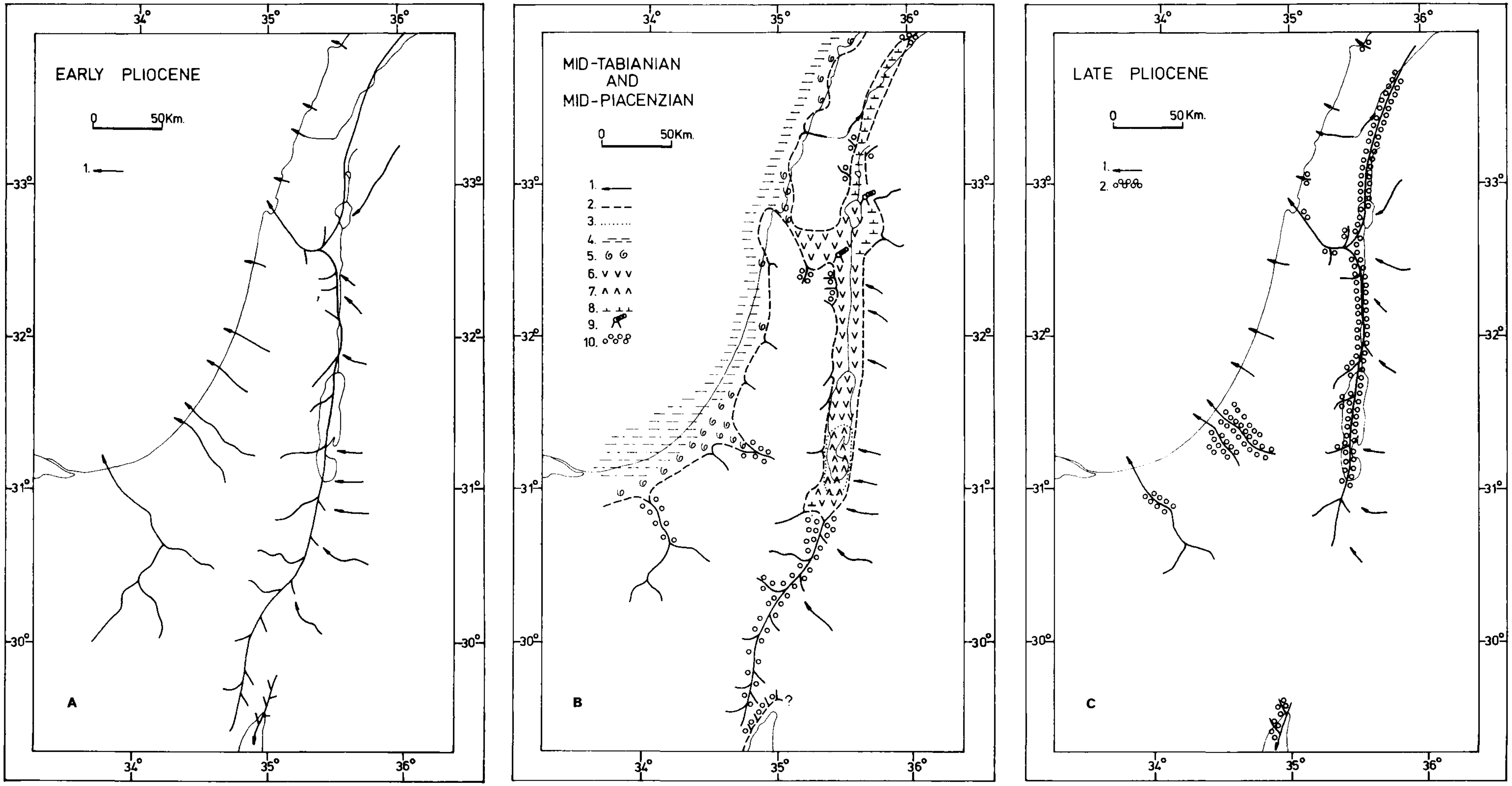


FIGURE 4.5. *Pliocene paleogeography of Israel: A (1) main river courses; B (1) rivers, (2) maximum extension of shorelines and lakes, (3) hypersaline lagoons, (4) deep sea, (5) shallow sea, (6) brackish lagoons, (7) areas of evaporitic deposition, (8) freshwater lakes, (9) volcanoes, (10) floodplains; C (1) rivers, (2) floodplains.*

tion of clastics and evaporites; and by less marine influence in the Yizre'el Valley, with propagation of the Tanur Conglomerate over the Tel Hai Limestone in the north. The farther areas were subject to erosional processes. The Piacenzian Transgression flooded the area once more, but to a somewhat lesser extent. The coastal plain, Elat, Be'er Sheva, Shefela, Eastern Galilee, and Yizre'el Valley areas were influenced in the same way as during the time of the Tabianian Transgression, now depositing the upper parts of the corresponding formations. In the Hula Valley, freshwater limestones were once more deposited. In the Golan, deposition of the Gesher-type sediments continued, and in the Central Jordan Valley the lagunal lower member of the Gesher Formation was deposited over wide areas. To the south, the influence of the Piacenzian Transgression invoked once more deposition of rock-salt, the "As" Member of the Amora Formation. The upper part of the Arava Conglomerate filled the channels leading from the Elat area to the Dead Sea Basin.

The Late Pliocene regression, which was much more extensive than at the middle Pliocene, caused shallowing of the Mediterranean and deposition in places of the more littoral Petah Tiqwa Member of the Yafo Formation (Gill 1965), whereas the littoral Piacenzian sediments were covered by conglomerates, the Ahuzam Conglomerate of the coastal plain and the upper part of the Eilot Conglomerate at the Elat area. Deposition of the Arava Conglomerate ceased, and the area began to be eroded, while clastics still filled, somewhat later, the Dead Sea area, comprising the upper part of the Amora Formation. North of the Dead Sea, rivers leading toward the retreating sea were developed in which conglomerates of the Samra Formation were deposited. Northward, the Gesher Formation became of a more freshwater character, and later the lakes dried up and were flooded by rivers in which the top conglomerate of the Gesher Formation was deposited. The Wadi Malih Gompholites and the upper part of the Tanur Conglomerate belong to this phase, the propagated regression of the Late Piacenzian sea.

Volcanic activity during the Pliocene was rather limited in area and intensity. Except for a small number of flows comprising the Intermediate Basalt and some tuff deposition—the Fejjas Tuff—both limited in areal distribution to the Central Jordan Valley and to the southern parts of the Northern Jordan Valley, no other conspicuous volcanic phenomena are known. Only subordinate (Steinitz *et al.* in press) Pliocene volcanic phenomena are known from the coastal plain, and no great volcanic activity is known from northeastern Israel, as compared with the preceding Middle Miocene Lower Basalt or the Cover Basalt of Preglacial Pleistocene age.

5

Quaternary Stratigraphy

The sedimentary sequences and erosional processes that influenced Israel during the Quaternary are the result of a combination of four main agents: changing climates, changing sea levels, tectonic activity, and volcanic eruptions. In the Preglacial Pleistocene, the area still had the rather flat-land morphology of Pliocene times. The principal depositional basins comprised marine and coastal environments of the Mediterranean to the west and the proto-Elat Bay to the south, and the continental areas were subject to fluviatile activity creating shallow, wide channels in which conglomerates were accumulated and terrestrial areas eroding down to form a vast peneplain. To the northeast, however, and on the Transjordanian Plateau quite far south, volcanic eruptions and soil formation were the more important processes. The transition to the Glacial Pleistocene was accompanied by the beginning of the Levantine faulting and upwarping system, which separated Israel (except for the limited area drained to the Bay of Elat) into three morphotectonic domains: the Mediterranean coastal plain, still influenced by sea level changes and to some extent by changing climates; the Jordan–Arava Rift Valley, divided into three subbasins in which lakes were formed and dried up, depending on climatic and tectonic conditions; and the hilly backbone that developed along the country, mainly influenced by fluviatile erosive processes themselves very much dictated by climatic factors, especially the mode and amount of precipitation.

Sedimentary, erosive, and pedogenic processes all result finally in a stratigraphic sequence and should be treated together, especially so for the Quaternary, for which time discussion of the continental events is of prime importance. Soils grade to marshes, conglomerates to limnic or marine sediments on the one hand and to erosive surfaces on the other, and terraces are sometimes developed over older rocks, grading to corresponding deposits. For this reason, these processes are here discussed together, in their stratigraphic sense, to make possible an understanding of synchronous phenomena and developing paleogeography. Climate plays a major role in Quaternary stratigraphy. Indeed, the Quaternary was long defined as the "Great Ice Age." Except for tectonic and volcanic activities, all other Quaternary processes are climatically controlled, such as eustatic sea-level changes, modes of fluviatile deposition and erosion, distribution of lakes, and soil formation. Climate will, therefore, be the basis for the stratigraphic discussion presented here. Climatic influence would naturally vary in the different domains, but, once the climatic events and successions are deciphered, correlations between the various sedimentary and erosive units of the coastal plain, the mountainous backbone, and the rift valley can be proposed (Horowitz 1974, 1975, 1976b). Radiogenic datings of intercalating volcanic rocks serve to date these successions (Horowitz *et al.* 1973; Siedner and Horowitz 1974).

Generally, the influence of different climates on erosion and sedimentation in Israel can be summed up as follows: The European glacials resulted in a pluvial climate in Israel, characterized by higher rainfall, some of it during the summer, which was rather evenly distributed over the rainy seasons. A much richer vegetation than at present was developed, which resulted in better and more extensive pedogenic processes and in the formation, in the mountainous areas, of gently dipping slopes on which colluvium was accumulated. The Jordan Valley was covered by lakes of considerable extension, and the coastal plain was much wider than at present due to the regressing sea and was covered by soils and marshes. Dunes that accumulated during those times are presently covered by the sea. The interglacials, on the other hand, resulted in a considerable aridity of the country, sometimes beyond present-day limits. Vegetation was poor, rains were torrential, the summer long and dry, and colluvium hardly accumulated in the mountainous areas. The preceding accumulations were eroded, sometimes forming steeply sloping hills and, more to the south, even canyons. The Jordan Valley lakes shrank to become playas or peat-forming marshes, and the coastal plain was covered by sand dunes. The nomenclature used in this discussion, as well as the stratigraphic subdivisions, are based on studies by many workers mentioned throughout the text. Some new groupings and names were needed to conform with new stratigraphic concepts that have not been discussed previously, but at every opportunity we have tried to retain those names that are in common use and have attained priority. This sometimes presented difficulties, since many of the workers described local sequences and gave names that proved to be synonyms to others previously used in another area for similar stratigraphic units. In these cases, an attempt has been made to stick to priority in usage, even when these names are less commonly used in studying our area.

Formations are traditionally defined in a type area and given a type section. The Quaternary sediments present some difficulties in this respect. A type section of a conglomerate bed or a paleosol has almost no meaning, due to the very frequent lateral and downstream changes in lithology and bedding. Therefore, some of the formations described here have never acquired a "formal" type section, and their lithology is only generally described. Another complication lies in the definition of a formation, which should have originally covered a continuous, defined area. This is not always the case with Quaternary formations. Some of them have primarily been deposited with no physical connection of their several components, connected only through a common cause of deposition. Such, for instance, is the case with a series of rivers depositing gravel, all leading to the same erosion base level. These are, however, treated here as a single formation. The concept of formation in Quaternary sediments is, therefore, expanded to include genetically connected domains in which sediments of similar types have been laid down. The formation name is, thus, applied to the products of an interconnected system.

MARINE SEDIMENTS

Quaternary marine sediments are known in Israel from the Bay of Elat to the south and the Mediterranean to the west. Both the Mediterranean and the Red Sea, including the Bay of Elat, have been continuously under marine conditions since the beginning of the Pliocene. At the end of the Miocene, the Mediterranean and the Red Sea were interconnected but dried up completely during the Messinian. At the beginning of the Pliocene, however, due to tectonic movements that deepened the Mediterranean area and opened its connection through the Straits of Gibraltar to the Atlantic, on the one hand, and deepened the Red Sea and opened its connection to the Indian Ocean through the Straits of Bab el-Mandeb, on the other hand, the two areas were again flooded by the sea and have remained as such to the present day. The deep sea domains of both basins exhibit continuous sequences of sediments from the beginning of the Pliocene through the present. The coastal areas. however, have been influenced by two superimposed processes, namely, global, geotectonically controlled transgressions and regressions and the eustatically controlled ingressions.

Very little is known of the Mediterranean and the Bay of Elat marine sediments because the entire sequences are under deep water. Geophysical investigations give some indication as to the nature of the sediments of both the Bay of Elat and the offshore Mediterranean. Several boreholes drilled in search of oil in the Israeli offshore Mediterranean give more information on this sequence. The upper parts of these boreholes were quite poorly sampled and analyzed, unfortunately, and only general information is available.

MEDITERRANEAN

The boundary between the Pliocene and the Pleistocene can be determined in the deep sea Mediterranean sediments only by their faunal content. It is generally accepted (see, for example, Moskovitz 1968) that the Quaternary began with a considerable cooling of the Mediterranean waters when northern elements intruded from the Atlantic. The most conspicuous is the appearance of the foraminifer *Hyalinea balthica*, together with a considerable increase in the percentages of *Globorotalia truncatulinoides* (Derin and Reiss 1973). In sections where *Hyalinea balthica* does not appear or is very rare, the last appearances of *Globorotalia nepenthes* are taken by Derin and Reiss (1971), Derin (1970, 1971), and Derin and Gerry (1970, 1971) as indicating the last Pliocene horizon. Everything that overlies the *G. nepenthes* zone is considered by these authors to be of Quaternary age. Since nothing better is to be found within the Mediterranean deep sea sediments, these criteria will be taken for establishing the base of the Quaternary sequence. An extensive geophysical study, based mainly on seismic profiles, was done by Almagor (1976). The geophysical profiles (Figures 5.1 and 5.2) show that Quaternary sediments along the Israeli offshore Mediterranean are in the form of a north–south elongated lens that thins toward the land and toward the open sea and thickens on the continental slope. This lens, where best developed, attains several hundreds of meters in thickness. The Quaternary marine sediments overlying the continental shelf down to about 100 m water depth are almost undisturbed, whereas sediments that cover the continental slope are considerably disturbed by slumpings, which can be seen on the geophysical profiles as slumping scars and mounds.

The Mediterranean Quaternary marine sediments have never been properly named. The Pliocene marls were defined as the Yafo Formation by Gvirtzman (1970), who extended this formational name to include also marly sediments of the lower part of the Quaternary sequence where *Hyalinea balthica* was found in the Yafo I borehole. The Yafo Formation, according to Gvirtzman, is overlain by the sandy Kurkar Group, which is diachronous because the Pliocene Pleshet Formation of the Be'er Sheva Basin is also considered by Gvirtzman as part of the Kurkar Group. The distinction is, therefore, only lithologic, and the base of the Kurkar Group is younger to the west. The picture is further complicated more to the west, at the outer shelf where sand has never been deposited, so that, according to Gvirtzman's definition, the term Yafo Formation should include the entire Quaternary sequence. However, the Pliocene Yafo Formation is only part of a sequence of shaly, marly deposits

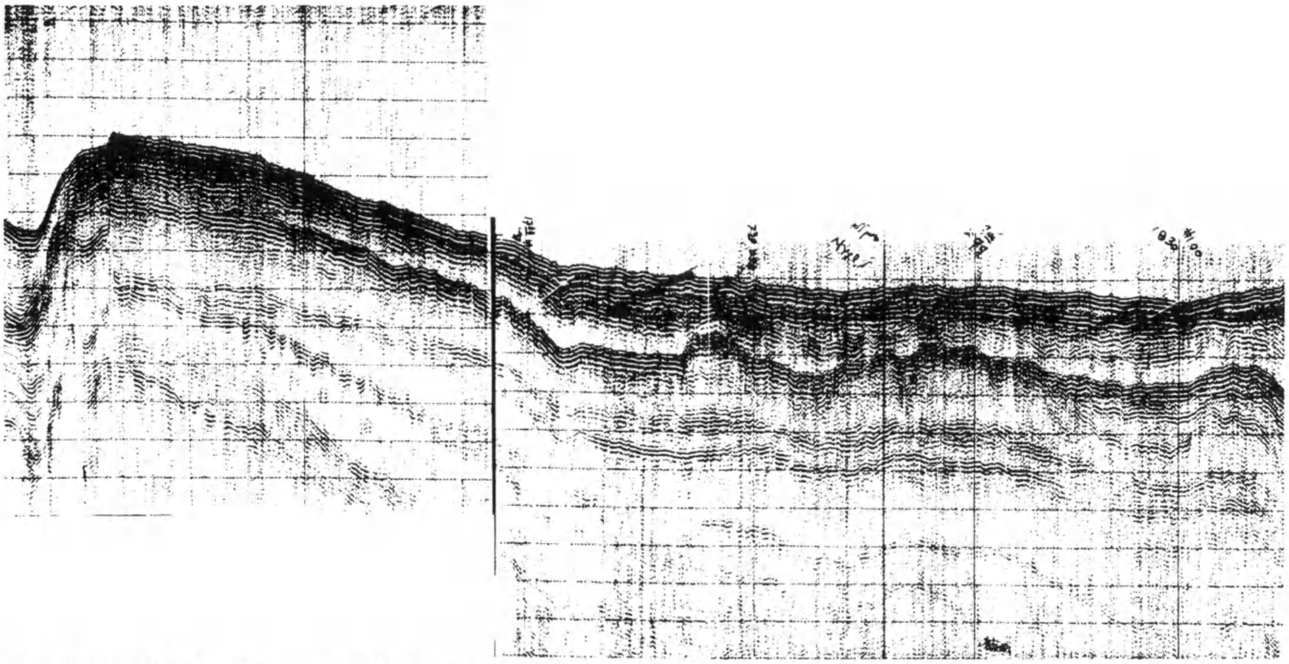


FIGURE 5.1. *Seismic profile along the offshore Mediterranean. The profile extends from the Carmel "Nose" to the left through the offshore area opposite Netanya to the right. Only the upper part of the penetrated sequence is of Quaternary age. (Courtesy of G. Almagor and the Division of Oceanography, Geological Survey of Israel.)*

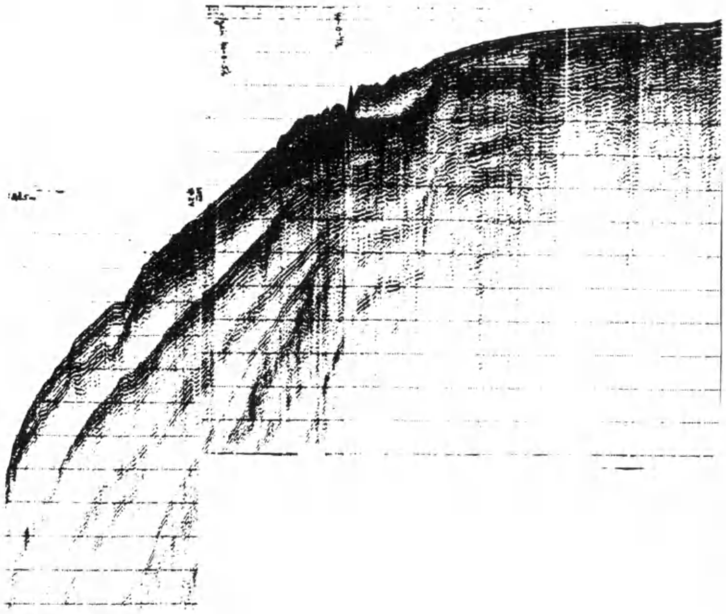


FIGURE 5.2. *Seismic profile across the Mediterranean continental shelf and slope, off Ashdod. The Quaternary marine sediments fill the trenches between the protruding submerged Kurkar ridges. (Courtesy of G. Almagor and the Division of Oceanography, Geological Survey of Israel.)*

known from the late Eocene onward in the Mediterranean coastal plain and termed the Saqiye Group. This term was first introduced by Loewengart (1928) and was later expanded by Gvirtzman (1970) to include the entire sequence from the late Eocene through the early Quaternary. It is suggested here, since the Quaternary deep sea sediments also comprise mainly shales and marls, to include them within the upper part of the Saqiye Group and to expand the upper limit of this group to include the Quaternary sequence as well. The term Kurkar Group should be retained only for coastal sediments from Pliocene through Recent that contain considerable amounts of quartz sand grains. These in fact mark the contribution of the Nile to the Israeli offshore sediments, which commenced at the beginning of the Pliocene period (Horowitz 1974b).

Quaternary marine sediments were penetrated by six boreholes drilled in the offshore Mediterranean (Figure

FIGURE 5.3. *Location map of the Quaternary sections and outcrops.*

5.3). These boreholes were drilled in search of oil, and, unfortunately, the upper 200–300 m were discarded and never logged. Therefore, no section is available in which the entire Quaternary sequence can be described, and no formation name is suggested for the sequence. The northernmost location of the offshore drilling, Foxtrot I, was drilled on the seaward extension of the Carmel Nose at coordinates N 253.509 E 138.927, under 43 m of seawater. The upper 217 m comprised silts and clays, apparently representing the Quaternary and the Pliocene. No logging was done on this sequence, and no paleontological study. At a depth of 260 m, Turonian limestones were hit. The second borehole, Item I, was drilled in 1971 off the coast of Netanya at coordinates N 199.080 E 133.557, under 37.6 m of seawater. The upper part of the sequence comprised light tan to yellow sandstone with calcareous particles and abundant shell fragments and other fossils, occasionally grading into sandstone and limestone coquina, with pyrite and some soft gray calcareous clay. Once more, no logging of the upper part is available for this borehole, and, apparently, it penetrated marine Quaternary sediments that grade into littoral sandstones. No further information is available as to the Quaternary sequence of this borehole.

Borehole Delta I was drilled not far from Item I, somewhat westward, at coordinates N 198.457 E 120.493, under a water depth of 130 m. Derin and Gerry (1970) assign the upper 300 m to the Quaternary. These comprise gray or dark gray clay with pyrite and fossils, somewhat calcareous, somewhat silty. The microfauna (Figure 5.4) of this section is quite rich, comprising abundant foraminifers such as *Sphaeroidinella dehiscens, Globigerinoides ruber, G. obliquus, G. elongatus, Orbulina universa, Islandiella, Ammonia,* Miliolids, *Bolivina, Bulimina, Uvigerina, Hyalinea balthica, Elphidiononion granosum, Elphidium crispum, Asterigerinata mamilla, Robulus,* and various species of *Cibicides.* The sequence includes also

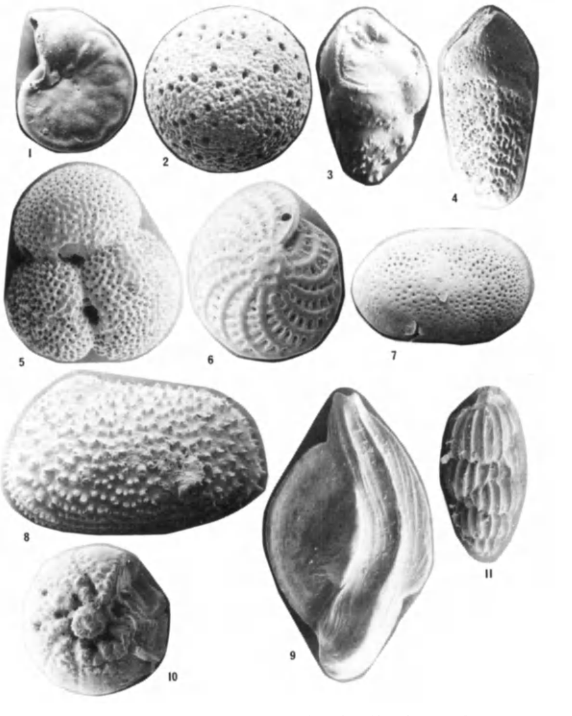


FIGURE 5.4. *Quaternary marine microfossils from the Mediterranean offshore drillings. Scales: 1–5, 100 μ; 6–11, 200 μ. 1,* Hyalinea balthica; *2,* Orbulina universa; *3,* Bulimina *cf.* marginata; *4,* Bolivina *sp.; 5,* Globigerinoides ruber; *6,* Elphidium crispum; *7,* Cytherella *sp.; 8,* Echinocythereis *cf.* pustulosa; *9,* Quinqueloculina *sp. (Miliolidae); 10,* Ammonia beccarii; *11,* Uvigerina *cf.* peregrina. *(Courtesy of B. Derin and E. Gerry, Israel Institute for Petroleum and Energy; SEM photographs by M. Dvorachek, Geological Survey of Israel.)*

abundant ostracods of the genera *Echinocythereis, Haplocytheridea, Henryhowella,* and *Aurilla,* together with abundant fragments of bryozoa and mollusks. The Pliocene–Pleistocene boundary at Delta I borehole presents some difficulties. The 50 m that underlie the 310 m depth marker do not contain *Hyalinea,* but, at the interval from 360 m down to 530 m, *Hyalinea balthica* and *Asterigerinata mamilla* are quite common. Derin and Gerry suggest that these are due to cavings. It is quite conceivable, though, that the Quaternary sequence begins at Delta I borehole at a depth of about 530 m, overlying the middle or even early Pliocene sediments over an unconformity or a hiatus. It should be noted in this connection that erosional unconformities and gaps between the Pliocene and the Quaternary sediments and basalts in almost the entire area of Israel have been previously noted (Bentor 1946; Horowitz 1974; Picard 1943; Schulman 1962). The westward extension of the latest Pliocene regression is not known in the Mediterranean coastal plain of Israel, but it might well have influenced the offshore sediments at Delta I and possibly other boreholes. Only a much more detailed study will indicate whether this is the case.

Borehole Joshua II was drilled in 1971 off the coast of Palmahim, in the middle of the structure called the Palmahim Graben, at coordinates N 148.940 E 109.200, under a water depth of 70 m. This borehole penetrated the longest and best documented of the marine Quaternary sequences hitherto known. The upper third of the sequence, from the sea bottom down to about 300 m, was neither logged nor sampled. From 300 to 330 m, the sediment comprises gray, very soft, plastic clay, somewhat silty, somewhat calcareous, with some quartz grains and many shell fragments and microfossils. From 330 to 410 m, the sequences comprise clay that is much less silty, with less fossil fragments. Down to 590 m, the clay is again more silty, with abundant microfossils and shell fragments. Between 590 and 605 m, a lumachel was encountered in which fragments of bivalves, echinodermata, bryozoa, and gastropods are quite common. Down to about 700 m, the sequence comprises again silty clay, somewhat sandy, somewhat calcareous, with quite abundant pyrite. From 700 m down to about 920 m, the sequence comprises gray clay with almost no quartz sand or silt. Down to about 1100 m, the clay becomes much more sandy, and quite abundant thin sand horizons appear within the sequence. The microfauna comprises more or less similar assemblages to those described from the Delta I borehole. The most abundant fossils for the middle part of the Quaternary sequence, from 300 down to 860 m, are *Asterigerinata mamilla, Ammonia, Elphidium, Cibicides, Hyalinea balthica, Globigerina, Globigerinoides, Globorotalia acostaensis, Orbulina universa, Cytheridea neapolitana, Cytherella costa,* and *Echinocythereis.*

Derin and Gerry (1971) define the age of this interval as Lower to Middle Pleistocene, becoming Calabro-Sicilian below 520 m. The interval from 860 to 950 m shows an increase in planktonic fauna, mainly *Globigerinoides, Sphaeroidinella dehiscens, Globigerina decoraperta, Globorotalia acostaensis,* and *G. inflata.* Derin and Gerry, based on the complete absence of Pliocene forms, are inclined to consider this sequence a continuation of the Pleistocene. The interval from 950 to 1020 m, comprising shales, sands, limestone, and dolomite fragments, presents some problems. *Hyalinea balthica* was found at the depth of 990 m and should indicate a Calabrian age for this sequence. Derin and Gerry, however, think that this might be due to cavings, because *Globigerina nepenthes,* which is a typical Pliocene microfossil, was also found. The interval below 1020 m is of middle Pliocene age. It should be noted that here again the same picture seen in Delta I borehole occurs. The base of the Pleistocene is not certain, and the first occurrences of *Hyalinea balthica* at a depth of 990 m could either be due to cavings or due to a hiatus between the middle Pliocene underlying sediments and the Quaternary *Hyalinea*-bearing transgressive sediments.

Borehole Echo I was drilled in 1971, south of Joshua II borehole, at coordinates N 136.978 E 109.550, under 37 m of seawater. The upper half of the Quaternary sequence, down to 323 m, was not sampled or logged, from 323 m down to 340 m, the sediments comprise medium gray, slightly silty, slightly calcareous clay with shell fragments, other microfossils, some quartz grains, and diminutive faunal elements that seem to indicate a somewhat lagunal facies for this interval. From 340 down to 670 m, the sediments comprise very soft clay, occasionally platy to massive shale with abundant shell fragments, microfossils, and some quartz grains. The microfauna of the upper part, from 310 down to 450 m, analyzed by Derin (1971), includes very rich microfossil assemblages, mainly benthonic foraminifers such as *Asterigerinata mamilla, A. planorbis, Ammonia, Elphidium, Globigerinoides, Orbulina,* and some mollusks. The lower part, from 450 down to 550 m, includes more or less similar forms, with the addition of *Globorotalia crassaformis,* rich *Uvigerina* fauna, and *Leptocythere.* It should be noted that *Hyalinea balthica* was not encountered in this borehole; therefore the Pliocene–Pleistocene boundary is uncertain. Derin is inclined to regard the interval down to 550 m as still of Pleistocene age on account of the absence of definite Pliocene fauna. The age of the underlying sedifrom 550 m down to 770 m, is also uncertain and is given in Derin as "undivided Pliocene." This confusion might indicate once more a hiatus at the top of the Pliocene strata, which possibly also influenced the base of the Quaternary sequence. The mixing of faunal elements in these hiata might be due to erosional and redepositional processes that took place during the late Pliocene regression and the consequent early Quaternary transgression.

Bravo I borehole was drilled off the coast of Ashqelon, at coordinates N130.421 E 96.471, in 1970, under a water depth of 73.5 m. No samples were taken down to 180 m except for a 2-m thick conglomerate layer at about 20 m below sea bottom. From 180 down to 195 m, the sediments comprise tan-gray reefy limestone with abundant shell fragments and other microfossils. From 195 to 350 m, the sediments comprise soft, light-gray clay, and, from 350 to 360 m, shell fragments and limestone pieces are quite abundant. From 360 to 375 m, pyrite and frosted quartz grains are abundant within the clay. The microfauna, according to Derin (1970), is very rich, grading in part to lumachel, containing *Asterigerinata mamilla, A. planorbis, Hyalinea balthica,* and various species of *Globigerinoides, Orbulina universa, Bolivina, Bulimina, Uvigerina, Bunthonia, Trachyleteris hystrix,* and fragments of bivalves, gastropods, codiaceous algae, and bryozoa. A Pleistocene age is attributed by Derin down to 350 m, where the sediments are thought to represent the Pliocene. The Pliocene–Pleistocene boundary is uncertain because *Hyalinea balthica* was found down to a depth of 610 m. Once more, Derin thinks that this might be due to cavings. Below 610 m, *Globigerina nepenthes* appears, marking the Pliocene, which Derin thinks might be the lower to middle Pliocene. It should be noted that *G. nepenthes* does not appear at the interval of 350–530 m, and the same picture described for the other boreholes, of Calabrian overlying middle Pliocene sediments with a pronounced hiatus, can also be seen in this borehole. Another borehole, Gal I, was drilled in 1969 off the coast of El-Arish in northern Sinai, at coordinates N 31°20′22″, E 33°44′57″, under 55 m of sea water. The sequence was never described in detail, and the upper part, about 200 m, was tentatively assigned to the Quaternary (L. Fleisher, Hana Oil Company, Tel Aviv, personal communication, 1977). The tentatively assigned Quaternary sequence comprises gray to dark-gray or black shale, fissile, slightly pyritic and fossiliferous, with no sign of unconformity to the underlying sediments.

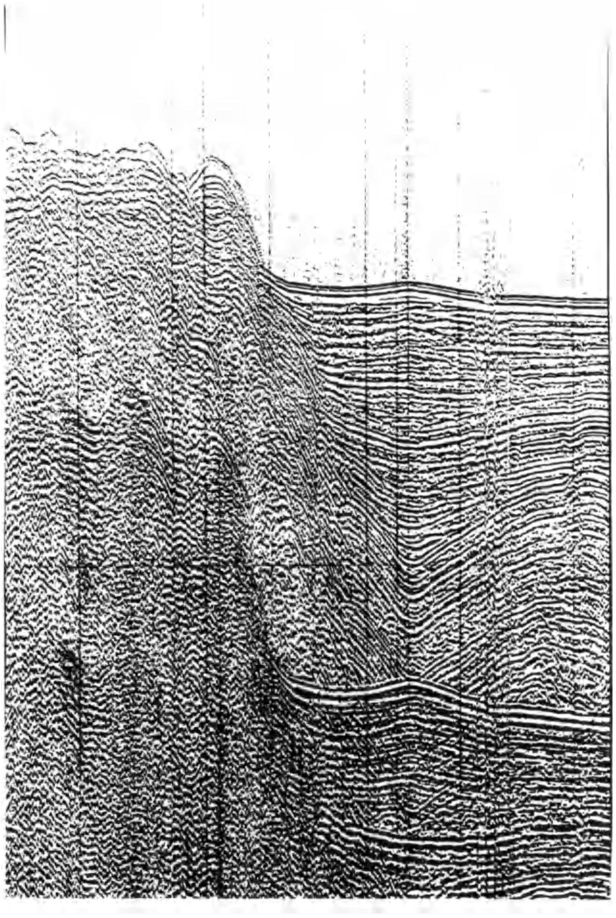
A considerable amount of study was done on the upper 5 or 6 m of the Quaternary sequence off the Mediterranean coast of Israel. It seems, according to Neev *et al.* (1976) and Almagor (1976), that some time during the latest Quaternary, tentiatively called "Würmian" by these authors, the sea regressed to a minimum of at least 130 m below its present-day level, thus causing the formation of a regressive, unconformable surface over which the transgressive Holocene sediments have been deposited up to the present. The planktonic forminifera and pteropod assemblages of this part of the sequence were studied by Reiss *et al.* (1971) and by Almogi-Labin and Reiss (1977), who, on the basis of relative frequencies of species, suggested that the upper 4 m penetrated the latest phase of the Würmian. Nir (1973) and Horowitz (1974d) have shown that the rates of deposition in the Eastern Mediterranean are quite rapid, and silt and clay are accumulated over the continental shelf at the rate of about 1 m in a thousand years. Therefore, the cores analyzed by Reiss *et al.* could not have penetrated the Würmian, and the changes in frequency of foraminifera considered to have been caused by cooling are probably a result of the higher primary productivity of the eastern Mediterranean during the more humid Atlantic period.

Much greater rates of primary productivity of the Eastern Mediterranean in Atlantic period times are shown by Rossignol and Pastouret (1971). Their data were from cores collected near the isle of Crete that were radiocarbon dated. Two cores from waters off the coast of Haifa were analyzed palynologically by Horowitz (1974d; see Chapter 6) and were correlated with radiocarbon-dated cores from the Hula Valley. No radiocarbon datings are given by Reiss *et al.* (1971). Luz and Bernstein (1976) analyzed the oxygen isotope ratios in two cores off the Palmahim area on the Mediterranean shelf and slope and showed some significant changes within the isotopic ratios of ^{16}O:^{18}O. They conclude, based on Reiss *et al.*'s stratigraphy, that these represent the last phase of the Würmian. It seems, though, that, as in the case of the foraminiferal assemblages, the oxygen isotope ratios represent a greater influx of freshwater into the Mediterranean during the Atlantic period, rather than any decrease of temperature.

Most of the sediments deposited during the Quaternary in the marine environment of the Mediterranean have been brought to the area by the Nile. This conclusion is based on the mineralogical composition of the sediments (Nir 1973), the heavy minerals (Nachmias 1969), and the pollen and spore spectra (Horowitz 1974b; Rossignol 1961). The sediments of the deeper sea are more clayey, interfingering with the littoral sandy and silty sediments to the west. They grade westward to the thin, deep-sea Mediterranean planktonic ooze encountered from the sea floor by many drillings (Rossignol-Strick 1976). The Quaternary marine sediments overlie the Pliocene Yafo Formation on the continental shelf, but the nature of contact is uncertain. In some localities it seems that the Quaternary overlies the upper Pliocene Petah Tiqwa Member quite conformably, but in other places it seems that a hiatus is encountered between the Quaternary and the underlying Pliocene sediments. Several regressive phases can be discerned within the continental shelf Quaternary marine sequence, but no systematic study of these has been done. They are indicated mainly by an increasing share of calcareous particles in the sediments, increasing amounts of sand and silt, and the more benthonic-neritic character of the fauna. Since no complete sequence has anywhere been analyzed, the number and nature of these regressions and their correlation with the littoral sediments, in which the regressions are quite well marked, is not clear.

BAY OF ELAT

Almost nothing is known of the deeper marine sediments of the Bay of Elat. The surface sediments in the center of the Bay mainly comprise foraminiferal and pteropod ooze, with some dark gray to brownish clays



(Horowitz 1966). An analysis of seismic profiles across the Bay of Elat (Figure 5.5; Z. Ben-Avraham, Weizman Instiue for Science, Rehovot, personal communication, 1977) shows that the southern part of the Bay is covered by quite thick (more than 2 km) soft sediments, apparently representing the entire Late Cenozoic. At the north of the Bay, however, this sequence is interrupted by at least two unconformities, which can be seen within the seismic profiles. Such major unconformities are known from the continental sediments around the Bay of Elat between the Miocene and the Pliocene sediments and between the Pliocene and the Quaternary, so that it seems that the upper several hundred meters, overlying the last unconformity, might be tentatively assigned to the Quaternary. No drillings were carried out within the Bay of Elat. Some cores several meters long were collected, but these give no further information as to the nature of the sequence. It seems, though, that the Quaternary sequence of the Bay of Elat mainly comprises foraminiferal and pteropod oozes deposited within the deep Bay, with the addition of clay minerals, most probably of aeolian origin.

FIGURE 5.5. *Seismic profile across the Bay of Elat. Note the rugged nearshore topography of the buried, submerged wadis and the rather flat-lying deep-sea sediments. Width of profile about 16 km, penetration 3 sec. (Courtesy of Z. Ben-Avraham, Weizmann Institute of Science.)*

LITTORAL SEDIMENTS

Quaternary littoral sediments are known from hundreds of boreholes drilled in the Mediterranean coastal plain, representing the changing conditions of the eustatically controlled oscillations of the Mediterranean in this area. In the Bay of Elat area, these sediments are much less known due to the lack of boreholes and of almost any other information.

MEDITERRANEAN

Littoral sediments of the Mediterranean were grouped by Horowitz (1974) on the basis of their microfauna and mollusks and on the basis of their ingressive and regressive indications into two formations, the Preglacial Pleistocene Ga'ash Formation and the Glacial Pleistocene Yarkon Formation, both included within the Kurkar Group, as suggested in Gvirtzman (1970). These sediments were referred to by Issar (1961, 1968) as the "Marine Pleshet Formation"; this was later revised by Gvirtzman (1970). The latter included within the Pleshet Formation only the Pliocene littoral sediments, originally designated as "Calcareous Sandstone of Philistea" by Hull (1886). The term "Pleshet Formation" as suggested by Issar would, therefore, not be applicable to the Quaternary sediments, which were later named by Horowitz (1974) the Ga'ash and the Yarkon Formations.

Ga'ash Formation

The Ga'ash Formation was designated by Horowitz (1974) to include marine–littoral sediments deposited by the Calabrian and the Sicilian ingressions. The type section was proposed at the Ga'ash I borehole, at coordinates N 181.450 E 133.710, about 20 km north of Tel Aviv (Figure 5.3), from a depth of 159 to 195 m (Figure 5.6). The sequence comprises alternations of dark gray calcareous sandstones and dark gray to blackish, somewhat marly but usually sandy, shales. Reference sections were proposed at the Reading 33-0 borehole, north of Tel Aviv, at depths of 145 to 172 m and at the Jaffa I borehole to the south of Tel Aviv at a depth of 167 to 216 m. The Ga'ash

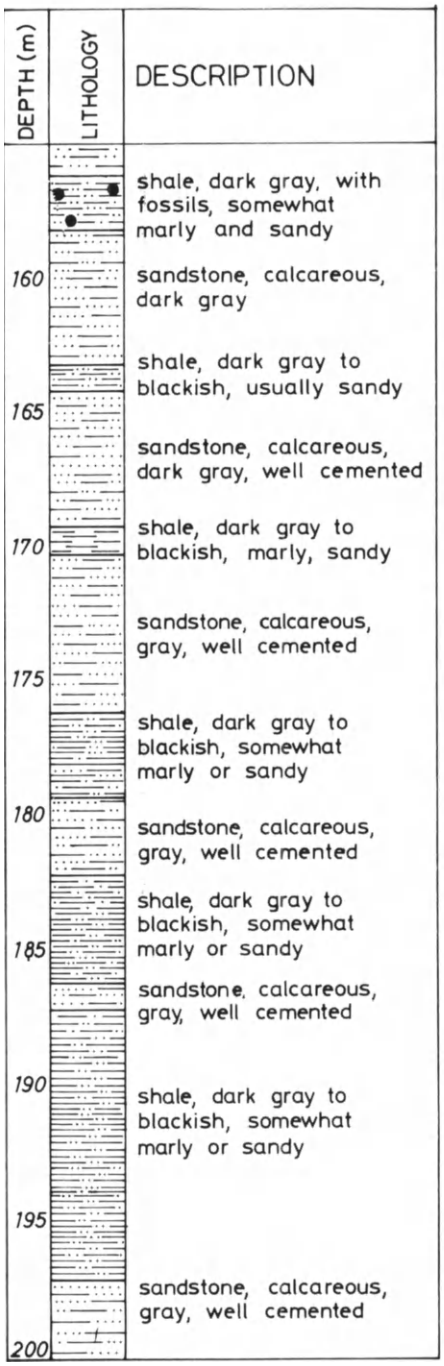


FIGURE 5.6. *Type section of the Ga'ash Formation at Ga'ash 1 Borehole.*

FIGURE 5.7. *The only known outcrop of the Ga'ash Formation silts and clays, which is rich in mollusks. Location: Nahal Besor, in Northwestern Negev.*

Formation crops out (Figure 5.7) at only one locality, in Nahal Besor, Northwestern Negev, near Kibbutz Urim. The sediments comprise some 20 m of gray calcareous, sandy marls, quite rich in mollusk shells, overlying the late Pliocene Ahuzam Conglomerate over a base conglomerate. To the east, the marls interfinger with coastal sediments and beachrocks, at an elevation of 110–125 m above m.s.l. The malacofauna of the Ga'ash Formation is described in detail by Moshkovitz (1963, 1968) from the boreholes. The malacofauna comprises about 50 species of mollusks, of which the most important are *Turitella pliorecens, Nucula placentina, Plicatula mytilina, Dentalium novemcostatum, Barbatia mytiloides,* and *Arcopagia corbis* (Figure 5.8), indicating a Calabro-Sicilian age.

Detailed analysis of the microfauna of the Ga'ash Formation is given in Reiss and Issar (1961) from the Reading 33-0 borehole, from the interval termed as the M-1 complex. The microfauna comprises foraminifers such as *Ammonia,* miliolids, *Porcellanea, Elphidium, Nonion,* globigerinidae, and others. Occurrences of *Hyalinea balthica* in this part of the sequence are noted in Moshkovitz (1968). It should be noted that almost all the foraminifers that appear at the M-1 Complex are also known from the Recent sediments of the offshore Mediterranean (Reiss *et al.* 1961), and only their percentages vary within the various stages defined at the Reading 33-0 borehole. The M-1 Complex consists of marine shales, mudstones, and clays, partly sandy and often pyritic. At the top and the middle of this complex, limestones and conglomerates, as well as sandy clay almost devoid of fauna, are present. The fauna, when present, is rich in molluscan shells and contains a relatively large number of species of foraminifera, belonging partly to genera known to favor moderately deep waters. Planktonic foraminifera are present, although in small numbers. According to Reiss and Issar, this complex was deposited in the Reading area in moderately shallow waters in an environment similar to the outer part of the present-day continental shelf, at water depths of approximately 50–80 m. The conglomerate horizons in the middle and at the top of the sequence denote shallowing of the sea. Details of the distribution of various foraminiferal groups within the section are given in Figure 5.9. Moshkovitz (1968) concludes that the Calabro-Sicilian sea was cooler than that of the Pliocene, based on the composition of the malacofauna and microfaunal assemblages.

Perath (1965) studied the benthonic microfauna from

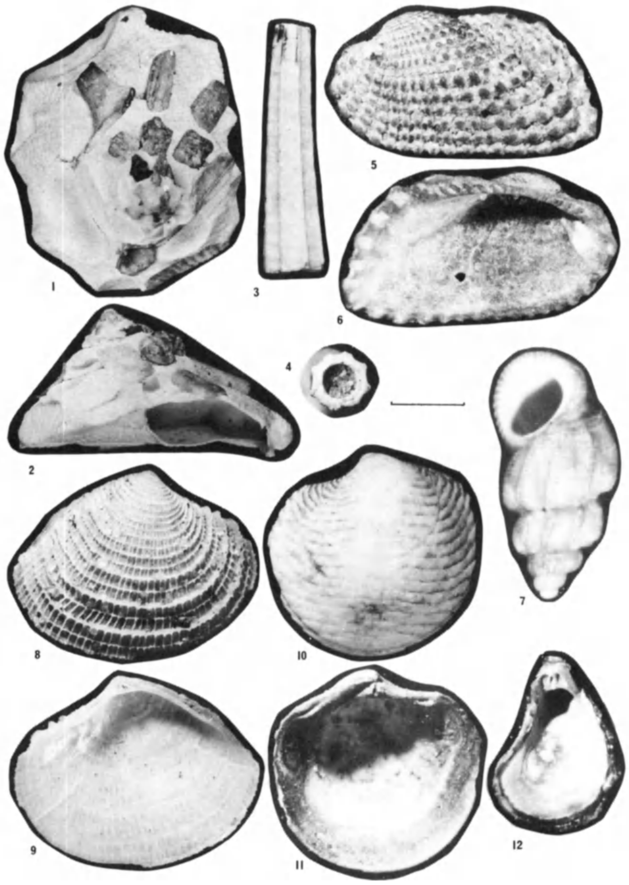


FIGURE 5.8. *Malacofauna of the Ga'ash Formation, from Ga'ash I and Reading 33/0 Boreholes. 1,2,* Xenophora crispa *(scale 12 mm); 3,4,* Dentalium novemcostatum *(scale 3 mm); 5,6,* Arca pulchella *(scale 3 mm); 7,* Alvania costata *(scale 1 mm); 8,9,* Arcopagia corbis *(scale 3 mm); 10,11,* Divaricella divaricata *(scale 3 mm); 12,* Plicatula mytilina *(scale 6 mm). (Courtesy of S. Moshkovitz, Geological Survey of Israel.)*

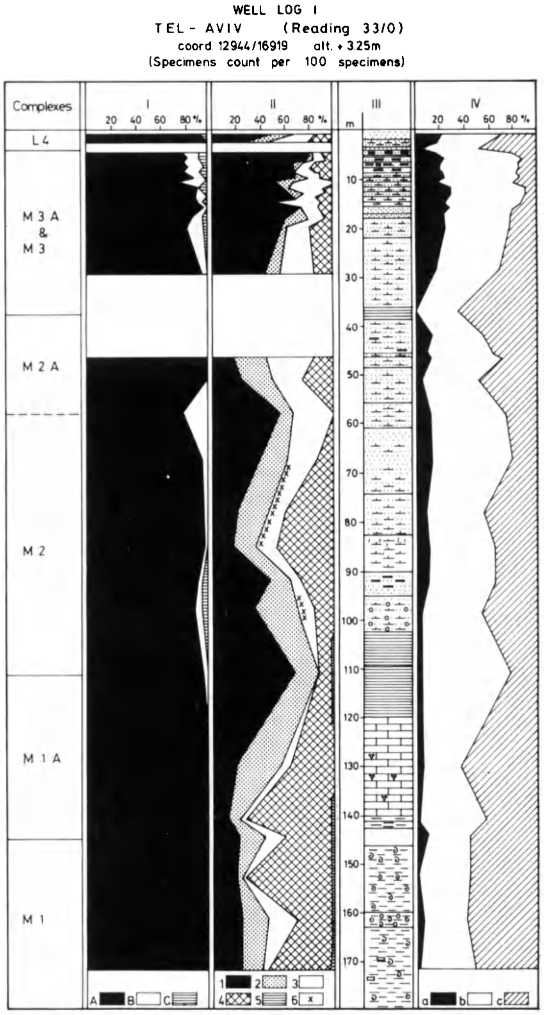


FIGURE 5.9. *Type section of the Yarkon Formation from Reading 33/0 Borehole, and the underlying Ga'ash Formation (M1): I, frequency of Quaternary (A), redeposited Eocene (B), and Cretaceous (C) foraminifera; II, frequency of bionomic groups of Quaternary forams (1)* Ammonia, *(2)* Elphidium *and* Nonion, *(3) Globigerinidae, (4) Miliolidae, (5) others, (6) occurrences of* Marginopora; *III, Lithology; IV, Frequency of heavy minerals (a) augite, (b) hornblende, (c) others. (From Reiss and Issar 1961.)*

the Jaffa I borehole. Most of the benthonic foraminifera are relics from the Pliocene, but the Calabro-Sicilian assemblages are much poorer in the number of species as compared with the Pliocene. This may indicate a drop in the average sea-water temperatures. Pollen analyses of the Ga'ash Formation are given in Rossignol (1969) from the Reading 33-0 borehole. The assemblages comprise very high percentages of allochtonous pollen grains and spores, brought by the Nile and deposited in the eastern Mediterranean. The autochtonous spectrum is characterized by high percentages of nonarboreal pollen, mainly derived from Gramineae and Cyperaceae, with some Compositae, *Artemisia* and *Asphodelus.* About 10% of Chenopodiaceae and *Ephedra* also appear. Arboreal pollen grains comprise mainly *Pinus,* either *P. halepensis* or, perhaps, another species of pine that is probably a relic from the Pliocene, when it appeared in high percentages (Horowitz 1974b; Horowitz and Zak 1968). Minor percentaged of *Quercus calliprinos* and *Olea europaea* also appear. This pollen assemblage indicates, according to Rossignol, a dry climate. Several hystrichosphere species and other unicellular algae are also described by Rossignol (1964a), which occur from the Pliocene to the present day with no major changes, and are, thus, of no stratigraphic importance.

Some outcrops of coastal sediments that occur at the northwestern Negev, in the Besor area, have been correlated by Horowitz (1974) with the Ga'ash Formation. These were designated as the "CP Unit" by Shachna'i (1967). The sequence is about 20–25 m thick, comprising sandstone and marls, rich in badly preserved mollusks, which indicates a littoral environment. Similar sediments were designated as the "Q-9 Unit" by Bar-Josef (1964) at the Ahuzam-Nir'am area, the "Lower Gravel Series" by Picard (1943), and "Villafranchian" by Avnimelech (1950). The Ga'ash Formation is not known from the northern part of the coastal plain of Israel. In the central coastal plain, it overlies the Pliocene sediments in the boreholes, mostly over sandy horizons, such as the Petah Tiqwa Coquina Member at the Ga'ash I and Jaffa I boreholes. The CP Unit, which, apparently, represents the only outcrops of the Ga'ash Formation, in the northwestern Negev overlies the Pleshet Formation and Ahuzam Conglomerate *sensu stricto*. The Ga'ash Formation is overlain in the coastal plain by the Yarkon Formation littoral sediments, of Glacial Pleistocene age. The CP Unit is overlain in the northwestern Negev by the Gaza Formation sandstones and paleosols.

The stratigraphic position of the Ga'ash Formation, its malacofauna, and the appearances of *H. balthica*, justify its assignment to the Calabro-Sicilian stages. This complex was not subdivided by Moshkovitz or by Reiss and Issar into the Calabrian and the Sicilian, but it seems that the conglomerate horizon in the middle of the M-1 Complex at the Reading 33-0 borehole denotes the regression that separated the Calabrian from the Sicilian ingressions.

Laterally, the Ga'ash Formation interfingers to the west with the lower part of the marine Quaternary sediments described earlier in this chapter. Eastward, the lower part of the Ga'ash Formation interfingers in the northwestern Negev with a conglomerate horizon, overlying the Ahuzam Conglomerate *sensu stricto* (Bar-Josef 1964; Shachna'i 1967). The upper part of the Ga'ash Formation, of Sicilian age, interfingers in the northwestern Negev with the calcareous sandstones of the Hirbet Harev Kurkar Member. To the north, in the Sharon and Carmel areas, the Ga'ash Formation interfingers with coastal terraces and beachrocks at elevations of 100–110 m (Calabrian) and 80–90 m (Sicilian). The Ga'ash Formation represents the Calabrian and Sicilian ingressions, of Preglacial Pleistocene age, in the Mediterranean coastal plain of Israel. The seawater, as compared with the underlying Pliocene, had considerably cooled, and northern elements such as *Hyalinea balthica* and *Arctica islandica* penetrated into the Mediterranean and inhabited especially its western part (Moshkovitz 1968). *Hyalinea balthica*, however, reached as far as the eastern Mediterranean in Preglacial Pleistocene times and is often found in Israeli offshore sediments of this age.

Yarkon Formation

Littoral sediments of Glacial Pleistocene age have been designated by Horowitz (1974) as the Yarkon Formation. The type section was proposed at the Reading 33-0 borehole (coordinates 12944–16916, Figure 5.9), north of Tel Aviv, near the Yarkon River (Figure 5.3), from which the formation acquired its name. Similar sediments were described in Issar (1961, 1968) and termed the "Pleshet Formation of Marine Origin," or sometimes, when the sediments comprise mainly clay, as the Sharon Formation. Reasons previously discussed have led Horowitz (1974) to discern the Yarkon Formation as a time-stratigraphic unit. The type section of the Yarkon Formation is described by Reiss and Issar (1961) from the Reading 33-0 borehole, from the surface down to a depth of 145 m. Reference sections were proposed by Horowitz from the Jaffa I borehole, from the surface down to a depth of 167 m, and in Haifa Bay at borehole Blue Band, drilled at Israel grid coordinates 24715–15410, from the surface down to a depth of 85.80 m, described in detail in Slatkine and Rohrlich (1964). The Glacial Pleistocene littoral sequence of Reading 33-0 borehole was divided by Reiss and Issar (1961), on the basis of the relative distribution of various species of foraminifera, into 6 complexes, which later were assigned as members of the Yarkon Formation (Horowitz 1974).

The lowermost member of the Yarkon Formation, M-la, extends from 145 to 111 m. It overlies the upper conglomerates and lagunar shales of the M-1 Complex of the Calabro-Sicilian Ga'ash Formation. The lower part comprises shales and the middle part limestone rich in fossils, overlain by clays and sandy loams. The fauna of the complex is rich in molluscan remains, corallinacean algae, and, especially, non-reef-building corals. The foraminiferal assemblage is relatively rich in species, although it contains less than the M-1 Complex. Species known to favor deeper waters are represented by a few specimens only. Planktonic foraminifera are very rare and sometimes absent. Percentages of brackish water and redeposited foraminifera are greater at the base and, especially, at the top of the M-la Member. In the Reading area, the member has been deposited in moderately shallow waters, in an area of the continental shelf similar to the present-day patchy and irregular belt of rocks and corals, at a depth of probably less than 50 m. The lower and upper strata of the member indicate regressive phases displayed by the conglomerates, swampy and lagoonal clays, sandstones and loams, as well as by the faunal composition of these strata.

Member M-2, from a depth of 111–58 m, is characterized mainly by calcareous sandstones with subordinate shales, as well as by conglomerates at its base, whereas clays, sands, and loams occur both at the base and at the top. The fauna is often rich in molluscan remains and calcareous algae. Corals are rare. The forminiferal fauna is composed of species known to favor moderately shallow waters, some of them warm waters. The number of species is smaller than in the preceding member, M-la. Planktonic foraminifera are absent, and species generally characteristic of cooler and deeper waters are represented by extremely rare specimens. Brackish water foraminifera occur more frequently, and especially at the base and top of the member, but also in its middle part. The warm water foraminifer *Marginopora* occurs quite frequently in these strata. The member is interpreted by Reiss and Issar as an ingressive deposit formed on the inner side of the continental shelf in warm waters, probably not deeper than 30 m. Surface salinity was probably low due to both currents and nearness to the shore. A minor regressive fluctuation is indicated by lithology and fauna in the middle part of the complex. At the top of the complex, grading into littoral, supralittoral, and terrestial deposits denotes renewed regression of the sea.

Member M-2a, from a depth of 58–37 m, is generally similar in lithology and fauna to the M-2 Member. Conglomeratic sandstones occur in the upper part of the complex, and the number of specimens belonging to warm water species, such as *Marginopora* and *Planorbulina*, increase. The same is also true of those species favoring shallow waters. Brackish water elements show the same frequencies as in the M-2 Member. They are more frequent at the bottom and top of the complex; this is also true of the number of redeposited foraminifera. The member is interpreted by Reiss and Issar as having been formed on the inner part of the continental shelf, in warm waters with low surface salinity, at a depth of probably not more than 30 m. Turbidity was low while bottom salinity was probably normal, as indicated by the frequency of *Marginopora*. Member M-3, from a depth of about 37 m to about 18 m, overlies Member M-2a with a loamy, sandy horizon and comprises calcareous sandstones. It is topped at about 15–18 m by a sandstone horizon, apparently of continental origin. Member M-3a begins above this sandy horizon and comprises shaly, calcareous sandstones with some pyrite and loam at the upper part, up to about 4.5 m below the surface. The marine parts of these two members, M-3 and M-3a, are separated by littoral to supralittoral and terrestrial deposits, denoting regressions of the sea. Member M-3 is characterized by a fauna that includes only a few species and is composed entirely of shallow water elements, the most prominent being brackish water ones, which occur in large numbers. These members are interpreted by Reiss and Issar as having been deposited during a shallow ingression near the shore, at a depth probably not exceeding 15 m. Both bottom and surface salinities were low.

Member L-4, which comprises the uppermost 4.5 m of the Reading 33-0 borehole, comprises continental sands at the bottom and the top, and the middle is intercalated by calcareous sandstones with fauna similar to that of the M-3 and M-3a members, although it contains still fewer species. The marine strata were, apparently, deposited during a very shallow ingression of the sea, at a depth probably not exceeding a few meters. It should be noted that the marine sediments of this last, L-4 Member ingression are always found above the present-day sea level (Avnimelech 1962).

The sequence of the Yarkon Formation sediments was penetrated by several boreholes at Haifa Bay (Figure 5.10), analyzed in detail in Slatkine and Rohrlich (1964). The sequence, about 90 m thick, comprises alternations of marine sediments, mainly calcareous sandstones and sandy shales, with abundant foraminifera and mollusk remains separated by continental sands and loams. Five transgressive cycles are discerned by Slatkine and Rohrlich. The lowermost, the MG cycle, comprises mainly glauconitic, micaceous sandy limestone and was correlated by Horowitz (1974) with the M-1a Member. Separated by a few meters of sand, most probably of continental origin, is the G-1 ingressive cycle, typified by appearances of *Marginopora* and correlated by Horowitz with the M-2 Member. The G-2 ingression appears quite high in the sequence, separated from the G-1 by some 30 m of continental sandstones and paludine sediments, mainly black shales, and comprises calcareous sandstones. The G-2 ingression also includes *Marginopora* and was correlated by Horowitz with the M-2a Member. Another 10 m of paludine sediments separate the G-2 from the G-3 ingressive cycle, which attains some 10 m in thickness. This member is devoid of *Marginopora* and was correlated by Horowitz with the M-3 and M-3a members. It is overlain by continental dune sandstones. In some places in Haifa Bay, another, almost Recent ingression called "Actuël" by Slatkine and Rohrlich was discerned. This is most probably the equivalent of the L-4 Member of Reiss and Issar (1961).

Rossignol (1962, 1964, 1969) analyzed palynologically the Yarkon Formation sediments along the coastal plain. The detailed results are presented in Chapter 6, but, in general, the ingressive sediments of the Yarkon Formation present more or less similar pollen spectral elements to those of the present day. It is concluded, therefore, that the Mediterranean ingressions took place during the interpluvials. The regressive sediments yeilded no pollen, but the entire sequence represents palynologically an interpluvial climate, which comprises a series of superimposed interpluvial phases throughout the Quaternary. In most of the boreholes analyzed, the Yarkon Formation overlies the Preglacial Pleistocene Ga'ash Formation, from which it is separated by regressive sediments, mostly sandstones, but sometimes conglomerates and paludine clays. The Yarkon Formation gradually interfingers to the west with the upper part of the marine Quaternary sediments of the Mediterranean; to the east it grades to the Gaza Formation calcareous sandstones and paleosols, of continental origin. In places, the ingressions terminate landward with some rare occurrences of beachrocks.

The Yarkon Formation was penetrated by many boreholes drilled along the Israeli coastal plain and underlies the present-day coastal area. It is still being deposited at present, west of the coastline. The Yarkon Formation sediments represent a period of ingressions and regressions of the Mediterranean that took place in Glacial

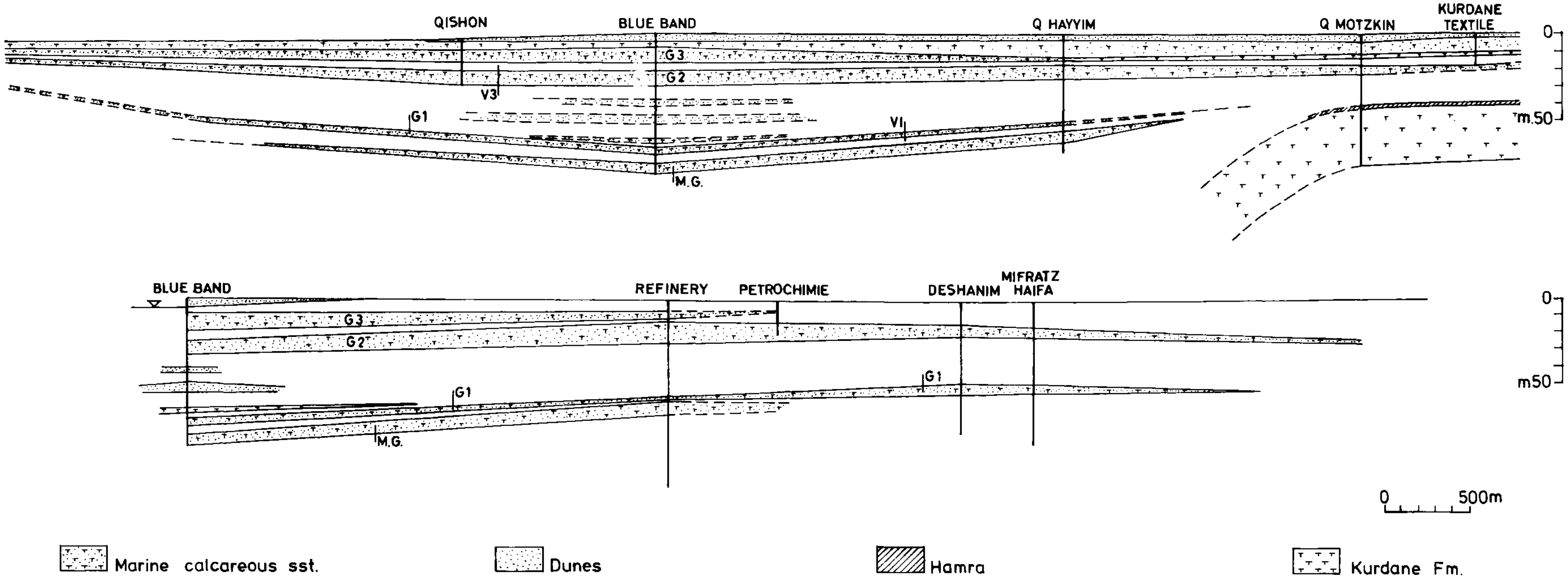


FIGURE 5.10. *Cross section of the Glacial Pleistocene littoral–marine sediments of the Zevulun Valley. MG, Milazzian; G1, Tyrrhenian; G2, Monastirian; G3, Late and Epi-Monastirian. (From Slatkine and Rohrlich 1964.)*

Pleistocene times. The ingressions are marked by the M-1a through L-4 Members. These ingressions were correspondingly correlated (Horowitz 1974, 1976) with the Milazzian, Tyrrhenian, Monastirian, Late-Monastirian, Epi-Monastirian, and Versilian stages. It should be noted that L-4 is a complete cycle, beginning and terminating with a regression. Rossignol (1969) subdivided the L-4 into the lower, Atlithian Ingression, the middle, Shefelian Regression, and the latest, "Actuél" Ingression. It should also be noted that the Mediterranean is presently in an ingressive phase. The age of the Yarkon Formation is Glacial Pleistocene, since it overlies the Ga'ash Formation, with its typical Calabrian and Sicilian faunas (Moshkovitz 1968). Its ingressive cycles correspond very well with the standard sequence of ingressive phases known for the Mediterranean area.

BAY OF ELAT

Very little is known of the Quaternary littoral sediments of the Bay of Elat. At present, these comprise two types of sediments. There are coral reefs, with associated sediments that occupy most of the interfluves, and, in the wadi outlets, conglomerates and arkosic sandstones are accumulated. Boreholes that have penetrated the littoral Bay of Elat Quaternary sequence are quite rare and, in fact, touch only the upper part. In some of these boreholes, reefy layers are found to intercalate with continental sediments, mainly arkoses. No study of these was carried out; no further information is provided; and no dating is available for these horizons. A thin coral-bearing layer was penetrated by a borehole just north of the Bay of Elat at a depth of about 3 m and was ionium dated at about 4000 B.P. Since tectonic movements are quite common in this area, no conclusions are made for this single observation.

Three successive coral terraces are known from the southern coasts of Sinai, described by many authors (for example, Friedman 1968; Hume 1906; Milne 1875; Nir 1971). The terraces were dated with the ionium method by F.Yaron (in Goldberg, 1970a), the lowermost yielding ages of around 110,000 years, the middle one around 200,000–250,000 years, and the upper apparently older than 250,000 years. The diagenetic processes were studied by Gvirtzman and Friedman (1977), who found that, the older the coral is, the more progressive is the diagenesis. The elevations of these terraces vary according to locality but are generally higher to the south, attaining, for the uppermost terrace, up to 20–25 m above m.s.l. (Figure 5.11).

FIGURE 5.11. *Three successive coral "raised" terraces. They have subsided since their deposition, which was noted when comparing their elevation with altimetry corresponding to their ages. Location: the southern sector of the Bay of Elat, near Wadi Kid.*

The ages of the terraces present a problem: If a terrace more than 250,000 years old is only some 20–25 m above sea level instead of the expected 30–40 m for this age as a minimum corresponding to eustatic sea-level changes, then the terraces should be regarded as subsiding and not as "elevated," as all authors state. This subsidence is stronger to the north, until at about midpoint of the Bay of Elat terraces are no longer encountered. In the Bay of Elat area, only the Island of Tiran, at its southernmost tip, has a sequence of tectonically elevated coral terraces (studied by Goldberg, 1963). However, due to tectonic complexity and scarcity of data, no picture could be drawn for Quaternary sea-level changes in this region. The present-day fringing reefs of the Bay of Elat began their growth only some 10,000 years ago, following the post-Glacial sea-level rise (Gvirtzman *et al.* 1977).

BEACHES AND SHORELINES

Ancient beaches and coastlines can be discerned by the ensuing processes of the coastline and the adjacent land surface. These processes were divided by Zeuner (1959) on the basis of two criteria, destructive and constructive. The destructive criteria are mostly visible when the sea approaches a hilly or mountainous terrain. A variety of morphologic phenomena can be seen, like undercut notches and grooves cut by the waves just above the abrasion platform, sometimes also accompanied by coastal caves. When the hills or mountains facing the sea dip quite steeply seaward, a coastal cliff is likely to be developed. Abrasive platforms and wavecut benches generally originated from mechanical destruction and chemical dissolution of the coastal rocks by the sea waves.

The elevation of the abrasive platform in relation to the sea level depends somewhat on energy of the waves and differences in tide. In the Mediterranean, and especially in the eastern part, the tidal differences are subordinate, and, therefore, the abrasive platforms are presently formed at sea level. Biological activity connected with the coast, and especially borings by sponges and by mollusks such as *Lithodomus* and *Pholas petricola*, which live in the intertidal zone, also serve as good indicators for approximate sea-levels.

Landward destructive criteria that might be connected with sea level are river terraces and nickpoints in rivers leading seaward. These are mainly formed due to changes in the energy profile of the river but could also be caused by sea level, tectonic, or climatic changes. These terraces and nickpoints are generally higher than the average sea-level that caused their formation, and, therefore, a careful examination must be carried out before attempting to connect these phenomena with a certain sea-level. Construction criteria are either sediments deposited by the sea in the subtidal zone, which would give a minimum elevation for an ancient coastline, or beachrocks deposited in the tidal zone, which are the best indicators for a coastline. Continental sedimentation is caused by the sea in cases where the coastal plain is rather flat-lying. Most common are the sand dunes that are pushed landward by the sea. Picard (1943) showed the connection of ancient dune ridges along the Israeli coastline with corresponding sea levels. Nir (1970) further elaborated on this phenomenon and stated that only the seaward slope of the ancient dunes should be taken into consideration, because their landward propagation is determined mainly by topographical barriers. The elevation of the basal seaward notch in a fossil dune ridge is taken by Nir as an indicator of an ancient sea-level.

Naturally, all these indicators are connected with sea level within a range of several meters, and, therefore, only the range of sea level can be determined accurately. When the sea propagates landward, it creates, especially over a flat country, an abrasion plate. When the sea regresses, it generally creates channeling of the former platform. The ancient dune ridges are indicators of still stands in the relative position of sea and land and can, therefore, be used only to determine those periods in which the sea was at its maximum landward or seaward position for a considerable span of time. Most authors regard these dune ridges as indicating transgressive phases of the sea (for example, Avnimelech 1962; Itzhaki 1955, 1961; Nir 1970; Picard 1943). Only Farrand and Ronen (1974) regarded sandstone ridges on the Carmel coast as indicating regressions. When it is understood that these dune ridges, or ensuing sandstone ridges, are indicative of stillstands in the position of the sea, it would be clear that regarding them as indicating transgressions or regressions depends only on the definition. We tend to use here the generally accepted definition for the Quaternary of Israel, namely, shorelines that are landward of the present-day coast are transgressive and those that are seaward are regressive. It will be seen later that sandstone ridges indicative of those regressive phases are in fact found under the present-day sea down to a depth of more than 100 m (Almagor 1976).

The dating of the various Quaternary shorelines presents a considerable problem. Whenever single occurrences of phenomena indicating ancient sea level have been detected, such as beachrocks in boreholes, etc., relative dating is very difficult and, in most of the cases, impossible. The sequence, as such, can be dated only when it is entirely preserved and exposed. The Quaternary beachrocks are almost of the same facies all along the sequence (Itzhaki 1961; Michelson 1970) and cannot be stratigraphically defined. There are, however, several points that can be used for stratigraphic definitions and correlations of the various sea-levels. The late Pliocene conglomerates and other sediments of the coastal plain could, in almost every locality, be stratigraphically identified as such (Derin and Reiss 1973; Gvirtzman and Buchbinder 1969; Horowitz 1974). Everything that over-

TABLE 5.1
Eustatic Mediterranean Ingressions of the Israeli Coastal Plain and Their Terrestrial Correlatives

Stage	Ingression	Littoral sediments	Elevation	Haifa Bay	Carmel Coast	Correlative rock unit of the Coastal Plain	Fossil dune ("Kurkar") Ridge and its elevation (m)
Recent	Recent (Actuél)	Recent	0	Recent	Recent	Hadera Dune Bed	Recent Dunes (20–30)
Versilian	Atlithian	L-4	2–3	"Actuél"	F	Tel Aviv Kurkar Bed	
Epi-Monastirian	Yarkon	M-3a	5–8	G-3	T-3	Dor Kurkar Bed	Ziqim Ridge (25)
Late Monastirian		M-3	10–12				
Monastirian	Poleg	M-2a	13–18	G-2	T-2	Ramat Gan Kurkar Mbr.	Yad Mordekhay Ridge (60)
Tyrrhenian	Azor	M-2	35–45	G-1	T-1	Gedera Kurkar Mbr.	Erez Ridge (80)
Milazzian	En Besor	M-1a	50–60	MG	PT	Tell Fara Kurkar Mbr.	Nir'am Ridge (120)
Sicilian	Eyal	M-1	80–90	—	"Sicilian"	Gerar Kurkar Mbr.	Yakhini Ridge (145)
Calabrian	"Calabrian"	(Ga'ash Fm.)	100–120	—	"Calabrian"	Haruvit Kurkar Mbr.	Hirbet Harev Ridge (190)

lies or cuts into the late Pliocene sediments is, therefore, of Quaternary age. In places where the overlying succession was entirely preserved, it could easily be divided into stratigraphic units denoting the various Quaternary stages (Table 5.1).

The fauna preserved within the Quaternary beachrocks must be used only with great care. Two faunal assemblages have been discerned for the Quaternary. The lower is characterized by cold-water fauna, typical for the Calabrian and Sicilian ingressions (Moshkovitz 1968). The cold water fauna persisted also, to some extent, during the Milazzian Ingression (Horowitz 1974), therefore regarded by some authors as the "Sicilian II" or "Late Sicilian" (see, for example, Nir 1970). The upper part is characterized by warm-water fauna and especially by the foraminifer *Marginopora* (Issar and Picard 1969). This species is used to define the Tyrrhenian through Recent ingressions. On the basis of occurrences of *Marginopora* (Issar 1961, 1968; Issar and Picard 1969; Nir 1970; Nir and Bar-Yosef 1976), the upper part of the coastal Quaternary sediments was divided into T-1, T-2, and T-3 ingressions, denoting various stages of the "Tyrrhenian." Comparing these with the classical Mediterranean sequences of the French Riviera, Horowitz (1974) indicated that the T-1 corresponds to the Tyrrhenian Ingression, the T-2 to the Monastirian Ingression, and the T-3 to the Late and Epi-Monastirian ingressions. It can be seen, therefore, that these faunal elements can be used only to define lower or upper part of the Quaternary in single outcrops or in boreholes, but, whenever a complete succession has been preserved, their first and last appearances could be used for stratigraphic correlations along the Israeli coastal plain. Dune ridges can be dated only in two situations: either when the entire sequence is preserved, as is the case in the northwestern Negev, or when paleosols bearing fossil mammals and artifacts have been preserved within the sequence of these dunes, enabling stratigraphic correlation with other sites. Regressive phases of the Mediterranean during the Quaternary could be discerned only by geophysical investigation offshore (Almagor 1976) and by dredging done to confirm that the highly reflective horizons are calcareous sandstones, of the same type denoting the fossil dunes on the coastal plain.

The Israeli coastal plain is divided into three sectors in respect to the Quaternary coastal deposits. The largest is the sector south of Haifa Bay, which includes two subsectors: the Carmel, which is a mountainous block standing against the sea waves, and the Sharon and Pleshet coastal plains, which are rather flat, gently seaward dipping plains enabling ingressions to propagate far landward. This sector is characterized by Quaternary coastal sediments ranging in elevation from more than 100 m for the Calabrian down to the present-day sea level for the most Recent ones. It seems that this sector did not suffer any tectonic movement during the Quaternary, because the successions follow similar elevations along its entire length, thus indicating stability in this sector. The Haifa Bay sector is a rapidly subsiding block facing the Mediterranean, which resulted in the marine ingressions depositing sediments that reach more landward the younger the ingression (Slatkine and Rohrlich 1964). No dune ridges are preserved in this area on the surface, and, apparently, most of them are buried under the subsequent younger sediment. The Western Galilee coastal plain is, apparently, also subsiding, but at a slower rate than the Haifa Bay sector. Several dune ridges were preserved along this sector, but at elevations not exceeding a few meters above the present-day sea level. The Tyrrhenian Ingression left coastal sediments (Issar and Kafri 1972) at an elevation of about 3 m above the present-day sea level, whereas beachrocks of the same ingression were preserved on the Carmel Block and south of it at elevations of 35–45 m (Michelson 1970).

NORTHWESTERN NEGEV

A cross section of the northwestern Negev, perpendicular to the Mediterranean coast, reveals several horizons of beachrocks and related phenomena at elevations grading from more than 100 m to the east down to the present-day sea level to the west (Avnimelech 1962; Itzhaki 1955, 1961; Nir 1970a; Nir and Bar-Yosef 1976; Picard 1943). The highest of these complexes occurs at elevations between 110 and 130 m, about 20 km or more to the east of the present-day coastline, which directly overlies and cuts into late Pliocene sediments. Beachrocks of this unit (Figure 5.12), containing some rolled and badly preserved mollusks, were defined as the "CP Unit" by Shachna'i (1967), "Q-9 Unit" by Bar Josef (1964), "Villafranchian" by Avnimelech (1950), and "Lower Gravel Series" by Picard (1943). Nir (1970a) and Nir and Bar-Yosef (1976) describe more occurrences of these beachrocks at Nahal Patish and at Nahal Gerar, this last outcrop also mentioned in Picard (1951). Another series of outcrops have recently been discovered by H. Bar-Ziv (Kibbutz Urim) and D. Gazit (Kibbutz Gevulot, personal communication 1977); these best expose the relations of the Calabrian beachrocks with the neighboring rock formations. The outcrop is at Bir Sheneq (coordinates 1055; 0695), near the bridge crossing Nahal Besor to Ze'elim, at an elevation of 110–125 m. The sequence comprises about 15 m of calcareous sandstones, rich in mollusks, especially *Glycymeris*, which overlie a base conglomerate, are interfingered by gravel, and are covered by a top conglomerate and paleosols of the Ze'elim Hamra Member. The sequence overlies Eocene rocks in which Pliocene burrowing shells have left their marks. The base conglomerate contains pebbles derived from the late Pliocene Ahuzam Conglomerate, which is exposed some 5 km to the east at an elevation of 140–150 m. The beachrocks grade to the west into calcareous sandy marls of the lower

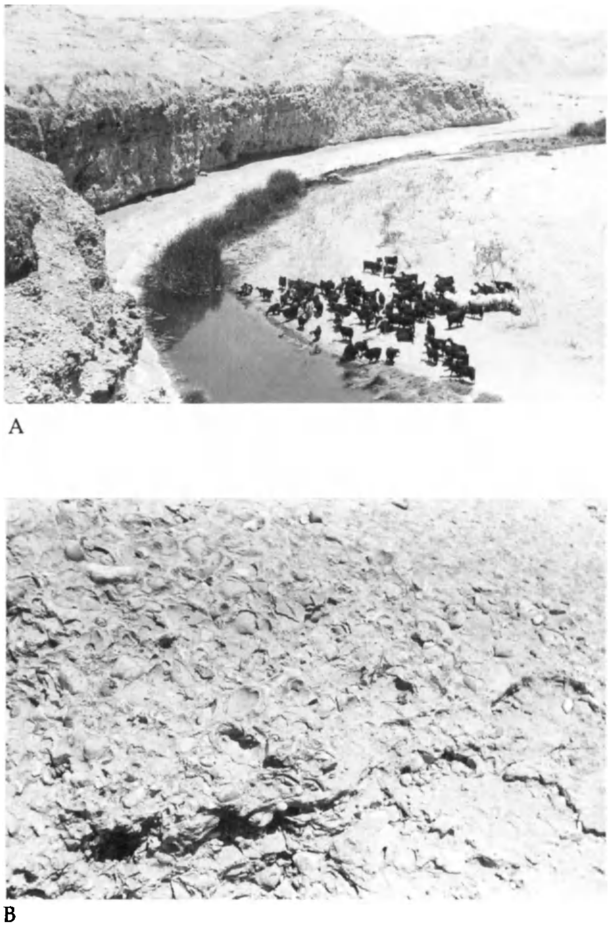


FIGURE 5.12. *A, The Calabrian beachrocks at an elevation of 110–130 m, at Nahal Besor, overlying Eocene limestones that bear burrowing marks of Pliocene fossils. The beachrocks are covered by the "lateral conglomerates of the Ga'ash Formation" and by the Ze'elim Hamra Member. B, Detail of beachrock, with* Gylcymeris, Pecten, Cardium, *and other shells.*

part of the Ga'ash Formation. They grade to the east into conglomerates and terrestrial calcareous sandstones of the Haruvit Kurkar Member and are associated with the Hirbet Harev fossil dune ridge. The profile of Nahal Shiqma near Tel Hasi also shows a phenomenon connected by Nir and Bar-Yosef (1976) with a marine ingression. At an elevation of 110 m, the wadi changes its form from a narrow channel to the east to a wide open bay to the west. All these phenomena are regarded by various authors as denoting the maximal eastward extension of the Calabrian Ingression.

Beachrocks at elevations of 80–90 m above the present-day sea level are reported by Nir (1976) from Tel Sharuhen (Figure 5.13), presently cut by the Nahal Besor, and from similar elevations in the Nir'am area (Nir 1970a). The best outcrops, however, have recently been reported by H. Bar-Ziv and D. Gazit from Wadi Jamila, a tributary of Nahal Besor, near Tel Fara (Sharuhen). The sequence, at an elevation of 80–90 m, comprises calcareous sandstone rich in mollusks, which overlies a base conglomerate, intermingles with gravel horizons, and is overlain by a paleosol of the Hasi Member. The sediments overlie an erosional relief cut into the Ga'ash Formation and its overlying paleosols. The beachrocks grade to the east into

FIGURE 5.13. *Sicilian beachrocks at an elevation of 80–90 m, Wadi Jamila, near Nahal Besor.*

FIGURE 5.14. *A, The Hirbet Harev Kurkar Ridge; B, The Yakhini Kurkar Ridge. Note that the relatively old ridges are almost flattened at present, due to erosion.*

FIGURE 5.15. *Milazzian beachrocks at elevation of 60 m, at En Besor.*

FIGURE 5.16. *The Nir'am Kurkar Ridge.*

FIGURE 5.17. *The Erez Kurkar Ridge.*

FIGURE 5.18. *The Yad Mordekhay Kurkar Ridge.*

terrestrial calcareous sandstones of the Gerar Kurkar Member, associated with the Yakhini Ridge (Figure 5.14). This dune ridge is scarcely preserved, due to subsequent erosion. Nir and Bar-Yoset (1976) define this ingression as the Eyal Ingression, of Sicilian age.

Beachrocks at elevations of 59–60 m are known near En Besor, at Nahal Besor (Nir 1970a), near Or HaNer (Figure 5.15), and in many other localities more or less at the same elevations. The Nir'am fossil dune ridge (Figure 5.16) is considered as the landward influence of this sea level, called by Nir (1970) the En Besor Ingression and attributed to be of a "late Sicilian" age. According to Horowitz (1974), the late Sicilian should be regarded as the Milazzian Ingression.

Beachrocks at elevatins of 30–35 m are quite rare but have been penetrated by many boreholes in the northwestern Negev (Issar 1961, 1968). The fossil dune ridge connected with this ingression is much better exposed than the former one, being much less destroyed by subsequent erosion, and could be traced from northern Sinai (Shata 1959) through the northwestern Negev (Nir 1970a) and the Sharon down to the Carmel foothills (Michelson 1970). The ingression that caused formation of this dune ridge is designated in Nir and Bar-Yosef (1976) as the Azor Ingression and is assigned an "early Tyrrhenian" age. The dune ridge east of the 35-m nick is designated by these authors as the Erez Ridge (Figure 5.17).

FIGURE 5.19. *The Ziqim Kurkar Ridge.*

Two subsequent levels in the northwestern Negev are described in Nir and Bar-Yosef (1976) as the Poleg Ingression, depositing beachrocks at about 18 m above the present-day sea level and causing formation of the Yad Mordekhay Ridge (Figure 5.18), and the subsequent Yarkon Ingression, depositing beachrocks at elevations of 6–8 m and causing formation of the Ziqim Ridge (Figure

5.19). The Poleg Ingression is assigned a "middle Tyrrhenian" (or Monastirian) age, and the Yarkon Ingression is assigned an "upper Tyrrhenian" (or Late and Epi-Monastirian) age by Nir and Bar-Yosef. Beachrocks connected with these ingressions were penetrated by many boreholes in the northwestern Negev, described in Itzhaki (1955) and Issar (1961, 1968).

SHARON

The contact of the Sharon coastal plain with the mountainous formations to the east occurs at elevations of 40–60 m above sea level. No indications of sea levels higher than 80–85 m are known from the Sharon, but it seems that the extensive littoral and marine depositions during Calabrian, Sicilian, and apparently also Milazzian ingressions (Moshkovitz 1968) in the Sharon coastal plain indicate that this area was totally submerged during these periods. Abraded surfaces at an elevation of 75–80 m are cut into Cenomanian rocks, reported in Nir and Bar-Yosef (1976), from the area between Ramat Hakovesh and Eyal. These are regarded by Nir and Bar-Yosef as remnants of the Eyal Ingression, of Sicilian age. Since younger fossil dune-ridges run continuously from the northwestern Negev throughout the Sharon, altimetric correlation between the 75–80-m elevated abraded surface at the Sharon and similar phenomena in the northwestern Negev seems conceivable. Indications for the succeeding 50–60-m En Besor Ingression, of Milazzian age, are quite rare in the Sharon and are most probably covered by colluvial soils at the foothills, which presently occur more or less at the elevation at which this ingression is expected to have left beachrocks and similar phenomena. As during the former ingressions, the Milazzian sea apparently covered the entire Sharon coastal plain.

Fossil dune ridges (Figure 5.20) indicating the succeeding three ingressions, of Tyrrhenian, Monastirian, and Late and Epi-Monastirian age, are very well preserved along the Sharon coastal plain. The Erez, Yad Mordekhay, and Ziqim ridges continue as such also through the Sharon, northward to the Carmel foothills. Beachrocks (Figure 5.21) deposited at elevations of 2–4 m above the present-day sea level are defined by Avnimelech (1962) as being deposited by the Flandrian Transgression, of early Holocene age. These appear along almost the entire coastal plain of Israel. Many beachrock horizons were penetrated by boreholes drilled in the Sharon (Ecker 1962; Issar 1968), but the same problems encountered in dating them at the northwestern Negev subsurface also persist here, and, being diachronous, they cannot be used as stratigraphic indicators.

CARMEL

Many authors have noted the existence of elevated beachrocks and marine terraces on the Carmel (for example, Karcz 1958; Kashai 1966; and Picard 1943), but only

FIGURE 5.20. *Kurkar ridges in the Sharon and Carmel coastal plain.*

FIGURE 5.21. *Versilian beachrock, 3–4 m above m.s.l., in the Sharon, overlying the Netanya Hamra and overlain by the Hadera Dune Bed.*

FIGURE 5.22. *Abrasion plates, developed on Cenomanian rocks near Haifa. The 110-m (Stella Maris) plate is in the upper righthand corner, where the lighthouse was built. The 80-m plate (Prosper's Tomb) is under the circular building, approximately at the middle of the slope. The 60-m plate is further down.*

FIGURE 5.23. *Undercut seawave notch at an elevation of 110 m, near Stella Maris, south of Haifa.*

Slatkine and Rohrlich (1964a, 1965, 1966) and Michelson (1970) have studied the entire sequence in detail. The Pliocene surface was developed on the Carmel (Horowitz 1974) at an elevation of approximately 200 m. Michelson (1970) reports two occurrences of terraces within the elevations of 100–125 m, comprising conglomerates and coastal pebbles accompanied by some calcareous sandstones, one about 700 m south of Ma'ayan Zevi at Israeli Grid coordinates 14430–21874 (Figure 5.22) and another at coordinates 14716–24824, close to the Stella Maris lighthouse at Haifa. The latter comprises only a flat morphologic terrace, whereas, within the former, quite rich coastal fauna was discovered, including many foraminifera, echinid plates and spines, bryozoa and rhodophycean algae, gastropods, and pelecypods. The fauna is not stratigraphically informative but seems to indicate coastal conditions. Terraces at elevations of around 80 m are much more abundant in the Carmel, and several outcrops of beachrocks containing rich fossil remains are described in Michelson (1970). The Stella Maris cave (Figure 5.23) is most probably an undercut notch of the 80-m sea level. The sediments comprise mainly calcareous sandstones, with up to 35% quartz grains. The cement is quite rich in mollusks and microfauna and sometimes grades to a lumachel. Karcz (1958) also described similar sediments at elevations of 85–90 m in Haifa. Many niches, undercut notches, and boring phenomena occur in the southern Carmel, accompanied by some badly preserved abrasive surfaces at elevations ranging mostly between 76 and 82 m. Nickpoints at Nahal Oren, Nahal Sheikh, and Nahal Galim at elevations of 80 m and in Nahal Lotem at an elevation of 90 m are also most probably connected with the same ingression.

Terraces at elevations of 55–60 m are also quite common in the Carmel. The most conspicuous is an outcrop at the northern slope of Nahal Sefunim (Figure 5.24) at Israeli Grid coordinates 14766–23826, at an elevation of 55–60 m, comprising a microconglomerate that grades to coarse, cemented calcareous sandstone and grits, which overlie Cenomanian rocks. The outcrop is about 5 m thick and about 30 m long. It contains some rolled and calcified faunal remains, mainly pelecypods, gastropods, ostracods, echinid spines, miliolids, and algae. Several flat platforms, like the one near Sha'ar Ha'aliya, just south of Haifa, occur at similar elevations and were most probably formed by the sea when it reached this elevation. These were described by Karcz (1958), Nir (1962), Slatkine and Rohrlich (1966), and Michelson (1970). The cave of Kebara (Figure 5.25), according to Nir and Bar-Yosef (1976), is considered to be an undercut notch developed into a cave, along the 55–60-m coastline. Slatkine and Rohrlich (1966) correlate these terraces, at elevations of 55–60 m, with the Milazzian terraces of Syria and Lebanon.

Terraces at elevations of 35–45 m (Figure 5.26), built mostly of calcareous sandstones, are quite common along the Carmel. These are also connected with a morphologic abrasive terrace developed on Cenomanian rocks, on which beachrocks were not encountered. Michelson (1970) presumes that, if beachrocks were deposited on the terraces, they were either removed by subsequent ero-

FIGURE 5.24. *Beachrocks at elevation of 60 m, at Nahal Sefunim, Mount Carmel.*

FIGURE 5.25. *The Kebara Cave, Mount Carmel.*

FIGURE 5.26. *Beachrocks at an elevation of 35–40 m, near Fureidis, Mount Carmel.*

FIGURE 5.27. *The caves at the outlet of Wadi el-Mughara (Nahal Me'arot), Mount Carmel: right, Tabun; middle, el-Wad; left, Skhul.*

FIGURE 5.28. *Hard cemented coastal conglomerate at the outlet of Nahal Oren, Mount Carmel, at an elevation of 35 m. The overlying colluvium contains Acheulian artifacts in the lower part and Mousterian in the upper.*

sion or perhaps covered by terrace breccia and calcareous crusts and soils. The calcareous sandstones at these elevations are quite rich in quartz, 30–50%, and contain some chert fragments and quite rich fauna. The most important element of the microfauna is the foraminifer *Marginopora,* which is very common in beachrocks deposited at the 35–45-m elevation. Many other species of foraminifera are also common, but this is the first occurrence of *Marginopora* on the Carmel, and its absence is quite notable in the higher terraces. The caves of Tabun and El-Wad (Figure 5.27), and apparently also the Sefunim Cave, are most probably undercut notches connected with the 35–45-m sea level. A fluviatile conglomerate, cropping out at the outlet of Nahal Oren (Figure 5.28) at an elevation of 33–34 m, very massive and well-cemented by calcareous cement, is also, according to Michelson (1970), connected with the 35–45-m ingression. The cement contains about 5% quartz grains, but also quite a lot of mollusk remains and shell fragments, especially *Glycymeris, Monodonta,* and *Donax.* A lumachel connected with this system at an elevation of 40–45 m is exposed near Kefar Zevi, containing mostly *Glycymeris,* with some microfauna. Quartz grains comprise 20–25% of the rock, and red clays, most probably derived from the Carmel terra rossa, give it a reddish color.

Terraces at elevations of 10–15 m are quite rare in the Carmel, since contact between the hills and the coastal plain is mostly at about 30–40-m elevation. But in one place, near Tel Mevorakh (Figure 5.29), at the entrance to Bet Hanania at coordinates 14345–21550, an abrasive platform comprising calcarenite, at an elevation of 10–12 m, crops out. The platform covers an area of 3–4 dunams and contains abundant solution potholes and other abrasion and dissolution phenomena similar to those occurring on the present-day abrasion platform. Relics of a coastal terrace are also reported by Slatkine and Rohrlich (1966) from near the Italian Hospital in Haifa, at an elevation of 12–14 m. The 10–15 m ingression left evidence in the Carmel coastal plain of a fossil dune ridge designated in Michelson as the T-2 Ridge (Figure 5.30), of attributed Monastirian age. This ridge is quite well developed and almost continuous along the entire Carmel coastal plain.

FIGURE 5.29. *Abrasive platform at 10–12 m, near Bet Hanania, southwest of the Carmel.*

FIGURE 5.30. *The "T-2" Kurkar Ridge in the Carmel coastal plain, comprising the Ramat Gan Kurkar at the base, the Nahsholim Hamra, in which Mousterian artifacts occur, and the lower part of the Dor Kurkar Bed.*

FIGURE 5.31. *The "T-3" Kurkar Ridge in the Carmel coastal plain.*

FIGURE 5.32. *The Atlithian (Versilian) beachrock near Atlith, about 2 m above sea level, covered by paludine clays of the Ta'arukha Hamra, of Atlantic age.*

Beachrocks at elevations of 5–6 m were encountered in a number of boreholes near Haifa and most probably correspond to a fossil dune ridge called T-3 by Michelson (Figure 5.31). Beachrocks at elevations of 2–3 m (Figure 5.32) above the present-day sea level are encountered almost along the entire length of the Carmel shore. They are covered in places by black paludine clays containing Neolithic remains (Prausnitz and Wreschner 1972), which, to the west, are covered by the sea (Figure 5.33). Michelson also shows that the sea level has risen about 2–3 m since Roman times, as can be seen from Roman quarries now covered by seawater (Figure 5.34).

HAIFA BAY

The Quaternary sediments of Haifa Bay have been studied in detail in Slatkine and Rohrlich (1964). The area is totally covered by Recent dunes and soils, with no indications of former sea levels on the surface; therefore, the entire study is based on boreholes (Figure 5.10). Calabrian and Sicilian sediments were not penetrated by these boreholes, and the Glacial Pleistocene sequence directly overlies the Pliocene Kurdane Formation. The MG Ingression, most probably correlative with the Milazzian, was encountered at depths of about 60–80 m. Sediments of this ingression do not contain *Marginopora* but are successively covered by three ingressions, designated G-1, G-2, and G-3, separated by continental sandstones and paludine deposits. G-1 and G-2 are quite rich in *Marginopora* and most probably correlate with the Tyrrhenian and Monastirian ingressions (Horowitz 1974, 1975). The Tyrrhenian is found at depths of about 50–60 m, the Monastirian at depths of 15–30 m. The Late and Epi-Monastirian ingressive sediments were encountered at depths of 6–12 m. Shorelines for these ingressions were delineated, based on a considerable number of analyzed boreholes, and indicate a rapidly subsiding basin (Figure 5.42).

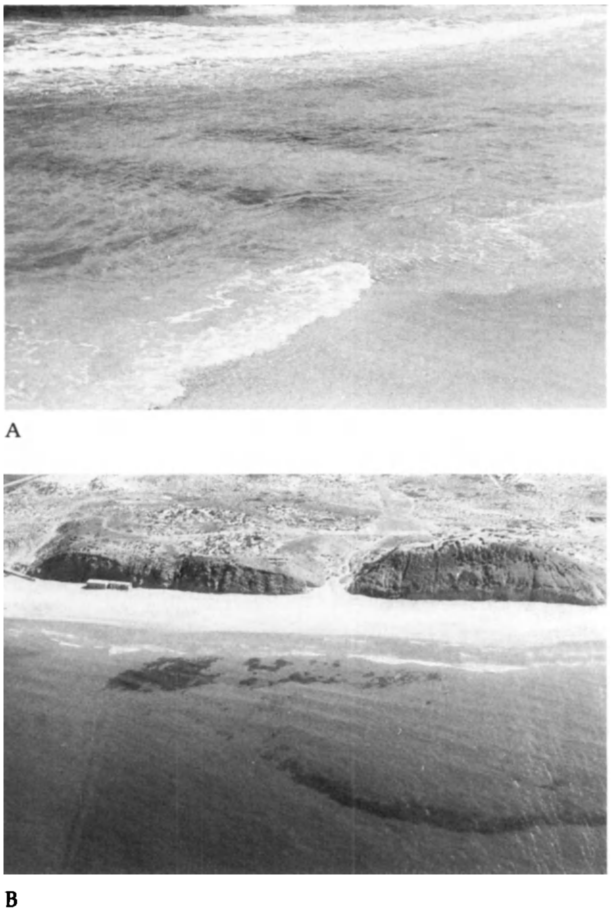


FIGURE 5.33. *A, Paludine clays, bearing Neolithic and Chalcolithic potsherds, of the Ta'arukha Hamra Bed, presently covered by the sea near Atlith (the dark patches between the waves); B, Atlantic Stage beachrocks, presently under 3-4 m of seawater, near Herzliyya, north of Tel-Aviv. (Photograph by Z. Herzog, Institute of Archaeology, Tel-Aviv University.)*

FIGURE 5.34. *Roman quarries, covered by seawater.*

WESTERN GALILEE COASTAL PLAIN

The distribution of Quaternary sediments in the Western Galilee coastal plain is rather limited in area. They do not extend more than 6 or 7 km inland from the present-day coastline, and their total thickness is approximately 40 m. The calcareous sandstones (Figure 5.35) at the base of the profile (Kafri 1972; Ronen and Amiel 1974) most probably denote the easternmost extension of the Milazzian, about 7 km from the present shoreline. In the absence of any indicative fauna, this is not very well-established. The Calabro-Sicilian is probably altogether missing in this area. These sediments are overlain, however, by continental loams containing Middle Acheulian artifacts, which are overlain, or perhaps interfinger to the west (Figure 5.36), with coastal sediments, mainly calcareous sandstones containing *Marginopora* and *Strombus bubonius*,

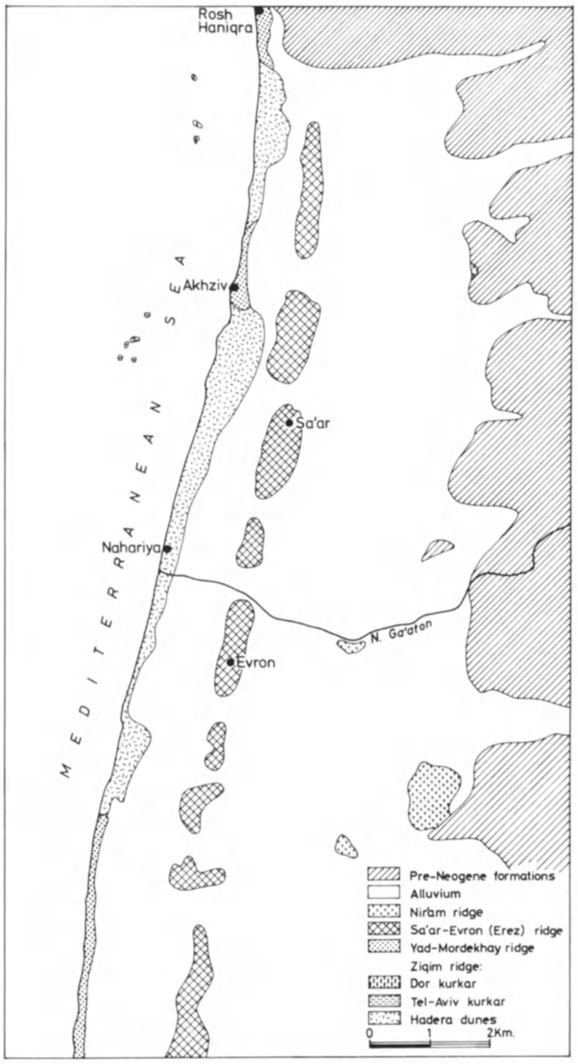


FIGURE 5.35. *Kurkar ridges in the Western Galilee coastal plain. (From Kafri 1972.)*

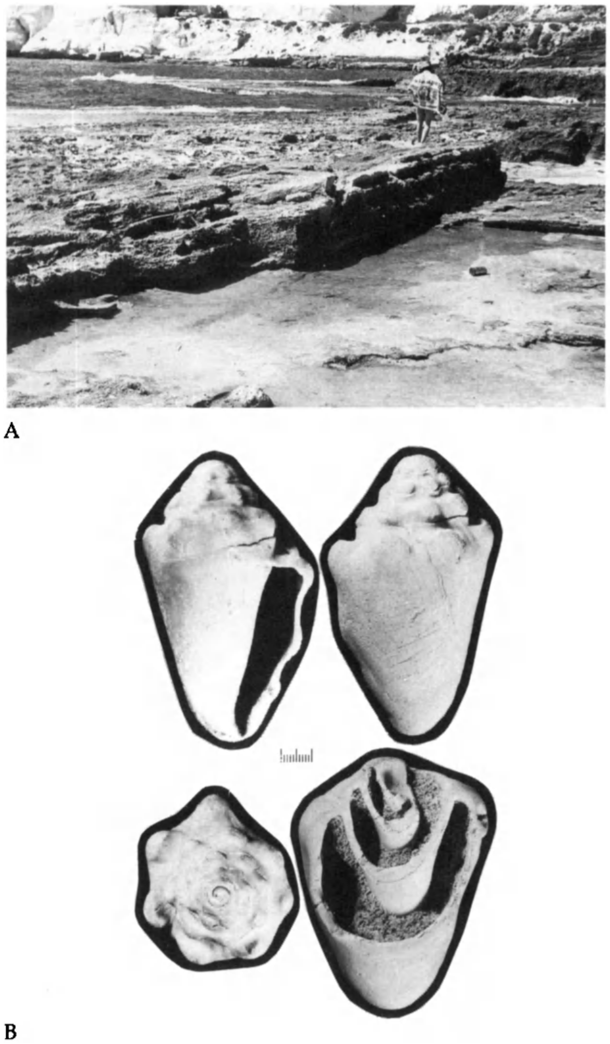


FIGURE 5.36. *A, Tyrrhenian beachrocks at Rosh HaNiqra, about at the present-day sea level; B,* Strombus bubonius *(scale 10 mm) from the Tyrrhenian beachrocks, some 15 km south of Rosh HaNigra, presently at sea level. (Courtesy of S. Moshkovitz, Geological Survey of Israel.)*

of Tyrrhenian age. The latter crop out about 2–3 m above the present-day sea level at the Rosh HaNiqra–Akhziv coast (Issar and Kafri 1972), probably delineating the eastward extension of the Tyrrhenian Ingression in this area. The landward side of this ingression is marked by the Sa'ar-Evron sandstone ridge (Figure 5.37), about a kilometer and a half east of the present-day coastline. Another ridge crops out on the coast of Akhziv and Rosh HaNiqra, probably of Monastirian age (Figure 5.37). Two other sandstone ridges are discernable in this area, both submerged under the sea (Figure 5.38). One protrudes as a group of three islets off the Rosh HaNiqra coast, about 1 km seaward, and the other protrudes as a group of small islets about 2.5–3 km off the Akhziv coast. No other data are available as to the dating of these ridges, but they seem to correspond to the Late and Epi-Monastirian.

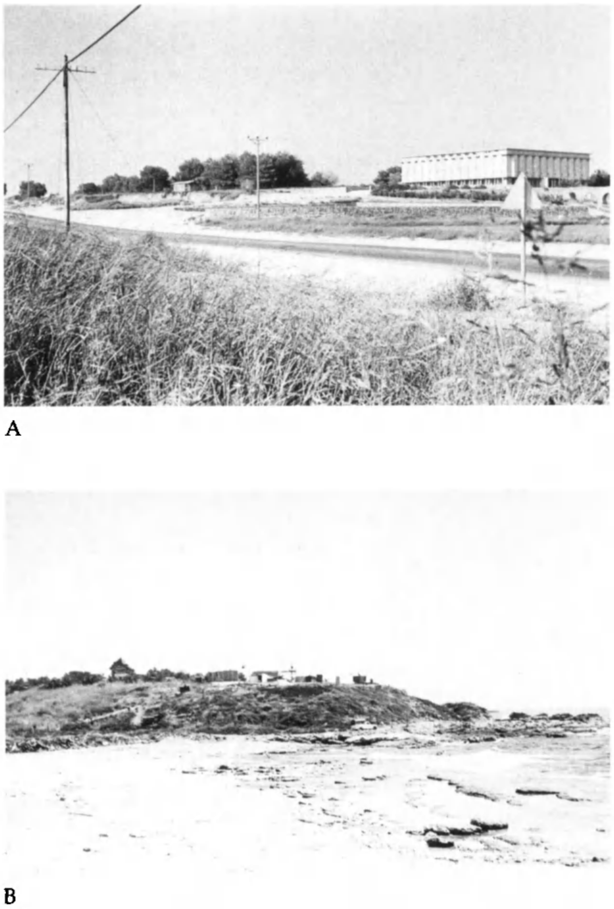


FIGURE 5.37. *Kurkar ridges in the Western Galilee coastal plain: A, the Sa'ar-Evron Ridge; B, the Akhziv Ridge.*

OFFSHORE

Detailed geophysical study of the offshore area (Almagor 1976; Neev *et al.* 1976) has shown that fossil dune ridges are preserved within the marine Quaternary sediments down to a depth of about 130–150 m (Figure 5.39). These are indicated on the geophysical profiles as highly reflective horizons, mainly due to the calcareous cement of the quartz-sandstone comprising these ridges. Six such ridges are discerned on maps provided in Neev *et al.* (1976) and in Almagor (1976). The shallowest occurs between 20 and 30 m below the present-day sea level, the second between 40 and 50 m, the third between 50 and 60 m, the fourth between 70 and 80 m, the fifth between 90 and 100 m, and the sixth between 120 and 150 m. Since the depths were defined only by geophysical survey, they cannot be regarded as exact in terms of altimetry; however, the occurrence of an entire sequence of regressive eustatic phases documented by fossil dune ridges is quite well-established.

FIGURE 5.38. *Calcareous sandstone (kurkar) islets off Akhziv, Western Galilee coastal plain.*

It is quite interesting to compare the state of preservation of the submarine ridges with those on the coastal plain. The submarine ridges are better preserved when going westward, toward the sea. The deeper the ridge is, the better it is preserved. On the coastal plain, too, the easternmost ridges are hardly preserved at all, whereas the westernmost ones are better preserved. This might imply something about the relative ages of the ridges. The easternmost are the more ancient ones and the westernmost are the youngest, which indicates that the eustatic oscillations had more or less the same amplitude and are, in fact, superimposed on a global regression, which has taken place since the maximum of the Calabrian Transgression. This agrees well with the basis for defining the Quarternary period (see Chapter 1) as a complete transgressive cycle, proceeding from maximum regession in late Pliocene times, through a transgression during the Calabrian, when the sea reached an elevation more than 120 m higher than the average present-day sea level, and regression since then, with superimposed eustatic oscillations.

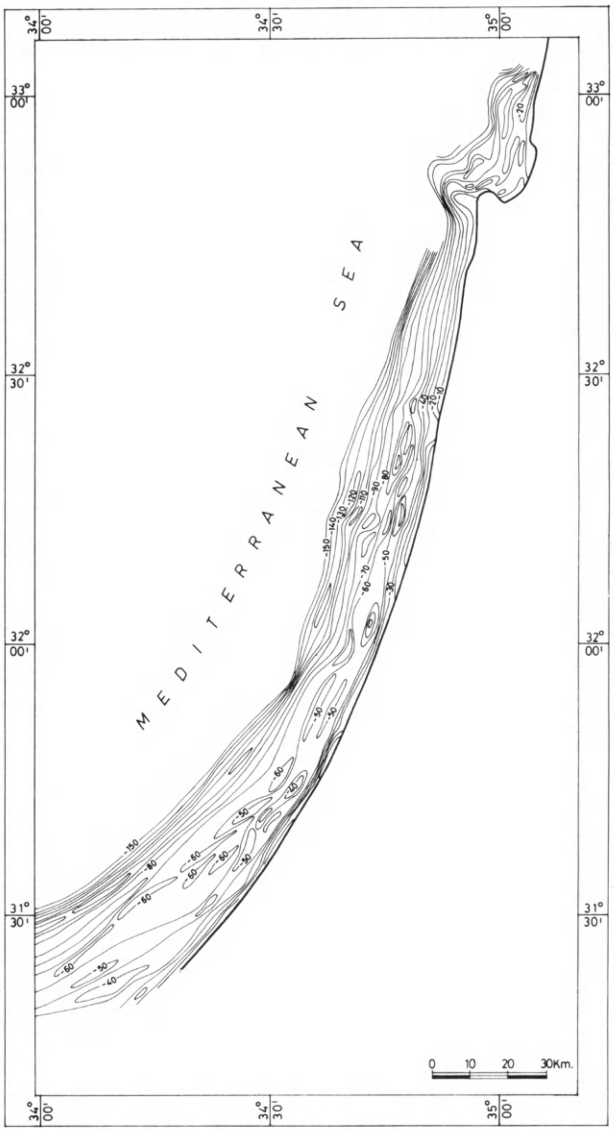


FIGURE 5.39. *Extension of submerged Kurkar ridges on the Israeli continental shelf. (From Neev* et al. *1976.)*

SHORELINES

Based on the occurrences of beachrocks and fossil dune ridges, several authors tried to compile the Quaternary shorelines for the various ingressions that have affected the coastal plain of Israel. Itzhaki (1961), Issar and Picard (1970), and Nir and Bar-Yosef (1976) dealt only with the transgressive shorelines on the coastal plain (Figure 5.40), whereas Avnimelech (1962) dealt also with some of the shorelines of the regressive phases (Figure 5.41). All these authors seem to agree as to the areas occupied by the eustatic ingressions and as to their sequence. The northwestern Negev and the southern coastal plain were most influenced by the ingressions. The Calabrian Ingression penetrated more than 20 km landward, whereas the succeeding ingressions penetrated less and less. The areas penetrated by the eustatic ingressions taper to the north until coming to the Carmel, in which the areal coverage by the ingressive seas is severely limited by the proximity of the mountain. Haifa Bay is once more occupied quite widely by ingressive seas, but, due to its tectonic subsidence, each of the ingressive phases deposited superimposed sediments on the preceding ones, at more or less the same areal extension (Figure 5.42). The Western Galilee coastal plain was hardly influenced at all by the ingressions.

The debate between various authors is, however, not so much concerning the extent of the various ingressions, on which everyone seems to agree, but as to the shape of the ensuing coastline. Avnimelech (1962) and Horowitz (1974) delineate straight coastlines more or less parallel in

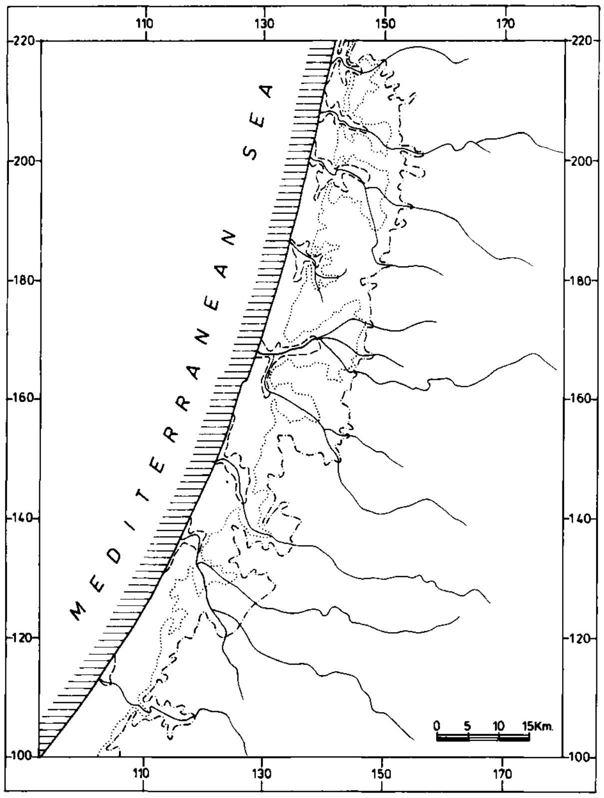


FIGURE 5.40. *Quaternary Mediterranean shorelines of Israel, according to Nir and Bar-Yosef (1976).*

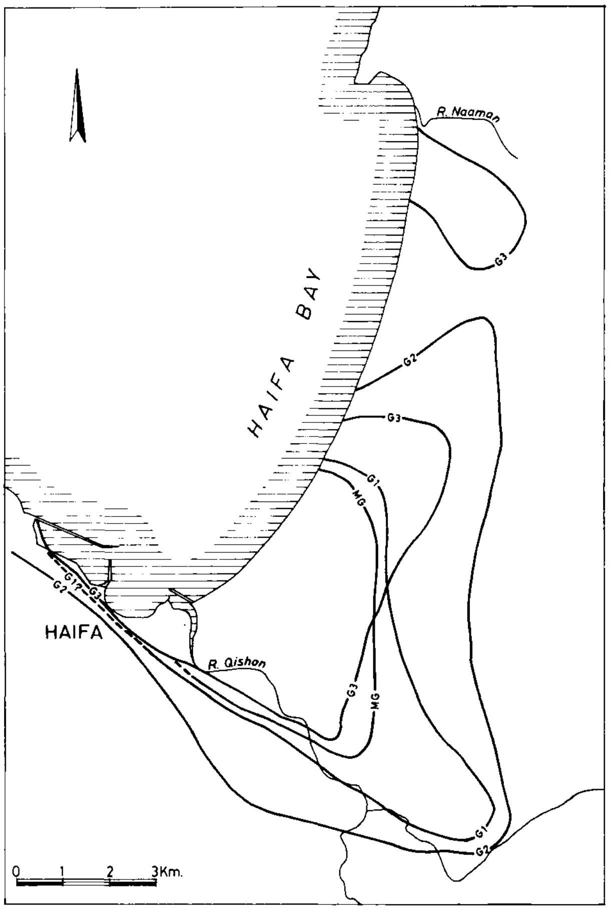


FIGURE 5.42. *Glacial Pleistocene shorelines of the Zevulun Valley. MG, Milazzian; G1, Tyrrhenian; G2, Monastirian; G3, Late and Epi-Monastirian. (From Slatkine and Rohrlich 1964.)*

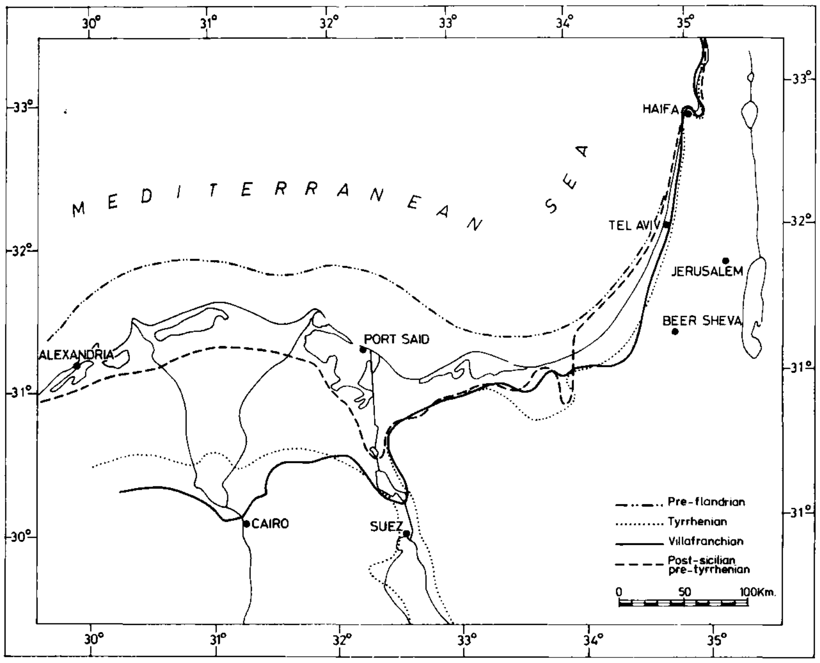


FIGURE 5.41. *Quaternary shorelines of the southeastern Mediterranean, according to Avnimelech (1962).*

nature and form to the present-day coastline. This is also agreed, more or less, by Issar and Picard (1970). On the other hand, Itzhaki (1961) and Nir and Bar-Yosef (1976) claim that the transgressive seas occupied more or less a topography parallel to that of the present-day, namely, that the sea penetrated the stream valleys, creating a great number of small bays, as well as some large bays and estuaries. It seems, however, that the evidence is against this latter picture. This conclusion follows largely from the continuity and straightness of the fossil dune ridges exposed all along the coastal plain (Almagor 1976; Emery and Bentor 1960; Horowitz 1975).

Taking also into consideration the data presented in Neev *et al.* (1976) and especially that presented in Almagor (1976) as to the submerged dune ridges, the ensuing picture can be drawn. The Calabrian Ingression reached landward to areas attaining up to 100–125 m in elevation. It regressed down to about 20–30 m below the present-day sea level. The Sicilian Ingression attained elevations on the order of 80 m above sea level, regressing to 40–50 m below sea level. The Milazzian Ingression reached up to about 60 m above sea level, regressing to 55–60 m below sea level. The Tyrrhenian, reaching 35–40 m above sea level, regressed to 70–80 below sea level. The Monastirian, which reached about 18–20 m above the present-day sea level, regressed to a depth of 90–100 m below sea level. The Late-Monastirian reached up to 12–15 m above sea level and regressed down to 120–130 m below sea level. Finally, the Epi-Monastirian reached an elevation of about 6 m above the present-day sea level and regressed down to 130–150 m. The following Versilian (or Flandrian) Ingression deposited sediments about 2–3 m above the present-day sea level and later regressed several meters. The present-day ingression covers the post-Versilian paludine sediments with beachrocks. This pattern of elevations is persistent along the coastal plain from the northern tip of the Carmel to the south, whereas north of the Carmel influences of the subsiding Haifa Bay and western Galilee Coastal Plain prevail. In the Haifa Bay area, the succeeding ingressions have penetrated several kilometers landward, all of them more or less to the same limit, whereas in the Western Galilee almost no influence of the ingressive phases can be felt. It seems that the subsidence of the regions north of the Carmel began only in Glacial Pleistocene times, concluded from the lack of Calabro-Sicilian sediments threre, the Malazzian directly overlying the Pliocene.

FIGURE 5.43. *The "Fjord" submerged wadi, south of Elat. (Photograph by D. Darom, courtesy of I. Paperna, H. Steinitz Marine Biology Station, Elat.)*

BAY OF ELAT

Almost no Quaternary sediments, such as beachrocks and others associated with ingressive phases of the sea, are known from the Bay of Elat area, which indicates that the shoulders of the Bay of Elat have been in a process of continuous subsidence during the Quaternary. Quaternary coastal terraces are known from the Red Sea and from Tiran Island, at the junction of the Bay of Elat and the Red Sea (Goldberg 1963). The latter are most probably of late Quaternary age and crop out due to the tectonic uplifting of the block that forms Tiran Island. Evidence for present-day rising of the sea level can be seen around the Bay of Elat as the sea ingresses into former wadi valleys (Figure 5.43) and by underwater canyons and gullies easily discernible in the geophysical reflection profile (Figure 5.44; Z. Ben-Avraham, Weizmann Institute for Science, Rehovot, personal communication, 1977). No further data are available for the Bay of Elat, and it seems that its subsidence is masking any evidence of former sea-level changes.

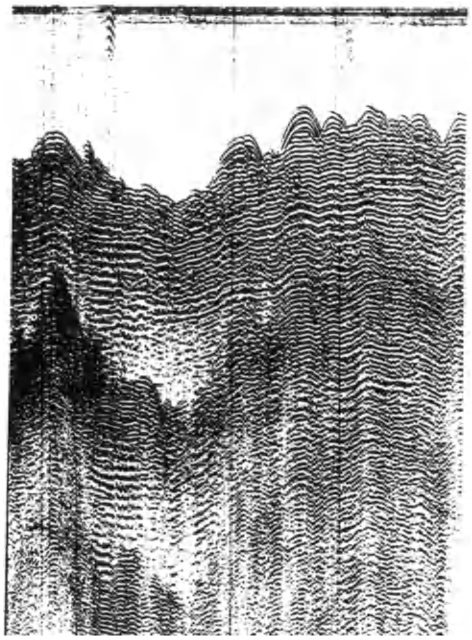


FIGURE 5.44. *Seismic profile along the Bay of Elat. The profile was taken not far from the coast, at a water depth of several hundred meters. Note the rugged, buried topography of submerged wadis. Length about 20 km, penetration 4 sec. (Courtesy of Z. Ben Avraham, Weizmann Institute of Science.)*

COASTAL PLAIN TERRESTRIAL SEDIMENTS

MEDITERRANEAN COASTAL PLAIN

Sediments of the Mediterranean coastal plain of Israel comprise a variety of facies influenced by four principle factors: the sea to the west, bringing and depositing sand dunes with some carbonate debris; the mountainous areas to the east, supplying alluvium through the drainage system leading to the Mediterranean; winds, which supply dust of clay and silt-size particles, coming mainly from the south and the southwest; and pedogenic processes, which take place *in situ* and modify these various deposits. The present section deals with sediments, whereas the preceding one dealt with morphological phenomena influenced by sea levels. It should be noted, therefore, that a fossil sandstone ridge comprises a morphologic phenomenon and is developed on the previously laid sediments with the aid of a landward-pushed dune. These ridges were described and named in the previous chapter; the present chapter describes and deals with the rock units that comprise the various cycles on the coastal plain. Different names were, therefore, used to denote the morphologic units, and the corresponding rocks deposited during the phase that created these morphologic phenomena. High sea-levels of the Quaternary resulted in a greater supply of sand coming from the sea and primarily deposited as dunes, whereas low sea-levels during pluvial climates have resulted in pedogenic and erosional processes that changed the lithological nature of the previously deposited aeolian sand dunes. High groundwater tables and locally restricted drainages, mainly due to blocking by sand dune ridges, have resulted in the formation of marshes in which organic sediments have been laid down.

The Quaternary terrestrial sediments of the coastal plain of Israel were defined by Horowitz (1974, 1975) as the Gaza Formation (Figure 5.58). The name is derived from a series of boreholes drilled in the Gaza coastal plain in the early 1940s that penetrated a sequence of calcareous sandstones and paleosols mentioned by Picard (1943). The calcareous sandstones, which mostly comprise the fossil dune ridges along the Israeli coastal plain, are known by the Arabic local name "kurkar," and the red paleosols are known by the local name "hamra." The paleosols occasionally grade into marsh deposits. Issar (1961, 1968) named these sediments according to their lithology. All the calcareous sandstone horizons have been defined as the Pleshet Formation, of either continental or marine facies, which also included beachrocks. All the paleosols have been grouped together under the term Rehovot Formation, which also included the paludine deposits. The sandstone and paleosols grade eastward in the direction of the mountains to several conglomerate horizons. Issar (1961, 1968) has named all these conglomerates, regardless of their stratigraphical position, the Ahuzam Conglomerate. Itzhaki (1955, 1961) has further divided the sequence into several paleosol horizons for which he gave Roman numbers, Hamra I, Hamra II, and Hamra III, and the calcareous sandstone horizons, for which he adopted names corresponding to the marine ingression that, apparently, caused their deposition.

Gvirtzman (1970) has amended the term Pleshet Formation to define only the Pliocene calcareous sandstones, as originally suggested by Hull (1886). Horowitz (1974) has shown that the Ahuzam Conglomerate follows the regressive phase of the Pliocene and, therefore, has a definite stratigraphic context; and, based also on Gvirtzman's emendation for the Pleshet Formation, has suggested that the terms "Pleshet" and "Ahuzam" for the Quaternary deposits no longer be used. The formational names listed in Issar were discontinued by Horowitz (1974) because a much greater refinement of the sequence had become available. Calcareous sandstones deposited in the littoral environment are grouped by Horowitz in the Ga'ash and Yarkon Formations, and only the terrestrial sediments are grouped in the Gaza Formation. The Gaza Formation is further subdivided into various members and beds to denote the different stratigraphic position of each of its constituents. Because of the mutual relationship between sandstones and paleosols, they are not regarded by Horowitz (1974) as two distinct formations but, rather, as a single formation subdivided into members of different lithology and paleoenvironmental significance.

The Gaza Formation, being of terrestrial origin and influenced mainly by sea levels and pedogenic processes, does not crop out at any one locality as an entire sequence, but, rather, comprises a composite section that could be followed at best in the northwestern Negev, going from the east seaward. This cross section is presented in Itzhaki (1961) in great detail and serves as the basis for Horowitz' (1974) subdivision. Some refinement is based, for the upper part, on studies by Avnimelech at the coastal cliff near Netanya (1950, 1952) and, for the lower part, on observations of H. Bar-Ziv and D. Gazit. The various members of the Gaza Formation were named after localities where they are best exposed.

The sequence of the Gaza Formation in the northwestern Negev coastal plain begins with the Haruvit Kurkar Member (Figure 5.45), associated with some gravel horizons named by Horowitz (1974) "Lateral Conglomerates of the Ga'ash Formation." Only a few outcrops can presently be seen, overlying the Ahuzam Conglomerate and associated with the Hirbet Harev Ridge. The sequence comprises several meters of cross-bedded calcareous sandstones, overlain by the Ze'elim Hamra Member in the Nahal Besor outcrops. In other localities, the Haruvit is overlain by younger sediments, always over an erosional relief. The Haruvit Kurkar Member is

FIGURE 5.45. *The Haruvit Kurkar Member, at an elevation of 200 m in the Western Negev.*

FIGURE 5.46. *The Gerar Kurkar Member in Nahal Gerar, Western Negev, where it overlies the Ze'elim Hamra (the slope below the cliff).*

FIGURE 5.47. *The Hasi Member in Nahal Shiqma, where the fluviatile facies is developed. A chopping tool and several bones were found in this outcrop.*

FIGURE 5.48. *The Tell Fara Kurkar Member, overlying hamra paleosols of the Hasi Member, which overlie the Gerar Kurkar at the bottom. Tell Fara (T. Sharuhen), Nahal Besor.*

the terrestrial correlative of the Calabrian beachrocks and the fluviatile HaMeshar and Bethlehem conglomerates. The Ze'elim Hamra Member (Figure 5.12) comprises (at the type locality near Bir Sheneq, in Nahal Besor) about two meters of red, clayey, sandy soil rich in calcareous concretions. It overlies the Calabrian beachrocks at this locality, over a thin conglomerate horizon with which it is intermingled at the base. The Ze'elim Hamra is overlain at the Nahal Gerar outcrop by the Gerar Kurkar Member (Figure 5.46), which corresponds to the Sicilian beachrocks. The Ze'elim Hamra was formed in the northwestern Negev following the regression of the Calabrian sea, under a pluvial climate.

The Gerar Kurkar Member (Figure 5.46) comprises, at the type locality in Nahal Gerar, some 10 m of cross-bedded calcareous sandstone of aeolian origin. It overlies the Ze'elim Hamra and the Haruvit Kurkar and underlies the Hasi Member fluviatile sediments and paleosols. This seems to be the terrestrial correlative of the Sicilian beachrocks, associated with the Yakhini Ridge. The Hasi Member, previously known as the Hasi Conglomerate due to its fluviatile nature, is found at the type locality near Tel Hasi (Figure 5.47). It overlies, in a series of outcrops along Nahal Besor, the Sicilian beachrocks and the Gerar Kurkar Member. Two facies are known for the Hasi: a fluviatile, comprising some 10–15 m of conglomerates, sandstones, and clays, in which a single chopping tool was found together with some bones, one of which probably belonged to a giraffe (M. Lamdan, Haifa Museum, personal communication, 1976); and the other a paleosol (Figure 5.48), comprising red, clayey, sandy soil with some calcareous concretions. The Hasi Member was formed under a pluvial climate, during the post-Sicilian regression, most probably corresponding to the Günz. The Tel Fara Kurkar Member (Figure 5.48) overlies the Hasi Member with a rather sharp contact, typically transgressive. At the type locality in Tel Fara on the bank of Nahal Besor, it comprises about 10 m of cross-bedded, aeolian calcareous sandstones, associated withe the Nir'am Ridge. The deposition of the Tel Fara Member was initiated by the En Besor Ingression of Milazzian age, and interfingering of the latter's coastal sediments and the Kurkar could be seen near En Besor. Tel Fara is overlain by the Dorot Hamra.

The Dorot Hamra Member, called by Itzhaki (1961) Hamra I, is about 2–3 m thick when it is best developed (Figure 5.49) and comprises red paleosols, locally grading into paludine deposits. This member is exposed at the northwestern Negev around the area of Dorot and Kefar Menahem, where it yielded artifacts of Early to Middle Acheulian affinity (Gilead and Israel 1975). The same hamra was certainly encountered in two other localities, a borehole near Gedera in which bones of *Leptobos* were found (A. Issar, Geological Survey of Israel, Jerusalem, personal communication, 1972) and at the quarry of Evron, in the Western Galilee coastal plain (Figure 5.50), where Middle Acheulian artifacts (Ronen and Amiel 1974) and bones of *Metridiochoerus evronensis* (Haas 1970; Issar and Kafri 1969, 1972) were encountered. The Dorot Hamra Member is overlain by the Gedera Kurkar Member (Figure 5.49), comprising mostly well-cemented calcareous sandstones. The Gedera Kurkar Member, attaining up to 20–30 m in thickness, is overlain by the Holon Hamra Member (Figure 5.51), which comprises up to 5–6 m thick red paleosols, grading locally into paludine deposits (Figure 5.52). The Holon Hamra Member crops out at the northwestern Negev, where it yielded a great number of Late Acheulian handaxes and other artifacts, together with some bone fragments (Ronen *et al.* 1972). In an excavation in this hamra member near Holon (Noy 1967), an assemblage of Late Acheulian artifacts was encountered, together with bones of *Hippopotamus, Equus, Dama, Bos,* and elephants. One of the more impressive finds at this site was an elephant tusk 1.78 m long. The same hamra crops out again at the Evron quarry, in a fluviatile–paludine facies containing Late Acheulian artifacts (Ronen and Amiel 1974) together with bones of *Hippopotamus* and *Elephas trogontherii* (Issar and Kafri 1972).

The Holon Hamra Member is overlain by the Ramat, Gan Kurkar Member, which bears more or less the same characteristics as all other kurkar members, namely, slightly cemented calcareous sandstones with a distinct cross-bedding of aeolian origin. The Ramat Gan Kurkar Member is overlain (Figure 5.23) by the Shefa'yim Member, comprising several beds. The lowermost is a hamra about 1–2 m thick, the Nahsholim Hamra Bed, which

FIGURE 5.49. *The Dorot Hamra, overlain by the Gedera Kurkar Member, near Dorot, Western Negev.*

FIGURE 5.50. *Fluvio-paludine facies of the Dorot Member at the Evron Quarry, Western Galilee.*

FIGURE 5.51. *The Holon Hamra Member, at Kissufim, Western Negev.*

FIGURE 5.52. *Paludine facies of the Holon Member, near Ruhama, Western Negev.*

FIGURE 5.53. *The Ramat Gan Kurkar Member, in the Sharon.*

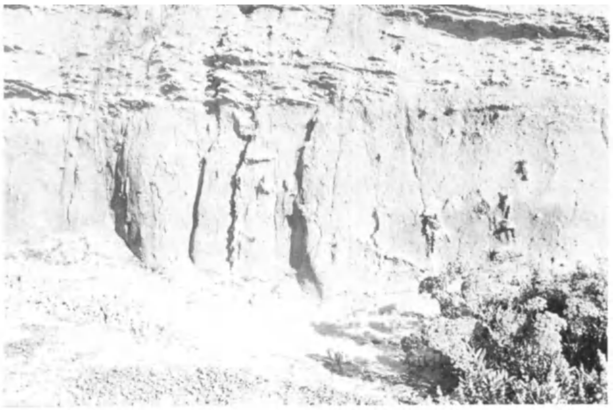


FIGURE 5.54. *The "Café au Lait," lateral equivalent of the Nahsholim Hamra Bed in the southwestern Sharon, overlain by the lower part of the Dor Kurkar Bed. Compare with the paleosol-paludine facies in Figure 5.30.*

FIGURE 5.55. *The lower part of the Shefa'yim Member. From bottom to top: lower part of the Dor Kurakar Bed; Tel Barukh Hamra; upper part of Dor; Netanya Hamra; Tel Aviv Kurkar. At the Tel Barukh beach, north of Tel-Aviv.*

FIGURE 5.56. *The upper part of the Shefa'yim Member. From bottom to top: upper part of Dor Kurkar Bed; Netanya Hamra in a paludine facies; Tel-Aviv Kurkar; Ta'arukha Hamra; Hadera Dune Bed. Near Kibbutz Shefa'yim, north of Tel-Aviv.*

yielded artifact assemblages of Mousterian affinity (Farrand and Ronen 1974; Garrod and Gardner 1935). The Nahsholim Hamra Bed grades laterally (Figure 5.54) into grey paleosols called by Avnimelech (1950) "Café au Lait." It is overlain by the Dor Kurkar Bed, which comprises cross-bedded aeolianites. A clear erosive surface divides the Dor Kurkar Bed into two parts, sometimes separated by a thin layer of red paleosol, the Tel Barukh Hamra (Figue 5.55). The Dor Kurkar Bed is overlain by the Netanya Hamra Bed (Figure 5.55), called by Itzhaki Hamra III, which builds most of the present-day coastal plain, and especially the Sharon. Many Epipaleolithic sites were encountered within this hamra horizon (Bar-Yosef 1970; Ronen *et al.* 1975), together with bones of *Dama* and other animals.

The Netanya Hamra Bed is overlain by the Tel Aviv Kurkar Bed, which is a rather thin (2–3 m thick only), calcareous sandstone, slightly cross-bedded. The Tel Aviv Bed is overlain (Figure 5.56) by the Ta'arukha Hamra Bed, in which Neolithic through Early Bronze I sites are quite abundant. The Ta'arukha Hamra Bed is 2–3 m thick, but in many localities it appears as paludine deposits, which are much more abundant than the paleosol facies. Both the facies encounter Neolithic, Chalcolithic, and EBI remains (see pages 319–321). The Ta'arukha Hamra Bed is overlain by the Hadera Dune Bed, which at the present day transgresses and covers all the preceding rock-units in the coastal plain of Israel (Figure 5.57). The Hadera Dune Bed is still active and can be seen covering historic settlements of different ages at different localities. In contrast to the other sandstone beds, the Hadera Dune Bed is not cemented, although it contains sometimes up to 10% carbonate grains. The upper part of the Gaza Formation grades in the northwestern Negev into loess, defined as the Ruhama Loess Member. This member overlies the Holon Hamra Member and continues to be deposited up to the present. It is discussed in more detail in this chapter under "Aeolian Sediments."

The Gaza Formation constitutes the entire sedimentary cover of the coastal plain of Israel. It is most widespread in

FIGURE 5.57. *The Hadera Dune Bed, near Hadera.*

the southern coastal plain and diminishes in area and thickness toward the north. In the central part of the coastal plain, the Sharon and the Carmel, where the earlier Quaternary ingressions have reached as far as the mountainous formations, the lower members of the Gaza Formation are absent, and only the upper parts appear. In the tectonically subsiding Haifa Bay coastal plain, the entire formation is buried under the Recent Hadera Dune Bed, whereas in the Western Galilee coastal plain, due to its partial subsidence, only fragments of this formation are preserved. The thickness of the Gaza Formation varies considerably from place to place. In no place does the entire formation crop out, and additions of local sequences give a total sequence of more than 200 m. This, of course, cannot be regarded as the true thickness, only as an apparent one. Boreholes that penetrated most of the sequence, such as those in the Gaza plain, encountered some 80–90 m of the Gaza Formation, and this figure should be considered as more or less representative of the true thickness (Figure 5.58).

The Gaza Formation unconformably overlies many previous rock units, mostly the Miocene and Pliocene sediments of the coastal plain, but in some places, such as the Carmel and possibly the Sharon, it also overlies Cenomanian and other limestone and dolomite formations. The upper limit of the Gaza Formation is the present-day surface of the Israeli Mediterranean coastal

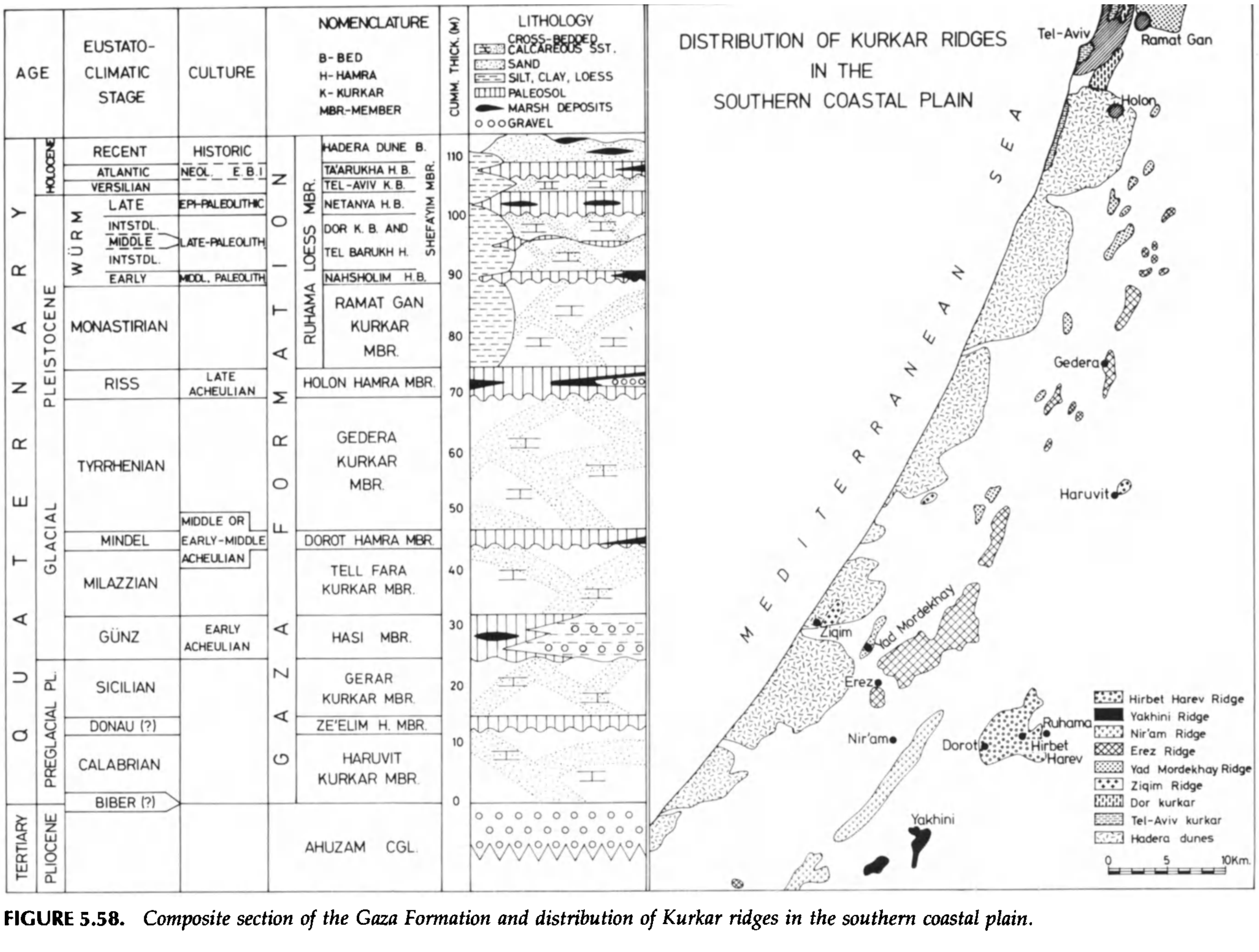


FIGURE 5.58. *Composite section of the Gaza Formation and distribution of Kurkar ridges in the southern coastal plain.*

plain. The Gaza Formation interfingers to the west with the littoral sediments of the Ga'ash and Yarkon Formations. Due to the considerable areal extension of the eustatic oscillations, these interfingerings take place over quite a wide area in comparison with the area occupied by the Gaza Formation itself, and, therefore, most of the boreholes that were drilled and analyzed in the coastal plain (for example, Ecker 1962; Issar 1961, 1968; Michelson 1970) have encountered both sediments of the Gaza Formation and sediments of the Ga'ash and Yarkon Formations, interfingering with each other. The Gaza Formation thins to the east and terminates toward the ascending slope of the coastal plain. Alluvial and colluvial deposits brought by the rivers from the mountains, mainly silts and gravel, interfinger with the sandy sediments of the Gaza Formation to the east. All these gravel horizons were called by Issar the Ahuzam Formation, a name that seems unjustified. However, since no detailed further study of those gravel horizons is available at present, no other name is proposed. In some rare localities, the Gaza Formation sediments interfinger to the east with spring deposits, such as the Ga'ton Travertine, which interfingers with the Holon Hamra Member east of Nahariyya.

Paleoenvironmental conditions that have affected the Gaza Formation sediments are a matter of dispute among various authors. Environments of deposition for the various rock units are accepted by most investigators, namely, that the calcareous sandstones represent fossil dunes pushed forward by the sea, the red hamra members represent paleosols, and the black, more clayey sediments are marsh deposits. The dispute concerns the modes of diagenesis and lithification of these sediments. Yaalon (1967) and Yaalon and Dan (1967) maintain that the lithification of the fossil dunes into the hard kurkar rocks and the pedogenic processes that result in formation of the red hamra are laterally synchronous and occur side by side under present-day conditions. Yaalon maintains that more than 10% of carbonate particles within the sand dune would result in its consolidation into kurkar, while less carbonate would turn the sand to hamra soil. Horowitz (1974) accepted that both processes are synchronous, but vertically, depending mainly on the climate. Horowitz takes into consideration the composition of the kurkar and hamra deposits; although the kurkar is considerably richer in carbonate than the sand dunes from which it originated (Gavish and Friedman 1961), most of the hamra paleosols do not contain carbonates at all. The typical hamra contains quartz sands coated by iron oxides, which give the red coloration of these soils, and a considerably amount of silts and clays. It is also agreed by all investigators that these silts and clays are of aeolian origin, as revealed in a detailed mineralogical study of the hamra in the coastal plain (Nathan 1961). The dust was, apparently, brought to the area by dust storms, as is also the situation today (Ganor 1975; Horowitz *et al.* 1975; Yaalon and Ganmor 1975).

Horowitz (1974) suggested that the decomposition and pedogenic processes of the upper part of the dunes took place only in pluvial climates, when the humidity was sufficient to maintain considerable vegetation cover on the surface. The vegetation cover and the higher humidity resulted in leaching down of the carbonate content of the upper part of the dune, which was consequently accumulated in the lower part, and in the oxidation of heavy, iron-rich minerals contained within the dune sands. It was suggested, therefore, that the dunes were deposited on the coastal plain during the higher sea-levels of the interpluvial periods and that the pedogenic processes took place during the regressive phases, under a pluvial climate. This idea emerged from the dating of the paleosols. Most of the hamra horizons contain artifacts of cultures that are known to be contained within sediments that yielded pluvial pollen spectra elsewhere in the country. Such are the Early and Middle Acheulian, the Late Acheulian, the Mousterian, and the Epipaleolithic. It is true that red, hamra-like soils could be formed under present-day conditions and are formed in some rare localities. Analysis of these localities showed that they enjoy much more humid local microclimates than the average. The wide distribution and the stratigraphic context of the hamra paleosols indicate their formation under pluvial climatic conditions. The picture is also quite clear when analyzing the outcrops. In almost no place can lateral changes of hamra to kurkar be seen, and mostly hamra layers are sandwiched between kurkar layers. Typical are also the contacts of the hamras with the underlying and overlying kurkars. The contact with the underlying kurkar is progressive and gradational, whereas the upper contact is always sharp (Figure 5.59), representing a new phase of covering of the area by sand dunes.

Fossil bones found within the hamra layers, and mainly within paludine sediments interfingering with the hamra, are of animals that needed wooded land and quite a lot of water, such as *Hippopotamus* and cervids. No

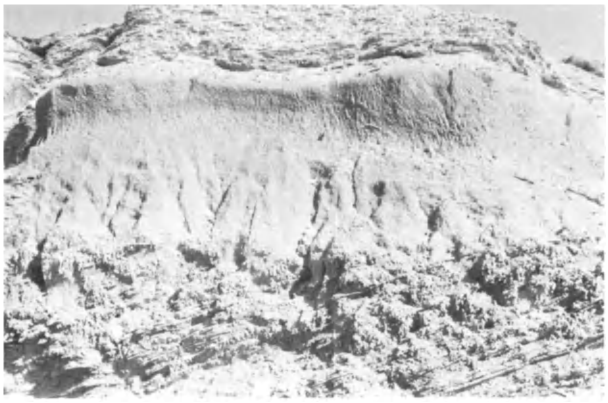


FIGURE 5.59. *The Tel Barukh Hamra paleosol, sandwiched between the lower and upper parts of the Dor Kurkar. Note that the lower contact is transitional, while the upper is sharp.*

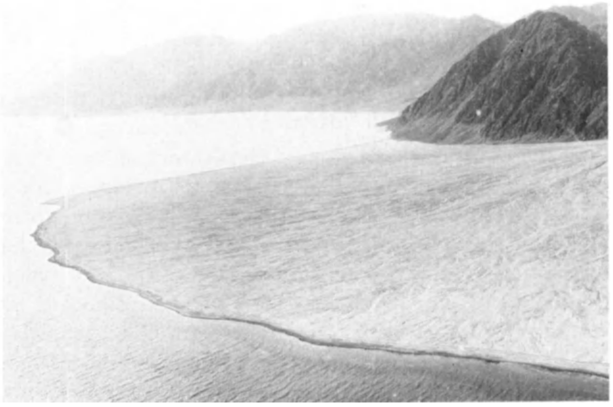


FIGURE 5.60. *Wadi outlet to the Bay of Elat, with the typical alluvial fan comprising gravel and sand. (Photograph by D. Darom, courtesy of I. Paperna, H. Steinitz Marine Biology Station, Elat.)*

pollen spectra are available for the Gaza Formation sediments, due to two reasons. Pollen are not preserved within the coarse sandstones, and since these sediments have undergone considerable oxidation processes, any pollen deposited within the sequence was probably readily destroyed. The age of the Gaza Formation is Pleistocene, since it overlies the Pliocene sediments and is still being formed at present. The relative stratigraphic ages of the various members and beds will be considered later, when discussing their probable correlations with other formations.

BAY OF ELAT

Terrestrial sediments are quite rare around the Bay of Elat due to the proximity of the mountains to the sea, which results only in the formation of some conglomerate beds (Figure 5.60) in the wadi outlets. Torrential floods, which are rare but very powerful in this area, remove almost everything, and the extremely arid climate does not favor any soil formation processes or any vegetation that would protect any sediment formed on the mountain slopes. However, just north of the Bay of Elat the area is occupied by sebkhas in which highly organic, black, fine-grained sediments accumulate. These sediments probably accumulated in the area throughout the entire Glacial Pleistocene and still accumulate today, mainly due to the continuous subsidence of the area. The subsidence results in high sea levels, causing development of salty marshes covered by dense, low vegetation, which serves as a trap for dust coming mainly with the northern winds. The prevailing direction of these winds, which is toward the Bay of Elat, prevents also any formation of coastal dunes. The coastal plain north of the Bay of Elat is flattened and covered by silty aeolian deposits (Figure 5.61).

FIGURE 5.61. *The coastal sebkha north of the Bay of Elat.*

RIVERS AND FLUVIATILE SEDIMENTS

River courses, drainage patterns, and deposition of fluviatile sediments depend mainly on the relations of the eroded areas with the corresponding base levels. The Levantine faulting phase that created the endoreic Jordan–Arava Rift Valley took place in the transition from the Preglacial to the Glacial Pleistocene. Consequently, drainage patterns and fluviatile processes changed considerably at this stage. The discussion is, therefore, separated into the Preglacial Pleistocene and the Glacial Pleistocene as two distinct phases in the fluviatile history of the Quaternary of Israel.

THE PREGLACIAL PLEISTOCENE

Preglacial Pleistocene rivers flowed to the Mediterranean and to the Bay of Elat, and their channels and gravels are known from the central and southern parts of Israel. To the north, the Cover Basalt flooded the area during this period, and no distinct drainage pattern could be developed before the Glacial Pleistocene.

HaMeshar Formation

The HaMeshar Formation was defined by Garfunkel and Horowitz (1966) as a sequence of fluviatile sediments (Figure 5.62) first identified at the ancient outlet of HaMeshar Valley, at coordinates 1408–9757. At this locality, the present Nahal Arod crosses the old stream channel obliquely and about 60–80 m of river deposits are exposed. This formation is indicated on various geological maps as "Q" or "Quaternary Alluvium," "NC" (Continental Neogene), "Quaternary–Neogene Hammada" (Bentor and Vroman 1957; Picard 1959), or "Alluvium and

FIGURE 5.62. *HaMeshar Formation conglomerates in the foreground, cut by Nahal Paran. In the background HaMeshar conglomerates overlie tilted Miocene sediments of the Hazeva Formation.*

Undivided Neogene–Quaternary Series" (Shaw 1947). In places, it was not mapped at all, since it was presumed to be a weathering product *in situ* of the underlying formations, mainly the flint-rich Eocene and Senonian chalks.

The conglomerates consist essentially of local components: flints derived from the Senonian Mishash Formation and from the Eocene rocks and various limestone and dolomite pebbles derived from Cretaceous and Eocene strata. The local character of the components of this conglomerate is conspicuous, the composition being strongly influenced by the surrounding outcrops. Allochtonous components, mainly magmatic, metamorphic rocks and quartzites, are usually found only in the vicinity of outcrops of the Arava Conglomerate, where they were redeposited. The sorting is poor; the size of the constituents varies from sand grains up to 20–30 cm or even more. The pebbles are angular to subrounded, but often the angular and subangular pebbles dominate. Beds of gravel composed mainly of angular flint fragments are common, especially in floodplains. Such gravel covers a wide area south of Be'erot Ada, near Nahal Qezev and Nahal Hiyyon and in the Kuntila plains. The matrix is loose, consisting of carbonatic silts or clays, which sometimes have a slight red coloration. The sandy horizons are composed of medium to coarse grains, most of them of flint and carbonate rocks, with some subordinate quartz. The grains are loosely cemented by a carbonate or clayey matrix. Clays and chalks, sometimes containing flint and limestone fragments, are found along Nahal Paran and may represent short periods in which lacustrine conditions prevailed, associated with the fluviatile system.

The sediment bodies of the HaMeshar Formation consist of wide sheets, up to 10 km or even more, representing the ancient floodplains. The much thicker channels protrude from the lower sides of these sheets. In some places, hills of the bedrock crop out through the alluvial cover. The HaMeshar Formation channels are sometimes cut obliquely by the present stream channels and are then exposed on the stream walls, as along Nahal Paran near Be'erot Ada, in Nahal Arod, and in Nahal Hiyyon. The channels can be recognized by the notably low position of the base of the sediments in relation to the shoulders of the present stream. In places where Recent streams follow the older ones, they are independent of local structure. Such is the case at Nahal Girzi, for instance. Floodplains may be absent where the channels cross relatively elevated country, such as the ridge of Eocene rocks that forms the southern boundary of HaMeshar Plain, or in Nahal Zihor, northwest and west of Shen Zihor.

Reconstruction of the channels (Figure 5.63) reveals a pattern that indicates a westward drainage, which began at the foot of the Central Negev Highlands, where the HaMeshar Formation wedges out, and proceeded toward the Southern Negev Plains and Sinai. To the east, no channels leading to the Arava were recognized, and this area apparently did not serve as an erosion base level. Thus, the present Nahal Hiyyon runs near the Arava on Eocene and Upper Cretaceous rocks, and the hilltops are covered by a 1-3-m-thick terrace of HaMeshar Formation gravels. No traces of channels were observed. The following main streams were recognized. One originated from HaMeshar Plain, continued across Nahal Paran, receiving several tributaries and reaching Sinai near Ramot Sagi, where allochtonous pebbles redeposited from the Arava Conglomerate are present. Another branch came from Nahal Hiyyon, receiving tributaries that came from the present Nahal Qezev and Nahal Zihor areas, and continued to the Kuntila Plains and Sinai through Nahal Girzi. The HaMeshar fluviatile system finally led to the Mediterranean through Wadi Quaraya and Wadi el Arish in northern Sinai. The southern parts of this drainage system are represented in Israel by alluvial sediments along the upper course of Nahal Shani and Biq'at HaYare'ah, which flowed west and northwest to join the Kuntila plains. Other branches of this drainage system passed through the Biq'at Uvda region. The "Neogene" sediments near Nahal Gerofit described by Eckstein (1963) were probably deposited by one of these branches and are presently step faulted. The flat-lying surface over which the Sede Boqer settlement is situated may also have been a part of the HaMeshar Formation drainage system (Issar 1977). It was apparently drained to the Mediterranean through the antecedent valley, which cuts the Boqer anticline west of the settlement and is connected with Nahal Lavan and Nahal Besor.

The HaMeshar Formation gravel overlies unconformably the Pliocene Arava Conglomerate (Garfunkel and Horowitz 1966; Horowitz 1974). The formation also overlies many older rocks, like the Miocene Hazeva Formation, the Senonian, Eocene, and sometimes late Cretaceous rocks. The HaMeshar Formation conglomerates are not covered by any younger formation in the Central and Southern Negev but are notably cut by most of the wadis leading toward the Dead Sea, that captured the former drainage toward the east (Nir and Bar-Yosef 1976).

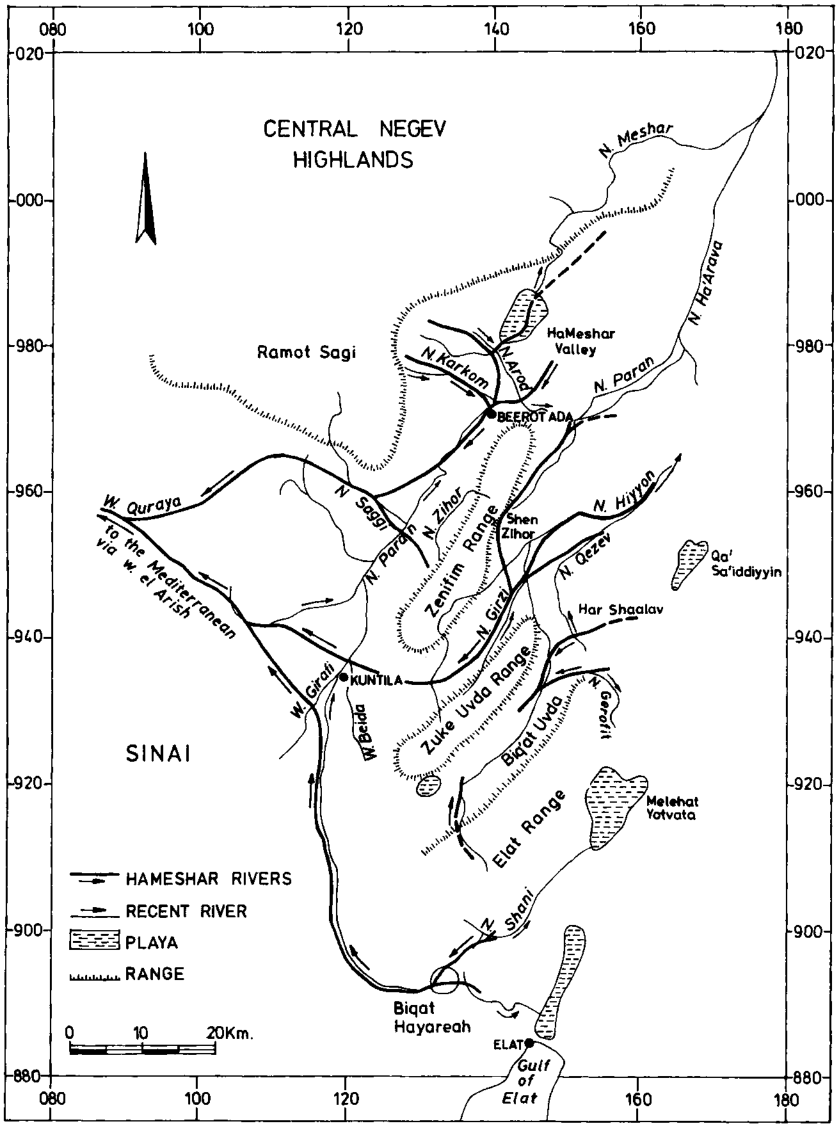


FIGURE 5.63. *The main channels of the HaMeshar System, leading to the Mediterranean, and their captures by the Glacial Pleistocene drainage system toward the Dead Sea. (From Garfunkel and Horowitz 1966.)*

Garfunkel and Horowitz (1966) assigned an early Pleistocene age to the HaMeshar Formation. This was based on its overlying the late Pliocene Arava Conglomerate and its incision by rivers leading to the present-day Dead Sea depression, which indicates that the HaMeshar Formation is older than the oldest formations accumulated within the Dead Sea Basin proper in Quaternary times. The latter were tentatively attributed a Günzian age by Horowitz (1974), which places the HaMeshar Formation within the stratigraphic limits of the Preglacial Pleistocene. The drainage system in which the HeMeshar Formation was consequently deposited led from the present Transjordanian plateau to the Mediterranean, without any influence of a topographic low in the present-day areas of the Arava and the Dead Sea, which indicates that these areas did not serve as an internal erosion base level, as is the present-day situation. This drainage system developed toward the retreating late Pliocene Mediterranean and was later filled by sediments due to the Calabrian and Sicilian ingressions, which considerably raised the Mediterranean base level and caused deposition of gravel over the wide floodplains of the system.

The HaMeshar Formation appears continuously at elevations ranging from around 200 m above sea level at the margins of the Arava, where the present-day Nahal Hiyyon joins the Nahal Ha'Arava, ascending up to more than 500 m above sea level at the area around Kuntila, and descending gently toward the Mediterranean through Wadi Quraya and Wadi el Arish. This fact indicates that the central part of the country was uplifted after the deposition of the HaMeshar Formation gravels, namely in Glacial Pleistocene times. No faunal or floral remains were encountered within the HaMeshar Formation outcrops, but in fact little effort has been made to look for them.

Bethlehem Conglomerate

In the early 1930s, a citizen of Bethlehem discovered a fossil-bearing site while digging a cistern in his yard. This was first mentioned by Bate in 1934 and excavated by Gardner and Bate in 1935–1936, the results published in 1937. Stekelis completed the excavation in 1940, and Hooijer summarized the faunistic assemblage in 1958. Clark (1961) examined the lithic finds, and Shaw (in Clark 1961) described the geology. The site is located at the highest topographical elevation in Bethlehem, 790 m above sea level, on a hill built of Senonian chalk. It is close to the watershed and not far from the axis of the Judean anticlinorium. In Shaw's opinion, the deposit consists of material filling a pipe or pothole in the chalk that caps the hill at this point. The deposit was considered, therefore, a residual one, formed practically *in situ* and as a result of terrestial weathering and solution of the chalk rock by rainwater. This view is opposed by Solomonica (1948) and Horowitz (1974). The fractured flint specimens collected from this deposit were proved to be natural by Clark's analysis. Shaw indicates that marshy and steppe conditions prevailed in the area of Bethlehem, which was much lower in the period of accumulation of the sediments than it is today. It is, therefore, likely that the Bethlehem deposit precedes the main tectonic movement that created the Rift Valley and warped the Judean hills.

The Bethlehem Conglomerate was designated by Horowitz (1974) to include a series of channel fillings that occur on the Judean anticlinorium (Figure 5.64). The type section was located at the center of the city of Bethlehem, where 10–12 m of these conglomerates occur, filling an erosion channel (Solomonica 1948). The sequence comprises rounded and subrounded flint pebbles embedded in reddish or brownish clays. Other occurrences of the Bethlehem Conglomerate are known from the vicinity of Jerusalem, at Talpiyot and on Mt. Scopus (the last mentioned occurrence was misidentified as the Hazeva Formation in Horowitz 1970a), where the conglomerates fill shallow erosion channels. Other outcrops are east and west of Jerusalem, at much lower elevations on both sides, indicating that the upwarping of the Judean anticlinorium took place after the deposition of the Bethlehem Conglomerate, in Glacial Pleistocene times. The conglomerate at Bethlehem yielded a rich vertebrate fauna, discussed in Hooijer (1958), comprising *Archidiskodon planifrons, Leptobos, Hipparion, Giraffa* cf. *camelopardalis,* and others, indicating a "Villafranchian" age and a steppe-like aspect of the area. The Bethlehem Conglomerate mostly overlies the mountainous formations of Late Cretaceous age, but it also cuts into Neogene erosive surfaces, still preserved on the Judean anticlinorium. A conglomerate of Neogene age, which is totally different from the Bethlehem Conglomerate, crops out near Bet Sahur, just east of Bethlehem, and is associated with an erosive surface cut and filled by the Bethlehem Conglomerate system.

FIGURE 5.64. *The Bethlehem Conglomerate: A, at the site where excavations took place in the late 1930s, and the Bethlehem fauna was uncovered (photograph by the late M. Stekelis, during the 1939 excavation season); B, filling a channel cut into Senonian chalk on Mount Scopus, Jerusalem, high above the present wadi bed.*

The conglomerates contain relatively high amounts, sometimes more than 1%, of titanium, and the clays that are associated with the pebbles are mainly kaoline, which indicate transportation of the clastics over a long distance (Y. Nathan, Geological Survey of Israel, personal communication, 1972). Quartzite pebbles, unknown in the near vicinity, are also embedded within the Bethlehem Conglomerate, pointing to its remote origin. The high titanium content of the clays might be connected with outcrops of the Cover Basalt known from Transjordan, the area that is suggested in Horowitz (1974) as the provenance of this river system. This river system (Figure 5.65) most probably led to the Mediterranean in the

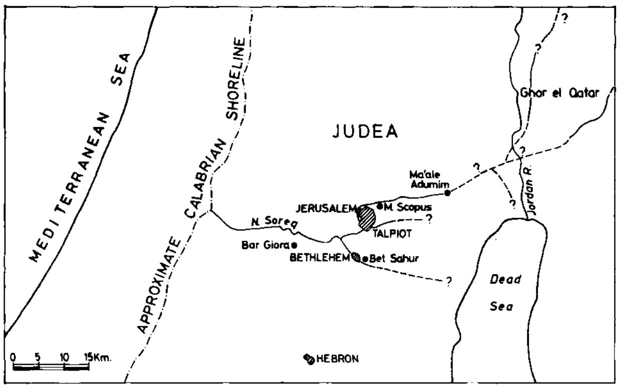


FIGURE 5.65. *Channel of the Bethlehem System. The Ghor el-Qatar intermediate lake is not drawn, due to lack of data concerning its extension.*

FIGURE 5.66. *An incised meander of Nahal Soreq.*

course of the present-day Nahal Soreq and is responsible for the formation of the latter's wide meanders (Figure 5.66), which are presently deeply incised (Butrimowitz 1973). Such meanders are very rare in other wadis in the Judea and Hebron areas, and most of the Bethelehem Conglomerate outcrops are in the upper reaches of the Nahal Soreq system. Some crocodile bone fragments were also found by Horowitz (1970a) in these sediments. The Bethlehem Conglomerate is cut by the present-day wadis of the Judea and Hebron anticlinoria, in which morphologic phenomena and gravel horizons of Glacial Pleistocene age are quite abundant. The lower contact, the incision by the Judean and Hebron wadis, and the typical fauna point toward a Preglacial Pleistocene age. The system was apparently formed toward the retreating late Pleocene sea and filled with sediments due to the influence of the Calabrian and Sicilian ingressions. The Bethlehem Conglomerate most probably interfingers with the Ga'ash and the lower part of the Gaza formations (Horowitz 1974).

Bender (1968) described the series of Ghor el-Qatar from the Southern Jordan Valley, the type section being at a location of the same name approximately 27 km north of the northern end of the Dead Sea. About 350 m of clastic, in parts steeply dipping rocks, are exposed. This sequence is composed of alternating conglomerates, conglomeratic sandstones, sandstones, marls, and marly clays. The argillaceous, marly, fine sandy matrix of the coarse clastics often shows the typical red color of the Mediterranean soils. This "Series of Ghor el-Qatar," known also as the "Series of Grain es-Sabt" (Blake and Ionides 1939; Daniel 1963), also occurs 2 km south-southeast of Qureima, where it is approximately 75 m thick, and in further localities at the eastern side of the Jordan Valley. At the Wadi el Hamme, north of Meishara, the Ghor el-Qatar Series overlies sediments of the late Pliocene Shagur Formation, which seems to be identical with the Samra Formation, as originally designated in Picard (1931). Huckriede (1966) found in the Series of Ghor el-Qatar *Melanopsis praemorsa,* ostracods, and poorly preserved remains of vertebrates and plants. He tentatively assigned an Early Pleistocene age to this fluvio-lacustrine formation. The Ghor el-Qatar Series is affected by the Levantine faulting system. The sequence underlies sediments of the Abu Habil Series, which seem to correlate with the Erk el-Ahmar–Ubeidiya Formations of the Central Jordan Valley. The characteristics and stratigraphic setting of the Ghor el-Qatar Series seem to indicate their possible correlation with the Bethlehem Conglomerate.

Other Fluviatile Sediments of Preglacial Pleistocene Age

Numerous locally restricted occurrences of conglomerates, interfingering with the Calabrian and Sicilian sediments of the coastal plain, have been reported by many authors (for example, Avnimelech 1936; Bar-Josef 1964, 1967; Issar 1961; Itzhaki 1961; and Picard 1943). Issar defined these conglomerates as part of the Ahuzam Formation. This name is, as discussed earlier, unacceptable, and these horizons are tentatively termed the "Lateral Conglomerates of the Ga'ash Formation." Several occurrences of conglomerates in the Upper Galilee, which sometimes interfinger with flows of the Cover Basalt, have been found by the present author, but their restricted occurrences did not permit any delineation of a drainage pattern. Some of these conglomerates are faulted by the border faults of the Hula Valley. No formation name has been suggested for these horizons.

Garof Conglomerate

The Garof Conglomerate (Figure 5.67) was designated by Garfunkel (1970) from Nahal Garof, which drains the Yotam Plain toward the Bay of Elat. The sequence comprises several meters of coarse conglomerates overlying the Pliocene Eilot Formation over a taphrogenic and

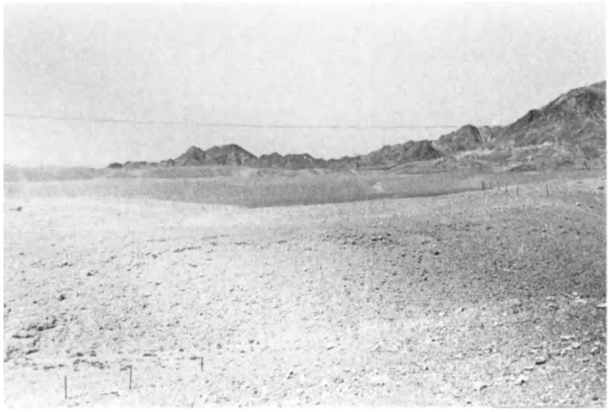


FIGURE 5.67. *The Garof Conglomerate wide floodplains, near Elat.*

erosional relief. It crops out in many localities around the Bay of Elat. In some places, it also overlies Cretaceous and Precambrian rocks. The Garof Conglomerate is cut in places by the present-day drainage pattern leading toward the Bay of Elat and in some localities is faulted by the Arava border faults. Garfunkel concluded that the Garof Conglomerate filled rather shallow, wide valleys that formerly led toward the Bay of Elat. He correlated the Garof Conglomerate with the Arava Conglomerate, which flowed to the Dead Sea Basin, and suggested its late Pliocene or early Pleistocene age. Horowitz (1974) showed that the Arava Conglomerate should be correlated with the Eilot Conglomerate, both of Pliocene age, whereas the Garof Conglomerate should be correlated with the HaMeshar Conglomerate. Both the Garof and the HaMeshar Conglomerates overlie Pliocene deposits and are cut by wadis leading to the present-day Rift Valley. No faunal or floral remains are reported from the Garof Conglomerate. It most probably represents a drainage system that was cut toward the retreating late Pliocene sea at the Bay of Elat area and was consequently filled with gravel due to the Calabrian and Sicilian ingressions, prior to the faulting of the Levantine System. A Preglacial Pleistocene age is, therefore, conceivable for this conglomerate.

GLACIAL PLEISTOCENE AND HOLOCENE

The almost flat, low-lying Preglacial Pleistocene peneplain over which the HaMeshar, Garof, and Bethlehem rivers have meandered and created vast floodplains has totally changed in the transition from the Preglacial to the Glacial Pleistocene, due to the activity of the Levantine Fault System. The central part of the country was upwarped (Horowitz 1974) to create the hilly, longitudinal backbone, and the Dead Sea–Jordan Rift Valley opened, which since then has acted as an endoreic base level (Garfunkel and Horowitz 1966; Picard 1943; Schulman 1962). These processes resulted in the formation of a new hydrographic system leading toward the internal basin of the Dead Sea, which system captured and cut through the former Preglacial Pleistocene river courses, with a considerable deepening of rivers and channels leading westward to the Mediterranean. The Bay of Elat, to the south, was also considerably deepened at this time. The resulting hydrographic net led toward three erosion base levels: the Mediterranean to the west, the Dead Sea–Jordan–Arava Rift Valley to the east, and a restricted drainage system that led to the Bay of Elat to the south. Fluviatile sediments of Glacial Pleistocene age are, therefore, known from the coastal plain, from the mountainous backbone, from the Jordan Valley System, and from the Bay of Elat System.

Coastal Plain

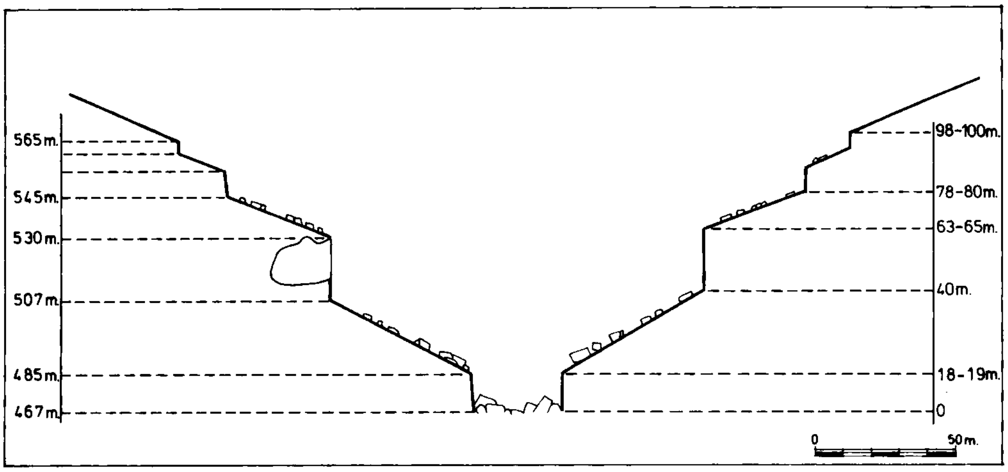
Fluviatile sediments of rivers and wadis leading to the Mediterranean are known all along the coastal plain of Israel. Issar (1961, 1968) named them the "Ahuzam Conglomerate," a name that is not used here for reasons discussed earlier. The outcrops are, however, quite restricted, and most of them have never been studied in detail. Therefore, no formational names are adopted for these outcrops. Conglomerates and microconglomerates at the Carmel foothills are described in Michelson (1970); these interfinger with corresponding marine and terrestrial sediments. Most of the ingressive eustatic phases have their fluviatile counterparts. One of the most prominent outcrops is at the opening of the Nahal Oren, about 20 km south of Haifa, where a coarse fluviatile conglomerate interfingers with the Tyrrhenian coastal sediments (Figure 5.28). Most of the other outcrops resemble this one. At the Sharon and Pleshet areas, in the central and southern coastal plain, most of these conglomerate horizons are covered by Recent soils, but many have been penetrated by boreholes (Issar, 1961; 1968). It is quite impossible to relate these fluviatile conglomerates to any particular horizon, mostly because they appear as point occurrences encountered within boreholes. The rather restricted occurrences of these conglomerates have not favored their detailed study.

Mountainous Backbone

The mountainous backbone of Israel is presently topped by the Preglacial Pleistocene erosive surface (Figure 5.68), which is curved toward the east and west due to uplifting. Transversal cross sections of rivers on both sides of the watershed, leading either to the Dead Sea erosional basin or to the Mediterranean, show more or less similar characteristics (Horowitz 1974, 1975) and are, therefore, dealt with together (Figure 5.69). Transversal cross sections of wadis in many localities around the country, the Galilee, Samaria, the Judea-Hebron mountains, and the Negev, show four distinct benches developed across the wadi profile on both sides. The

FIGURE 5.68. *The Preglacial Pleistocene erosive surface of Judea.*

FIGURE 5.69. *Cross section of Wadi Hareitun, Judean Desert, at the locality of the Oumm Qatafa Cave, showing the four benches cut into the Preglacial Pleistocene plateau. (From Neuville 1951.)*



benches are mostly developed on bedrock where a gentle slope suddenly becomes a much steeper one. It should be noted that these benches were observed on rocks of totally different ages and lithologies, so that they are, most probably, a result of different erosion regimes within the area (Figure 5.70) and not due to the characteristics of the bedrock. Some local occurrences of small cliffs and other phenomena related to the bedrock characteristics are omitted from this discussion. The two uppermost benches (Figure 5.71) are always developed on bedrock, and no gravel horizons are known to be associated with them. They are rather high on the topography, comprising the upper half of the wadi profile. They are not always preserved and sometimes are covered by soils or have been eroded by subsequent weathering. Of the two lower benches, the lowermost one is almost always developed over a conglomerate horizon that comprises coarse to medium gravels intermingled with colluvial materials (Figure 5.72). This conglomerate bed was defined by Buchbinder (1969) as the Nahshon Conglomerate, and the type section was taken at an outcrop on the western foothills of Judea, where about 20–25 m of this conglomerate crops out. The type section comprises pebble horizons intermingled and interfingered with clays and loams. The Nahshon Conglomerate overlies a relief that is cut much more gently than the present-day one. Its upper surface reveals a very gentle relief and is presently cut by Recent wadis, which form steep slopes, sometimes grading to cliffs. The difference between the rather flat, gentle topography during the

FIGURE 5.70. *Morphologic benches, developed on Middle Cenomanian chalk and limestone in the Western Galilee. Compare also with benches developed on different rocks, shown in Figures 5.71 and 5.74–5.76.*

FIGURE 5.71. *The two uppermost benches in the Judean hills.*

FIGURE 5.72. *The Nahshon Conglomerate.*

FIGURE 5.73. *Gentle slopes of the Nahshon Conglomerate in Judea, cut by the steep present-day erosion, in an initial stage at one of the wadi heads.*

time of formation of the Nahshon Conglomerate and its subsequent cutting by the steep-walled channels (Figure 5.73) is quite striking throughout the country (see also Goldberg 1976 for the Negev).

A variety of artifacts was found within the sediments of the Nahshon Conglomerate, ranging from Mousterian (Crew 1976) at the base up to Epipaleolithic and sometimes even Neolithic (Echegaray 1966) at the top. The Nahshon Conglomerate is quite common in all the wadis leading from the mountainous backbone westward and eastward. The well-known terrace of El-Khiam (Echegaray 1966) in Wadi Hareitun, leading toward the Dead Sea, comprises part of this formation. Artifacts of Epipaleolithic through Neolithic were found by Echegaray in the upper part of this terrace, which is about 20 m thick at the place of excavation. Only the upper part of the terrace was excavated. Toward the Dead Sea, the Nahshon Conglomerate interfingers with the Würmian Lisan Formation. Comparable conglomerates appear also in the Central Negev Highlands (Goldberg 1976), in which artifacts of Mousterian through Epipaleolithic cultures were encountered (Marks 1976). These terraces comprise intermingled horizons that are rich in aeolian silts and loess-like material (Figure 5.74).

Vita-Finzi (1966) named the alluvial Hasa Formation, which occurs on the upper reaches of Wadi Hasa on the Transjordanian Plateau leading to the Dead Sea. This formation had been previously known as the "Upper Terrace." The gravels comprising the Hasa Formation yielded Mousterian artifacts in their lower part and Kebaran in their upper part. The gravel fills wide, shallow wadis that predate the present-day cliff-like erosion. Another, intermediate terrace is reported from Wadi Hasa that is younger than the Hasa Formation and is also cut by the present-day cliff-forming flood erosion. It seems that both the morphologic setting and the artifact contents of the Hasa Formation serve as a good basis for correlating it with the Nahshon Conglomerate.

The second bench, from below, seems to be mostly on bedrock (Figure 5.75), but in some localities conglomerates and gravel (Figure 5.76) comprise part of this bench. A sequence of about 4 m of this comglomerate, comprising mainly flat pebbles floating in a red, clayey, muddy substance, was named by Horowitz (1974) the Baq'a

FIGURE 5.74. *Nahshon terraces in Nahal Aqev, Central Negev.*

FIGURE 5.75. *The Baq'a bench, developed on Senonian chalk covered by hard calcrete ("nari"), in the Hebron mountains.*

FIGURE 5.76. *The Baq'a Conglomerate, forming a bench in a wadi of the Judean Desert.*

Conglomerate. The type section was taken near Jerusalem, and the sediments in this locality yielded very rich assemblages of Late Acheulian artifacts (Arensburg and Bar-Yosef 1966; Stekelis 1948). The relics of the Baq'a Conglomerate present similar characteristics to those of the Nahshon Conglomerate. They overlie a gentle relief, developed as a rather gentle slope and cut quite steeply by subsequent erosion. Two subsequent cycles of steep erosion cut through this conglomerate. The terraces of the Baq'a Conglomerate are known from the Jerusalem area, from some rare localities in the Negev, and from some occurrences in the Carmel and the Upper Galilee (Marks 1976; Olami 1976; Ronen *et al.* 1974; Stekelis 1948).

Extensive pollen analyses of the Nahshon Conglomerate sediments in the Central Negev were carried out by Horowitz (1976a); these are discussed in Chapter 6. In general, these pollen spectra, as well as the faunal remains (Tchernov 1976), indicate a more humid climate for the time of deposition of this formation in the Central Negev. This also seems to be verified by occurrences of fossil spring deposits interfingering with these terraces in the Central Negev (Goldberg 1976), in which Mousterian artifacts were found to be embedded. No data for the Nahshon Conglomerate are as yet available for the Judea and the Galilee areas. Horowitz (1974) suggested that the two alternating kinds of slopes that cut into the mountainous backbone of the country represent two different climates: a humid, pluvial climate, in which vegetation was quite rich and rainfall was more evenly distributed over the year, leading to the formation of gentle slopes; and an interpluvial climate, the situation at present, which is characterized by much poorer vegetation and by torrential rains, both factors favoring steeply incised torrential flood erosion. It is suggested, therefore, that this change in the slopes has occurred at least four times during the incision history of the mountainous backbone rivers, since the end of the Preglacial Pleistocene. The upper two benches preserve no sediments and are, therefore, quite difficult to date. The lower two have some sediments with artifacts that help to date them. The lowermost, Nahshon Conglomerate, is of Würmian age, as indicated by its floral and faunal remains and by the interfingering with the Würmian Lisan Formation, which was radiocarbon dated (Neev and Emery 1967). The Baq'a Conglomerate is most probably of Rissian age, since artifacts of the Late Acheulian appear in Rissian sediments in many parts of the country, like Gesher Benot Ya'akov, south of the Hula (Horowitz 1973), and other localities. The upper two, older benches were tentatively assigned by Horowitz (1974) to the Mindel and the Günz pluvials, since they are definitely older than the Riss but younger than the Preglacial Pleistocene surface, into which they are incised.

Jordan Valley

The Jordan–Dead Sea Rift Valley was occupied by successive lakes throughout the Glacial Pleistocene in which lacustrine sediments were accumulated. Most of these lacustrine beds are intercalated with fluviatile deposits coming from the surrounding mountains. Most of these fluviatile deposits are considered as lateral facies of the lacustrine beds, rather than as independent formations. Some of them, however, have acquired formation names, especially when outcrops are conspicuous. The Hula Group (Horowitz 1973), comprising mainly lacustrine and paludine formations, grades to the north to a thick sequence of fluviatile sediments, of which about 600 m were penetrated by the Hula I borehole, north of the former Hula Lake and swamps (Figure 5.91). The fluviatile sediments comprise mainly conglomerates, of which basaltic pebbles form the major part, and intercalate with paleosol horizons. Due to the lack of any indicative fauna or flora in these conglomerates and to the fact that they have been studied only in boreholes, no subdivision of this sequence is given, and it is generally considered as the lateral equivalent of the Hula Group. A similar picture ensues also in the southern part of the Dead Sea Basin, where the Arava I borehole has penetrated more than 1000 m of gravels, which yielded scarce pollen spectra of a nature similar to those obtained from the Upper Dead Sea Group lacustrine sediments penetrated by the Melekh Sedom I borehole and discussed in Chapter 6. Once more, no subdivision of this sequence is available, and it is regarded as the lateral equivalent of the Upper Dead Sea Group (Horowitz 1974; Neev and Emery 1967).

The Hazor Gravel is the oldest Glacial Pleistocene fluviatile formation of the Jordan Valley (Figure 5.77). The type section was proposed by Picard (1963), southwest of the Hula Valley, near the tell and settlement of the same name. The sequence comprises about 40–50 m of rather coarse gravel, the pebbles being derived mostly from Eocene and Cenomanian rocks and some basalts. The matrix and cement is fine-grained carbonate. This formation crops out only in the vicinity of Hazor-Ayyelet

FIGURE 5.77. *Hazor Gravel, interfingering with a thin layer of Gadot Formation chalk, south of the Hula Valley.*

FIGURE 5.78. *Gravel within the Ubeidiya Formation.*

HaShahar area. It overlies unconformably the Preglacial Pleistocene Cover Basalt and is overlain by the Yarda Basalt. The gravel horizons grade laterally, eastward, to the chalky and carbonate Gadot Formation, of Günzian age (Horowitz 1973). Neither faunal and floral remains nor artifacts were encountered within the Hazor Gravel. The Hazor Gravel was most probably deposited in a river leading to the Hula Basin in times when the lacustrine Gadot Formation was deposited in the lake, which extended south of the present-day lake's border. The lowest part of the sequence penetrated by the Hula I borehole most probably corresponds to the Hazor Gravel. Two distinct fluviatile phases (Figure 5.78) can be discerned within the Ubeidiya Formation lacustrine sediments (Bar-Yosef and Tchernov 1972; Picard and Baida 1966). These will be dealt with in the discussion of the Ubeidiya Formation, under "Lacustrine Sediments." Bender (1968) describes hard, conglomeratic, partly pisolitic limestone from the eastern side of the Jordan Valley, which unconformably overlies the Preglacial Pleistocene Ghor el-Qatar Series. These limestones were observed at several localities, for example, near Abu Habil. They are older than the "Middle Pleistocene Basalt-Volcanism" and contain in their upper parts pebble tools of Oldowan type. They were, accordingly, placed in the Middle Pleistocene by Huckriede (1966). These fluviatile sediments are unconformably overlain, over an angular tilting, by the Würmian Lisan Formation and by basalts that are correlative to the Raqqad and Yarmouk basalts. The Abu Habil Series seems to correlate with the Erk el-Ahmar–Ubeidiya formations of the Central Jordan Valley.

The Naharayim Formation (Figure 5.79) was defined in Picard (1943) to include a series of fluviatile deposits about 30–40 m thick that crop out at the outlet of the Yarmouk River into the Jordan Valley. The sequence comprises coarse conglomerates intermingled with brown paleosols. They yielded rich pluvial pollen spectra, discussed in Chapter 6, together with some Late Acheulian handaxes. The Naharayim Formation overlies the Yarmouk Basalt and is overlain by the Würmian Lisan Formation, and, therefore, is assigned a Rissian age in Horowitz (1974). The Naharayim Formation comprises part of the Jordan Group and will be discussed later in more detail. Bender (1968) correlates poorly consolidated gravels with a red, argillaceous matrix containing Paleolithic artifacts of Acheulian affinity exposed at the Kufrinja-Yabis area with the Naharayim Formation. These sediments overlie the Abu Habil Series and are in turn overlain by the volcanic rocks that correspond to the Raqqad Basalt and by the Würmian Lisan Formation.

FIGURE 5.79. *Naharayim Formation channel comprising coarse gravel, overlying the Ubeidiya and underlying the Lisan Formation, Central Jordan Valley.*

The Lisan Formation lacustrine sediments, of Würmian age (Neev and Emery 1967), interfinger with conglomerates that came by rivers from the adjoining mountains (Figure 5.80). These conglomerates, while still in the mountainous area, fall within the definition of the Nahshon Conglomerate discussed earlier, but in the Dead Sea area they have sometimes acquired the name "Samra Formation" or "Samra Facies" (Begin 1975; Begin *et al.* 1974; Bentor and Vroman 1960). Picard (1931) described a sequence of conglomerates that occur not far from Hirbet

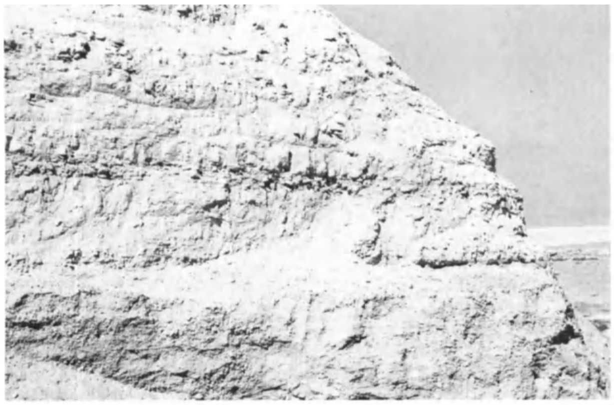


FIGURE 5.80. *Conglomerates interfingering with the Lisan Formation lacustrine sediments.*

FIGURE 5.81. *The "Upper Terrace," north of Jericho.*

es-Samra, north of Jericho, and seem to be a part of the Late Pliocene regressive system (Horowitz 1974). The area of Jericho was inaccessible to Israeli geologists from 1947 until 1967, and the use of the term "Samra" to denote any conglomerate within the Dead Sea Group was quite widespread. Horowitz (1974) called attention to the original use of the term by Picard and advised not using the term "Samra" for unidentified gravel beds or for gravel beds that are not part of the Pliocene fluviatile system. Bender (1968) also correlated conglomerates near Hirbet es-Samra as lateral equivalents of the Lisan Formation. It should be noted that conglomerates that are equivalent to the Lisan Formation and interbed within the lacustrine sediments appear near Hirbet es-Samra, but these were not included in Picard's original description.

The Fatza'el Member of the Lisan Formation, which overlies the Lisan lacustrine sediments in the Central and Southern Jordan Valley, is almost mostly of fluviatile origin but will be discussed later, together with the entire Jordan Group. Other fluviatile sediments corresponding in age to the Fatza'el Member occur near En Gev east of Lake Kinneret and yielded quite rich Epipaleolithic artifact assemblages, together with human skeletons. These fluviatile sediments have not been named as yet but are the lateral correlatives of the Late Pleistocene–Recent Tabgha Formation, which is deposited within the Lake Kinneret area. Another conglomerate bed was found near En Gev on a hill facing Lake Kinneret at an elevation of about 40–50 m above the present-day lake's level. This conglomerate horizon yielded Late Acheulian handaxes and other artifacts that are comparable with those excavated at the Rissian Benot Ya'akov Formation (Nir and Bar-Yosef 1976).

The "Upper Terrace" was described and discussed in Picard (1932), and the term "Oberterasse" was adopted for gravel terraces on the flanks of tributaries of the Jordan River. The upper part of the Upper Terrace overlies the uppermost lacustrine part of the Lisan Formation. This is quite clear at the mouth of Wadi Qilt (Nahal Kelet) near Jericho (Figure 5.81). Vita-Finzi (1964) also describes the "Lower Terrace," as referred to by Picard (1932), which can be seen in many of the wadis as a 3–4-m-high terrace (Figure 5.82), containing potsherds. It is generally better bedded than the Upper Terrace, and the gravel is often finer and more rounded. The sediments are probably derived from the earlier Upper Terrace. The Lower Ter-

FIGURE 5.82. *The "Lower Terrace" (and some other undefined terraces) in Nahal Zin, south of the Dead Sea.*

FIGURE 5.83. *The "Zor," the Jordan River's floodplain.*

race is presently cut steeply by wadis leading to the Dead Sea Basin.

The Jordan River, which is the most conspicuous fluviatile phenomenon of the Jordan Valley, connecting the Hula, Kinneret, and Dead Sea Basins, has created two distinct fluvio-morphological phenomena: its floodplain, which is very conspicuous from the Kinneret down to the Dead Sea, incised into Lisan Formation sediments (Figure 5.83) and locally called the "Zor"; and its delta, formed as it approaches the Dead Sea. The Jordan Delta to the north of the Dead Sea comprises mainly carbonate sediments, which are precipitated from the Jordan waters as they enter the Dead Sea.

Bay of Elat

The Glacial Pleistocene wadis leading to the Bay of Elat have cut their courses into rather flat, steep-walled, valleys and canyons filled by the Garof Conglomerate (Figure 5.84). River terraces are, however, quite rare in this area, mainly for two reasons. First, the area around the Bay of Elat, even during the pluvial periods, was relatively arid in comparison to the rest of the country; therefore, the torrential rains prevailed, giving place to rather severe erosion. Second, the continuous subsidence of the area around the Bay of Elat, which has taken place since the Preglacial Pleistocene, also did not favor formation of river terraces. Some relics of river terraces, built mainly of rock debris and coarse fragments of the nearby metamorphic, magmatic, and sometimes sedimentary rocks, are reported by Nir (1968) and Garfunkel (1970) at altitudes of about 1–30 m above sea level (Figure 5.85) in some of the wadis leading to the Bay. In most of these wadis only one or two terraces are developed, and they have never yielded any material, either fauna, flora, or artifacts, that would help in their chronological assessment; therefore, no further discussion of these is given here. Vita-Finzi)1964) described a river terrace that is well developed and particularly impressive in Wadi Yutm and its tributaries, leading to the Bay of Elat and joining the Bay just north of Aqaba, on its eastern side. The terrace comprises mainly weathered igneous material. The fans are especially steep, so that the height of the terrace varies greatly according to the position of the main channel. In places it exceeds 30 m, but the maximum depth of fill may be far greater, as bedrock was not observed on the wadi floor. Wadi Yutm has built up a large fan of these materials where it leaves the hills and enters Wadi Araba. This terrace is also reported by Vita-Finzi from the sandstone country further north, in Wadi Mussa, but in this locality it is rather subordinate, most probably due to the nature of the rock in the area. A similar feature has also been observed in two eastward flowing wadis on the Transjordanian Plateau, Wadi Jordan, and Wadi Wuheiba. Vita-Finzi tends to correlate this terrace with the "Upper Terrace" developed in many of the Transjordanian valleys. It seems that this "Upper Terrace" corresponds, as discussed earlier, to the Nahshon Conglomerate.

FIGURE 5.84. *Nahal Shelomo, south of Elat, cutting into the Garof Conglomerate.*

FIGURE 5.85. *The "10–30 m" terrace, in Nahal Shelomo, south of Elat.*

FIGURE 5.86. *A succession of terraces at the Timna erosion cirque, north of Elat.*

The only area in the vicinity of the Bay of Elat that displays a series of Glacial Pleistocene fluviatile terraces is the Timna erosion cirque, about 30 km north of Elat, which drains to the Southern Arava (Figure 5.86). These terraces were studied in detail by Horowitz (in press [a]). A succession of five fluviatile terraces was recorded in the Timna erosion cirque, comprising mainly coarse conglomerates that cut into one another. No formational names were given to these terraces, and the cumulative thickness of the sediments comprising them is in the range of 100–150 m. The uppermost, oldest surface was tentatively regarded by Garfunkel as correlative with the Garof Conglomerate. It is quite tempting to correlate, therefore, the remaining four terraces with the four benches known from the rest of the country, but, since no positive evidence is available, this assumption is, at present, only a remote hypothesis. The present-day erosion at the Timna Cirque is of the same type as in the rest of the Negev, namely torrential and canyon-cutting floods, and does not form any gently dipping surfaces as are exposed by the upper parts of the terraces. It was assumed, therefore, by Horowitz (in press [a]) that these terraces indicate different climatic conditions from those of the present-day, and, in comparison with the conditions at the Central Negev (Goldberg 1976), it was concluded that the sediments accumulated in rather wide, shallow wadis during more humid, pluvial periods, whereas they were eroded to form canyons during the arid interpluvials with their torrential floods. This hypothesis does not take into consideration the possibility of tectonic movements that might have changed the base of erosion at the nearby Arava, but it seems that some climatic influence must be considered because the flat-lying tops of the terraces are never tilted, and, therefore, even if tectonic movements had lowered the erosion base level and created some different morphology, they could not account for the different style of erosion displayed by the terraces at the Timna cirque. Vita-Finzi (1964), while analyzing occurrences of conglomerate horizons on the Transjordan Plateau, which drains both west to the Dead Sea area and east to the El-Jafr internal drainage basin, concluded that the character of the Late Quaternary fluviatile deposits suggests that base-level influences have played a negligible part in their formation and that the main factor involved in the terrace's formations is the mechanism of climatic changes.

AEOLIAN SEDIMENTS

The Quaternary aeolian sediments in Israel comprise sand dunes and loess. Coastal sand dunes are well developed (Figure 5.57) all along the Mediterranean coastal plain and have been discussed in detail earlier. Inland sand dunes are known from the Western Negev, where they have been pushed from the Mediterranean coast by western winds. Only Recent sand dunes are known from this area, especially from the regions of Haluza and Ruheibe. Inland dunes are also known from the Central and Southern Arava (Figure 2.63), where they are redeposited by the prevailing northern winds in this area, having originating from outcrops of Paleozoic formations. Some restricted occurrences of sand dunes are also known from the northern Negev and especially from the Rotem Plain, where they originate from the Miocene Hazeva Formation sandstones. No Quaternary inland dunes are known, and, if they exist, they are most probably covered by the Recent dunes.

LOESS

Extensive loess accumulations are known from the northwestern Negev and the Be'er Sheva Basin, designated in Horowitz (1974) as the Ruhama Loess Member of the Gaza Formation. The type section for the Ruhama Loess Member was taken between Ruhama and Dorot, where the sequence attains 25–30 m in thickness, displaying alternating layers of white and buff colors (Figure 5.87). The white layers are richer than the buff in calcareous material and probably represent the B horizon of ancient paleosols (Yaalon and Bruins 1977). The buff layers are richer in organic material and were probably deposited during humid, pluvial periods. Some of these layers grade into paludine dedeposits (Figure 5.88). The Ruhama Loess overlies the Dorot Hamra Member, of Mindel age in the Ruhama-Dorot area, and is presently steeply eroded by the recent drainage system, forming typical badlands (Figure 2.58). The upper layer of the Ruhama Loess Member contains Mousterian, Epipaleolithic, and Chalcolithic industries (Marks 1976; Perrot 1965). Pollen analyses of the upper part of the loess deposits in the Avedat-Aqev area (Horowitz 1976a), dis-

FIGURE 5.87. *The Ruhama Loess Member. The white layers are richer in carbonates, due to pedogenic processes in the more humid periods.*

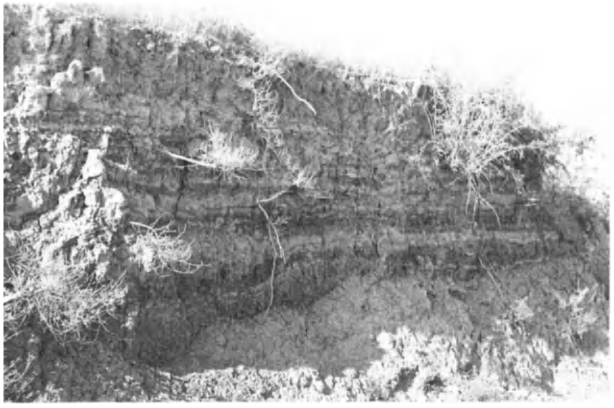


FIGURE 5.88. *Paludine facies of the Ruhama Loess.*

cussed in detail in Chapter 6, indicate that the loess was deposited under climatic conditions that were considerably more humid than those at present. The loess in the Central Negev and, to some extent, also in the Be'er Sheva Basin and in the northwestern Negev is presently wind-deflated, occurring in areas where the present wind erodability (Yaalon and Ganor 1966) is intermediate to very high. The wind deflation of the loess in these areas occurs mainly due to dust storms of both easterly and westerly origin (Yaalon and Ganor 1975; Yaalon and Ginzbourg 1966).

The petrography of the loess in the Be'er Sheva basin was studied in detail by Ginzbourg (1963). The loess at the Be'er Sheva Basin was first described by Bayer (1917) and Range (1922). Range was the first to define the loess as of aeolian origin. Picard and Solomonica (1936) concluded that most of the loess in the Be'er Sheva Basin was reworked and redeposited and must, therefore, be mainly of fluviatile origin. Petrographic analysis of the loess (Ginzbourg 1963) showed that about 50% of the material comprises grain sizes between 9 and 68 μm. The loess of the Be'er Sheva Basin comprises two layers. The primary loess is prismatic and hard and the secondary layer is bedded soft. The two loesses are separated in most places by a thin gravel horizon. The loess contains a considerable amount of carbonate, which increases to the west, or close to outcrops of carbonatic bedrock. The carbonates are mostly concentrated as concretions at a depth of the average penetration of rainwater. The carbonate particles are mostly of a clay size, less than 2 μm. The primary loess contains less carbonates than the secondary. Clays are more abundant in the northeastern and the northern parts of the Be'er Sheva Basin. Clays are probably of aeolian origin, secondarily washed. The clay share is higher near localities where floods enter the Basin. In general, the clay mineral share in the loess is around 20%. The most common minerals comprising the loess are quartz, calcite, and feldspar. The dominant heavy minerals are hornblende, epidote, opaque minerals, mica, and zircon. Secondary minerals also appear, and the more abundant are augite, rutile, garnet, tourmaline, hypersthene, and staurolite. Rare grains of kyanite, olivine, anatase, and titonite also occur. The most common clay mineral is illite, and some montmorilonite and kaolinite are also present.

Ginzbourg (1963) concludes that the main direction from which dust is brought and deposited in the Be'er Sheva Basin is the southwest or west, and winds from these directions are responsible for the major part of loess deposition. This conclusion is based on the composition of the heavy mineral spectrum and on the state of preservation of zircon and hornblende. Those two minerals show progressive weathering to the east or deeper in the sequence, proving that they were weathered in the process of deposition of the loess and after it was buried. The heavy mineral assemblages of the loess show similarity to the spectra collected from the Wadi el Arish sediments. It seems, therefore, that most of the loess is brought to the northwestern Negev from the central and northern Sinai areas. Analysis of atmospheric dust (Ganor 1975) and of pollen spectra recovered from the dust carried by dust storms (Horowitz *et al.* 1975) also point to a southwesterly provenance. Yaalon (1969) also points to the areas of central and northern Sinai as the source for the loess and atmospheric dust of Israel and postulates that the dust is mostly collected by storms from the wide wadi beds of northern Sinai. Yaalon claims that wind would, in general, not be able to blow out material directly from the rocky desert or from desert pavement surfaces. Only after the dust has been washed out onto the wadi floor or fan surfaces is the wind able to deflate it and transport it out to the fringes of the desert. The aeolian dust brought to Israel by the southwesterly dust storms (Ganor 1975) is mainly deposited at present in the northwestern Negev area, where the vegetation cover is sufficient to trap it, but some of the dust finds its way to other areas of Israel and is trapped by vegetation all over the country; it is included with almost every type of soil in Israel (Dan 1966). The aeolian contribution to paleosols of the hamra type was discussed by Nathan (1961).

FIGURE 5.89. *Wind deflated area, previously covered by loess, Central Negev.*

The principal agents that control the deposition and accumulation of the loess on the desert fringe are rains and vegetation. There seems to be an optimum annual amount of rain that is necessary to maintain the steppe vegetation of low shrubs and grass, with full coverage of the area that acts as the best dust trap. This annual amount seems to be in the range of 250–300 mm, and the more fully it is dispersed over the year, or over the rainy season, the more dust is accumulated as loess. Under more arid conditions, wind deflation takes place and former loess deposits are eroded. This is the present-day situation of the loess in the Central Negev (Figure 5.89). Indeed, pollen analyses of the Central Negev Loess have indicated that it accumulated under a climate that is comparable to the present-day climate of the Shefela region of Israel. Under a more humid climate, the loess will turn into soil. Yaalon and Bruins (1977) have discerned at least six paleosol horizons within the Ruhama Loess Member, which most probably means that more humid conditions have occurred in this area than in the Central Negev. The aeolian loess of Israel, being deposited on the desert fringe, is, therefore, a very sensitive indicator of past climatic changes. These will be discussed in detail later. It seems that the loess in the northwestern Negev was accumulated during the dry interpluvial periods, and during the humid pluvial phases it turned into soils, whereas the loess in the Central Negev, which is more to the south and much more arid, was accumulated only during humid phases and is, at present, wind deflated (Horowitz 1974, 1976a).

LACUSTRINE SEDIMENTS

Lacustrine sediments of Preglacial Pleistocene age are unknown in Israel. Except for some short periods in which wide floodplains of the HaMeshar and Bethlehem drainage systems locally turned into lakes, no limnic occurrences are known from this period. The succeeding Levantine faulting, which created the endoreic Jordan–Dead Sea–Arȧva Rift Valley in the transition from Preglacial to Glacial Pleistocene times, furnished suitable conditions for the formation of lakes in this area. Lakes occupied the Jordan–Dead Sea Rift Valley throughout its entire history, persisting until the present. Three subbasins were formed (Figure 5.90) within the Jordan Valley, in which the subsidence is much more pronounced than in the rest of the valley (Horowitz 1968a, 1973, 1974; Picard 1932, 1943, 1965). Groups of sedimentary formations of Glacial Pleistocene age were accumulated in each of these three subbasins. These subbasins are also quite conspicuous on the residual gravity map (Y. Folkman, Institute for Petroleum Research and Geophysics, personal communication, 1973). Subsidence was almost continuous in the subbasins throughout the entire Glacial Pleistocene, but two phases of tectonic activity are much more pronounced, one in the middle of the Glacial Pleistocene (Picard 1943) and another near its termination, about 18,000 years ago (Neev and Emery 1967). The deepest of the subbasins is the Dead Sea Basin, in which the Glacial Pleistocene deposits attain more than 2 km in thickness (Horowitz 1968b). This seems to be an inheritance of Pliocene times, in which several kilometers of sediments were accumulated in the same area (Zak 1967). The second deepest is the Hula Basin, in which 1700 m of Glacial Pleistocene sediments were encountered (Horowitz 1973; Yuval 1967), and the third is the Central Jordan Valley Basin, south of the present Lake Kinneret, in which several hundred meters of correlative deposits were encountered (Picard and Baida 1966). In most other areas of the Jordan Valley, almost no Glacial Pleistocene deposits have been accumulated except for a thin veneer of late Pleistocene lacustrine sediments of the Lisan Formation, which in most cases directly overlies Neogene or older rocks (Schulman and Rosenthal 1968). Some basaltic flows are known to be intercalated with the lacustrine sediments of the three subbasins, and these are discussed in detail under "Volcanic Rocks." The Glacial Pleistocene rocks that were formed within the Hula Basin were designated by Horowitz (1973) as the Hula Group. The rocks that accumulated in the Central Jordan Valley Basin have been termed by Horowitz (1974) the Jordan Group, and those known from the Dead Sea area were considered by Neev and Emery (1967) as the Upper Dead Sea Group. Most of the lacustrine sediments grade laterally into fluviatile gravel horizons, discussed earlier. Some of the formations interfinger with travertines and other spring deposits discussed further on.

THE HULA GROUP

The Hula Group comprises an asymmetric plano-convex lens-shaped body (Figure 5.91) that occupies the continuously subsiding Hula Basin. The upper part of the lens is about 25 km long, 6–7 km wide (Figure 5.92). The maximum thickness was encountered during a geophysical survey in the southern sector of the Basin, near the northern shore of the now artificially drained Hula Lake. Borehole Hula I penetrated about 600 m of lateral fluviatile equivalent of the Hula Group at the north of the Basin, near Bet Hillel, and Borehole Emek Hula I encountered 450 m of the Hula Group lacustrine sediments at the center of Lake Hula. Correlations with outcrops of the formations penetrated by Emek Hula I show that it encountered only the upper part of the Hula Group. The

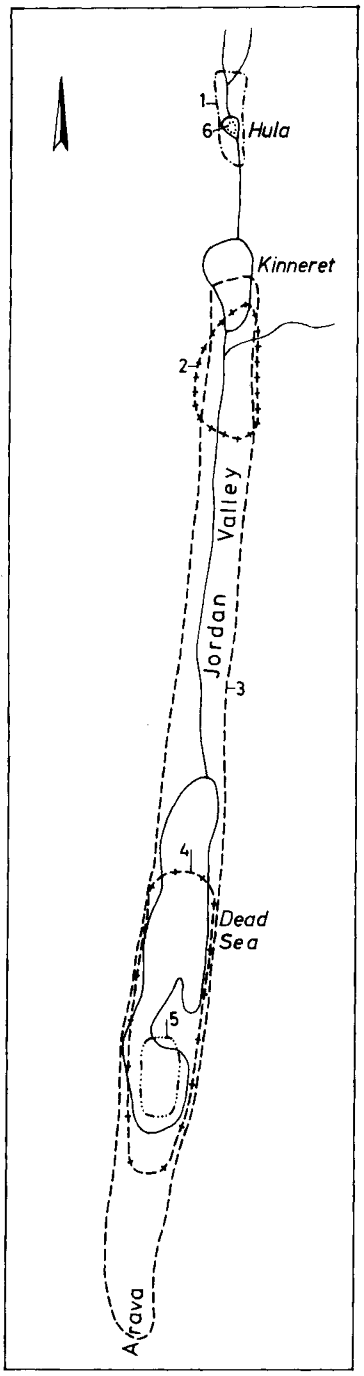


FIGURE 5.90. *The Glacial Pleistocene lakes of the Jordan Valley: 1, maximum extension of the Hula Lake in pluvial times; 2, approximate area of the Erk el-Ahmar and Ubeidiya lakes; 3, maximum extension of the Lisan Lake (to the south, the extension of former pluvial lakes of the Dead Sea Basin); 4, area of maximum subsidence in the Dead Sea Basin; 5, approximate minimum extension of interpluvial lakes of the Dead Sea Basin; 6, approximate minimum extension of interpluvial lakes and peat bogs in the Hula Basin.*

lower part is exposed on the elevated block of Gadot-Korazim, south of the Hula Valley proper, and most probably accounts for at least another kilometer of sediments in the central part of the Basin (Horowitz 1973).

The Hula Group overlies the Preglacial Pleistocene Cover Basalt, and in some localities the Pliocene and older rocks, over a taphrogenic and erosional relief. The known sediments of the Hula Group were all laid down in a shallow freshwater environment, which was either a shallow lake in which chalk was deposited together with marls and clays rich in organic material or a paludine environment that deposited peat and organic sediments. Most of the sediments are very rich in shallow-water mollusks (Tchernov 1973). It is presumed that this shallow basin character existed from the beginning of the deposition of the Hula Group through the present, compensated by a slow, continuous isostatic subsidence. Some minor volcanic eruptions and some stronger subsidence phases are discernible. The distribution of the Hula Group formations is confined to the Hula Valley and never extended much beyond its limits. The Korazim-Gadot elevated block acted as a barrier to the south since times of deposition of the lower part of the Hula Group and still does so today. To the north, the Hula Basin is bordered by the elevated block system of Metulla-Marj Ayyun, to the east by the elevated Golan Plateau, and to the west by the elevated Naftali Mountains.

The lower formations of the Hula Group were never penetrated by boreholes, and only their thin lateral parts are exposed at the Gesher-Benot Ya'akov area. The upper part was penetrated by boreholes and was also studied in much more detail from outcrops. The outcrop at Gesher-Benot Ya'akov is the result of tectonic movements of a very small block, about 1 by 5 km, which is presently a downthrown block between the blocks of Korazim-Gadot to the west and the Golan Plateau to the east. Less than 4500 years ago (radiocarbon date by I. Carmi, Weizmann Institute for Science, *in letteris,* 1970), this block was somewhat uplifted, which brought to light some of the buried strata, but it still remained downthrown in comparison to its neighbors. Studies of the Hula Group were carried out by Picard (1952, 1963, 1965) based on analyses of a series of boreholes drilled to a depth of 120 m in the Hula Valley (Grader 1952) and on analyses of the Gesher-Benot Ya'akov outcrop. The upper 120 m of the Hula Group were considered by Picard to be representative of the entire Pleistocene. Palynological analyses and radiocarbon datings (Horowitz 1969, 1971) proved that the sequence represents only the late Pleistocene, from Riss-Würm Interpluvial through Recent. Cowgill (1969), in a study of Lake Hula, presented analyses of a 54-m-long core, but, except for some new radiocarbon dates that only help to confirm previous ones, her findings do not add much to that already known. Picard (1963) summarized the stratigraphy of the Gesher-Benot Ya'akov

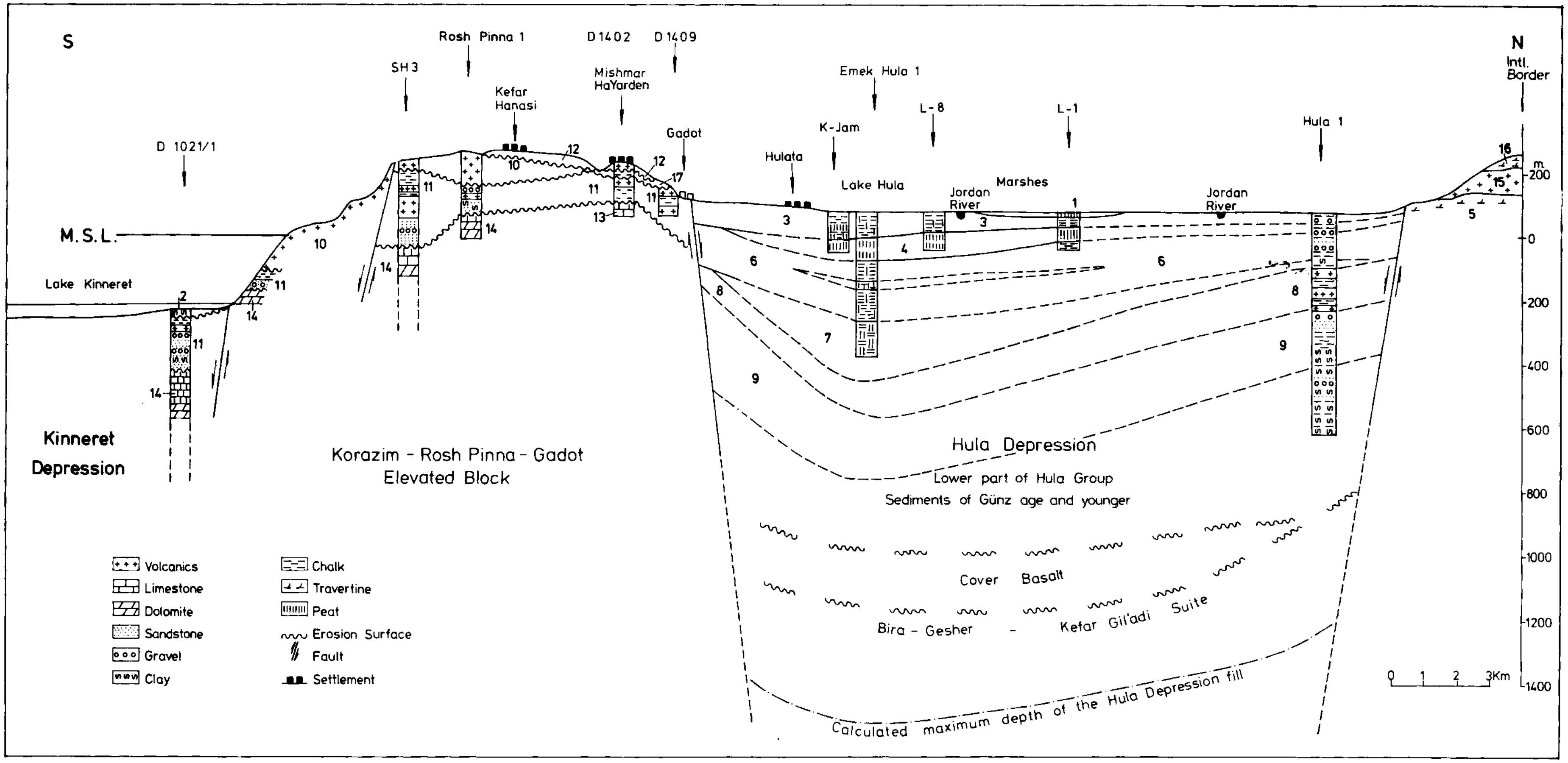


FIGURE 5.91. *Longitudinal cross section of the Northern Jordan Valley: 1, Mallaha Formation; 2, Tabgha Formation; 3, Ashmura Formation; 4, Hulata Formation; 5, Kefar Yuval Travertine; 6, Benot Ya'akov Formation; 7, Ayyelet HaShahar Formation; 8, Upper Mishmar HaYarden Formation, interfingering with Yarda Basalt; 9, Lower Mishmar HaYarden Formation; 10, Cover Basalt; 11, Bira Series and Intermediate Basalt; 12, Yarda Basalt; 13, Eocene limestones; 14, Cenomanian–Turonian Formations; 15, Hasbani Basalt; 16, Dan Travertine; 17, Gadot Formation. (From Horowitz 1973.)*

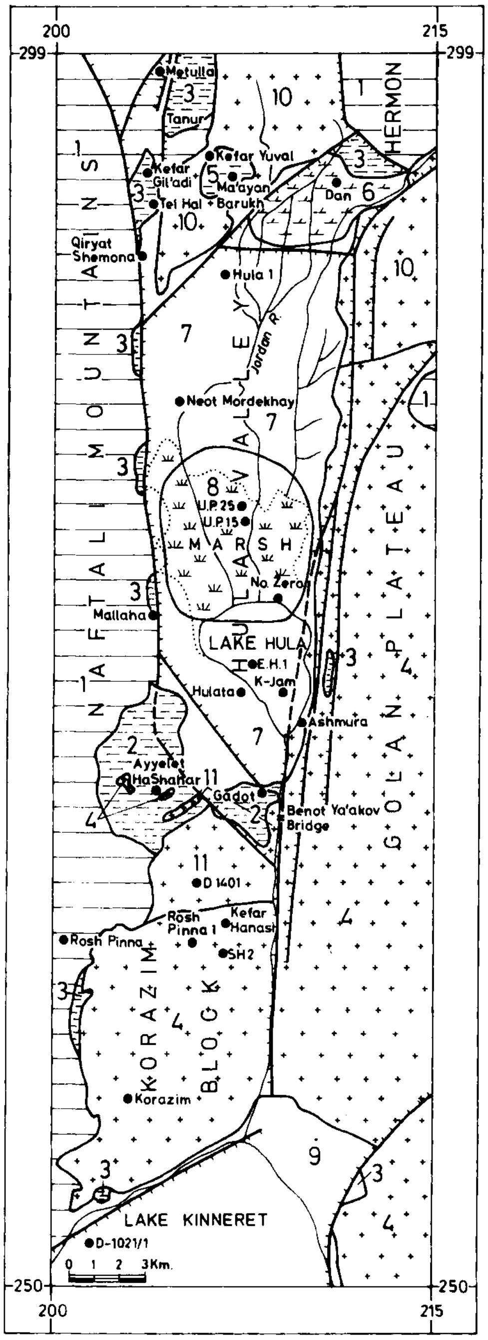


FIGURE 5.92. *General geological map of the Hula Valley: 1, Pre-Neogene Formations; 2, Gadot ormation; 3, Bira Series (Pliocene); 4, Cover Basalt; 5, Kefar Yuval Travertine; 6, Dan Travertine; 7, Ashmura Formation; 8, Approximate extension of the Mallaha peat bogs; 9, Tabgha Formation; 10, Hasbani Basalt; 11, Yarda Basalt. (From Horowitz 1973.)*

outcrop, indicating tilted strata, which he correlated with the Ubeidiya Formation of the Central Jordan Valley. These strata are unconformably overlain by strata about 7 m thick, which Picard thought to be ancient Jordan terraces, and to which he attributed "Acheulian through Levalloisian" age. Following recent heavy machinery intrusions in the area, much more of the outcrop has become visible, and some modifications were made to Picard's descriptions by Horowitz (1973). Schulman (1967) made some comments on Picard's (1963) stratigraphy of the volcanic rocks on the Korazim-Gadot Block. The details will be discussed for each of the formations separately.

Gadot Formation and Hazor Gravel

The Gadot Formation and Hazor Gravel, interfingering with each other (Figure 5.93), were defined by Picard (1952) in the vicinity of the Gadot–Ayyelet HaShahar–Mahanayim area. Picard called this formation the "Gadot Chalk." The type section, near Kibbutz Gadot, comprises about 25–30 m of white to buff lacustrine chalk (Figure 5.94), in which some rare melanopsids were found. Pollen grains are rather scarce in these sediments, but the obtained spectra indicate a pluvial climate, discussed in detail in Chapter 6. The Gadot Formation is observed in the southern sector of the Hula Valley, from about the southern end of the former Hula Lake south to the main road leading from Rosh Pinna to Gesher-Benot Ya'akov.

FIGURE 5.93. *Interfingering of Gadot Formation chalk and Hazor Gravel, near Tel-Hazor.*

FIGURE 5.94. *The Gadot Formation chalk, at Kibbutz Ayyelet Ha-Shahar.*

The Gadot Formation overlies the Preglacial Pleistocene Cover Basalt on an erosional and taphrogenic unconformity. The contact is quite clear near Ayyelet HaShahar; the sequence was also penetrated by several boreholes (Fleischer 1968). The Gadot Formation is overlain in the Gesher-Benot Ya'akov area by a paleosol horizon about 2 m thick, over which the Mishmar HaYarden Formation rests. Elsewhere, whenever it is not exposed, it is covered by flows of the Yarda Basalt, which fill an erosional relief cut quite deeply into the Gadot Formation chalk (Figure 5.95). As a result, it seems sometimes that the Gadot Formation overlies the Yarda Basalt. This situation was, in fact, described by both Picard (1963) and Schulman (1967). Horowitz (1973) proved that the Yarda Basalt overlies the Gadot Formation chalk and has shown the nature of contact between the two. It should be noted that the Yarda Basalt is much younger than the Gadot Formation and also overlies the Mishmar HaYarden Formation at the Benot Ya'akov outcrop. The Gadot Formation chalk grades laterally to the west to the Hazor Gravel. The Hazor Gravel (Figure 5.77) comprises rather coarse conglomerates deposited by a river leading to the lake in which the Gadot Formation was deposited. At Tel Hazor, the Hazor Gravel is overlain by the Yarda Basalt (Picard 1965). The Gadot Formation chalk, while cropping out, is covered by a rather thick nari (calcrete) crust that sometimes forms small caves and rock shelters. No artifacts or vertebrate remains are known from the Gadot Formation or the Hazor Gravel.

Picard (1963), based on the opinion that the Gadot Formation overlies the Yarda Basalt, correlated the Gadot with the Würmian Lisan Formation of the Central and Southern Jordan Valley. Schulman (1967) observed that the Gadot Formation is sandwiched between two basalt sheets, and therefore he correlated it with the Ubeidiya Formation of the Central Jordan Valley. Horowitz (1973) showed that the Ubeidiya Formation should be correlated with the Mishmar HaYarden Formation and that the Gadot Formation should be correlated with the Erk el-Ahmar Formation of the Central Jordan Valley, presumably of Günzian age. The Gadot Formation represents the first pluvial lake that occupied the Hula Basin at the beginning of Glacial Pleistocene times. The lake extended beyond the present-day Basin limits, and it seems from the type of sediments that it was several tens of meters deep, most probably deepening toward the central part of the Basin, which is presently buried under the rest of the Hula Group. The Gadot Formation, together with the overlying Mishmar HaYarden Formation, was affected by the Middle Pleistocene faulting phase of the Jordan Valley.

FIGURE 5.95. *Gadot Formation chalk overlain by Yarda Basalt, near Kibbutz Gadot.*

Mishmar HaYarden Formation

The Mishmar HaYarden Formation (Figure 5.96) was designated by Horowitz (1973) in an outcrop just north of the bridge at Gesher-Benot Ya'akov that crosses the Jordan River south of the Hula Valley. These beds are called in Picard (1963, 1965) the "Tilted Freshwater Series." The type section near the bridge at Gesher-Benot Ya'akov comprises several meters of lacustrine chalks and marls, very rich in mollusks and vertebrate remains. The top

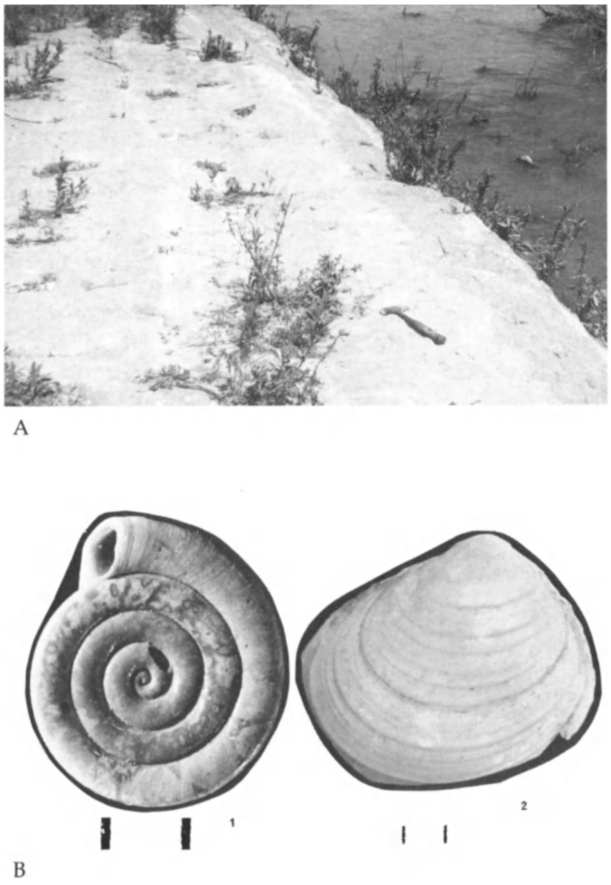


FIGURE 5.96. *A, The lower, chalky part of the Mishmar HaYarden Formation at the Gesher Benot Ya'akov outcrop, lying almost vertically; B, Mollusks from the Mishmar HaYarden Formation: 1,* Anisus spirorbis; *2,* Pisidium casertanum. *Scale: 1 mm. (Courtesy of E. Tchernov, Department of Zoology, the Hebrew University of Jerusalem.)*

layer comprises about 30–40 cm of peat. The Mishmar HaYarden Formation is known only from this locality but most probably underlies the upper part of the Hula Group in the Hula Basin. Among the vertebrate remains, *Hippopotamus* is the most common. The rest of the bone material has not yet been identified. Among the rich mollusk fauna, the following species were identified by Tchernov (1973): *Theodoxus jordani, Valvata saulcyi, Bulimus hawaderiana, Melanopsis praemorsa, Lymnaea lagotis, L. palustris, Planorbis planorbis, Gyraulus piscinarum, Anisus spirorbis, Segmentina nitidae, Ancylus fluviatilis, Succinea pfeifferi, Pisidium casertanum,* and *Unio terminalis.* Several artifacts were found in the Mishmar HaYarden Formation. Although the conclusions are uncertain for this assemblage, it generally corresponds to the assemblages known from the site of Ubeidiya in the Central Jordan Valley (O. Bar-Yosef, Department of Archaeology, Hebrew University of Jerusalem, personal communication, 1971; Stekelis 1966). Nir and Bar-Yosef (1976), however, have had reservations about this attribution of the artifacts. Pollen analyses of samples collected from the outcrop of Mishmar HaYarden Formation, discussed in detail in Chapter 6, show a prevalence of oak grains, which make up about 75% of the total pollen counted. This is definitely a pluvial pollen spectrum.

The Mishmar HaYarden Formation overlies at the Benot Ya'akov outcrop a reddish-brown clay (Figure 5.97), most probably a paleosol, about 2 m thick, which overlies the Gadot Formation. It is covered by a basalt sheet of Yarda Basalt (Figure 5.98). The sequence is strongly tilted, from 45° to 90°, and only the base and lower part of the formation crop out. Its upper part is buried due to faulting and was also most probably eroded prior to the onset of the Yarda Basalt sheet. The Mishmar HaYarden Formation was deposited by the second pluvial lake of Glacial Pleistocene age in the Hula Basin. Its correlation with the Ubeidiya Formation is accepted by Horowitz (1973), Picard (1963), and Tchernov (1973). Picard (1963) regards the age of these strata as "Villafranchian," but as it was thought at that time that the Ubeidiya deposits (Stekelis *et al.* 1960) were also "Villafranchian," this is not surprising. Tchernov (1973) and Horowitz (1973) suggested a Mindel age for the Mishmar HaYarden Formation, corresponding to the accepted age of the Ubeidiya Formation (Bar-Yosef and Tchernov 1972). The radiogenic age for the overlying sheet of the Yarda Basalt is 640,000 ± 120,000 years B.P., which gives the Mishmar HaYarden Formation a somewhat older age (Horowitz *et al.* 1973).

FIGURE 5.97. *The paleosol at Gesher Benot Ya'akov, separating the Gadot chalk (left) from the Mishmar HaYarden Formation (right).*

FIGURE 5.98. *The upper, peaty part of the Mishmar HaYarden Formation, overlain by Yarda Basalt, both tilted, at the Gesher Benot Ya'akov outcrop.*

Ayyelet HaShahar Formation

The Ayyelet HaShahar Formation was named by Horowitz (1973) from the Emek Hula I borehole (Figure 5.91) by its total depth, 455 m up to 340 m. The formation is known only from this borehole; its base was not penetrated and is unknown. At the type locality, the lithology is for the most part highly organic chalk, grading frequently into peat. The known thickness is 115 m, but it was assumed to be approximately 200–250 m, probably maintaining the same lithologic characteristics throughout. The Ayyelet HaShahar Formation most probably overlies the Yarda Basalt, but, if the basalt flow has not reached the center of the Hula Basin, as might be the case, this Formation most likely overlies the Mishmar HaYarden Formation. This Formation is overlain, conformably, it is assumed, by the Benot Ya'akov Formation at the Emek Hula I Borehole. Some of the conglomerates penetrated by the Hula I and Ne'ot Mordekhay Boreholes, to the north of the Hula Basin, are probably lateral time equivalents of the Ayyelet HaShahar Formation. No part of this Formation crops out in the Benot Ya'akov area or elsewhere. The Ayyelet HaShahar Formation contains some mollusks that have not yet been identified. Most of them, however, are melanopsids, *Melania* and *Theodoxus.* Pollen analyses of the Formation, discussed in detail in Chapter 6, show a rather low arboreal pollen share, less than 20%, shared by oak and olive, with a very small amount of pistachio. The prevailing elements are pollen from marsh vegetation, Gramineae and Cyperaceae. This assemblage is typical of an interpluvial stage. No other fossils are known for the Formation. The restricted distribution and lithological characteristics of the Ayyelet HaShahar Formation indicate that it was deposited in times of shrinkage of Lake Hula, which remained only as marsh depositing organic sediments under interpluvial climatic conditions.

The tectonic position of the Formation is not clear. At Benot Ya'akov, the underlying Mishmar HaYarden Formation is severely faulted, whereas the unconformably overlying Benot Ya'akov Formation is only weakly tilted. The tectonic movement that caused the faulting of the Mishmar HaYarden Formation and the Yarda Basalt could have occurred sometime during the deposition of the Ayyelet HaShahar Formation. No signs of unconformity were discerned within the penetrated sector of the Emek Hula I borehole. This may either be because of poor sampling or because the fault occurred during deposition of an earlier as yet unpenetrated sector of the formation or because the borehole was drilled in the middle of the basin, far from the main faultline. Horowitz (1973) assumed the age of the Ayyelet HaShahar Formation to be of Mindel–Riss Interpluvial times, based on its interpluvial palynological characteristics and on its being sandwiched between the Mindel Mishmar HaYarden Formation and the Rissian Ya'akov Formation. The Ayyelet HaShahar Formation probably overlies stratigraphically the Yarda Basalt and is, therefore, younger than 640,000 years, the radiogenic age obtained for that lava (Horowitz *et al.* 1973).

Benot Ya'akov Formation

The Benot Ya'akov Formation was named by Horowitz (1973) from the Emek Hula I borehole (Figure 5.91), where the sequence is fully developed. It extends from a depth of 340 m up to 155 m. A lateral, very restricted sequence of this formation crops out along the Jordan River from the Hula Valley down to Gesher-Benot Ya'akov and was called by Picard (1943, 1952) the *Viviparus* beds, due to its rich malacofauna, comprising mainly *V. apameae* (Figure 5.99). The sequence at Emek Hula I borehole consists mostly of limnic chalk, very rich in mollusk remains, of which *Viviparus apameae* forms a major constituent. At a depth of 215–235 m, there is a horizon particularly rich in organic material. The formation extends from the bridge at Gesher-Benot Ya'akov north into the Hula Valley, and its upper part was penetrated by many boreholes drilled in the Hula Basin. The upper part was named by Picard (1952) the "Lower Lacustrine Series." About 3–5 m of the littoral facies of the Benot Ya'akov Formation at the Gesher-Benot Ya'akov area were described by Picard (1963) as terraces of the Jordan River. The sediments there comprise very coarse littoral conglomerates, merging northward into limnic chalk bearing enormous quantities of *Viviparus* shells. The strata also contain some other mollusks, of which the most abundant are (Tchernov 1973) *Valvata saulcyi, Bythinella* sp., *Bulimus hawaderiana, Melanopsis praemorsa,* and *Pisidium casertanum;* less frequent are *Theodoxus jordani, Lymnaea lagotis, Gyraulus piscinarum,* and *Unio terminalis.* The outcrop at Gesher Benot Ya'akov yielded rich vertebrate fauna, described in detail in Hooijer (1959, 1960). These comprise bones and teeth of *Elephas trogontherii, Equus* cf. *caballus, Dicerorhinus merckii, Sus* cf. *scrofa, Hippopotamus amphibius, Dama* cf. *mesopotamica, Cervus* cf. *elaphus,* cf. *Bison priscus,* and *Stegodon mediterraneus.* This outcrop also yeilded rich assemblages of implements made both of flint and basalt (Stekelis 1960). The handaxe assemblage was defined by Gilead (1970) as of Late Acheulian industry.

Pollen spectra of the Benot Ya'akov Formation, both from the Emek Hula I borehole and from samples collected from the outcrop, are discussed in detail in Chapter 6. They show some 40–50% of arboreal pollen, almost

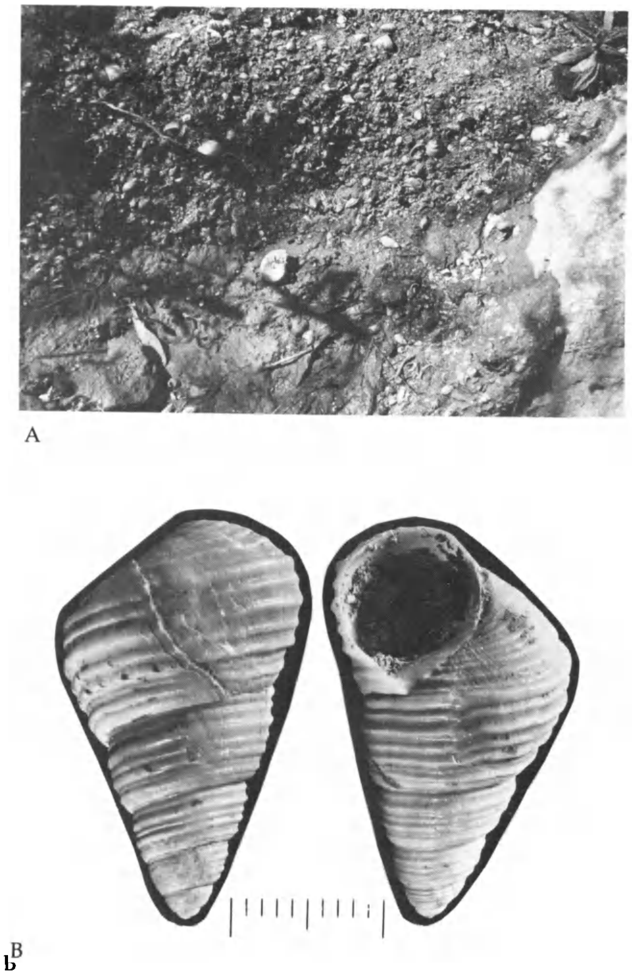


FIGURE 5.99. *A, The Benot Ya'akov Formation, with its rich malacofauna at the Gesher Benot Ya'akov outcrop; B,* Viviparus apameae *(scale 10 mm) from the Benot Ya'akov Formation. (Courtesy of E. Tchernov, Department of Zoology, the Hebrew University of Jerusalem.)*

entirely derived from oaks. Typical, although appearing only in small quantities in this formation, are pollen of *Fagus*, which appear in correlative sediments down to the Dead Sea area. The nonarboreal pollen spectrum is rather rich in number of species, indicating a well-developed field vegetation in addition to marsh vegetation and forest. The pollen spectra indicate a pluvial climate for the time of deposition of this formation, with an interstadial recorded in the Emek Hula I borehole from 315 up to 270 m. The interstadial is characterized by a drop in arboreal pollen and an increase in pollen of Gramineae and Cyperaceae, and also by a higher percentage of organic material in the sediments. The organic materials are from marches, which were closer to the center of the Basin. This was probably caused by shrinkage of the lake during the drier interstadial phase. Ehrlich (1973) analyzed the diatoms (Figure 5.105) at the top of the Benot Ya'akov Formation penetrated by Borehole L-7, at a depth of 100.75 up to 107.5 m, drilled at the northern end of the Hula Lake. She defined the diatom assemblage as the eco-stratigraphic unit *Stephanodiscus astraea* Zone (H5). This zone is characterized by an abundant freshwater flora with the following dominant planktonic species: *Cyclotella kutzingiana, Melosira ambigua, Stephanodiscus astraea,* and *Fragilaria* spp. Accessory benthonic species are usually present: *Navicula menisculus, N. pupula, Stauroneis smithii, Cymatopleura solea, C. elliptica, Surirella biseriata, S. capronii,* and others. Zone H5 seems to represent the uppermost stage of a fairly deep alkaline lake (Ehrlich 1973). It should be noted that this assemblage defines only an eco-stratigraphic unit of local significance and cannot serve for correlations with other assemblages, such as those collected from Birket Ram (Ehrlich and Singer 1976).

The Benot Ya'akov Formation overlies the Ayyelet HaShahar Formation in the Emek Hula I borehole, most probably conformably. At the Gesher–Benot Ya'akov outcrop, the Benot Ya'akov Formation overlies tilted strata of the Mishmar HaYarden Formation and the Yarda Basalt, over a base conglomerate (Figure 5.100). The top of the Mishmar HaYarden Formation at the outcrop is covered by a conglomerate, over which the Würmian Ashmura Formation lies unconformably. In Emek Hula I borehole, however, the Benot Ya'akov Formation is conformably overlain by the Hulata Formation. The Benot Ya'akov Formation grades laterally to the south into conglomerates, most probably deposited by rivers that approached the Benot Ya'akov Lake. It most likely behaves in the same manner to the north, and some of the conglomerates penetrated by boreholes drilled in the northern part of the Hula Valley seem to be time equivalents of this formation. Further north, these conglomerates interfinger with spring deposits of the Kefar Yuval Travertine, discussed further on. The lower and upper parts of the Benot Ya'akov Formation have been deposited in a lake that extended beyond the limits of the present-day Hula Lake. The middle part of the formation was deposited in a very restricted lake or in marshes during an interstadial, drier phase.

FIGURE 5.100. *Base conglomerate of the Benot Ya'akov Formation (right), overlying tilted Yarda Basalt.*

Picard (1952) considered the *Viviparus* beds to be of Mindel age because they overlie the presumably "Villafranchian" earlier deposits. Hooijer (1959, 1960) assigned a Mindel–Riss Interpluvial age to the deposits by comparison of their vertebrate fauna with the interpluvial fauna of the Orontes Valley, some 300 km north of the Gesher–Benot Ya'akov site. Horowitz (1973) assigned a Rissian age to these sediments, which was confirmed by Tchernov (1973). This dating is based mainly on the stratigraphic and paleoclimatic situation of the Benot Ya'akov Formation, being the second older formation of pluvial characteristics penetrated below the surface in the Hula Valley. Hooijer's assumption (1959) was rejected because one cannot assign an interpluvial or an interglacial affinity to sediments in Israel in comparison with European fauna. The climates that prevailed in Europe in interglacial times, giving place to the typical European interglacial faunal assemblages, are probably comparable to those prevailing in Israel in pluvial times, whereas during the dry and warm interpluvials the country suffered a semiarid climate that could not maintain these faunal elements. The Benot Ya'akov Formation unconformably overlies the Yarda Basalt, which yielded a radiogenic age of 640,000 years (Horowitz *et al.* 1973). Its lateral equivalent, the Kefar Yuval Travertine, is overlain by the Hasbani Basalt, which yielded ages in the range of 70,000–80,000 years (Siedner and Horowitz 1974). These dates put a limit to the radiogenic age of the Benot Ya'akov Formation, but it seems that the age must lie in the earlier part of the range, since it is likely that the Ayyelet HaShahar Formation separates the Yarda Basalt and the Benot Ya'akov Formation stratigraphically.

Hulata Formation

The Hulata Formation was defined by Horowitz (1973) from the Number 0 First Test borehole, drilled at the northern border of the Hula Lake. The same sequence was defined in Picard (1952) as the "Main Peat." The sequence (Figure 5.91) at the type locality comprises 54 m, of which the lower 20 m and the upper 19 m consist of massive peat. The middle 15 m consist mainly of peat, with some limnic chalk intercalations. No fauna was recovered from this formation, except for some sponge spicules (Ehrlich 1973). Pollen analyses of the Hulata Formation are discussed in detail in Chapter 6, from the K-Jam and the Emek Hula I boreholes. They are characterized by the extreme paucity of arboreal pollen and the almost total predominance of marsh vegetation pollen, Gramineae and Cyperaceae. These indicate a dry interpluvial climate, probably unable to maintain forest vegetation, which as a result degenerated into a poor Mediterranean maquis on the surrounding mountains. Plant microfossils other than pollen comprise quite rich assemblages of Chrysostomataceae cysts and phytoliths.

The diatom content (Figure 5.105) of the samples from the Hulata Formation (Ehrlich 1973) is generally low to very low and comprises the ecostratigraphic *Epithemia* Zone (H4). The zone is characterized by dominant epiphytic species, such as *Epithemia turgida, E. zebra, E. sorex, Cocconeis placentula,* and *Opephora martyi,* and by benthonic–planktonic forms, such as *Melosira arenaria, Fragilaria construens,* and *Pinnularia viridis. Melosira turgida* is common in most of the samples. These diatom species usually occur together, but one of them highly exceeds the others in number along a short interval, then is replaced by another species, which in its turn is replaced by a third, and so on. Other benthonic and epiphytic forms occur irregularly in small quantities throughout the zone. The most frequent of these are *Fragilaria intermedia, Gyrosigma attenuatum, Cymbella ehrenbergii, Gomphonema constrictuum, G. parvulum, G. intricatum, Navicula perrotettii, Synedra ulna,* and *Amphora ovalis.* The high percentage of epiphytic diatoms in this zone and the abundance of Chrysostomataceae cysts and phytoliths are indicators of a very shallow, eutrophic water environment. Deposition, according to Ehrlich (1973), occurred under alkaline conditions in a shallow marsh invaded by aquatic plants. The Hulata Formation thins out to the north but thickens to the south and somewhat also to the east, toward the deeper part of the Basin, where the share of limnic chalk in its sequence increases. The thickest sequence, about 75 m, was encountered in Emek Hula I borehole. The type section, however, was proposed at the locality where the peat is best developed. No outcrops of the formation are known, and its subsurface distribution within the Valley is rather limited.

FIGURE 5.101. *Lateral conglomerates of the Hulata Formation (left), overlain by the Ashmura Formation over a base conglomerate.*

A rather thin conglomerate horizon (Figure 5.101), about 1 m thick, consisting mostly of flint pebbles, is exposed at the Benot Ya'akov area, separating the upper conglomerate of the Benot Ya'akov Formation from the base conglomerate of the overlying Ashmura Formation. This conglomerate may represent a lateral equivalent of the Hulata Formation. In the center of the Hula Basin, where the Hulata is best developed, it overlies conformably the Benot Ya'akov Formation and is, in turn, conformably overlain by the Ashmura Formation. Toward the margins of the basin, however, hiata between the Hulata and the underlying and overlying formations occur until the Hulata totally disappears, leaving the Ashmura Formation to overlie the Benot Ya'akov Formation directly. The pollen spectra and the highly organic nature of the sediments point toward shallow marshes as the environment of deposition for the Hulata. This is also verified by the diatom assemblages. The former Benot Ya'akov Lake shrank to become the marshes in which the Hulata Formation was deposited. The pollen spectra indicate an interpluvial climate for deposition of the Hulata, and Horowitz (1971) assigned it to the Riss–Würm Interpluvial. The Hula Valley at this time was partly covered by marshes in which Gramineae, Cyperaceae, and Compositae, most probably *Inula viscosa,* grew. The mountainous vegetation was rather poor, comprising scattered stands of oak, pistachio, cypress, and olive trees.

Ashmura Formation

The Ashmura Formation was designated by Horowitz (1973) as encompassing the uppermost 80 m of Emek Hula I borehole. The sequence was called by Picard (1952) the "Upper Lacustrine Series." The type section comprises white to gray limnic chalk, almost barren of mollusk remains, except for the upper few meters. The upper part of the Ashmura Formation yielded quite rich malacological assemblages (Tchernov 1973) comprising *Theodoxus jordani, Valvata saulcyi, Bythinella* sp., *Bulimus hawaderiana, Melanopsis praemorsa, Melanoides tuberculata, Lymnaea lagotis, Gyraulus piscinarum, Ancylus fluviatilis, Succinea pfeifferi, Pisidium casertanum, Unio terminalis, Sphaerium* sp., and *Corbicula fluminalis.*

Pollen analyses of the Ashmura Formation indicate that it was deposited during three pluvial phases separated by two interstadials, for its major part, whereas the uppermost part represents the interpluvial conditions of the Holocene, with a short semipluvial phase of the Atlantic. Analyses of the diatom (Figure 5.105) assemblages (Ehrlich 1973) indicate that the limnic chalks are typified by the *Cyclotella kutzingiana* eco-stratigraphic zone (H3). This zone is characterized by a very abundant diatom flora. The dominant species are *Cyclotella kutzingiana, C. kutzingiana* var. *planetophora, Melosira ambigua,* and *M. granulata.* Benthonic diatoms are accessory to the planktonic forms, and the most frequent are *Navicula menisculus, Stauroneis smithii, Nitzschia angustata, Surirella* spp., *Cymatopleura* spp., *Fragilaria construens,* and others. Epiphytic forms are fairly rare. This assemblage was encountered from the uppermost part of the Ashmura Formation penetrated by the lower part of UP-6 Borehole. In the K-Jam borehole, this zone differs slightly from the type zone. The upper part is fairly characteristic, whereas, below it, there is a sudden decrease both in the total number of diatoms as well as in the typical flora, including a complete absence of *Cyclotella kutzingiana,* whereas *Melosira granulata* dominates. Epiphytic diatoms do not occur. Ehrlich notes that the diatom assemblage of the *Cyclotella kutzingiana* zone bears a great similarity to that of the *Stephanodiscus astraea* zone, which is typical for the Benot Ya'akov Formation. The same planktonic species predominate, accompanied by the same accessory benthonic forms. She concludes that the sediments were deposited in a fairly deep freshwater lake under alkaline conditions similar to those that prevailed during deposition of the Benot Ya'akov Formation. The peaty and highly organic layers of the Ashmura Formation are characterized by the *Epithemia* eco-stratigraphic zone, same as the comparable deposits of the Hulata Formation.

The uppermost part of the Ashmura Formation, which was penetrated by boreholes drilled in the north of the Hula Lake area, yielded diatom assemblages of the *Cymbella hulensis* eco-stratigraphic zone (H2). This zone is characterized by an abundant epiphytic diatom flora. The dominant species are *Cymbella hulensis* and its variety *C. h.* var. *curta, C. affinis, Cocconeis placentula,* and *Epithemia* spp. Benthonic–epiphytic diatoms are regularly associated with the dominant forms. The most frequent are *Synedra ulna, Amphora ovalis, Cymbella microcephala, Navicula gastrum, N. pupula, Gomphonema constrictum,* and *G. parvulum.* In the lower part of this eco-stratigraphic zone, *Cyclotella kutzingiana* and *Melosira ambigua* may be quite common, whereas they occur less frequently toward the top, and not at all in the uppermost part. The diatom assemblages of the *Cymbella hulensis* zone denote the progressive transition from a fairly deep lake to a shallow one, under continuous alkaline conditions.

The Ashmura Formation is known from many boreholes drilled in the Hula Basin and from outcrops along the Jordan outlet from the Hula Lake (Figure 5.102), down to the bridge at Gesher–Benot Ya'akov. It continued to be deposited in the Hula Lake up to the present, in areas where the lake still persisted in postpluvial times. The Ashmura Formation thins out toward the margin of the Basin. To the south, it was deposited on the Gadot elevated block until about 4500 years ago, when the deposition ceased abruptly due to an uplifting of this block. *Unio* and *Corbicula* shells, which appear in the uppermost part of the Ashmura Formation on the Gadot block, were radiocarbon dated at 4630 ± 60 years B.P. (I. Carmi, Weizmann Institute of Science, *in litteris* 1970). To the north, where the shrinkage of the Hula Lake began progressively during post-Atlantic times (Horowitz 1971), the Ashmura Formation has been gradually covered by the Mallaha Formation peat. The Ashmura Formation overlies conformably the Hulata Formation in the subsurface. It changes its lithological character, which is mostly limnic chalk and marls in the center of the Basin, to a much more organic facies, sometimes grading into peat toward the north of the Basin. In this area, only palynological characteristics help to define the lower contact of the Ashmura over the Hulata Formation peats. At the Gesher-Benot Ya'akov outcrops, the Ashmura Formation overlies the Benot Ya'akov Formation over a thin base conglomerate, sometimes separated from the latter by another conglomerate horizon, most probably correlative with the Hulata Formation (Figure 5.101). Further to the north, the Ashmura grades into conglomerates and paleosols, which in part interfinger with the Dan Travertine.

The Ashmura Formation was deposited in a lake that occupied the Hula Valley in Würmian through Recent times. The area occupied by the lake, and the relations between the areas of the lake and the marshes to the north, were mostly determined by the climate. During the pluvial phases the lake expanded, whereas during the interstadial and postpluvial periods the lake shrank (Fig-

FIGURE 5.102. *The Ashmura Formation, north of the Gesher Benot Ya'akov area.*

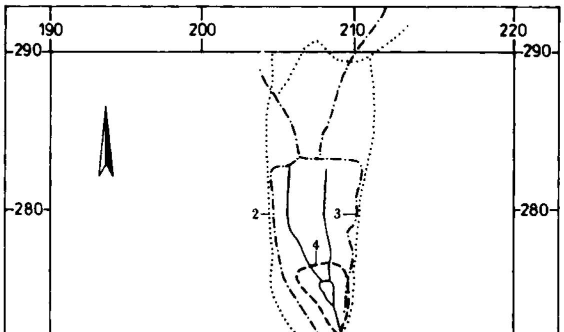


FIGURE 5.103. *Hydrography of the Kinneret and Hula regions during the Riss–Würm Interpluvial, Early and Late Würm Pluvial, showing results of the changing climates and tectonic movements: 1, Riss–Würm; 2, Early Würm; 3, Late Würm; 4, Present day.*

FIGURE 5.104. *The Mallaha Formation peat.*

ure 5.103). A radiocarbon date for a peat layer of the Ashmura Formation penetrated by Borehole K-Jam at the north of the Hula Lake, from a depth of 30 m, yielded an age of 18,800 ± 195 years B.P. (HV 1725). Calculations based on the rate of sedimentation indicate that the deposition of the Ashmura Formation began some 70,000 years ago. Artifacts that have been found within the Ashmura Formation sediments in the Gesher-Benot Ya'akov outcrop include almost an entire sequence from Mousterian through the Chalcolithic and the Early Bronze Age (O. Bar-Yosef, Department of Archaeology, Hebrew University, Jerusalem, personal communication, 1971).

Mallaha Formation

The Mallaha Formation (Figure 5.104) was defined by Horowitz (1971) at the UP-15 Borehole, drilled in the center of the marsh area north of the Hula Lake (Bein 1967). It was referred to by Picard (1952) as the "Upper Peat." At the type locality, 12.7 m of peat were penetrated. Faunal remains are quite scarce in this formation. Pollen analyses are discussed in detail in Chapter 6, indicating that the Mallaha Formation was deposited under climatic conditions that resemble those of the present, with only some minor fluctuations. The diatom assemblage (Figure 5.105) of the Mallaha (Ehrlich 1973) comprises the *Eunotia* eco-stratigraphic zone (H1). This zone is characterized by a fairly poor epiphytic diatom flora and by abundant sponge spicules, phytoliths, and Chrysostomataceae cysts. The most frequent diatom species are *Fragillaria construens*, *F. pinnata*, *Melosira arenaria*, *M. turgida*, and *Synedra ulna*. Some acidophilous forms, which are quite rare in other zones, seem to be characteristic of this zone, although they are accessory. These are *Eunotia pectinalis*, *E. valida*, *Stauroneis phoenicenteron*, and *Pinnularia viridis*. The alkalophilous *Cocconeis placentula* and *Epithemia* are lacking. The entire assemblage indicates, according to Ehrlich, a somewhat more acid environment than was observed for the underlying sedimens, The diatom assemblages indicate a very shallow eutrophic alkaline environment with a mixture of slightly acid water. Ehrlich suggests that the peat was probably deposited in a very shallow marsh, under alkaline conditions.

The Mallaha Formation overlies diachronously the Ashmura Formation in a restricted subbasin (Figure 5.92) north of the Hula Lake (Bein 1967). It has been deposited in the marsh area north of the lake up to the present. The Mallaha grades laterally to the east, west, and north into the Recent soils of the Hula Valley, whereas to the south it grades to the upper part of the Ashmura Formation, which was still deposited in the lake until its recent artificial drainage. The Mallaha Formation was deposited in a series of marshes that developed to the north of the

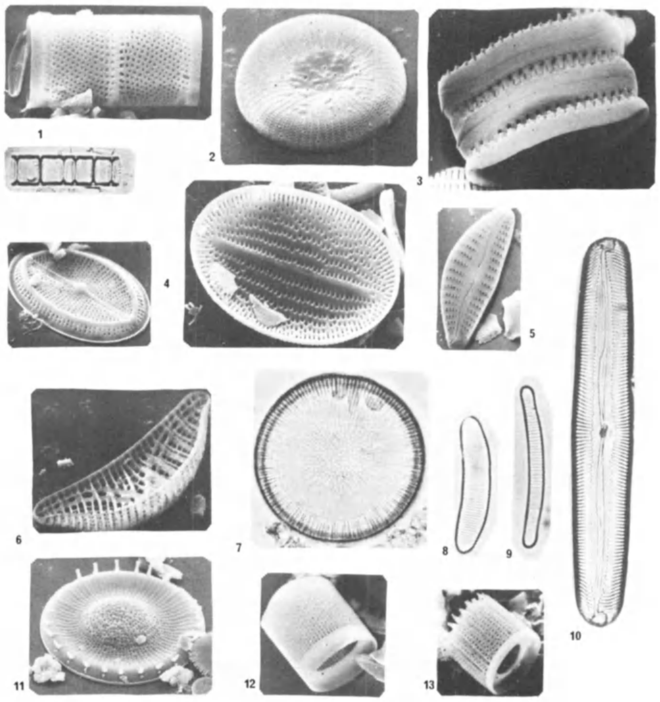


FIGURE 5.105. *Diatoms from the Hula Group: 1,* Melosira ambigua *(above: SEM ×1500; below: LM ×400); 2,* Cyclotella kutzingiana *(SEM ×2000); 3,* Fragilaria pinnata *(SEM ×2400); 4,* cocconeis placentula *(left: SEM ×480; right: SEM ×1400); 5,* Symbella hulensis *(SEM ×1100); 6,* Epithemia sorex *(SEM ×1200); 7,* Melosira arenaria *(LM ×400); 8,9,* Eunotia *spp. (LM ×400); 10,* Pinnularia viridis *(LM ×400); 11,* Stephanodiscus astraea *(SEM ×600); 12,* Melosira turgida *(SEM ×800); 13,* M. granulata *(SEM ×720). (Courtesy of A. Ehrlich. SEM photographs by M. Dvorachek, Geological Survey of Israel.)*

Hula Lake due to its shrinkage in post pluvial times. Radiocarbon dates for the Mallaha indicate that the deeper parts began to be deposited about 4500 years ago (Horowitz 1971). To the south, closer to the lake, the base of the Mallaha Formation becomes progressively younger.

JORDAN GROUP

Six formations that crop out at the Central Jordan Valley Basin were designated by Horowitz (1974) as the Jordan Group. Four of these formations were deposited in lakes, grading laterally into fluviatile conglomerates, and two are mainly of fluviatile origin. The Jordan Group overlies unconformably, over a taphrogenic relief, the Preglacial Pleistocene Cover Basalt, and it has been intermittently deposited up to the present. Many of the beds encountered within the Jordan Group yielded rich faunal, floral, and artifact assemblages, bearing witness to the antiquity of man in this area. Most of the sediments of the Jordan Group are known from outcrops that came to light due to at least two severe tectonic phases that affected them, one approximately at the middle of the Glacial Pleistocene, and the second toward its end. The Jordan Group occupies the shallowest of the Jordan–Dead Sea Rift Valley subbasins. Lakes occupied this area, depositing lacustrine and fluviatile sediments only during the more humid, pluvial periods. Intercalations of basaltic flows are known within the sequence and help to date it. The age of the Jordan Group is Glacial Pleistocene. Radiogenic (K/Ar) analyses of the upper flows of the underlying Cover Basalt reveal ages in the range of 1.7 million years (Siedner and Horowitz 1974). The overlying Jordan Group sediments are, therefore, younger and span up to the present. The Central Jordan Valley is a closed basin, and its lacustrine sediments interfinger only with conglomerates coming from the hills to the east and west. The Central Jordan Valley Basin has always acted as an intermediate for the Jordan River, which flows from the Hula Basin to the Dead Sea.

Erk el-Ahmar Formation

The Erk el-Ahmar Formation (Figure 5.106) was defined by Horowitz (1974) from the Central Jordan Valley. This sequence, of which only a single outcrop is known on the road from Gesher to Menahemya near the Jordan River, has been dealt with by many authors. Blanckenhorn (1914) was the first to describe these sedimentary rocks and, together with the Ubeidiya Formation, ascribed them to the "*Melanopsis* Stufe," of "Lower Pleistocene" age. Blanckenhorn and Oppenheim (1927) studied some of the malacofauna of this outcrop. Picard (1932) included both the Erk el-Ahmar and the Ubeidiya sequences in the "Levantinische Stufe" and studied some of the mollusk assemblages. Schulman (1959) also dealt with the two formations as a single unit. Picard (1965) reconsidered the inclusion of Erk el-Ahmar as part of the Ubeidiya Formation. U. Baida (Water Planning for Israel, Tel Aviv, personal communication, 1964) was the first to note that the outcrop at Erk el-Ahmar is different from the outcrop at the site of Ubeidiya and probably antedates it. The outcrop at Erk el-Ahmar comprises some 80–90 m of clays and marls, occasionally varved and with rare occurrences of silts and sands. The exposed sequence of the Erk el-Ahmar Formation is truncated by later erosion, and the base, except for one point, is not exposed. The exposed sequence, therefore, represents only a part of the entire formation, and the given thickness is only a minimal figure.

The Erk el-Ahmar Formation was faulted and tilted by the middle Pleistocene tectonic phase that affected the Central Jordan Valley. The strata dip from 25° to 40° to the east and disappear under the Jordan River. The formation also includes several rich mollusk-bearing strata, studied in detail by Tchernov (1975). The malacofauna comprises 18 species of mollusks, of which only 7 were also found in

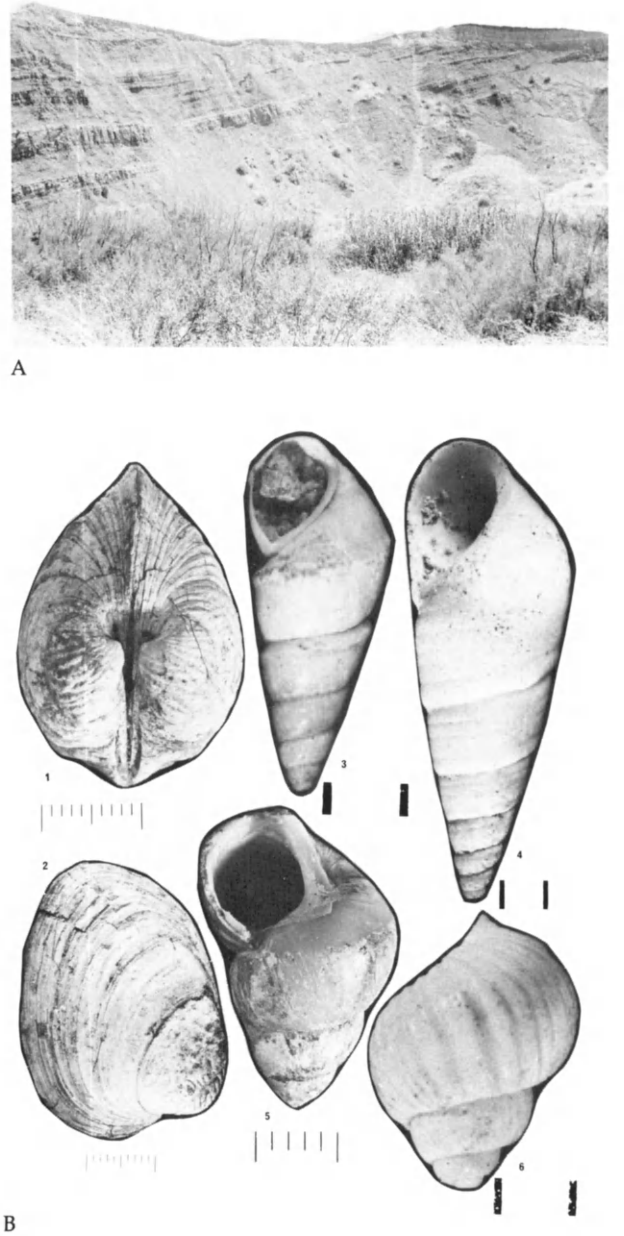


FIGURE 5.106. *A, The only outcrop of the Erk el-Ahmar Formation, capped by horizontally lying Lisan Formation sediments; B, Mollusks from the Erk el-Ahmar formation: 1,2,* Unio subrectangularis *(scale 10 mm); 3,* Falsipyrgula barroisi *(scale 1 mm); 4,* Melanoides jordanica *(scale 1 mm); 5,* Viviparus unicolor *(scale 5 mm); 6,* Bulimus costatus *(scale 1 mm). (Courtesy of E. Tchernov, Department of Zoology, the Hebrew University of Jerusalem.)*

the overlying Ubeidiya Formation. Among the species found in Erk el-Ahmar, five are extinct: *Viviparus apameae, Bythinia multicostata, Melanoides dadianas, M. jordanicus,* and *Unio subrectangularis.* Four species must have subsequently receded from Israel, since they are not found in younger deposits. Two, *Hydrobia acuta* and *Dreissena chantrei,* are characteristic of the freshwater beds of the Pliocene and have never been found in Pleistocene deposits other than the Erk el-Ahmar, and *Viviparus unicolor,* which at present inhabit the Nile system, is unique to this site in Asia. *Melanopsis doriae* is restricted to Mesopotamia. Four endemic species characterize the beds of Erk el-Ahmar: *Unio subrectangularis, Melanoides jordanicus, Bythinia multicostata,* and *Viviparus unicolor.* Only two species of pulmonates were found at Erk el-Ahmar: *Lymnaea lagotis* and *Gyraulus pscinarium.* Pollen assemblages from the Erk el-Ahmar Formation are discussed in detail in Chapter 6. They point to Glacial Pleistocene rather than to Pliocene characteristics and to pluvial climatic conditions. Recently, some artifacts were found in the Erk el-Ahmar Formation. The formation overlies the Preglacial Pleistocene Cover Basalt at the site and is uncomformably overlain by the Würman Lisan Formation. Based on the correlation proposed by U. Baida, it seems that the Ubeidiya Formation overlies the Erk el-Ahmar. No lateral equivalents of the Erk el-Ahmar Formation are known.

The Erk el-Ahmar, according to its sediments and malacological fauna, was deposited in fresh to brackish lacustrine conditions, which most probably developed in the Central Jordan Valley Subbasin after the main activity of the Levantine Fault System. The age of the Erk el-Ahmar Formation is somewhat uncertain. Most authors regarded it as correlative with the Ubeidiya Formation and assigned various ages to the sequence, from Early Middle Pleistocene to Pliocene. Baida showed that the Ubeidiya Formation overlies the Erk el-Ahmar and regarded the latter as a lower member of the Ubeidiya Formation. Tchernov (1975) proved that the malacofauna of the Erk el-Ahmar bears more ancient characteristics than that of the Ubeidiya. The same was proved true when the charophytes of both formations were analyzed (Y. Lipkin, Department of Botany, Tel-Aviv University, personal communication, 1976). Based on its fossil content, Horowitz (1974) defined the Erk el-Ahmar outcrop as a separate formation overlying the Cover Basalt and underlying the Ubeidiya Formation. The Cover Basalt is of Preglacial Pleistocene age. Its upper flows yielded a radiogenic age of 1.7 million years (Siedner and Horowitz 1974). The Ubeidiya Formation is considered as broadly of Mindel age (Bar-Yosef and Tchernov 1972). This situation puts the Erk el-Ahmar temporarily in the Günz. Its palynological characteristics also indicate a pluvial climate, which strengthens the assumption of a Günzian age, as suggested by Horowitz (1974, 1975). Tchernov (1975) regards the formation as of early Pleistocene age, definitely predating the Ubeidiya Formation but younger than the late Pliocene Gesher Formation. The Erk el-Ahmar Formation may be partly correlative to the lower part of the Abu Habil series from Transjordan, described in Bender (1968).

Ubeidiya Formation

The Ubeidiya Formation was defined by Picard and Baida (1966) but had been previously studied by various authors. Blanckenhorn (1897) was the first to describe this formation and named it the "*Melanopsis* Stufe" because of the large quantities of *Melanopsis* shells that are found in many of its layers. Picard (1934) included the formation within his "Levantinische Stufe." Results from studies of the first detailed cross sections of the Ubeidiya were published by Stekelis *et al.* (1960) following the discovery of many implements of Abbevillian, or Oldowan affinity together with some fragments of a hominid skull and teeth. The type section was selected by Picard and Baida (1966) at the site of Ubeidiya, in trenches dug by bulldozers during excavations (Figure 5.107). The term Ubeidiya Formation had been previously suggested by Picard (1963), but no type section was attempted at that stage. The thickness of the sequence at the Ubeidiya site is 190 m, but this figure should be considered as a minimum, since the base is not exposed and the top is truncated. The formation comprises four members of alternating limnic and fluviatile nature.

Clay, Silt, and Limestone Member (Li). This is the oldest member of the Ubeidiya Formation (Figure 5.108) that has so far been excavated; it is 52 m thick. It comprises lacustrine deposits composed mainly of clay and silt varves, of hard oolitic limestone beds, soft chalk and marls, and silty, rarely sandy layers. Except for the varves, the beds of this member are rich in freshwater mollusks and vertebrates, which are primarily fish remains, of species not yet determined. The varved beds are rich in secondary veins of well-crystallized idiomorphic gypsum. In the uppermost varves, some well-preserved plants were found, among which Lorch (1966) has determined *Rhus tripartita, Pistacia lentiscus, Myriophyllum* sp., and *Ranunculus* sp. *Melanopsis* shells are very abundant, but neither human implements nor land vertebrates have been discovered in this member.

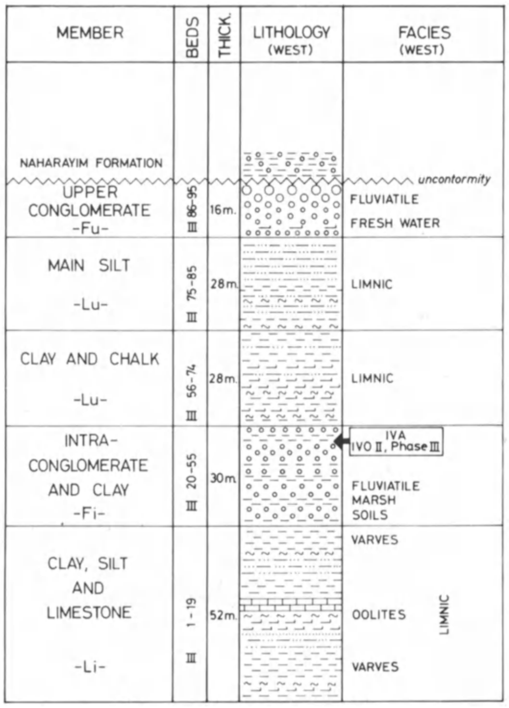


FIGURE 5.107. *Type section of the Ubeidiya Formation, at the site. (After Picard and Baida, 1966a.)*

Intraconglomerate and Clay Member (Fi). This member (Figure 5.109), which attains 22–30 m in thickness, appears with facies changes on both flanks of the eastern miniature anticline that was exposed at the site during excavations. The western flank is entirely composed of clays and conglomerates, mostly consisting of quartz and assorted angular river gravels, with a varying matrix of clay, chalk, marls, silt, and basaltic sand. Some beds contain artifacts, among which choppers and cores are common (Stekelis 1966). The beds contain many freshwater gastropods and ostracods, together with well-preserved vertebrate bones. The clay beds sometimes contain freshwater gastropods and ostracods, together

FIGURE 5.108. *Li Member of the Ubeidiya Formation.*

FIGURE 5.109. *Fi Member of the Ubeidiya Formation.*

with interspersed gravel and other clastic material. Some unfossiliferous, reddish-brown clays that, apparently, represent paleosols are also included within this member. At the eastern anticlinal flank, the conglomerates become thinner and the components are of a smaller size, often very sandy and silty. Clays are predominant on the eastern flank, in which limestone and chalky beds are intercalated. The differences in lithology seem to point, according to Picard and Baida (1966), to a facies change from river accumulation to the west to lake and swamp deposition to the east. Greater numbers of *Melanopsis* and other shells are also found in the eastern beds.

This eastern flank was first excavated and the preliminary results published in Stekelis *et al.* (1960) According to Stekelis (1966; although presently doubted), the hominid remains, most probably representing *Homo erectus* (Tobias 1966), were derived from this sector. The artifacts recovered from this sector were classified by Stekelis (1966) as the Israel Variant of Olduvan II Culture, Phase I, consisting mainly of choppers, flakes, and cores, whereas, in the upper part of the sector, chopper, spheroids, polyhedral picks, cuboids, flakes, and cores are defined by Stekelis as the Israel Variant of Olduvan II Culture, Phase II. Among the vertebrates determined by Haas (1966) are *Megantereon megantereon, Crocuta* sp., *Equus stenonis, Bison* sp., *Camelus* sp., *Stegodon* sp., *Archidiskodon* sp., *Dicerorhinus* cf. *etruscus, Cervus ramosus, C. philisii, C. senezensis, Dama* sp., *Megaceros* sp., *Gazellospira* sp., *Ursus* cf. *etruscus, Leptobos* sp., *Hipparion* sp., *Sus strozzi, Giraffa* cf. *camelopardalis, Hippopotamus amphibius,* and some rodents. Other variants of the Olduvan II Culture were determined by Stekelis (1966) in upper layers of this member.

Main Silt Member (Lu). This member (Figure 5.110) comprises lacustrine, occasionally well-bedded white-grayish-yellow silts, with some silty marl layers and clay, and contains ostracods throughout. It attains 56 m in thickness. The lower part comprises mainly well-bedded limnic clay, chalk, and chalky marl in which ostracods, gastropods, and fish remains are quite abundant.

FIGURE 5.110. *Lu Member of the Ubeidiya Formation.*

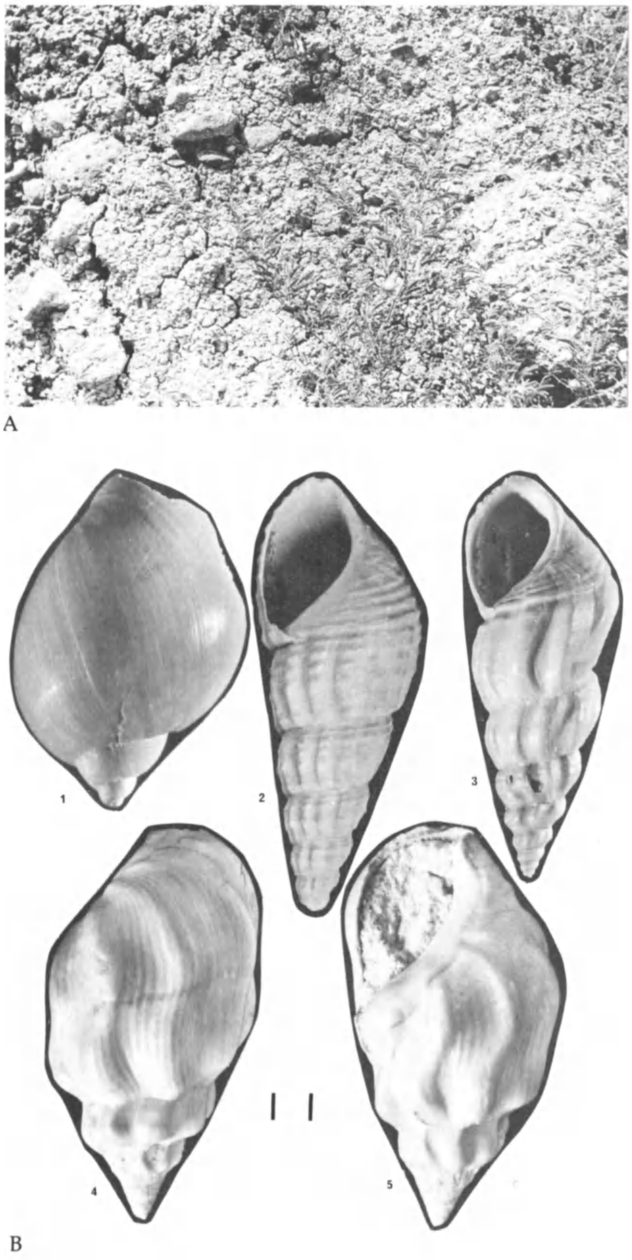


FIGURE 5.111. *A, The Fu Member of the Ubeidiya Formation; B, Mollusks from the Ubediya Formation: 1,* Lymnaea lagotis; *2,* Melanoides tuberculata; *3,* M. dadiana; *4,5,* Melanopsis praemorsa. *Scale 1 mm. (Courtesy of E. Tchernov, Department of Zoology, the Hebrew University of Jerusalem.)*

Upper Conglomerate Member (Fu). This member (Figure 5.111) comprises 16 m of conglomerates that range in size from microconglomerate to big boulders and consist mainly of basalt, with some flint and a few limestone components. The clastic layers reveal repeated cycles of graded, well-rounded and sorted pebbles, occasionally interrupted by unsorted and less-rounded gravels. The uppermost layer comprises big and fairly rounded basaltic boulders up to 80 cm in diameter and smaller, flat pebbles, up to 10 cm in diameter, whereas toward the base the finer clastics are interspersed in a 2-m-thick, marly chalk layer. No fossils or artifacts have been found in this member.

Pollen analyses of the Clay, Silt, and Limestone Member (Li) (Horowitz, in Bar-Yosef and Tchernov 1972) are discussed in detail in Chapter 6. The pollen spectrum is characterized by a very high percentage (more than 80%) of arboreal pollen almost entirely derived from oaks, thus indicating pluvial conditions during the time of deposition. The malcological assemblage of the Ubeidiya Formation was studied by Tchernov (1973) and comprises *Theodoxus jordani, Valvata saulcyi, Bulimus hawaderiana, Melanopsis praemorsa, Melanoides tuberculata, M. dadiana, Lymnaea lagotis, Planorbis planorbis, Gyraulus piscinarum, Ancylus fluviatilis, Unio terminalis, U. semirugatus, Leguminaia chantrei,* and *Cobicula fluminalis.*

The Ubeidiya Formation crops out only in the vicinity of the site. It most probably overlies the Erk el-Ahmar Formation and is overlain in an angular and erosional unconformity by the Naharayim and the Lisan formations. No lateral equivalents of the Ubeidiya are known, but it seems that the lacustrine sediments become more of a fluviatile nature to the west. The Ubeidiya was faulted and tilted by the middle Pleistocene tectonic movement of the Central Jordan Valley, whereas the overlying Naharayim Formation is almost flat-lying. Horowitz (1974) and Siedner and Horowitz (1974) have shown that the Yarmouk Basalt should be considered as stratigraphically overlying the Ubeidiya, based on morphological analyses of the relative situation of the two formations, although no contact between the two is known.

The Ubeidiya Formation was deposited in a rather wide, shallow lake that occupied the Central Jordan Valley, shrinking and expanding several times during the sedimentation of the sequence. The age of the formation was regarded by early workers as late Pliocene or early Pleistocene. Picard (1963, 1965), Picard and Baida (1966), and Stekelis *et al.* (1960) assigned a "Villafranchian" age for the Ubeidiya, mainly based on the occurrences of mammals such as *Dicerorhinus etruscus,* which is known from the Villafranchian faunas of Europe. Tchernov (1968) and Horowitz (1968) discussed the vertebrate faunal assemblage of the formation and indicated that the age of the assemblage should not be judged by earlier faunal elements, which might be relics, but, rather, according to the appearance of new species, especially *Equus stenonis,* which indicates a Middle Pleistocene age where it is found in Europe. Tchernov (1973) also showed that the Ubeidiya is younger than the Erk el-Ahmar, based on the different malacological assemblages. Bar-Yosef and Tchernov (1972) while comparing the artifacts from this assemblage to the dated series at Olduvai Gorge, conclude that the Ubeidiya should be regarded as of a Mindel age, a conclusion that Horowitz (1974) accepts.

The radiogenic age of the Ubeidiya was determined by Horowitz *et al.* (1973) in comparison with the correlative Mishmar HaYarden Formation in the Hula Valley. The Mishmar HaYarden Formation is overlain by the Yarda Basalt, which yielded an age of 640,000 ± 120,000 years B.P. A flow of the Yarmouk Basalt was dated by Siedner and Horowitz (1974) to 690,000 ± 140,000 years B.P., thus proving that the two basaltic phases are broadly correlative. Since these lavas overlie the Ubeidiya Formation, the latter should be regarded as older than 700,000 years, but probably not much more so. Bar-Yosef and Tchernov (1972), in comparison with the dated sequences at Olduvai Gorge, also agree to this figure. An attempt to use ionium to determine the Ubeidiya's age (Bender and Kaufman 1971), yield ages between 128,000 and more than 300,000 years. These dates are regarded by the authors themselves as nonvalid, and they state that "in the light of the high number of inconsistencies, no geochronological significance can be attached to any of the calculated apparent dates [p. 117]." The Ubeidiya predates the tectonic phases which affected the Central Jordan Valley during the Middle Pleistocene. This formation seems to be correlative to the upper part of the Abu Habil Series in Transjordan, described by Bender (1968) in which Huckriede (1966) reported Abbevilian artifacts.

Naharayim Formation

The Naharayim Formation (Figure 5.79) was defined by Picard (1965) but was mentioned also in earlier publications. The type section was located near the dam of the Ruthenberg power plant on the Yarmouk River, about 2 km from its confluence with the Jordan, south of Lake Kinneret. The sequence comprises 20–30 m of gravels and brown loams, in which some rare melanopsids occur. The pollen spectrum of this formation indicates pluvial conditions, with occurrences of some *Fagus* grains, discussed in detail in Chapter 6. Correlative conglomerates are described in Bender (1968) from the eastern side of the Jordan Valley south of the Yarmouk, containing Late Acheulian artifacts (Huckriede 1966). The Naharayim overlies the Yarmouk Basalt and is overlain by the Raqqad Basalt and the Lisan Formation. The formation thins to the west, and in the are of the site of Ubeidiya it attains only one or two meters in thickness, totally disappearing further south. No lateral correlatives are known. The Naharayim represents what was a huge delta of the Yarmouk River in times of much greater activity of this water course, in a pluvial climate. The fact that this pluvial period is characterized by fluviatile rather than lacustrine sediments in the Central Jordan Valley was attributed by Horowitz (1974) to the preceding faulting phase, which affected all the underlying formations and, apparently, opened the drainage from the Central Jordan Valley to the Dead Sea area, without leaving suitable conditions for the formation of a lake. The artifacts and pollen spectra point to a Rissian age for this formation. Its radiogenic age is between 690,000 and 70,000 years, dates that were encountered for the underlying Yarmouk Basalt and the overlying Raqqad Basalt (Siedner and Horowitz 1974).

Lisan Formation

The Lisan Formation covers the Central and Southern Jordan Valley, down to about 40 km south of the present Dead Sea. The northern limit of outcrops of this formation lies more or less in a line connecting the east and west shores of Lake Kinneret, from Migdal to somewhat north of En Gev. Although the Lisan Formation covers the entire central Jordan Valley, it is much better developed and exposed at the southern Jordan Valley and the Dead Sea area and will, therefore, be described in much more detail when dealing with the Upper Dead Sea group.

Tabgha Formation

The Tabgha Formation (Figure 5.112) was defined by Horowitz (1968) as emcompassing the sedimentary sequence deposited in Lake Kinneret from the time of its formation, about 18,000 years ago, up to the present. The type section of the Tabgha was taken from Borehole D-1021-1 (Figure 5.91), drilled in Lake Kinneret offshore from Tabgha, at its northern part. The sequence comprises 22 m of dark brown to black clays. The clays are loose, mostly comprising fine clastic particles with subordinate quartz, chert, basalt, limestone, and dolomite sand-sized grains. The formation paves the entire floor of Lake Kinneret and crops out in the area north of En Gev up to the Buteiha, where parts of it were deposited during an expansion phase of the lake. Bones of *Hippopotamus*, *Bos*, and other vertebrates were found in these outcropping sediments. The pollen spectra and diagram for the Tabgha Formation are discussed in detail in Chapter 6, indicating that the lower part of the formation was deposited under pluvial conditions. The upper part was deposited in a climate that resembles that of the present. The maximum known thickness of the Tabgha is the 22 m penetrated by the type borehole, but a geophysical survey of Lake Kinneret (Z. Ben-Avraham, Weizmann Institute of Science, personal communication, 1977) indicates that, at the central parts of the lake, it might attain to about 30 m. The formation overlies, at the northern part of the Kinneret, Pliocene and Miocene sediments, and to the south it overlies the Würmian Lisan Formation. To the east and west, it interfingers with conglomerates brought by the wadis during floods. To the north, the Jordan River supplies most of its fine clastics, with no conglomerates. The Tabgha thins out toward the shores of Lake Kinneret, until totally replaced by gravel. The malacofauna of Lake Kinneret was investigated by Tchernov (1973), comprising the species *Theodoxus jordani*, *Pyrgula barroisi*, *Bulimus hawaderiana*, *Melanopsis praemorsa*, *Melanoides tuberculata*, *Unio terminalis*, *U. semirugatus*, and *Corbicula fluminalis*. These species persist in the lake to the present.

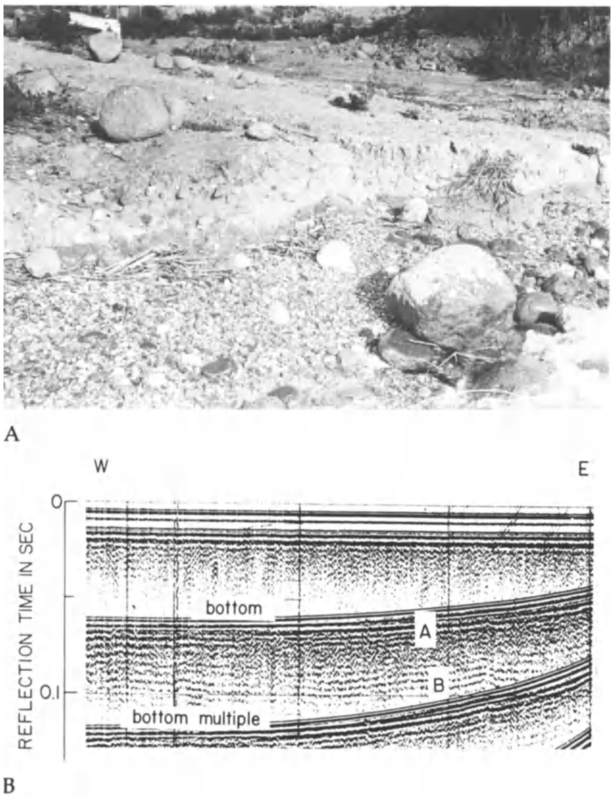


FIGURE 5.112. *A, Outcrop of the Tabgha Formation silts on the Kinneret eastern shore; B, reflection profile of the Tabgha Formation sediments from the Lake Kinneret bottom. The deposits comprise soft, unconsolidated silts. (Courtesy of Z. Ban-Avraham, Weizmann Institute of Science.)*

Lacustrine Sediments of Bet She'an

Neev (1967) described a lacustrine sequence (Figure 5.113) from the southern sector of the Central Jordan Valley, near Bet She'an. The sequence comprises several meters of brown to black clays and silts, very rich in *Melanopsis* shells. Chalcolithic potsherds and artifacts are quite common within the sequence, whereas Early Bronze Age remains were encountered on the surface. The *Melanopsis* shells yielded a radiocarbon age of around 5000 B.P. These lacustrine sediments occupy most of the area of the uplifted block on which the town of Bet She'an

FIGURE 5.113. *The Bet She'an Lake sediments (dark) overlying the Lisan sediments (light).*

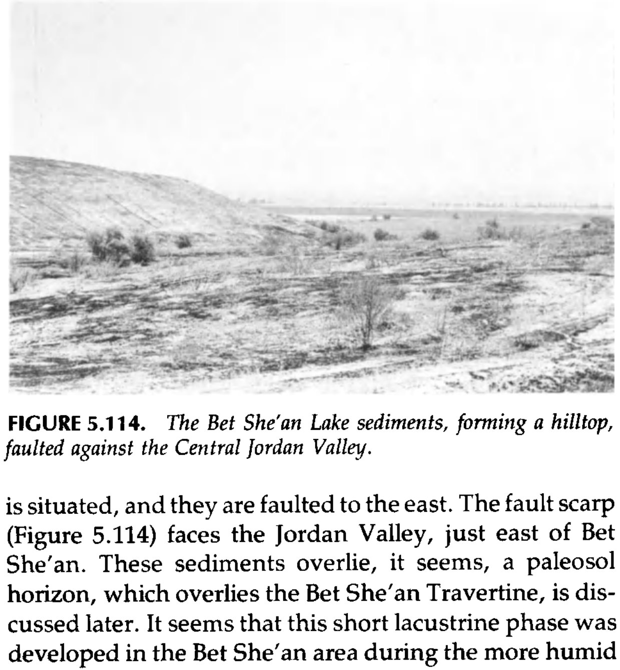


FIGURE 5.114. *The Bet She'an Lake sediments, forming a hilltop, faulted against the Central Jordan Valley.*

is situated, and they are faulted to the east. The fault scarp (Figure 5.114) faces the Jordan Valley, just east of Bet She'an. These sediments overlie, it seems, a paleosol horizon, which overlies the Bet She'an Travertine, is discussed later. It seems that this short lacustrine phase was developed in the Bet She'an area during the more humid Atlantic period and ceased its existence due to the post-Atlantic faulting, known also from the Hula Valley. The Early Bronze Age people, consequently, found a very rich organic soil on which they settled in large numbers.

Lacustrine Sediments of Yavne'el

Bentor (1946) described a sequence of about two meters of lacustrine sediments in the Yavne'el Valley, not far from the settlement of the same name. He ascribed to them a Pleistocene age, since they overlie the Preglacial Pleistocene Cover Basalt. Bentor states that these lacustrine sediments were deposited in a lake that developed in this area locally, due to blockage of the Wadi Fejjas drainage. The outcrop, apparently in one of the wells dug in the Yavne'el area, could not be relocated, and further information is not available.

UPPER DEAD SEA GROUP

The term "Dead Sea Group" was suggested by Zak (1967) to encompass the entire sedimentary sequence deposited in the Dead Sea Basin, since it was first created taphrogenically in early Pliocene times. The Sedom and Amora formations (Zak 1967) comprise the Pliocene sector of the Dead Sea Group, and the term "Upper Dead Sea Group" was suggested by Neev and Emery (1967) to encompass the entire Pleistocene sequence of the Dead Sea Basin. The sequence was penetrated by the Melech Sedom I borehole and was palynologically analyzed by Horowitz (1968b). The palynological analyses are given in Chapter 6. The lower part of the sequence penetrated by the Melech Sedom I Borehole overlies the Amora Formation at a depth of about 2600 m. It comprises gravels and conglomerates, in which no pollen was preserved, down to a depth of about 2000 m. These gravels most probably correspond to the Bethlehem Conglomerate on the Judean anticlinorium and to the Ghor el-Qatar Series to the east (Bender 1968). The upper 2 km comprise mostly lacustrine chalks and clays, sometimes interfingering with fluviatile conglomerates and gravel horizons. Pollen analyses of this sequence reveal its Glacial Pleistocene age and indicate that the sediments were deposited under changing pluvial and interpluvial conditions. Four pluvial phases were discerned within the sediments comprising the upper 2 km penetrated by the Melech Sedom I Borehole. No faunal remains are known for this sequence. Toward the margin of the Dead Sea Basin the lacustrine sediments merge into fluviatile conglomerates and sometimes into rock-salt units (Neev and Emergy, 1967).

The uppermost formation of the Upper Dead Sea Group, the Lisan Formation, covers wide areas in the Southern and Central Jordan Valley; its lacustrine facies changed rather abruptly about 18,000 years ago due to faulting, which deepened the Dead Sea Basin (Neev and Emery 1967). In the Dead Sea area itself, the "Unnamed Post-Lisan Sediments" have been deposited since that time and up to the present. About 90% of the sequence comprising the Upper Dead Sea Group is known only from the Melech Sedom I Borehole, and, except for its general lithology and palynological characteristics, discussed in Chapter 6, no further information is available. A deep borehole drilled at the Lisan Peninsula is described in Neev and Emery (1967). It comprises mostly rock salt, overlain by several tens of meters of the Lisan Formation. Neev and Emery correlate the rock salt with the Upper Dead Sea Group, with its interfingering rock-salt tongues encountered in the Mezada structure holes. Zak (1967), however, correlates the rock salt penetrated at the Lisan Peninsula with the rock salt of the Sedom Formation and indicates that, in both localities, the rock salt is overlain by the Lisan Formation sediments. Since no further information is available on the el-Lisan I borehole, no definite conclusions could be drawn, but it seems that Zak's correlation is more conceivable, mostly because the

Melech Sedom I borehole, which penetrated the entire Upper Dead Sea Group, did not encounter any rock salt.

Lakeshore Sediments of Hazeva

Sneh (in press) has described a succession of four terraces deposited at the shorelines of ancient lakes near Hazeva, south of the Dead Sea (Figures 5.115–5.118). The lowermost and, consequently, the youngest of these terraces (Figure 5.115) is connected with the Lisan Formation and was deposited by the lake in which the deposition of the latter took place. Above the Lisan shoreline terrace occurs a higher one (Figure 5.116) consisting of lacustrine, fluviatile, and spring deposits, designated by Sneh (in press) as the Seif Formation. The type section is located at Nahal Seif (coordinates 1730–0284). The sequence, 3–4 m thick, comprises vuggy and micritic, brown to greenish limestone, together with pebbly and angular fragments. Sandy limestones containing *Melania* sp., interfingering with conglomerates, were observed to the south of Nahal Bitron and north of the Ma'ale Aqrabbim road. Pebbly limestones and travertines, 8–10 m thick, forming a steep cliff, crop out at En Yahav (coordinates 1680–0035), where they are overlain by travertines of a younger age. In places, a conglomerate appears at the base of the Seif Formation. The Seif travertines are not connected in any way with modern springs, as are those of En Rahel and En Tamid, which have deposited travertines up to the present. The Seif Formation occurs in many small, isolated outcrops in the Hazeva area and is known also to the south, as far as the confluence of Nahal Paran and Nahal Ha'Arava (Sakal 1967). Travertines occurring in the Makhtesh HaQatan erosion cirque (Gill 1965) and in the area of Nahal Zihor (Sakal 1967) are also correlated by Sneh with this formation. The Seif mostly overlies Neogene and older rocks, which crop out unconformably in the Hazeva area and the other localities already mentioned. It is eroded, and the channels are filled with sediments of the lowermost terrace, deposited by the Lisan lake and the rivers running into it. Mousterian artifacts were found on top of the Seif Formation *in situ* (Sneh, in press) and prove that it is older than the Lisan Formation, since Mousterian artifacts are known from the base of the Lisan (Picard 1965).

Two other terraces (Figures 5.117 and 5.118), higher and consequently older than the Seif Formation, are

FIGURE 5.115. *The Lisan Lakeshore Terrace (most of the flat surface) cutting into the Seif Lakeshore Terrace in the Hazeva area.*

FIGURE 5.116. *The Seif Lakeshore Terrace, overlying the Seif Lake sediments in the Hazeva area.*

FIGURE 5.117. *Relics of the Third Lakeshore Terrace forming hilltops in the Hazeva area.*

FIGURE 5.118. *Relics of the Fourth Lakeshore Terrace forming the highest hilltops in the Hazeva area.*

described by Sneh from the Hazeva area, mostly developed as conglomerates, probably deposited in a lakeshore environment or one intimately connected with a lakeshore. Sneh ascribes the relative altimetric positions of the four terraces to tectonic movements that supposedly affected the Dead Sea Basin throughout the Pleistocene. It seems, however, that they correspond to periods of expansion of lakes in the Dead Sea Basin, most probably influenced by pluvial climatic conditions. This is quite clear for the youngest, Lisan Lake (Begin *et al.* 1974; Rossignol 1969b), and it seems that quite similar conditions also affected the previous lakes, as can be seen from pollen analyses of the Upper Dead Sea Group at the Melech Sedom I borehole. Several lake-shore terraces (Figure 5.119) are also known from the northern sector of the Southern Jordan Valley, from Jiftlik up to Merma Feyyad. They are quite conspicuous as horizontal terraces, adherent to the steeply dipping Eocene and Miocene strata in this area. No more than three of these terraces can be observed at one locality. These terraces are at higher elevations than the Lisan Formation sediments and are very much affected by erosion. They are considered to have been deposited by lakes that existed in the area prior to the Lisan Lake. No faunal remains, flora, or implements were found in these terraces, and, therefore, no correlation is proposed and no time stratigraphic assignment is given to them.

Lisan Formation

The Lisan Formation sediments are very conspicuous in the Central and Southern Jordan Valley and have been described and discussed by many authors. The first to describe in detail the Lisan Formation and its lithologic characteristics was Anderson (1852), who studied the formation at the Lisan Peninsula. Lartet (1869) describes a section of the formation from the Ze'elim Plain, north of Mezada, on the west bank of the Dead Sea. Lartet was the first to define the formation as the "Dépots de la Liçan" and also as "Marne de la Liçan," named after the Lisan Peninsula, which is built of rocks of this formation. Lartet also referred to the Lisan Formation as "Anciens Dépots de la Mer Morte," indicating that the present-day Dead Sea deposits are not different in nature from the Lisan Formation sediments. Hull (1886) referred to the sequence as "Ancient Deposits of Salt Sea," Blanckenhorn (1914) as "Lisanmergel," Picard in three publications, first (1937) as the "Lisan Stage," then (1938) as the "Lisan Marl," and finally (1943) as the "Lisan Series" or "Lisan Deposits." The formation was amended and given its formal name, the Lisan Formation, by Bentor and Vroman (1960). Because there are these different views of the formation, no formal type section is given. Reference sections were, however, published in Zak (1967), Neev (1964), Neev and Emery (1967), Picard and Baida (1966), Begin *et al.* (1974), and Begin (1975).

FIGURE 5.119. *Lakeshore terraces older than the Lisan, north of Jiftlik, southern Central Jordan Valley. The foreground is the upper surface of the Lisan Lake sediments.*

A detailed account of the Lisan by Langozky (1961), who studied its lithology and geochemistry, resulted in subdivision of the formation into two members: the lower, clastic, Hamarmar Member and the upper, evaporitic, Ami'az Member. Bentor (1961a) also studied the geochemistry of the formation, and Begin *et al.* (1974) studied its lithology, distribution, minerology, and diatom assemblages. Pollen analyses of the lower, Hamarmar member are given in Rossignol (1969b). Some analyses of the sediments and diatoms of the Lisan near Jericho are given in Meister (1968), and the clastic and heavy mineral assemblages were studied by Wiersma (1970). Detailed descriptions of the formation are also given in Bender (1968). The oxygen isotope composition of the formation sediments was studied by Katz *et al.* (1977).

The study by Begin *et al.* (1974) is the most comprehensive to date and is the only one that gives and compares descriptions of the formation both from the Southern and the Central Jordan Valley sectors. This study is the basis for the following discussion; however, some emendation of the nomenclature is proposed here. The columnar section of the Lisan made by Begin *et al.* near Deir Shaman at coordinates 1992–1621 is regarded as typical for this formation. The sequence comprises 58 m, of which the lower 17 are not regarded by these authors as belonging to the Lisan *sensu stricto.* This lower part is mainly clastic (Figure 5.120) and is referred to by Begin *et al.* as the "Samra Formation." It seems that this part corresponds to the Hamarmar Member of Langozky (1961). It definitely does not agree with Picard's (1931) original definition for the Pliocene Samra Formation, discussed previously. The pollen spectra of this member (Rossignol 1969b) are typical for the Late Pleistocene of the Jordan Valley. It is, therefore, suggested to retain Langozky's name and to refer to this member as the lowermost member of the Lisan Formation, called the Hamarmar Member. The next member, designated by Begin *et al.* as the "Laminated Member," comprises 25 m of finely laminated aragonite (Figure 5.121). This is the lower part of Langozky's

FIGURE 5.120. *The Hamarmar Member.*

FIGURE 5.121. *The Ami'az Member, with the lower, Laminated Bed, and the upper, White Cliff Bed.*

FIGURE 5.122. *The Fatza'el Member.*

Ami'az Member. The upper part of the Ami'az Member, designated in Begin *et al.* as the "White Cliff Member," comprises 6–7 m of laminated aragonite and clay with gypsum beds on top and is overlain by the "Unnamed Clastic Unit." The Unnamed Clastic Unit comprises mainly red clays and silts (Figure 5.122), which grade laterally into conglomerates. This member was defined by Horowitz (1974) as the Fatza'el Formation. The four members are separated from each other by slight erosional unconformities (Begin *et al.*, 1973; Zak 1967). Since all these sediments were deposited in the Dead Sea Basin during the last pluvial phase, it is suggested to include all of them within the Lisan Formation and to subdivide the formation into three members: the Hamarmar, Ami'az, and Fatza'el. The Ami'az Member can be further subdivided into the Laminated Bed and the White Cliff Bed.

The lowest, the Hamarmar Member, is mainly composed of detrital sediments such as clays, shales, sands, gravels, conglomerates, and, more rarely, of oolitic limestones and lacustrine chalk. Its base is mostly not exposed, but to the south, in the Hazeva area, it unconformably overlies and is younger than the Seif Formation (Sneh 1972). The Hamarmar Member is overlain by the Ami'az Member with a slight unconformity, which in places is even angular, the Hamarmar Member being somewhat tilted. The Laminated Bed comprises the typical Lisan varved sediments. Its thickest section is at Deir Shaman, where it attains 26 m. It is mostly comprised of very fine, varve-like white and dark laminae. The white laminae are usually monomineralic, composed mainly of aragonite needles, frequently associated with diatom frustules. In some localities, the laminae are intermingled with gypsum or even composed solely of gypsum. No anhydrite or dolomite was identified in the white laminae of the Laminated Bed; some calcite and very few traces of halite were rarely found. The dark laminae are composed mainly of calcite, most of it reworked microfossils, nannofossils, and other rock fragments. Quartz, dolomite, clay minerals, gypsum, and halite do occur in many cases. The clay mineral assemblage is typified by kaolinite, montmorillonite, illite, and palygorskite in various proportions, the proportions differing from section to section, but usually homogeneous within the same section. At the Dead Sea Basin, kaolinite is the predominant clay mineral, with montmorillonmite also abundant; illite and palygorskite are also present. In the Central Jordan Valley, montmorillonite usually predominates, with lesser amounts of kaolinite, illite, and palygorskite, in that order. North of the Dead Sea, the Laminated Bed contains some gypsum intercalations, occasionally with native sulphur concretions, which occur at definite horizons in the upper part of the Laminated Bed. To the north and south, gypsum intercalations are rare, but detrital intercalations are more common. In the Central Jordan Valley, the Laminated Bed is mostly detrital, with almost no aragonite laminae. In this area, a characteristic paper-like sediment occurs, made of almost pure diatomite, It is a white, soft, laminated sediment that is very conspicuous in outcrops because of its coherence and flexibility. It is constituted of very fine diatomite laminae that are usually devoid of detritus.

The White Cliff Bed is usually composed of two cliff-forming units. It is thickest in the Mezada area and attains

15 m. This bed has a higher chemical versus detrital sediment ratio than the Laminated Bed and always contains two or more relatively thick beds of gypsum or aragonite in the Dead Sea Basin. It is, however, well bedded and also contains laminated sediments. Gypsum occurs at the top of this bed. The white laminae of the White Cliff Bed are more gypsiferous than those of the Laminated Bed. Sulphur concretions are found within this bed at the Mezada area. The minerology of the dark laminae of the White Cliff Bed is similar to that of the same lanimae in the Laminated Bed. In the Central Jordan Valley, two or three diatomite beds, 10–30 cm thick each, were encountered and could be correlated with the White Cliff Bed. Between the diatomite horizons, clastic intercalations, together with rare aragonite laminae, occur. Within the clastic sediments, some beds rich in freshwater gastropods are found. The gastropods were defined by Tchernov (1973) as *Theodoxus jordani*, *Bythinella* sp., *Bulimus hawaderiana*, *Melanopsis praemorsa*, and *Ancylus fluviatilis*.

The Fatza'el Member was first noted by Vita-Finzi (1964), who gave a brief description of the strata cropping out at Wadi Fasayil, north of Jericho. The Fatza'el Member comprises clastic sediments that overlie the White Cliff Bed. They are very consistent in appearance and are composed of shales, silt, and clays. To the north of the Dead Sea Basin, the unit is reddish, resembling soils, and contains beds with freshwater gastropods, mainly *Melanopsis*. The Fatza'el Member was not observed from Mezada southward. This might be due either to nondeposition or to subsequent erosion. Since this member is not covered by any sediments, it is always partly eroded. The thickest sequence occurs at Wadi Fatza'el (Fasayil), where about 15 m of the member are exposed, comprising mainly conglomerates and red loams. Numerous Epipaleolithic artifacts were found in the Fatza'el Member sediments, and a detailed description of the stratigraphy and the finds are given in Bar-Yosef *et al.* (1974). Pollen spectra of the Lisan Formation are discussed in detail in Chapter 6 (also see Alon 1976; Rossignol 1969b). In general, they are characterized by pluvial assemblages, indicating that the most widespread phases of the Lisan Lake coincided with the three pluvial phases known for the Würmian of the Jordan Valley (Horowitz 1971).

Analysis of the diatoms of the Lisan Formation in Begin *et al.* (1974) showed that in most of the sections the clastic sediments of the Hamarmar Member are sterile, as are most of the clastic units interbedded within the entire formation. Exceptionally, a poor freshwater microflora was found in the clastic sediments of the Fatza'el Member, north of Bet She'an. The Laminated Bed is frequently rich frequently rich in diatoms, but the diatom content decreases strongly toward the gypsiferous levels, and beds containing primary gypsum are usually sterile. There is a clear difference in total diatom content between the Central Jordan Valley and the Dead Sea Basin. The diatoms constitute only an accessory fraction in the sediments of the Dead Sea sub-basin, whereas they may constitute an important part of the sediments in the Central Jordan Valley, becoming the main constituent in genuine diatomites. The diatomite laminae are composed of densely intricate, interwoven, diatom frustules, mostly belonging to euryhaline forms. In the Central Jordan Valley and in the northern part of the Dead Sea Basin, diatoms occur abundantly in the Laminated and the White Cliff beds. As a rule, only euryhaline forms are found in the white laminae, whereas in the dark laminae many freshwater diatoms occur, together with the euryhaline forms. The lower part of the Laminated Bed is characterized by the *Nitzschia vitrea* eco-stratigraphic zone, comprising only euryhaline forms. Most of the Laminated Bed comprises the *Nitzschia lembiformis* ecostratigraphic zone, typified by euryhaline diatoms and some frequent freshwater forms. The central part of the Laminated Bed is typified by the *Nitzschia sigma* eco-stratigraphic subzone, which contains euryhaline forms almost solely, with very rare freshwater diatoms. The White Cliff Bed does not contain any diatoms in the Dead Sea Basin, but in the Central Jordan Valley it is typified by the *Rhopalodia gibberula* eco-stratigraphic zone, containing mainly euryhaline diatoms and fairly rare freshwater forms. The Fatza'el Member is typified in the Central Jordan Valley by the *Gomphonema* eco-stratigraphic zone, typified by the prevalence of *Gomphonema longiceps*, which is a freshwater form.

The Lisan Formation overlies the Seif Formation to the south, in the Hazeva area, and the Naharayim Formation and the Raqqad Basalt to the north, in the Central Jordan Valley. It is overlain by the Unnamed Post-Lisan Sediments of the Dead Sea in that area and by the Tabgha Formation and the Bet She'an Travertine in the Central Jordan Valley. The Lisan Formation was deposited in a lake that occupied the Central and Southern Jordan Valley during Würmian times. The transition from the White Cliff Bed to the Fatza'el Member in the Southern Jordan Valley and the Dead Sea area and to the Fatza'el Member and the Tabgha Formation in the Central Jordan Valley occurred some 18,000 years ago due to a tectonic phase that deepened the Dead Sea Basin and created Lake Kinneret, more or less with the present-day configuration (Horowitz 1968a; Neev and Emery 1967). Pollen analyses and diatom assemblages indicate that the Lisan was deposited during three pluvial phases, separated by two interstadials. The first pluvial phase is characterized by the pluvial pollen spectra recovered by Rossignol (1969b) from the Hamarmar Member and by the *Nitzschia lembiformis* subzone at the lower part of the Laminated Bed. The first interstadial is characterized by the *Nitzschia sigma* subzone in the center of the Laminated Bed. The second, rather short pluvial phase is characterized by the *Nitzschia lembiformis* eco-stratigraphic subzone in the upper part of the Laminated Bed, and the second interstadial is characterized by the *Rhopalodia gibberula* zone of the White Cliff Bed. The third pluvial phase is characterized by the *Gomphonema* zone of the Fatza'el Member and by pollen spectra from this member, in which the arboreal pollen share goes up to 30%, in comparison to 5% at present (Alon 1976). Artifacts found within the Lisan range from Mousterian at the base (Picard 1965) to Epipaleolithic at the top of the Fatza'el Member (Bar-Yosef *et al.* 1974).

The recession of the Lisan due to the faulting that created the Dead Sea Basin in its present configuration left a series of terraces that can be seen around the present-day Dead Sea. These terraces are dealt with in detail by Bowman (1974). The Lisan lacustrine sediments grade into fluviatile conglomerates toward the margins of the lake. In most places, they interfinger with the Nahshon Conglomerate. Similar relations were reported by Vita-Finzi (1964) and Bender (1968) from the eastern side of the Dead Sea Basin. The Lisan Lake was encircled by carbonatic tufa (Figure 5.150) deposits, which appear in many localities. These comprise hard, laminated limestones that were proved by Buchbinder *et al.* (1974) to be of algal origin.

Dating of the Lisan Formation

John C. Vogel

The Ami'az Member has been dated by two independent radiometric methods: by radiocarbon (Vogel and Waterbolk 1972) and by ionium (^{230}Th) (Kaufman 1971). The results of both sets of data are shown in Figure 5.123. For purposes of comparison the radiocarbon dates are here expressed in terms of a ^{14}C half-life of 5730 years, which is more accurate than using the conventional half-life value of 5568 years, with which radiocarbon dates are normally calculated. The two methods give essentially the same results, although the ^{230}Th dates are, on an average, somewhat higher. The best straight lines through the two sets of data suggest that the discrepancy increases from 2000 years at the top to 4000 years at the base of the formation. However, since the uncertainty of the individual ^{230}Th dates is ±2000–3000 years, the observed difference is not entirely conclusive. On the basis of the ^{14}C dates, the deposit accumulated between 36,000 and 15,600 years B.P. (or 35,000 to 15,150 years B.P. on the conventional ^{14}C time scale), whereas the ^{230}Th dates suggest accumulation between 40,400 and 17,400 years B.P. Irrespective of whether the differences between these two dating methods are real or not, the results, when taken together, date the final period of the Lisan Lake to the second half of the Last Glaciation.

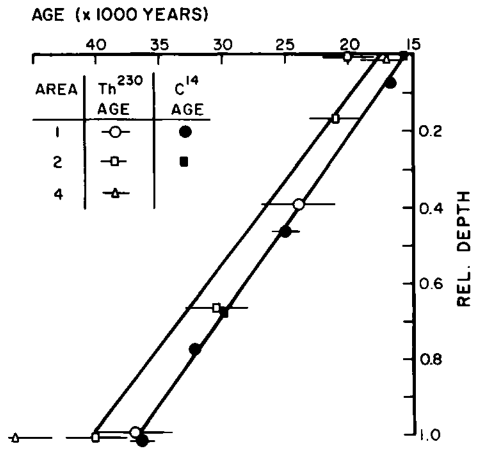


FIGURE 5.123. *Radiogenic ages of the Lisan Formation.*

The Hamarmar Member was also dated by the ^{230}Th method, suggesting accumulation from 60,000 years B.P. or earlier to 40,000 years B.P. The extensive Lisan Lake, therefore, existed during most of the Pleniglacial period of the Last Glaciation. Thus, the Pleniglacial must have been a period of higher rainfall in the catchment area, or of lower evaporation, or both. The Fatza'el Member is somewhat younger than these dates. It can be concluded, therefore, that the sedimentation of the three members of the Lisan Formation took place from about 70,000 until about 11,500 or 12,000 years ago, during the Würmian pluvial. The age for the base of the Lisan Formation is also given in Siedner and Horowitz (1974) from the Central Jordan Valley, where it overlies the Raqqad Basalt. The correlative Hasbani Basalt was dated at around 70,000–80,000 years ago (Siedner and Horowitz 1974), and the Lisan Formation is, therefore, younger. The water of the Lisan Lake, as can be seen from its shore terraces (Bowman 1974), attained an elevation of 180 m below the present-day sea level, which is only about 50 m below the Würmian sea level. The water depth at the deeper part of the Lisan Lake exceeded 100–200 m, as determined from the types of sediments (Begin *et al.* 1974) and from the stable isotope composition (Katz *et al.* 1977).

Post-Lisan Sediments of the Dead Sea

The post-Lisan Sediments of the Dead Sea are described in Neev and Emery (1967) and in Neev (1964). The best-known post-Lisan sediments are in the southern basin of the Dead Sea, where many structure holes have been drilled and have penetrated several tens of meters of younger sediments before penetrating the Lisan Formation. These sediments are characterized by layers of coarsely crystalline rock salt interfingering with gray, dark brown, and reddish clays, silts, sands, and gravels. Beds of rock salt dominate in the deeper, northern part of the Dead Sea, where they are overlain by only 30–60 cm of soft mud and are interbedded with a few relatively thin marl horizons. At the southern border of the Dead Sea, the gravel, sand, silt, and clay beds predominate over the rock salt, probably because of the proximity of the Arava Valley, the chief source of detritus. Dark brown clay beds and a few thin peaty horizons in the south are clearly swamp deposits. The rock salt was deposited in a shallow environment, as was inferred by Neev and Emery from its interfingering with oxidized detrital sediments, which are typical of the present-day shallow environments of the Dead Sea.

LACUSTRINE SEDIMENTS OF THE TRANSJORDANIAN PLATEAU

Two occurrences of Late Quaternary lacustrine sediments are known from the Transjordanian Plateau, one on the northern Golan, encountered within the crater lake of Birket Ram, which is still being deposited, and the other at the El Jafr Plain about 150 km south of Amman, which is presently dry.

Birket Ram

Birket Ram is a small, elliptical lake (Figure 5.124) occupying an explosion crater in the northern Golan. A borehole, P-8, was drilled by Water Planning for Israel in the deepest part of the lake. The water depth where Borehole P-8 was drilled was 11 m. The sediments comprise mainly brown to black, fine clays grading locally into true diatomite. Several reworked volcanic tuff horizons are intercalated with the sequence. The fact that Birket Ram lake occupies an explosion crater was established by Mazor (1968) and Flexer (1969). Mor (1973) showed the connection of the Birket Ram explosion crater with basaltic flows in the vicinity. These basaltic flows have been dated by Siedner and Horowitz (1974) and Siedner (*in litteris* 1977) at around 70,000 years B.P. Pollen analyses of the sequence are discussed in detail in Chapter 6. The pollen diagram (Weinstein 1976) shows that the Birket Ram sequence was deposited during the three humid phases of the Würmian pluvial, separated by two interstadials and followed by the Holocene. Ehrlich and Singer (1976) describe three major diatom zones in the Birket Ram sequence. Zone I, from 92.5 to 54 m, is characterized by the dominance of centric freshwater diatoms, of which the most abundant are *Stephanodiscus astraea* and *Cyclotella ocellata*, indicating a deep and slightly alkaline water. In Zone II, from 54 to 44 m, all the centric species are replaced by pennate forms, such as *Eunotia* spp., *Pinnularia* spp., and *Epithemia zebra*. In addition, abundant cysts of Chrysostomataceae were also recorded, indicating a shallow, slightly acidic, marshy environment. Zone III, from 44 m to the top of the core, is relatively poor in diatoms. Pennate forms dominate here also, with *Cocconeis placentula* as the dominant species. This zone was also deposited in a shallow marshy environment, but slightly alkaline.

Radiocarbon dating (Ehrlich and Singer 1976) of a sample collected from a depth of 36 m yielded an age of 29,300 ± 400 years B.P. By extrapolation, these authors concluded that the lacustrine sediments began to be deposited at about 108,000 years B.P., and the deep lake turned into shallow marshy conditions about 48,000 years B.P. These dates are earlier than those suggested by Weinstein (1976) for the beginning of lacustrine deposition in the crater lake. Weinstein compared the pollen diagram with pollen analyses for the Lisan Formation and a pollen diagram for the Hula Valley (Horowitz 1971) that were dated by the radiocarbon and ionium methods and estimated an age of 60,000–70,000 years B.P. for the contact of lacustrine sediments over the basalts and tuffs. The date suggested in Weinstein is more acceptable because the Birket Ram explosion crater belongs to a volcanic phase dated at 70,000–80,000 years ago (Mor 1973; Siedner and Horowitz 1974). The date suggested by Ehrlich and Singer (1976) is, therefore, rejected since it is based only

FIGURE 5.124. *The Birket Ram explosion crater.*

FIGURE 5.125. *The el-Jafr Basin. (Satellite imagery, courtesy of NASA, EROS Program, and J. Otterman, Department of Environmental Sciences, Tel-Aviv University.)*

on a single radiocarbon determination in the range in which radiocarbon is practically nonsignificant, as well as on an extrapolation based on this doubtful date.

El Jafr Basin

The El Jafr Basin is situated about 150 km south of Amman and is presently a dry, endoreic basin fed by a system of wadis (Figure 5.125). The present-day precipitation in the area is less than 50 mm per year. Huckriede and Wiesemann (1968) indicated that during the Würmian pluvial phases the center of the El Jafr Basin was covered by a freshwater lake occupying an area of 1000–1800 km^2. The Würmian freshwater lake was rich in mollusks and ostracods; limestones and marls were deposited, reaching a thickness of up to 25 m. These limestones and marls are overlain by brackish sediments containing brackish-water lamellibranchs, which are overlain in turn by sheets of unsorted gravel. The lower part of the section yielded numerous Mousterian artifacts. The next stage is characterized by aeolian deposits overlain by mudflat playa deposits. The mudflats contain numerous Epipaleolithic artifacts, together with some Middle Paleolithic artifacts of the Matakhium Culture. It seems that the Early and Late pluvial phases of the Würmian are recorded by lacustrine and mudflat sediments in the El Jafr Basin. During the short Middle Würmian pluvial phase, no lake was formed in the area, but vegetation was sufficiently developed to trap the aeolian deposits. No important changes in the morphology of the basin occurred during the Holocene. Detailed description of the sediments, fauna, and artifacts of the El Jafr Late Pleistocene lacustrina deposits are given by Huckriede and Wiesemann (1968).

VOLCANIC ROCKS

Quaternary volcanic activity is the continuation of widespread eruptions known to have taken place in the Levant throughout the entire late Cenozoic period. The earlier manifestations of late Cenozoic volcanic activity are known mainly from the Sinai (Steinitz *et al.*, in press), where dikes, sills, plugs, and some limited flows of early Miocene age, around 20 million years old, are known. Only a single occurrence of this volcanic phase is known from Israel—the plug at Wadi Ashosh in the Central Arava (Levite 1966). Apparently, some volcanic activity took place in this period also in Transjordan, in the Wadi Sirhan area (Bender 1968). Middle Miocene volcanics are widespread in Israel. They are known from the subsurface and from several outcrops along the coastal plain (Domzalsky 1967; Folkman and Yuval 1976; Gvirtzman 1970), termed the National Park Volcanics. The Lower Basalt, also of middle Miocene age (Blake 1928), is known from outcrops and the subsurface in the Yizre'el Valley and the Central Jordan Valley (Schulman 1959, 1962), and some rare occurrences of Pliocene volcanics are known from the coastal plain (Steinitz *et al.* in press) where basalts at outcrops yielded ages of around 5–6 million years. A single occurrence of this phase is also known from the Arava, a dike near En Yahav (Steinitz *et al.* in press). In the Central and Northern Jordan Valley, Pliocene volcanic rocks are much more abundant. The Intermediate Basalt and the Fejjas Tuff (Schulman 1962) both interfinger with Pliocene sediments in the Central Jordan Valley and are known from boreholes and some outcrops south of the Hula Valley, on the Korazim-Gadot Block (Fleischer 1968; Horowitz 1973). Outcrops of the Pliocene volcanics are also known to be interfingering with Pliocene sediments from the southern part of the Golan Plateau (Michelson 1972).

Quaternary volcanism is known only from northeastern Israel, from the areas of the Yizre'el Valley, the Central Jordan Valley, the Galilee, and the Northern Jordan Valley. These are only a lateral manifestation of the large-scale volcanism on the Golan Plateau and further east, which covered an area of approximately 100,000 km^2 (Bender 1968; Dubertret 1966; Mor 1973). Quaternary volcanism of the Golan Plateau and northeastern Israel comprises mainly fissure-erupted basaltic flows, with subordinate cinder cones and point eruptions of locally restricted basaltic flows. The Quaternary sequence of the Golan Plateau is made up almost entirely of volcanic rocks, whereas in the Jordan Valley these interfinger with sediments. Potassium–argon datings of the basalts considerably helped in geochronological assignment of the various formations (Horowitz *et al.* 1973; Siedner and Horowitz 1974; Siedner *et al.* in preparation).

COVER BASALT

The Cover Basalt has been described and studied by many authors. It was noted by Lartet (1869), who described the basalts that cover most of the eastern Galilee and the Golan, and who distinguished between basalt that predates the Levantine faulting and basalts that he attributed to the Quaternary, which postdate the formation of the Jordan Rift Valley. Various names have been adopted by different authors for the Cover Basalt, such as "Upper Basalt Flows" (Blake 1928), "Upper Basalt" (Picard 1936), "Plateau Basalt" and "Cover Basalt" by others, and "Pliocene Basalt" (Oppenheim 1962). The most common name today is Cover Basalt, derived from the large areal extension of this basaltic formation.

Schulman (1962) gives a type section for the Cover Basalt from the western fault scarp of the Central Jordan Valley, near Jabul, coordinates 1980–2192, where seven successive flows of the Cover Basalt crop out, in one of the reaches of Nahal Isaskhjar. The thickness of the type section is 100–120 m. The rock is mostly olivine or idingsite basalt, with granular or ophitic textures, sometimes grading to plagioclase basalt. Porphyritic basalt with phenocrysts up to 5 mm across, comprising mainly plagioclase, are quite common. The olivine and idingsite crystals also occur as phenocrysts, a few millimeters across. Each of the flows is 10–20 m thick, and most of them present similar characteristics (Figure 5.126). The base of the flow is mostly irregular, over which comes a sole, 30–100 cm thick, consisting of massive rock with some rare vesicles. Joints are scarce and irregular, and vesicles solitary, mostly spherical. The lowermost 5–10 cm sometimes contain many pressed, elongated vesicles overlain by pipe vesicles. The lower contact is glassy, and so are the margins of the jointed blocks. The lower part of the flow, 1–4 m, which overlies the sole, is entirely massive, with no vesicles, and subhorizontal sheeting is quite well-developed. From this part upward, columnar jointing gradually develops. Columnar jointing is quite well-developed in most of the flows comprising the Cover Basalt. The thickness of the colonnades varies from place to place, and it seems that there is some connection between the thickness of the colonnades and the thickness of the individual flow in which they are developed. The thickness of the colonnades varies from 20 to 120 cm. They are mostly wider at the base and taper upward toward the top of the flow. Most of the colonnades are hexagonal, but pentagonal and septagonal ones are quite common.

Colonnades comprise more than half the thickness of the entire flow. At the lower part, the colonnades contain almost no vesicles, but these gradually appear upward. Horizontal fracturing gradually develops toward the tops of the colonnades and is quite typical for the flows of the Cover Basalt. Vesicles of the colonnades are mostly large, solitary, and oval. The number of vesicles and the frequency of the horizontal fractures increase toward the upper part of the colonnades. The vesicles are stretched, with rather flat floors and convex roofs, attaining up to 20 cm in diameter. The flat floors of neighboring vesicles sometimes appear like simulated bedding, with vertical irregular fracturing. The vesicles' voids are mostly irregular, but the floor and the apparent bedding are subparallel to the orientation of the flow. The large vesicles are always devoid of any secondary filling. The outer faces of the prisms are glassy, and the glass shell might attain a thickness of up to 2 cm. Subordinate surface secondary calcite sometimes fills the cooling fracture between the individual columns. Some of the columns are typically curved, most probably in the flow direction of the lava, a result of the irregularity of the area over which the lava flowed. The colonnade is overlain by a vesicular phase, which is different from flow to flow. It attains up to 5–6 m in thickness and gradually passes through an AA scoria or pahoehoe roof. AA klinker roofs are quite rare in the Cover Basalt. The scoria that comprises the roof of the Cover Basalt flows is mostly vesicular, clean, and without any secondary filling; its specific gravity is quite low. Most of the flows are fully preserved, including the roofs. Paleosols separating flows are unknown from the Cover Basalt sequence. Hydrothermal calcite veins or travertine sometime fill joints irregularly in the Cover Basalt, mainly close to faults and fault zones. Metasomatic replacement of the the basalt in fault zones by hydrothermal calcite is quite common, producing a breccia-like rock, but, even in these cases, the basaltic rock that has not been replaced displays empty vesicles. The type section of the Cover Basalt comprises 7 flows, but, in some of the sequences, up to 10 flows were observed, obtaining a total thickness of over 150 m (Bentor 1946). The lowermost 2–3 flows are magnetically normal, but most of the sequence is magnetically reversed (Freund *et al.* 1965; Nur and Helsley 1971).

The Cover Basalt is known from the Yizre'el Valley, the Central Jordan Valley, eastern Galilee, and the Hula Valley. Most of the flows are a result of fissure eruption, and a number of dikes and dike swarms are known, which are connected and sometimes also partly intrude the Cover Basalt sequence. The best-documented are a swarm of camptonite dikes near Yavne'el and several basaltic dikes that crop out on the main road leading from Nazareth to Tiberias, cutting through Eocene limestone (Figure 5.127). Another rather conspicuous dike that fed the Cover Basalt system crops out in the Upper Galilee, near Yir'on, and is connected with the sequence of flows that cover the Yir'on–Bar'am–Alma Plateau. At least one central volcano from which flows connected with the Cover Basalt sequence were erupted is known, comprising the site of Karne Hittin (Golani 1962). The volcanic neck of Karne Hittin (Figure 5.128) is mostly built of medium-to-coarse grained theralite (Oppenheim 1962) and towers above its surroundings due to its resistance to erosion. The thickness of the Cover Basalt varies from place to place. It attains up to 150 m near Yavne'el (Figure 5.129), but the top here is always truncated, and this should be regarded as a minimum figure. In the eastern Galilee, and especially on the mountainous block, it does not attain more than a couple of meters (Saltzman 1964).

The Cover Basalt occurs also in the southern areas of the Golan Plateau, east of the Kinneret and on the northern part of the Gilead mountains southeast of Lake Kinneret. The paleomagnetic polarity of the Cover Basalt on the southern Golan Plateau (Michelson 1972) is similar to the paleomagnetism measured in the Cover Basalt west of the Kinneret (Freund *et al.* 1965; Nur and Helsley 1971). Michelson (1972) has shown that the Cover Basalt sequence of the southern Golan Plateau is covered to the north and northeast by younger basalt flows, which he, with no further details, generally assigns to the Pleis-

FIGURE 5.126. *Flow of the Cover Basalt.*

FIGURE 5.127. *Dike of the Cover Basalt, cutting through Eocene limestone near Lake Kinneret.*

FIGURE 5.128. *Karne Hittin, a volcanic neck connected with the Cover Basalt system.*

FIGURE 5.129. *Sequence of flows of the Cover Basalt, near Yavne'el.*

tocene. These basalts will be discussed later. The Cover Basalt overlies formations of different ages, always over an erosional relief, and sometimes fills preexisting canyons up to several tens of meters deep. The youngest formation overlain by the Cover Basalt is the late Pliocene Gesher Formation (Schulman 1962). The top of the Cover Basalt is always truncated, mostly due to consequent faulting and erosion connected with the Levantine System. The Cover Basalt is overlain by two Günzian formation, the Gadot Formation at the Hula Valley and the Erk el-Ahmar Formation at the Central Jordan Valley.

Radiogenic ages for the upper flows of the Cover Basalt are in the range of 1.7–2.0 million years (Siedner and Horowitz 1974). It seems that the lower flows of the Cover Basalt, with normal paleomagnetism, cooled during the Gauss Normal Epoch, whereas the upper part cooled during the Matuyama Reverse. The Cover Basalt was, therefore, formed in northeastern Israel during most of the Preglacial Pleistocene. It is considerably affected by processes connected with the Levantine Faulting. The Cover Basalt presents a typical basin and range, tilted block country east of Lake Kinneret (Figure 5.129) and the Central Jordan Valley and was affected by the upwarping process of the mountainous backbone of the country (Schulman 1962). It seems that the radiogenic and paleomagnetic dating of the Cover Basalt represent good absolute dates for the Preglacial Pleistocene, because it overlies the late Pliocene and underlies the Glacial Pleistocene deposits of the Jordan Valley (Horowitz 1973).

YARDA BASALT

The Yarda Basalt (Figure 5.130) was designated in Picard (1963) to include a volcanic sheet appearing on the elevated Gadot block, just south of the Hula Basin. The type section was taken near Hirbet Yarda, where about 40 m of the basalt crop out. The sequence comprises two or three flows superimposed on one another, with no separating paleosols. The rock comprises fine-grained plagioclase basalt with abundant equidimensional olivine crystals. Idingsitization is quite rare in the fresh outcrop.

FIGURE 5.130. *The Yarda Basalt, faulted against the Hula Valley.*

The basalt is mostly dense, with only a few vesicles, which are more abundant at the base and the top of each flow, sometimes filled with secondary calcite. The paleomagnetic polarity is always normal. The source for the Yarda Basalt is not known, but several ridges in the vicinity of the Mahanayim Airfield may represent dikes from which the lava was poured out. The Yarda Basalt crops out about midway on the elevated Korazim–Gadot Block, which separates the Hula from the Kinneret Lake, and trends northward, dipping about 3° in the direction of the Hula Valley. The basalt flows show typical flow structures, such as locally developed domes. The roofs of the flows mostly comprise pahoehoe, but sometimes an AA klinker is developed. These domes comprise part of the hills running along the Gadot elevated block. The basalt is probably quite abundant on the Golan Plateau (Michelson 1972; Mor, 1973; Picard 1965). Another occurrence of a basalt sheet that most probably corresponds to the Yarda Basalt was penetrated in the Hula I borehole in the north of the Hula Basin, at depths of 284–312 m (Picard 1963). The possible correlatives of the Yarda Basalt on the Golan Plateau will be discussed later.

Potassium–argon dating of the Yarda Basalt at the Benot Ya'akov outcrop yielded an age of 640,000 ± 120,000 years B.P. (Horowitz *et al.* 1973). The Yarda Basalt overlies the Cover Basalt at the central part of the elevated Korazim–Gadot block south of the Hula Valley and progressively overlies younger sediments to the north. It mostly overlies the Gadot–Hazor complex on the Gadot elevated block, filling an erosional relief. The famous Tel Hazor (Picard 1963) is situated on a sheet of the Yarda Basalt that covers the Hazor Gravel. The flows of the Yarda Basalt have mostly flattened the preexisting relief cut within the Gadot Formation sediments, but at some localities, such as Hirbet Yarda, the Gadot Formation is presently topographically above the Yarda Basalt, which led Picard (1963) to the assumption that the Gadot is younger than the Yarda. The youngest formation overlain by the Yarda Basalt, however, is the Mindelian Mishmar HaYarden Formation, which is quite conspicuous at the Benot Ya'akov outcrop (Figure 5.98). The Yarda Basalt is faulted and, at the Benot Ya'akov outcrop, is tilted at an angle of about 60°. It is overlain, over an angular and erosional unconformity, by the Rissian Benot Ya'akov Formation (Figure 5.100). The basalt most probably corresponds laterally to the Ayyelet HaShahar Formation of Mindel–Riss age, but no contacts or interfingerings between the two are known. It is quite difficult to assess the system in which the basalt was formed. If the ridges near the Mahanayim Airfield are really the dikes from which this basalt was poured out, then this is about the only occurrence of basaltic effusions within the rift valley proper. It is quite clear, however, that basalts of the same age cover areas on the Golan Plateau, but, due to the scarcity of potassium–argon datings in this area and due to the rather thick cover of younger basalts on the Plateau, the characteristics of this system cannot be delineated at the moment. The stratigraphic age of the Yarda Basalt is late Mindel or Mindel–Riss, which corresponds quite well with its radiogenic age. Its normal paleomagnetic characteristics put it at the beginning of the Brunhes Normal Epoch.

YARMOUK BASALT

The Yarmouk Basalt was designated by Picard (for example, 1932) as a rather high basaltic terrace (Figure 5.131), appearing at the confluence of the Yarmouk and Jordan Rivers. This basalt was noted by Noetling (1886) and Blanckenhorn (1914); the latter named it the "Ez-Zeyyatin Lava." This name is, in fact, more descriptive than Picard's "Yarmouk Basalt," but, since the latter is presently in common use, it will be retained here. The Harza Engineering Company (1955) also describes this basalt, under the term "First Valley Flow." Bender (1968) used the term "Yarmouk Basalt" suggested by Picard. The only detailed study to date of the basalt was carried

FIGURE 5.131. *The Yarmouk Basalt (upper terrace) and the Raqqad Basalt (lower terrace), at the outlet of the Yarmouk River to the Jordan Valley.*

out by Michelson (1973). Its type section is taken at the confluence of the Yarmouk and Jordan Rivers, where the basalt forms a terrace about 200 m above the present-day thalweg. It seems that the sequence comprises a single flow, somewhat vesicular at its lower part, but otherwise mostly massive alkali olivine basalt. The top of the flow has deteriorated into soil. Its magnetic polarity is normal. Relics of the basalt can be found all along the Yarmouk River gorge at elevations ranging from 100 to 200 m above the present-day thalweg, but mostly around 200 m. The thickness is in the range of 5–25 m.

The Yarmouk Basalt was most probably extruded from several central sources, some of which are still to be seen on the shoulders of the Yarmouk River, from which location they flowed down and filled the Yarmouk Gorge to create the presently higher terraces. Potassium–argon dating of the basalt yielded (Siedner and Horowitz 1974) an age of 680,000 ± 50,000 years B.P. and (Siedner *et al.* in preparation) 560,000 years B.P. Most of the basalt rests unconformably on eroded Eocene rocks that form the Yarmouk Gorge. This gorge is younger than the Cover Basalt, which forms the flat-lying basaltic formation on top of the Gilead mountains, into which the Yarmouk Gorge is cut. In the area of Naharayim, where the Yarmouk River enters the Jordan Valley, the basalt probably overlies the Ubeidiya and the Erk el-Ahmar formations (Horowitz 1974; Horowitz *et al.* 1973). The basalt is faulted in the Jordan Valley and overlain by paleosols and gravels of the Rissian Naharayim Formation. No lateral equivalents for it are known. The basalt probably represents a system of central eruptions of rather local distribution that poured basalts into the already existing Yarmouk Gorge; the gorge at this time was about 200 m higher than its present-day thalweg. The stratigraphic age is late Mindel or Mindel–Riss, which, together with its radiogenic age, corresponds and correlates with the system that also extruded the Yarda Basalt in the Hula area.

HASBANI BASALT

The Hasbani Basalt (Figure 5.132) is described by Picard (1963) in the northern sector of the Hula Valley. It is also described by Dubertret in the southern sector of the Beqa'a in Lebanon (1929, 1952). The type section of the Hasbani Basalt was taken by Picard in the Hasbani Gorge, north of the Hula Valley, where about 30 m of the sequence are exposed. A considerably thicker sequence, about 100 m, was apparently penetrated by the Hula I Borehole in the northern part of the Hula Valley. The sequence comprises several well-preserved flows of a rather massive alkali olivine basalt. The surface features of the lava fields are quite prominent in the northern Hula Valley, and elongated ridges and domes capped by typical AA klinkers are widespread in the area. The Hasbani Basalt overlies the Kefar Yuval Travertine of Rissian age and is overlain by the Dan Travertine of Würmian age (Horowitz 1973). It interfingers with the lateral conglomerates of the upper part of the Hula Group, most probably overlying the Mishmar HaYarden and underlying the Ashmura Formation, interfingering with lateral conglomerates of the Hulata Formation. No sources of eruption are known for the Hasbani, but correlative flows of basalt were extruded from central sources on the Golan Plateau and flowed down to the Hula Valley just south of the Hermon, and these seem to be of similar type. The Hasbani was extruded somewhere to the north of the Hula Valley and flowed southward. The terminal tongues of the basalt flows of the Hasbani are quite clear in the northern Hula Valley; one comprises the basaltic ridge just east of Qiryat Shemona, and others comprise several ridges further to the east. The Hasbani was potassium–argon dated (Siedner and Horowitz 1974) at 73,000 ± 14,000 years B.P.

FIGURE 5.132. *The Hasbani Basalt, north of the Hula Valley.*

The stratigraphic age of the Hasbani Basalt is Riss–Würm Interpluvial, which corresponds well with the radiogenic age. Correlative flows on the Golan Plateau yielded radiogenic ages (Siedner and Horowitz 1974) in the same range as the Hasbani. The El Furn Flow yielded an age of 79,000 ± 13,000 years B.P., and the Aleqqa Flow yielded an age of 64,000 ± 13,000 years B.P. The stratigraphic position of the Hasbani Basalt can be seen quite clearly in the locale of the Banias waterfall, where it overlies the Kefar Yuval Travertine and is overlain by the Dan Travertine. The basalt is massive columnar in this outcrop and is about 20–25 m thick. The colonnades in this outcrop show conspicuous bellies pointed in a southward direction, which might indicate the flow direction of the Hasbani in this area.

RAQQAD BASALT

The Raqqad Basalt (Figure 5.133) was first defined in Noetling (1886) from Wadi Raqqad, a tributary of the Yarmouk River. Noetling, and, later, Blanckenhorn

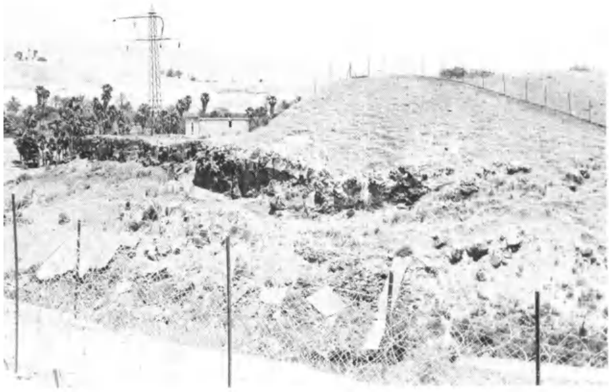


FIGURE 5.133. *The Raqqad Basalt at Naharayim, overlying the Naharayim Formation gravel and overlain by the Lisan Formation sediments.*

(1914), refer to this volcanic phase as the "Rukkad Lava." Picard (1932), for example, regarded the Raqqad and the Yarmouk Basalts as a single unit, whereas the Harza Engineering Company (1955) regarded this phase as the "Second Valley Flow." The Raqqad was studied in detail by Michelson (1973). The type locality of the Raqqad is Wadi Raqqad, where about 20–30 m of basalt fill the preexisting gorge. The rock comprises mainly alkali olivine basalt and is rather massive. The Raqqad Basalt overlies the Eocene rocks that comprise the Raqqad and Yarmouk gorges, forming terraces of elevations of 30–60 m above the present day thalweg. In the Naharayim area, close to the confluence of the Yarmouk and Jordan rivers, the Raqqad Basalt overlies the Rissian Naharayim Formation and is overlain by Lisan Formation lacustrine sediments. Lateral equivalents of the Raqqad Basalt are not known, and in other localities the Lisan Formation directly overlies the Naharayim Formation. The source of the basalt in the Yarmouk–Raqqad area is not known, but it seems to be of central source type, since the areal distribution of the basalt flow is quite limited.

Flows that are similar in every respect to the Raqqad Basalt are described in Bender (1968) from the eastern side of the Jordan Rift Valley, down to the Dead Sea. The volcanic necks that extruded these lavas are sometimes to be seen on the Transjordanian Plateau. The lavas flowed in preexisting valleys, and, when coming to the Jordan Valley, overlie conglomerates in which Late Acheulian artifacts were found (Huckriede 1966). These lavas are also covered by Lisan Formation sediments, so that their correlation with the Raqqad Basalt is quite obvious. Bender (1968) describes a number of volcanic occurrences on the Transjordanian Plateau, some of which might be correlated with the Raqqad basaltic phase. Bender, following Picard, does not differentiate between the Yarmouk and the Raqqad basaltic phases; therefore, only occurrences that overlie the Naharayim Formation gravel or other gravel horizons bearing Late Acheulian artifacts could be definitely assigned to the Raqqad phase. The most conspicuous occurrences of this phase in Jordan are the large volcanoes south and east of Rashadiya: Jebel el-Hikkir, which towers to about 1400 m; Jebel el-Rudeisiya, 1585 m; and Jebel el-Qirana, 1366 m, all of which extruded basalt flows overlying gravels that contain Late Acheulian artifacts. In some volcanoes, craters and calderas are very well preserved, as they are, for example, in Tel Burma and Jebel Uneiza. The upper surfaces of these flows are quite well-preserved and, apparently, were not subjected to considerable subsequent erosion. Some fissure eruptions in Jordan are also correlated by Bender (1968) with this phase, but, since the rocks of these volcanoes do not interfinger with any sediments, no definite conclusion could be reached. Basalts of the same phase are also reported from the central and northern Golan (Mor 1973), to be discussed later. The stratigraphic position of the Raqqad Basalt, separating the Rissian Naharayim Formation from the Würmian Lisan Formation, places it within the Riss–Würm Interpluvial period. The Raqqad is, therefore, correlative with the Hasbani Basalt phase in the northern sector of the Hula Basin. No potassium–argon dating at the type-locality of the Raqqad is available, but correlative rocks discussed earlier indicate an age in the range of 70,000 years B.P.

GOLAN VOLCANIC SEQUENCE

The volcanic province of the Golan has been studied in detail by many authors; for example, Bender (1968), Boom (1968), Dubertret (1929, 1966), and Wetzel and Morton (1959). The first detailed study of the succession of flows on the Golan Plateau was carried out by Mor (1973), in the central sector. Michelson (1972) refers to all the younger basalts that overlie the Cover Basalt in the southern Golan as "Undifferentiated Young Basalts." Wolfart (1966) also dealt with the petrography of the Golan basalts. Dubertret (1929) was the first to identify the rocks as alkali olivine basalts. The alkali olivine basalt nature of the volcanic rocks on the Golan has been noted by almost all investigators, and it seems also, according to the detailed analysis of Mor (1973), that the entire sequence of basalts on the Golan comprises the same type of rock. No differentiation could be made, based on petrography, between the various units and the various flows within the Golan volcanic sequence. The sequence comprises also pyroclastic rocks, sometimes connected with lava flows, which show close petrographic affinities to the alkali olivine basalts. Some xenoliths, mainly comprising essexite and dunite, were found within volcanic bombs in some localities. Soudry and Bogosh (1971) state that the scoria particles are probably a glassy equivalent of the basalt. The petrographic similarity throughout the volcanic sequence of the Golan led many authors to the conclusion that the entire sequence is connected with a single major source and that the various lava flows and pyroclastic extrusions are, in fact, an expression of a single, continuous volcanic phase.

Mor (1973) divided the Golan volcanic sequence into two principal units: the "Cover Basalt" which was thought to be equivalent to this formation in the Galilee and the southern Golan, to which Mor assigned an upper Pliocene through middle Pleistocene age. More pointed to the possibility that most of what he calls the "Cover Basalt" sequence of the central Golan is younger than the formation. of the same name in the Galilee and the southern Golan. It is, at the central Golan, further subdivided into three members. This "Cover Basalt" is overlain by the Golan Formation, of middle to late Pleistocene age. The Golan Formation is subdivided into five members, and overlies the "Cover Basalt" on a considerable hiatus, represented by a buried topography and by paleosols. The two volcanic phases differ considerably from each other. The lower is, for the most part, paleomagnetically reversed, comprising mainly basalts and subordinate amounts of pyroclastics, whereas the second is paleomagnetically normal and comprises mainly pyroclasts of rather limited distribution, for which the central sources and volcanoes are clearly observed in the area. The Golan basaltic sequence has never been traversed at one locality, and it is, therefore, quite difficult to assess its thickness. Moreover, the basaltic flows taper considerably, so that exact figures are irrelevant. It seems that the thickness of the described sequence exceeds 200 m (Mor 1973). The entire volcanic sequence is probably much thicker, in the range of 700–800 m, but the undelying basalts are most likely of Neogene age (Bender 1968). The potassium–argon datings of the basalts presented here were done by Siedner *et al.* (in preparation).

The name "Cover Basalt," assigned by Mor (1973) for the lower part of the volcanic sequence that crops out on the Golan Plateau, seems inadequate and inaccurate. Mor himself states that these basalts could be younger than the typically defined Cover Basalt of the eastern Galilee and the Central Jordan Valley (Schulman 1962). The radiogenic ages seem to verify this assumption, and, therefore, it is suggested not to use the term "Cover Basalt" for the Golan sequence. No new name for the sequence is suggested here, and it is proposed to refer to the members of this unit by their own names, rather than to group them together. Three members are discerned within the "Cover Basalt." The "Undivided Lower Basalt" (Ba) is a tentative name for all the basaltic flows from the base of the sequence overlying the Eocene rocks up to the point of contact with the overlying Dalwe Basalt. This member is best exposed at Nahal Orvim, east of the Hula Valley (Figure 5.134), and comprises nine flows. Each of the flows is rather thin, not exceeding several meters, up to a maximum of 15 m in thickness. The flows are separated from each other by thick accumulations of red, clayey paleosols. The entire sequence attains some 75 m in thickness. The lowermost two flows are paleomagnetically reversed, the succeeding two flows are normal, and the overlying five flows are once more reversed. The approximate potassium–argon age for the lowermost flow at Nahal Orvim is 1.8 million years, for the second and third flows 1.4 million years, for the fourth and fifth flows 1.2 million years, and for the uppermost four flows 1 million years B.P. These ages place the undivided sector of the lowermost part of the "Cover Basalt" at a younger stratigraphic age than the Cover Basalt of the Central Jordan Valley and the Galilee, which yielded ages in the range of 1.7–2.8 million years (Siedner and Horowitz 1974).

The entire sequence of Nahal Orvim was formed during the Matuyama Reversed Epoch. The third and fourth flows, which show normal paleomagnetic polarity, seem to be too old for the Jaramillo Event and somewhat too young for the Gilsa Event. However, since the potassium–argon ages are only point ages, an isochron age might correlate these two flows with either of the two normal events. It seems more probable, though, that these two flows were formed during the Gilsa Normal Event. The Nahal Orvim sequence is affected by the border faults of the Hula Basin, probably a manifestation of the intra-Pleistocene faulting phase, of post-Mindel–pre-Riss age, which is known to have caused some severe faulting at the Benot Ya'akov area, some 10 km south of Nahal Orvim. The Dalwe Basalt (Bd) appears morphologically with a very rugged topography, having few clear flows and lava domes formed with gentle slopes. It is, for the most part, paleomagnetically reversed and yielded an age of approximately 1 million years B.P. The Shiban Scoria (ScS) comprises several scoriaceous and basaltic scoria cones that appear on top of the Dalwe Basalt lava domes. No paleomagnetic reading for the Shiban Scoria could be taken, and the radiogenic age is once more in the range of 1 million years.

The Golan Formation overlies the previously mentioned three units, over an erosional surface that is paved in most places by thick, clayey, red paleosols. However, in some rare cases the Golan Formation overlies the

FIGURE 5.134. *The sequence of flows at Nahal Orvim, on the east fault scarp of the Hula, overlying well-stratified Eocene limestones.*

underlying rocks over an erosional unconformity with no paleosols. This hiatus seems to be of considerable length (Mor 1973). The paleosols probably represent low areas within the ancient topography, which was also dissected by a number of channels later filled with the overlying basalts and tuffs. The areas that are directly covered by the Golan Formation were probably subject to erosion during this interval. The Golan is subdivided into five members. The lowermost, the Muweisa Basalt (Bm), comprises numerous clear, thin flows that overlie each other. It mostly displays weak normal paleomagnetic characteristics. Its potassium–argon age is about 350,000 years. The Odem Scoria comprises numerous scoria and pyroclastic cones, some of considerable dimensions, that overlie the Muweisa Basalt. The cones are mostly arranged (Figure 5.135) along clear, straight lines. Neither paleomagnetism nor potassium–argon ages were measured for this member. The En Zivan Basalt is a general name for the basaltic flows extruded from the Odem Scoria cones. The basalt is very rugged, mostly devoid of soils, and displays strong normal paleomagnetic characteristics. Its potassium–argon age is about 500,000 years. Despite the stratigraphy proposed in Mor, the En Zivan Basalt appears to be older than the Muweisa Basalt. It seems that the Muweisa flowed and encircled the Oden Scoria cones, which created the apparent picture of these cones protruding above the Muweisa Basalt flows. The El Furn Basalt comprises only a single, rather limited flow, consisting of typical ropy basalt. It is paleomagnetically normal and was dated by Siedner and Horowitz (1974) at 79,000 ± 13,000 years B.P. The Avital Tuff (Figure 5.136) comprises a series of volcanic tuffs, pyroclastics, and clays, which appear in the Kuneitra Valley. It was mostly deposited in the water of some small marshes and lakes and comprises graded-bedded sinerites. The Avital Tuff has a maximum thickness of 36 m (Soudry and Bogosh 1971) but thins to about 10–12 m to the east. It overlies a paleosol, about half a meter thick, which in turn overlies basalt, most probably the Muweisa Basalt. The Avital Tuff in the Kuneitra area passes gradually upward into brown soils. At the transition zone of the tuff to the soil, some Mousterian artifacts were collected by Mor (1973). He concluded that these artifacts belong to the Avital Tuff phase and, therefore, proposed a chronostratigraphic correlation of the Avital tuffs with the earliest Würmian. A single potassium–argon dating for the Avital Tuff yielded an age of 370,000 years, which suggests that the Avital Tuff belongs to the final extrusion phase of the Muweisa Basalt. The Mousterian artifacts seem to overlie it and, thus, do not seem to belong to the sequence. It is quite conceivable that they do not, since they were found in the transition from the tuff to the soil. This idea is further strengthened by some finds of Late Acheulian artifacts (O. Bar-Yosef, personal communication, 1973) that seem to overlie the Avital Tuff, not far from Kuneitra.

FIGURE 5.135. *One of the Odem Scoria cones, on the Golan.*

FIGURE 5.136. *The Avital Tuff, near Kuneitra.*

The volcanic activity in the central Golan can, therefore, be discerned as comprising several phases. According to this scheme, the lowermost flow at Nahal Orvim corresponds to the uppermost flow of the Cover Basalt of the Central Jordan Valley and the southern Golan. This conclusion is strengthened by the geochemical and trace-element characteristics of this flow, which differ from the rest of the flows in Nahal Orvim but are quite similar to the Cover Basalt flows of the Central Jordan Valley (I. Brenner, Geological Survey of Israel, personal communication, 1977). Another phase of activity occurred about 1.2–1.4 million years ago, depositing a number of flows in the Nahal Orvim section. It should be noted that all the flows in this section are of local significance, thin and separated by paleosols from each other, which indicates that they do not represent extensive volcanic activity but, rather, short phases of volcanic eruptions separated by long periods of subareal exposition accompanied by pedogenic processes. The next period of volcanic activity is manifested in the upper four flows of Nahal Orvim, together with the Dalwe Basalt and the Shiban Scoria; this activity occurred about a million years ago. The En Zivan phase, which is connected with the Odem Scoria, occurred more than 500,000 years ago and is probably correlative to the Yarmouk and the Yarda Basalts. The ages obtained for these three units are within the range of analytical error. Another phase occurred about 350,000 years ago, forming the Muweisa Basalt, which was terminated by the extrusion of the Avital Tuff. The El Furn Basalt represents the volcanic activity that occurred some 70,000 years ago. This activity was quite limited in the central Golan but is quite widespread in the northernmost Golan, at the foothills of the Hermon range, where it flowed over all the other basaltic formations down to the Hula Valley. It is also observed in the southern Golan, forming the Raqqad Basalt. This phase is known, as discussed earlier (Bender 1968), from the Transjordanian Plateau, down to about 100 km south of the Dead Sea.

KARST, CAVES, AND TRAVERTINES

The phenomena grouped in this subchapter are all a result of subsurface water movement within carbonate formations. These phenomena are quite abundant in the central part of Israel, which is chiefly built of various types of carbonate rocks of late Cretaceous and early Cenozoic age. Karstic processes take place quite widely at present, and most of the larger springs in Israel are fed by karstic aquifers. These karstic aquifers presently supply more than 70% of the water consumed in the country.

Karstic processes have taken place in the country throughout the entire Quaternary but were reactivated and rejuvenated in the transition from the Preglacial to the Glacial Pleistocene, when the mountainous backbone was considerably elevated and the Jordan–Dead Sea Rift was formed. Consequently, the groundwater pattern totally changed, and groundwater that before flowed only to the west began to flow both to the west and to the east, divided by the longitudinal groundwater watershed. The activity along these aquifers resulted in some surface karstic landscapes, especially developed in the northern part of the country, where rainfall is considerably higher, by the formation of karstic caves within the limestone formations, which were consequently opened due to the continuous elevation of the mountainous backbone and the deepening erosion and to travertines that were deposited at the outlets of these karstic aquifers, mainly to the east and west of the mountainous backbone.

KARSTIC PROCESSES AND LANDSCAPES

Mandel (1961) divided the active karstic processes in Israel into two main groups. The first comprises surface processes, which produce karst landscape and are presently active only in northern Israel, in the Upper Galilee, where the annual rainfall exceeds 750 mm. These surface karstic landscapes were dealt with in detail by Gerson (1967, 1974). The second group encompasses subterranean karst, which results in the formation and widening of caves and karstic aquifers. These processes seem to be active at present, under the actual climatic conditions, as far south as the Be'er Sheva Basin. In Samaria, Judea, and the Hebron hills, suface karst phenomena are presently not formed because of insufficient rainfall, which is less than 750 mm per year; this amount is set by Mandel as the limit for surface karst formation. Karst phenomena in the mountainous backbone of the country are mostly developed in limestones and sometimes in dolomites. The karstic dissolution and recrystallization processes are usually developed along joints and faults, but caves and larger karstic voids are, for the most part, limited to fossil reef cores, which are quite abundant in the Cenomanian and Turonian strata of the country. Very extensive karst activity can be seen presently at Mt. Sedom, in the southern Dead Sea area, by the extensive dissolution of rock salt of the Sedom Formation by rain and floodwaters (Figure 5.137). Mandel (1961) also states that karstic phenomena are not limited by the erosion base level, and, in fact, they continue to be formed even below the elevation of the base level, as long as the groundwater is flowing.

The karst landscape in the Upper Galilee is mostly developed on Cenomanian and Turonian rocks, but some small caves and karstic phenomena are to be seen also in the Eocene limestones. Caves are quite rare in the area, and this is attributed by Gerson (1974) to continuous tectonic activity in the Galilee, which does not permit

FIGURE 5.137. *Karstic cave at Mount Sedom, Dead Sea area.*

hydrologic stability for the long periods necessary for the formation of large caves. Most of the karstic phenomena in the Galilee result from the combination of downward movement of the water through karstic veins with quite intense fluviatile activity. The most common karstic phenomena in the Galilee are sink holes (Figure 5.138) of a rather restricted size, and a number of dolinas. Only one polje was developed in the Galilee, which is the Biq'at Qadesh in the Naftali Mountains. It was developed in two stages, the first by fluviatile erosion and the second by karstic processes.

Karstic landscape of Quaternary age is quite rare in Israel, mostly due to subsequent erosion; but, at least in two localities, karstic forms are preserved. One is the large polje of Emek Hamikhmetat, a large intermontane valley of the Samaria mountains (Gerson 1967), and the other is a small dolina not far from Jerusalem (Mandel 1961). The ages of these two phenomena are not known, but it is quite clear that they were formed under a more humid climate than prevails in these areas today. Subsurface karstic activity has been known throughout Israel, including the Central and sometimes even the Southern Negev, where these processes are, at present, nonactive. This, once more, is evidence of more humid climatic conditions in the country during former periods, but, since no dating is available for the karstic aquifers, their occurrence is of no great significance. An interesting argument for karst phenomena was brought forward by Bloch and Picard (1970), who discussed the possibility of the Dead Sea's being a sink hole of karstic origin. They claim that geologic reasoning, supported by physical and chemical data, suggests that the 400-m-deep subsea trough of the northern half of the Dead Sea was not formed by fault movement but by dissolution of a salt body during the last 15,000 years.

CAVES

Caves in Israel are generally developed within reef cores of Cenomanian and Turonian strata (Figure 5.139) and sometimes within limestones of Eocene age (Figure 5.140). It seems that there is no dispute as to the karstic origin of caves in Israel, save for several that face the Mediterranean Sea on the Carmel western slope. Suggestions have been raised by several authors as to these caves, the main one being that they represent wave-cut notches and niches created by the ingressing Pleistocene seas. Since sinter and travertine deposits are found in most of the westward-facing caves, such as Sefunim, Tabun, Kebara, and others, it seems unreasonable to imply wave-cut activity as the sole agent of formation for these caves. The westward-facing Carmel caves were most likely formed due to karstic processes, later exposed and maybe also slightly widened by wave activity.

The karstic caves of Israel can be divided into two groups, the nonactive, high-level caves and the buried,

FIGURE 5.138. *Active sinkhole in the Upper Galilee.*

FIGURE 5.139. *Cenomanian reef core at el-Wad Cave, Mount Carmel.*

FIGURE 5.140. *The Amud Cave, near Lake Kinneret, in Eocene limestone.*

active ones. The only certain wave-cut caves are to be found in Rosh HaNiqra, at the northern border of Israel (Figure 5.141). Active caves have the disadvantage for the investigator of not being exposed to the surface under normal conditions, but many boreholes have encountered such caves, especially in the Cenomanian and Turonian strata of the country. These strata have, there-

FIGURE 5.141. *Recent undercut notches at Rosh HaNiqra.*

fore, acquired the term "loss of circulation zone" in oil-drilling jargon. It is quite difficult to assess the degree of activity in these caves, but it is clear that the karstic aquifers are active cave-forming agents, since average rainwater contains no carbonates, whereas the groundwater obtained from the karstic aquifers is quite rich in calcium carbonate, proving that considerable dissolution of carbonate rocks takes place under present-day conditions in the subsurface. A large underground cave (Figure 5.142) that gives a good example of present-day activity was found not long ago near Jerusalem, at Hartuv, due to quarrying activities. This cave contains numerous stalactites and stalagmites, some still in the process of formation. Another cave in which stalagmites and stalactites are present, but to a much lesser extent, is the Namer (tiger) Cave in the Upper Galilee (Bar-Yosef 1965), but this is a rather small cave in comparison to the one near Jerusalem. The Namer Cave seems to be slightly active in the present. Another system of caves that are to some extent active in the present are those around Alma in the eastern Upper Galilee (Gerson 1974), but these caves are also of lesser volume. Typically, the caves in the eastern Upper Galilee are connected with sink holes to the surface, whereas the others are fed mainly through fissures and joints.

FIGURE 5.142. *The Hartuv Cave, Judean hills, which is active today. (Photograph by A. Hay, Institute of Archaeology, Tel-Aviv University.)*

FIGURE 5.143. *A series of fossil caves in the Upper Galilee, known as the "Gate of the Heaven."*

FIGURE 5.144. *The "Bears' Cave," Upper Galilee, presently totally ruined and situated on top of the mountain.*

Of the nonactive caves, some in the upper part of the mountainous backbone are totally ruined, and only relics are to be found. The Gate of the Heavens cave in the Upper Galilee is quite conspicuous (Figure 5.143). Relics of nonactive caves that contained fossil bones are known from two localities; in the Upper Galilee (Figure 5.144), where travertines that contain abundant bear bones (*Ursus speleus*) were found (E. Tchernov, Department of Zoology, Hebrew University of Jerusalem, personal communication, 1976), and in the Judean mountains, where fissures connected with a cave containing bones of

Middle Pleistocene mammals (Tchernov 1968b) were discovered. An interesting fossil cave (Figure 5.145) that is almost totally ruined was found in the Central Negev Highlands, south of Makhtesh Ramon, at the northern rim of the HaMeshar Plain. This cave contains well-developed stalactites and stalagmites and indicates that at some former stage karstic processes and cave formation went at least as far south as the Central Negev.

Open, inactive caves occur on the wadi slopes, and the exposure of those still preserved as caves has been dated from the late Pleistocene onward. This becomes clear when analyzing the human implements embedded within sediments filling these caves. The oldest is the Oumm Qatafa Cave, containing some Late Acheulian artifacts that were accumulated during Rissian times (Neuville 1951). The Oumm Qatafa Cave is situated in the Judean Desert, where the relative rate of erosion and rainfall is rather low. In the north of the country the oldest deposits were found in the Tabun and Amud Caves, with sediments of Riss–Würm Interpluvial age (Jelinek *et al.* 1973; Turville-Petre 1927). Most of the other caves were not exposed before the late Riss–Würm Interpluvial or the beginning of the Würm Pluvial and were first inhabited by Mousterian people.

TRAVERTINES AND SPRING DEPOSITS

The carbonate nature of most of the rocks comprising the mountainous backbone of Israel influences the groundwater geochemical composition, and most of the Israeli groundwaters are quite rich in carbonates. As a result, almost every spring deposits some carbonate sinters and travertines in the vicinity of its outlet. These spring deposits are abundant along the Quaternary sequence of Israel, but in most cases they are only of local occurrence and significance. Many of the Glacial Pleistocene formations have in their lateral extensions some intermingling of spring deposits and travertines. These will not be discussed. However, we will take up formations deposited during certain periods of the Glacial Pleistocene, mostly as a joint result of pluvial climatic conditions and some faulting. These are large travertine sheets that may attain tens of meters in thickness and have acquired independent formational status. The more important of these are connected with the Jordan–Dead Sea Rift Valley, but some occurrences are also known along the coastal plain, and especially along the Western Galilee coastal plain, where the karstic aquifers crop out close to the coastal plain itself. The Carmel area does not display large travertine bodies, probably due to its limited catchment area, resulting in rather limited amounts of water available to the springs.

Ga'ton Travertine

The Ga'ton Travertine is a name adopted by Horowitz (1974) to designate fossil travertine horizons in the Western Galilee (Figure 5.146). The description of the travertine is given in Issar and Kafri (1972). Thick travertine and tufa deposits are found along the Ga'ton stream valley. They form at their top a flat morphological terrace with a steep V-shaped slope of the present Ga'ton valley. The travertine extends from the foothills to the west, where it reaches an altitude of 60 m above sea level, to the present outlet of the Ga'ton springs, at an altitude of 200 m. The travertine and tufa deposits contain calcified stems and roots of plants, brown clays, and lenses of small rounded pebbles. Two Late Acheulian handaxes and several teeth of the cervid *Megaceros* sp. were found within the clays on top of this travertine. A few tens of meters of travertine, similar to that described earlier, reaching an altitude of 190 m above sea level, are found in Nahal Yehi'am. Both travertines were probably formed by ancient springs, which are today above the water table. The age of these travertines is considered by Horowitz (1974) to be Rissian, based on the occurrences of the Acheulian handaxes.

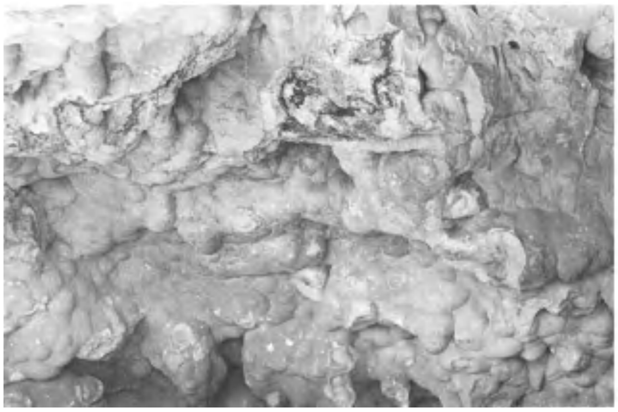


FIGURE 5.145. *HaMeshar Cave, Central Negev.*

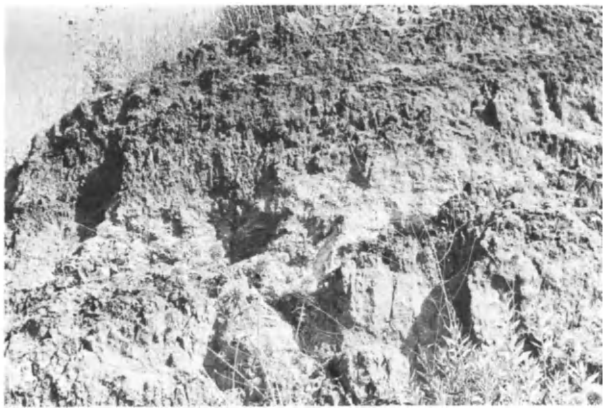


FIGURE 5.146. *Ga'ton Travertine and paleosols, east of Nahariyya.*

Kefar Yuval Tavertine

A travertine formation about 20–30 m thick (Figure 5.147) was designated by Picard (1963) as the Kefar Yuval Travertine. Outcrops of this travertine occur near Ma'ayan Barukh and Kefar Yuval in the northern Hula Valley, where they contain Late Acheulian artifacts (Stekelis and Gilead 1966). These travertines underlie the Hasbani Basalt and are correlated by Horowitz (1973) with the Rissian Benot Ya'akov Formation. They were formed by strong spring activity, which was probably a combined result of higher humidity and availability of water in Rissian times, together with some faulting in the northern Hula Valley, which exposed the Jurassic karstic aquifer of the Hermon. An attempt to date the Kefar Yuval Travertine (H. Schwarcz, McMaster University, *in litteris* 1977) has failed, most probably because the travertine is not pure, contaminated by many other rock fragments.

Seif Travertine

The Seif Travertine (Sneh, in press) is a lateral correlative of the Seif Formation, which predates the Lisan Lake in the Hazeva area, south of the Dead Sea. The Seif Travertine (Figure 5.148) chiefly occurs in the Hazeva area but was found also in the Makhtesh HaQatan (Gill 1965), in the Menuha anticline, and in Nahal Zihor (Sakal 1967). It is always represented by small, isolated outcrops that overlie, over an erosional unconformity, different parts of the Hazeva and older formations. Lithologically, it consists mainly of travertines, pebbly limestones, and conglomerates. In places, a conglomerate appears at the base of the travertine. The Seif Travertine is not connected in any way with recent springs and attains some 4 m in thickness, sometimes containing fossil *Melania* shells. Mousterian artifacts were found on top of this travertine, indicating that it is probably older than the Würmian. It seems that the Ga'ton, the Kefar Yuval, and the Seif travertines are correlative, all being of Rissian age.

FIGURE 5.147. *Kefar Yuval Travertine.*

FIGURE 5.148. *Seif Travertine, near Hazeva, high above the Lisan Lakeshore terrace.*

Dan Travertine

The Dan Travertine is the name given by Horowitz (1973) to those spring deposits termed by Picard (1963) "Younger Travertines." The type section and best exposure are in several quarries and road cuts (Figure 5.149) along the Qiryat Shemona–Dan road, where the travertines are some 25 m in thickness. The travertine comprises loose, yellow-to-brown rock, containing some *Melanoides tuberculata* and *Melanopsis* shells, and in places is very rich in leaf impressions, mainly of *Populus* and *Salix*. The Dan Travertine also crops out at the Banias waterfall, where it overlies the Hasbani Basalt. Mousterian through Epipaleolithic artifacts are sometimes found within this travertine. The Dan Travertine was probably deposited in the north of the Hula Valley due to spring activity during the humid pluvial climate of the Würmian.

Post-Lisan Tufa Deposits

Post-Lisan travertines and tufa deposits (Figure 5.150) are described by Neev and Langozky (1961) from the

FIGURE 5.149. *Dan Travertine, overlying the Hasbani Basalt at the Banias waterfall.*

FIGURE 5.150. *Post-Lisan Tufa deposits.*

FIGURE 5.151. *Bet She'an Travertine, overlain by the Bet She'an Lake deposits.*

southern basin of the Dead Sea, encircling the regressive shores of the Lisan Lake. Buchbinder *et al.* (1974) proved that some of these travertines are, in fact, algal deposits. It seems that these travertines are a result of the more humid climate during the third pluvial phase of the Würmian, which succeeded the retreat of the Lisan Lake due to tectonic activity.

Bet She'an Travertine

The Bet She'an Travertine was designated by Picard (1929) as the "Kalksinter von Beisan." The name was given for a terrace (Figure 5.151) that was first described by Anderson (in Lynch 1852), on which the town of Bet She'an is situated. It consists of calcareous sinter, 20–30 m thick, and is attributed a Late Pleistocene or Holocene age. It seems that this terrace overlies the Lisan Formation sediments in the area and is overlain by the Bet She'an Atlantic lacustrine sediments. The formation is faulted to the east, forming a cliff above the Central Jordan Valley in this area.

Other Spring Deposits

Other spring deposits are of interest only if they can be dated either by artifacts or by the ionium method. Goldberg (1976) reported a spring deposit in the Central Negev, in the Avedat/Aqev area, which contained Mousterian artifacts. The travertines were dated by H. Schwarcz (*in litteris,* 1977) and yielded an age of 65,000 ± 2500 years B.P. at Nahal Aqev, for a travertine with flake tools; another sample from the same locality yielded an age of 73,700 ± 4600 years B.P. A deeper layer in this deposit gave an approximate age of 370,000 ± 150,000 years, which is probably a result of leaching and incorporation of older rock fragments. Bar-Yosef *et al.* (1974) report a travertine bed from Wadi Fatza'el, which they correlate with Upper Paleolithic and Middle Paleolithic artifact-bearing strata in nearby areas. The travertine, which is supposedly coeval with Mousterian tool-bearing layers, was dated at 136,000 years B.P., an older age than expected for this site. Another sample of this travertine was dated and yielded an age of 62,800 ± 4400 years B.P. This material was of a very poor quality, and the age, although consistent with archaeological data, is considered doubtful by Schwarcz. Another travertine dated by Schwarcz was collected from the E-Zutiye Cave. This is a large cave on the Wadi Amud cliffs, near Lake Kinneret, which yielded material of Late Acheulian–Yabroudian, as well as Mousterian artifacts. Yabroudian artifact-bearing travertines yielded ages close to 95,000 ± 13,000 years B.P., which seems in accord with the stratigraphic age for this culture in Israel, being of Riss-Würm Interpluvial time (Horowitz, in Jelinek *et al.*, 1973).

PALEOSOLS

Paleosols are known from the entire Quaternary sequence in Israel and from almost every region of the country. *Ex definitio,* paleosols are soils that were formed in a landscape that differs from that of the present day (Yaalon 1970). Three groups of paleosols can be distinguished: buried paleosols; paleosols that cover areas in which the landscape has considerably changed since the time of formation of the soils; and buried paleosols, which were reexposed due to erosive processes. These paleosols do not necessarily represent the entire original profile. Sometimes the upper parts are eroded, or the soil even suffers diagenetic processes after its burial. The best-exposed paleosol horizons are the hamra beds in the coastal plain of Israel. These mostly comprise stratigraphic paleosol horizons, discussed in detail earlier. The hamra paleosols were formed during periods of low eustatic sea levels, pluvial climate, and rich vegetation, which resulted in very good leaching of the carbonates from the sand dunes from which the hamra soils were developed, with some addition of aeolian dust. Some heavy, black, clayey marsh soils accompany the hamra paleosols in the coastal plain. The calcareous sandstones, locally called *kurkar*, which comprise the fossil dune ridges along the coastal plain, are also regarded by several authors as paleosols. Yaalon (1970) stated that the hamra and the kurkar calcareous sandstones are forming side by side under a climate that has not changed much during the Quaternary. Horowitz (1974), based mainly on the recognition of the stratigraphic setting of the hamra paleosols, suggested that both the paleosols and the calcareous sandstones have been formed during pluvial periods by leaching of the carbonates from the upper part of dunes and secondary enrichment of the calcareous sandstone below.

Paleosols are also known to interfinger with the northwestern Negev and the Pleshet coastal plain loess deposits (Dan 1966; Yaalon 1970; Yaalon and Bruins 1977). The latter authors described up to six stratigraphic–calcic horizons, which represent B horizons of buried paleosols within the loess sequence of the area around Netivot in the northwestern Negev. These authors regard the paleosols as indicating climatic changes in this area. The loess sequence of the northwestern Negev mostly overlies a buried hamra paleosol, which stratigraphically comprises the Dorot Hamra Member of the Gaza Formation discussed previously. The extreme difference between the conditions that were necessary for the formation of the red hamra paleosol and the overlying loess sequence, including its paleosols, is regarded by Dan (1966) as indicating quite a conspicuous climatic change in this area. Paleosols and loess paleosols are also known from the Negev and Sinai areas, where they are mostly exposed, but they occupy wind-deflated topography on which soil is not formed today. Some of these paleosols and loess accumulations were proved by Horowitz (1976a) to be of stratigraphic significance, bearing artifacts of different cultures and yielding pollen assemblages indicating much more humid climatic conditions for the time of accumulation and formation. These paleosols are quite common in the Negev and usually appear nowadays as terraces eroded by stream activity. The paleosols in the Negev are generally of Würmian age, but earlier ones were discovered in the area of Be'er Sheva, which yielded Late Acheulian handaxes, most probably of Rissian age. However, early paleosols are quite rare in the Negev because they were never buried and were subsequently eroded.

Some of the paleosols that appear in the Central Negev, especially the Mousterian horizons, are reddish in color. This red coloration presents quite a problem in the Near East. Basically, red soils such as terra rossa are considered typical for the Mediterranean climate. The red coloration derives from disintegration of iron-bearing heavy minerals into sesquioxides. This process needs relatively high temperatures and high humidity, with humidity as the more important factor. It should be noted that in no area of Israel are red soils formed today, the climate being too arid for these processes. Horowitz (1974) suggested that the red coloration, typical of buried paleosols at many locations in Israel, indicates formation during the more humid pluvial periods. It seems that at every locale in which red paleosols occur in a definite stratigraphic context, they were formed during the pluvials. This is quite clear from the hamra paleosols of the coastal plain and also for the loess paleosols and regosols of the Central Negev (Horowitz 1976a), where pollen spectra have helped to define the paleoclimate. Yaalon (1970) suggested that the red coloration of the desert paleosols derives from their high salt content, which acts as a hygroscopic agent maintaining enough humidity for the disintegration of the iron-bearing minerals. However, these paleosols in the Negev are always connected with pluvial phases, which seems to corroborate Horowitz's assumptions.

It seems that the extensive areas covered by terra rossa on the mountainous backbone of Israel also represent paleosols for the most part. This is concluded because the terra rossa does not usually show an A horizon, which must have been removed. On the other hand, soils that are formed today in the coastal plain (Ravikovitz 1969) are grayish or brownish in color and do not have the red coloration.

The age of the terra rossa on the mountainous backbone cannot be assessed exactly because in most places it is devoid of any stratigraphically significant fossils or artifacts. In some places, however, artifacts were found embedded within the terra rossa, presumably paleosol here, which by correlation with pollen-bearing sediments of the coastal plain and the Jordan Valley proved to be of pluvial origin. These are chiefly paleosols connected with the Würmian Nahshon Conglomerate and the Rissian Baq'a Conglomerate. Terra rossa soils seem to be typical for the present-day northern Mediterranean region, such as Greece, Italy, and Spain, areas that enjoy a considerably higher rainfall than the Near East under present climatic conditions, including some amount of summer rains. Similar climatic conditions prevailed in Israel (Horowitz 1971) during the more humid pluvial phases, when the climatic belts were pushed several hundred kilometers south of their present-day position.

Paleosols also occur in the Jordan Valley, mostly interfingering with lacustrine and fluviatile deposits. Red paleosols are known to intermingle with the Rissian Kefar Yuval Travertine, which has yielded Late Acheulian handaxes. Paleosols are known to intermingle with the Naharayim Formation, of the same age. Some paleosol horizons are known from the Ubeidiya and Erk el-Ahmar Formations, sometimes also displaying the typical reddish-brown coloration. A paleosol horizon separating the pluvial formations of Gadot and Mishmar HaYarden at the Gesher Benot Ya'akov outcrop south of the Hula Valley is stratigraphically of an interpluvial age and does not show any red coloration. It is grayish-brownish in color and differs considerably from those paleosols attributed to a pluvial paleoclimate. Paleosols connected with the Preglacial Pleistocene Bethlehem Conglomerate also display a typical red, Mediterranean, coloration. The paleoclimates for this period are not known in detail, but, at any rate, these paleosols were formed in the vicinity of water, as can be seen from the intermingling gravel, sometimes containing bones of aquatic animals like crocodiles (Horowitz 1970a). Basaltic paleosols of Quaternary age, of the terra rossa type, are known from the sequence of Nahal Orvim, on the eastern fault scarp of the Hula Valley (Mor 1973). They range in age from 1.8 to 1 million years, determined by potassium–argon dating of the interfingering basaltic tongues (Siedner *et al.*, in preparation). No further information is available for these paleosols. Some of the paleosols connected with the Nahshon and the Baq'a conglomerates in the Galilee, such as those appearing on the Yir'on-Bar'am plateau, are also derived from the underlying basalts, mostly the Cover Basalt of Preglacial Pleistocene age, and are of the basaltic terra rossa type (Ravikovitz 1969).

NARI

The nari, from Arabic *nar*, meaning fire (because of the use of this rock in lime production by the local inhabitants), is a hard calcrete rock that covers most of the chalky formations within the Mediterranean climate areas of Israel (Figure 5.152). The processes involved in the formation of the nari are regarded by Dan (1977) and Yaalon (1970, 1975) as of pedogenic origin. The nari in places covers the entire landscape and is formed, according to Yaalon, by the dissolution of the surface calcareous dust and its deposition and crystallization in a B horizon or in the contact between B and C horizons. The overlying soil was probably washed by subsequent erosion. According to Yaalon, the nari is at present generally formed in areas that enjoy an annual rainfall of 300–400 mm. The nmari never exists in areas where the rainfall is less than 100 mm or over 600 mm, and it is typial for the semiarid climate. The nari crust is up to a few meters thick, and a typical profile consists of three distinct horizons. It is capped by a brown to reddish thin laminar crust up to 2 cm thick, often cracked and discontinuous and very hard. The underlying upper nari is 50–180 cm thick, grayish, somewhat softer than the laminar nari, and passes gradually into a grayish-white, very soft lower nari, which is 50–200 cm thick and is easily eroded. Its boundary with the parent rock is gradual. The parent chalk rock is usually harder than the lower nari. The nari contains microfossils and rock fragments derived from the parent rock (Goldberg 1958) and is sometimes covered by soils of the rendzina type (Dan *et al.* 1972).

In various places, the nari covers the entire landscape and is, therefore, very young. In places such as the southern part of the Hebron structure, it is definitely younger than, and covers stratigraphically, the Würmian Nahshon Conglomerate. Radiocarbon datings of the calcareous components of the nari (Kaufman *et al.* 1973) yielded ages in the range 13,000–20,000 years for the seven samples analyzed. These ages correspond well with the late Würmian pluvial phase and might point to the formation of nari as the B horizon of a soil that was formed in the Mediterranean area of Israel during the more humid pluvial period. Older, buried nari horizons are quite rare, and, whenever discovered, they contained no means for stratigraphic dating. These older horizons sometimes underlie the Nahshon and Baq'a Conglomerates, and in places even the Preglacial Pleistocene Bethlehem Conglomerate. It seems, though, that most of the nari exposed on the mountainous backbone of the country at present is of late Würmian age. The nari was extensively used for buildings, especially by the Iron Age people in Israel (Shilo and Horowitz 1975).

FIGURE 5.152. *Nari (calcrete crust): A, developed over the entire landscape of Senonian chalk, Judean Desert; B, with pockets of red, terra rossa soil.*

ABSOLUTE DATINGS

Absolute dating of the Quaternary sequence of Israel has been carried out using various methods. The radiocarbon method was adopted for the upper part of the sequence in many localities and many formations in the country. The potassium-argon method was used to date basalts, and uranium-thorium methods were used to date carbonate rocks, principally fossils and travertines. Attempts at dating cave sediments using racemization processes of amino acids (Bada and Masters-Helfman 1976) have not yet yielded any significant results.

POTASSIUM-ARGON DATES

Potassium-argon datings of Quaternary basalts were carried out by Horowitz *et al.* (1973), Siedner and Horowitz (1974), and Siedner *et al.* (in preparation). The potassium-argon determinations were made on alkali olivine basalts that were nonamygdaloidal, fine-grained, and commonly porphyritic. The phenocrysts are mostly olivine, which occurs either alone or accompanied by augite and labradoritic plagioclase in various proportions. The matrix includes plagioclase in the range andesine-labradorite, augite, olivine, and, in some varieties, nepheline with analcite. Argon isotope ratios were measured statically on a Varian GD-150 mass spectrometer equipped with a vibrating reed electrometer, using an Ar-38 enriched spike. A correction of 295.5 for the atmospheric ^{40}Ar:^{36}Ar ratio was used in calculating the ages. Peak magnitudes were calculated by extrapolation from successive scans back to the opening of the argon extraction line to the mass spectrometer. The decay constants adopted were

$$\lambda\beta = 4.72 \cdot 10^{-10} \text{ per year}$$
$$\lambda e = 0.584 \cdot 10^{-10} \text{ per year}$$

and the ^{40}K:K ratio = $1.19 \cdot 10^{-2}$ at.%. Potassium content was determined by atomic absorption on a Perkins-Elmer 303 instrument, using a bracketing procedure for calculating the results. Errors in the individual ages reflect analytical uncertainty only and were calculated for each analysis at the one-sigma level. Despite the large error shown for the Quaternary basalts, which for the most part reflects the high level of atmospheric argon contamination, the calculated ages are clustered closely into groups differing by an order of magnitude and are in excellent agreement with available stratigraphic evidence. The data, therefore, present several intense but discrete episodes of volcanism for the Quaternary sequence of northeastern Israel.

The upper part of the Preglacial Pleistocene Cover Basalt was dated between 1.7 and 2 million years, to which the first flow encountered within the Nahal Orvim sequence also correlates. The stratigraphic significance of these dates presents a problem. It is clear that the dates for the Cover Basalt give a maximum age for the Günzian, which overlies the Cover Basalt, and for the principal activity along the Levantine faulting, which postdates the Cover Basalt (for example, Schulman 1962). The correlation between the Cover Basalt and the Preglacial Pleistocene sediments of the country (Horowitz 1974, 1976b) seems well established. The Cover Basalt dates, therefore, indicate an age for the upper part of the Preglacial Pleistocene. The main problem involved concerns the lower age for the Preglacial Pleistocene. The upper flows of the Cover Basalt are paleomagnetically reversed, cooled during the Matuyama Reversed Epoch. The lower two or three flows are, however, paleomagnetically normal and were assigned to the Gauss Normal Epoch by Horowitz (1974). The possibility should not be excluded, though, that the normal flows were cooled under the Olduvai Normal Event, and, if this is accepted, the Cover Basalt was poured out during a much shorter time than suggested by Horowitz (1974). This has important bearings on the problem of the beginning of the Preglacial Pleistocene. Paleomagnetic ages given for the beginning of the Calabrian differ according to various authors, and it seems that two main groups exist: The first begins the Calabrian at about 1.8 million years ago, and the second at about 2.8 million years ago (Cooke 1973). If the lower flows of the Cover Basalt were cooled under the Olduvai Normal Event, then the date of 1.8 million years for the beginning of the Calabrian should be adopted, but, if they were cooled under the Gauss Normal Epoch, then the 2.8-million-years limit is much more acceptable. It seems that, at the present state of knowledge, it is quite difficult to assess which of these dates should be accepted for the transition from the Pliocene to the Quaternary.

Potassium-argon dates for the Golan basaltic sequence indicate several phases of volcanic activity, the more conspicuous occurring about 1.3 and 1 million years ago, respectively. These phases are not known within the Jordan Valley proper. Another volcanic phase occurred about 500,000 to 700,000 years ago. This phase is quite widespread and is known from the Golan Plateau and from the Northern and Central Jordan Valley. The potassium-argon dates for this phase, comprising the En Zivan, the Yarmouk, and the Yarda basalts, have some implications for the development of the Jordan Valley. These basalts are faulted in the Jordan Valley by the middle Pleistocene faulting phase, which was called by Picard "Intra Graben Faulting Activity," and is, therefore, set at a younger age than that attributed to these basalts. On the other hand, these basalts cap the Mishmar Hayarden and possibly also the Ubeidiya Formation over an erosional unconformity, which means that the Mindel Pluvial must be older than 640,000 years. The Rissian sediments, on the other hand, overlie this basalt and are definitely younger. Another volcanic phase, around 350,000 years old, is quite widespread on the Golan but is not known from the Jordan Valley. The next, rather widespread phase, known from the Golan and the Northern and Central Jordan Valley, is the El Furn-Hasbani-Raqqad basaltic phase, which is also known from Transjordan down to about 100 km south of the Dead Sea. These basalts are dated at about 70,000 years old. They separate the Rissian and the Würmian sediment. This age sets a lower limit to the Würmian and corresponds very well with dates achieved for the beginning of this period by radiocarbon and uranium-thorium methods, to be discussed later. Naturally, it also sets an upper limit for the age of the Rissian sediments.

The potassium-argon datings of basalts in northeastern Israel give a chronostratigraphic framework for the Quaternary stratigraphy of Israel and for the major tectonic events in the Jordan Rift Valley, but these dates seem to have a significance that goes much beyond the borders of Israel, serving as a point of correlation between the Quaternary sequences of Europe and Africa. The Quaternary sequences of Europe are known mainly from paleoclimatic implications, and rocks suitable for radiogenic dating, especially of the earlier phases of the Quaternary in Europe, are scarcely available. Thus, most of the figures given for the European Quaternary absolute ages are only assumptions, mainly based on determinations of rates of deposition. This, of course, is quite hypothetical, because, although rates of deposition can be calculated with a high degree of certainty, nothing is known about rates of erosion and amounts of deposits that were removed during the rather long periods in which hiata occur in the sedimentary record of Europe.

It should be noted that no continuous section of the entire Quaternary is known from Europe. Also, climatic correlations between Europe and the tropical areas, especially of East Africa, are questionable, although suggestions have been raised either for correlation of glacials with pluvials in Africa or, on the contrary, for correlations of European glacials with interpluvials in Africa. On top of that, it seems that most of the African Rift Valley lakes were principally controlled by local tectonic movements and not so much by changing climates, so that a paleoclimatic correlation between East Africa and Europe is practically impossible in the present state of our knowledge. On the other hand, the East African sequences have yielded a considerable amount of datable materials in the form of volcanic flows and ashes, which interfinger with the Quaternary sediments. These were potassium-argon dated, and the dates serve as a base for the stratigraphy of the East African Quaternary. By cross-correlation of the paleoclimatic events in Europe with those recorded for Israel and of the radiogenic ages recorded in Israel with those known from East Africa, it seems possible now to tie the Quaternary sequences of Europe and East Africa together, which seems of great importance for understanding the development of early hominids and their spreading and migration processes.

URANIUM-THORIUM DATES

Uranium-thorium measurements have been made for various carbonate rocks of late Quaternary age in Israel by Kaufman (1971), Bender and Kaufman (1971), and H. Schwarcz (*in litteris,* 1977). The principle of this method involves the differences in solubility between uranium and thorium salts in water. Thorium 230 is practically nonsoluble in water, and it is suggested that the water from which the carbonates are precipitated contains only uranium 234, which subsequently, by radioactive decay, produces thorium 230, also known as ionium, within the carbonates. The half-life time for this process is about 75,000 years, and ages up to about 300,000 years can be measured using this method. It seems, however, that, due to technical limitations, most of the results are of only a preliminary nature, and they are accepted by the various investigators themselves only when supported by other evidence. Kaufman (1971) analyzed many samples from the Dead Sea area. The results show that the ages obtained for the upper and lower Lisan samples are internally consistent, both vertically and laterally, and in fair agreement with radiocarbon ages. Kaufman also analyzed sediments of the Amora and Sedom Formations in the Dead Sea area, known to be of Pliocene age (Horowitz 1974; Zak 1967). A series of dates for the Amora Formation are in the range of 200,000-300,000 years. It seems that these dates cannot be accepted; the reason for the radiogenic error is not known. The Sedom Formation sediments are older than 400,000 years, a result that, in fact, is meaningless. The results obtained for the Ami'az Member of the Lisan Formation seem to be more reliable and indicate that the lower part of the Ami'az Member was deposited some time between 60,000 and 40,000 years ago, whereas the upper part of the Ami'az Member was deposited from about 40,000 years ago up to about 18,000 years ago. These dates correspond well with dates obtained for the Würmian sequence elsewhere in the country and in other areas.

Bender and Kaufman (1971) studied thorium 230 ages for fossils from the Ubeidiya Formation. Twenty-one samples were analyzed, comprising gastropods and pelecypods. Although there appears to be a rough correlation of increase in apparent age with stratigraphic age, there are many serious inconsistencies, and Bender and Kaufman state that no geochronological significance can be attached to any of the apparent ages. These results reinforce previous conclusions that apparent ^{230}Th ages obtained on fossil gastropods and pelecypods are not generally reliable. The ages obtained for the Ubeidiya Formation, ranging from 120,000 down to 300,000 years B.P., are, therefore, of no significance, and its age is much better defined by potassium–argon determination of the overlying Yarda and Yarmouk basalts, indicating that the Ubeidiya is older than 640,000 years. H. Schwarcz (*in litteris,* 1977) analyzed several occurrences of travertines from Israel, mostly associated with prehistoric artifacts. Once more, the question of the reliability of the results seem crucial. Dates that were found for strata containing Mousterian artifacts seem to correlate well with ages known for this culture in Israel, in the range of 50,000–60,000 years ago. The Yabroudian culture, which is transitional from Late Acheulian to the Mousterian, was dated at about 90,000 years ago, which is roughly acceptable. Other samples that were anlyzed either did not yield any apparent ages or yielded ages that were greater than 300,000 years ago. These, for some of the sites, seem to be inconceivable, such as for the late Acheulian Ma'ayan Barukh site, for which the estimated age ranges between 100,000–150,000 years. It seems that the use of the uranium-234–thorium-230 decay series for dating Quaternary sediments still needs to be highly refined. Sediments that are in the range of the last 100,000 years seem to give apparent ages that are consistent with other dating methods, such as radiocarbon, whereas sediments that are older, no matter how much older, seem to give totally inconsistent results. Although advocates of this dating method claim that it could be used for ages down to about 300,000 years ago, it seems that ages obtained for rocks older than 100,000 years ago are doubtful and, if not strengthened by other evidence, should not be relied upon.

RADIOCARBON DATES

Numerous radiocarbon dates are available for the Late Pleistocene-Holocene sequence of Israel, obtained both from sediments and from fossils, of which most were collected from prehistoric and archaeologic sites. The radiocarbon dates suffer from two considerable disadvantages—contamination of the samples, especially those connected with prehistoric and archaeologic sites, and inaccuracy of the radiocarbon dating method. Contamination is considerable in multilayered sites in which organic materials have percolated and infiltrated from the upper layers to the lower ones. This phenomenon resulted many times in obtaining much younger ages for ancient strata and cultures. Contamination results also from the penetration of roots, from the burrowing activity of animals, and from the fact that the remains from burned wood can make the obtained ages considerably older. For instance, juniper trees that are more than 1000 years old are presently known to grow in northern Sinai. If these are burned and consequently dated, the obtained age will be much older. Henry and Servello (1974), in a compendium of radiocarbon dates derived from Near Eastern prehistoric deposits, indicate that only about 60–70% of the dates can be regarded with a considerable degree of confidence, the reason apparently being contamination. Most of the unreliable dates, especially for the earlier part of the sequence, are too young.

The second point concerns the primary production of radiocarbon in the atmosphere. This production is attributed to cosmic radiation and is considered constant for the Late Quaternary. It is, however, clear that cosmic radiation intensity cannot be regarded as constant. We know now of changes in the magnetic field of the earth that influence the Van Allen belts, which act as filters for cosmic radiation. We also know of sunspot activity that considerably increases cosmic radiation. As it seems, climatic changes have also been caused by changes in the radiation that the earth receives from the sun due to variation in their relative positions in space (Mesolella *et al.* 1969). All these factors influence to a certain degree the primary production of radiocarbon in the atmosphere, but this production cannot be calculated at present and has never been taken into account. Some attempts at correcting the radiocarbon ages for the period 3000 to 6000 B.C. were done and show considerable differences between the corrected radiocarbon ages and the ages calculated by tree rings. The correction based on tree rings cannot, however, be extended to older sediments, because no trees of these ages are known. Therefore, it remains for us at present to regard the late Quaternary radiocarbon time-scale only as expressing radiocarbon years, which do not necessarily correspond to sidereal years. The figures listed in the following are, thus, expressed only in radiocarbon years.

Radiocarbon dates for the upper parts of the sequences of the Dead Sea (Neev and Emery 1967; Vogel and Waterbolk 1972), for the Hula and Kinneret Basins (Horowitz 1971), and for the Mediterranean (Horowitz 1974d) have resulted in some estimates of the rate of deposition in these basins. Intrapolation and some extrapolation of these dates make it possible to establish a radiocarbon time-scale for the Würmian Pluvial and the Holocene of Israel. Various other dates (Carmi *et al.* 1971; Kaufman *et al.* 1973; Neev *et al.* 1973) permitted correlations of other geological phenomena with the suggested time-scale. Radiocarbon datings of prehistoric sites appear in numerous reports and are summed up in Henry and Servello (1974). These permit correlations of prehistoric sites with the late Quaternary radiocarbon time scale. The beginning of the Würmian was calculated by extrapolations from rates of deposition and aided by potassium–argon and ionium datings. It seems that the Würmian began about 65,000–70,000 years ago and terminated about 11,000 years B.P. This corresponds very well with dates obtained for the Würmian in Europe (van der Hammen *et al.* 1967). The first pluvial phase of the Würmian lasted up to about 45,000 years ago. During this period, the Mousterian people occupied the country, down to the Negev and Sinai. The first interstadial occurred between 45,000 and 32,000–35,000 years ago. The climate was very dry, and very few occupational levels are known for this period from Israel. A transitional culture from the Middle to the Upper Paleolithic was encountered in the Central Negev (A. E. Marks, S. M. U., Dallas, *in litteris,* 1976). It is quite possible that Mousterian people still occupied the northern part of the country during this time, or at least at the beginning of this time. The second pluvial phase of the Würmian is recorded between 34,000 and 20,000–22,000 B.P. In this period, the country was settled, once more down to the Negev and Sinai, by Upper Paleolithic people. The industries of Upper Paleolithic affinity are almost continuous in the northern part of the country, whereas in the Negev and Sinai only the peaks of humid phases permitted settlement. The second interstadial is a rather short one and is recorded between 20,000–22,000 years B.P. and 16,000–18,000 B. P. The transition of the Upper Paleolithic to the Epipaleolithic occurred in this time but is known only from the north of the country. The third Würmian pluvial phase is known from about 18,000 up to 11,000 or 12,000 B.P. and is characterized by Epipaleolithic settlement of the country, which again went down to the Negev and Sinai. The Holocene, which began some 11,000 years ago and continues through the present, is characterized by the present-day climate, except for the Atlantic period, which was radiocarbon dated at about 7000–4500 years ago, in which the climate was considerably more humid. The settlements of Chalcolithic and Early Bronze I people, who inhabited the country in Atlantic times, are known down to the Negev and southern Sinai.

CONCLUSION: STRATIGRAPHIC CORRELATIONS

Stratigraphic correlations of the various Quaternary formations of Israel are summed up in Table 5.1. The basis for the correlations differs somewhat from the Preglacial to the Glacial Pleistocene. During the Preglacial Pleistocene, the landscape was rather flat, and the area of Israel was crossed by several large rivers flowing in wide, flat floodplains. In these times, sea-level changes considerably influenced erosional and depositional processes in the hinterland. Higher sea levels resulted in deposition in the river channels. In the transition from the Preglacial to the Glacial Pleistocene, however, the area was strongly affected by the Levantine Faulting phase, accompanied by uplifting of the mountainous backbone of the country. This left a rather wide coastal plain in the western part of the country, where previous processes, in fact, continued, whereas the mountainous areas, being much higher than the average sea-level even during ingressions, were much more influenced by climatic factors than by sea-level changes. The Jordan–Dead Sea Rift Valley acted during the Glacial Pleistocene as an endoreic erosion base level, in which the climate and local tectonics considerably influenced the distribution and patterns of lakes.

The Preglacial Pleistocene formations are, therefore, correlated by sedimentary principles, whereas the Glacial Pleistocene sequences are correlated by the influence of climatic changes. The use of faunal remains for cross-correlation is quite limited for the Quaternary of Israel, especially when dealing with totally different environments. However, two important indicators appear for Quaternary oscillations of the Mediterranean. The lower part is characterized by cold-water fauna, of which *Hyalinea balthica* is a representative, whereas the upper part, from the Tyrrhenian on, is represented by a warm-water fauna of which the foraminifer *Marginopora* is a good indicator. The lower part, therefore, encompasses the Calabrian, Sicilian, and Milazzian ingressions, and the upper part encompasses the Ryrrhenian, Monastirian, Late-Monastirian, Epi-Monastirian, and Versilian. The first occurrences of each of these two foraminifera seem to be quite good chronostratigraphic indicators. As a consequence, only wherever the entire sequence is preserved can one assign chronostratigraphic subdivisions that are more exact than "lower" or "upper" parts of the littoral or marine Quaternary. Marine ingressions are typical for the interpluvials and correspond to the European interglacials. This was proved by the recurrence of interpluvial pollen assemblages within the ingressive sediments (Rossignol 1969). The interpluvial climates also resulted in strong, steep erosion in the mountainous areas and rather restricted occurrences of lakes in the Jordan Valley. On the coastal plain, dunes accumulated, forming dune ridges parallel to the transgressive coast.

During pluvial periods, the picture totally changed. In the coastal plain, soils were formed, comprising at present paleosol horizons interbedded within the sandstones deposited by the ingressive seas. In the mountainous areas, the erosion was milder, and conglomerates and colluvial materials accumulated in the wide valleys, whereas in the Jordan Valley the pluvial periods are characterized by a considerable expansion of the lakes, depositing lacustrine sediments. On these bases, it is quite clear that the coastal plain maintained its character throughout the entire Quaternary, and alternate, recurrent sedimentation of similar types of sediments occurred throughout the period. In the mountainous areas and in the Jordan Valley, the Preglacial Pleistocene rock formations differ considerably from the Glacial Pleistocene formations by their tectonic setting. The Preglacial Pleistocene rivers deposited conglomerates and gravels, which were later uplifted and incised by the Glacial Pleistocene wadis due to their considerably more pronounced relief. In the Jordan Valley, the Preglacial Pleistocene rocks do not differ from those appearing in the rest of the country,

TABLE 5.2
Correlation of Chart of the Quaternary Formations of Israel

AGE		MEDITERRANEAN EUSTATIC STAGE	CLIMATO-STRATIGRAPHIC STAGE	ABSOLUTE AGE	LOCAL INGRESSION	MARINE SEDIMENTS	MEDITERRANEAN COASTAL PLAIN						MOUNTAINOUS BACKBONE				JORDAN VALLEY		
							LITTORAL SEDIMENTS	BEACHROCK ELEVATIONS		KURKAR RIDGES AND THEIR PRESENT ELEVATIONS	TERRESTRIAL SEDIMENTS: MEMBERS AND BEDS OF THE GAZA FORMATION		ELAT	NEGEV	JUDEA	GALILEE	HULA	CENTRAL JORDAN VALLEY	DEAD SEA BASIN
								CARMEL AND SOUTH	HAIFA BAY										
QUATERNARY	HOLOCENE	RECENT		~ 4,500	"ACTUÉL"	UNDIVIDED DEEP - SEA SEDIMENTS OF THE MEDITERRANEAN AND BAY OF ELAT	RECENT SEDIMENTS	0	0	RECENT DUNES (+) 40	HADERA DUNE BED	RUHAMA LOESS MEMBER	UNNAMED SUCCESSIONS OF WADI TERRACES				HULA GROUP MALLAHA FM. ASHMURA FM.	JORDAN GROUP TABGHA FM. OF LAKE KINNERET	"UNNAMED POST LISAN SEDIMENTS" OF THE DEAD SEA UPPER DEAD SEA GROUP
			ATLANTIC	~ 7,500			YARKONA FORMATION	(-) 5-6			TA'ARUKHA HAMRA BED				"LOWER TERRACE"			BET SHE'AN LAKE	"LOWER TERRACE"
		VERSILIAN		11-11,500	ATLITHIAN		L 4 MBR.	(+) 2-3	(-) 3	"PLATE" (UNDEVELOPED RIDGE)	TEL AVIV KURKAR B.								
	PLEISTOCENE		WÜRM LATE	17-18,000						(-) 130-150	NETANYA HAMRA B.				NAHSHON CONGLOMERATE AND "UPPER TERRACE"		DAN TRAVERTINE	LISAN FM. AND "UPPER TERRACE" BET SHE'AN TRAV. FATZA'EL MBR.	HASA FM.
		EPI-MONASTIRIAN		20-22,000	YARKON (UPPER)		M 3A MBR.	(+) 6-8	(-) 6	UP. ZIQIM (+) 30	UPPER PART OF DOR KURKAR BED								
			MIDDLE	28-32,000						(-) 120-130	TEL BARUKH HAMRA BED							AMI'AZ MBR.	
		LATE MONASTIRIAN		40-45,000	YARKON (LOWER)		M 3 MBR.	(+) 12-15	(-) 12	LO. ZIQIM (+) 25	LOWER PART OF DOR KURKAR BED								
			EARLY	60-70,000						(-) 90-100	NAHSHOLIM HAMRA B. (CAFÉ AU LAIT)							HAMARMAR MBR.	
		MONASTIRIAN		0,12-0,13M	POLEG		M 2A MBR.	(+) 18-20	(-) 15-30	YAD MORDEKHAY (+) 60	RAMAT GAN KURKAR						HASBANI BSLT. HULATA FM.	RAQQAD BASALT	
	GLACIAL		RISS	0,3-0,35M						(-) 70-80	HOLON HAMRA MBR.				BAQ'A CGL., GA'TON TRAV.		BENOT YA'AKOV FM. KEFAR YUVAL TRAV.	NAHARAYIM FM.	SEIF TRAV. AND LAKESHORE TERRACE
		TYRRHENIAN		0,6-0,65M	AZOR		M 2 MBR.	(+) 35-45	(-) 50-60	EREZ (+) 80	GEDERA KURKAR MBR.						AYYELET HASHAHAR FM.		
			MINDEL	1,0-1,2M						(-) 55-60	DOROT HAMRA MBR.				BENCH		YARDA BASALT MISHMAR HAYARDEN FM.	YARMOUK BASALT UBEIDIYA FM.	ABU HABIL SERIES 3RD LAKESHORE TERRACE
		MILAZZIAN		1,4-1,5M	EN BESOR		M 1A MBR.	(+) 50-60	(-) 60-80	NIR'AM (+) 120	TELL FARA KURKAR MBR.						UNNAMED PALEOSOL		
			GÜNZ	1,8-1,7M						(-) 40-50	HASI MEMBER				BENCH		HAZOR-GADOT FMS.	ERK EL-AHMAR FM.	4TH LAKESHORE TERRACE
	PREGLACIAL PL.	SICILIAN		2,0-2,1M	EYAL		GA'ASH FORMATION	(+) 80-90	?	YAKHINI (+) 140-150	GERAR KURKAR MBR.		GAROF CGL	HAMESHAR FM.	BETHLEHEM CGL.	COVER BASALT			GHOR EL-QATAR SERIES
			DONAU	2,5-2,4M						(-) 20-30	ZE'ELIM HAMRA MBR.								
		CALABRIAN		2,9-2,7M	"CALABRIAN"			(+) 100-130	?	HIRBET HAREV (+) 190-200	HARUVIT KURKAR MBR.								
			BIBER				EROSION AND CHANELLING												

and they were, consequently, affected by faulting, whereas the Glacial Pleistocene deposits comprise a series of successive lacustrine suites.

No stratigraphic subdivisions are suggested for the Quaternary marine sediments encountered in the deep sea boreholes, chiefly because no detailed information is available. The littoral sediments were divided according to their faunal assemblages into the Ga'ash Formation, of Preglacial Pleistocene age, and the Yarkon Formation, of Glacial Pleistocene age. The Ga'ash Formation was deposited by the Calabrian and Sicilian ingressions, which, by their higher sea-level, caused deposition of gravels and conglomerates within the river systems of HaMeshar and Bethlehem. A similar situation can be seen in the area of the Bay of Elat, where the Garof Conglomerate was deposited in connection with the Calabro-Sicilian ingressions. The Ghor el-Qatar Series of the Dead Sea area is also considered as correlative to the Preglacial Pleistocene conglomerate of HaMeshar, Garof, and Bethlehem. The coastal plain terrestrial correlatives of the Ga'ash Formation are the Haruvit Kurkar, the Ze'elim Hamra, and the Gerar Kurkar Members, which overlie and interfinger with the conglomerates.

In the north of the country, however, the late Pliocene sediments are covered by volcanic rocks of the Cover Basalt, which were poured out over this area throughout the entire Preglacial Pleistocene. The faulted Cover Basalt at the Central and Northern Jordan Valley is covered by Glacial Pleistocene sediments. It is quite clear, therefore, that all these rock units that are sandwiched between the late Pliocene and the Glacial Pleistocene sediments could be assigned to the Preglacial Pleistocene and are, therefore, correlative. The vertebrate fauna encountered in the Bethlehem Formation only strengthens the above assumptions. This fauna is assigned a Villafranchian biofacies, which is older than the Glacial Pleistocene vertebrate fauna encountered in the Jordan Valley Glacial Pleistocene sediments (Bar-Yosef and Tchernov 1972). The fauna encountered at Bethlehem also points to the general landscape that prevailed in the area during Preglacial Pleistocene times. Most of the bones are of long-legged animals such as elephants, *Hipparion,* and giraffes, indicating a rather wide, flat, open-savannah-type landscape. This is also corroborated by the type of sediments filling the wide channels of the HaMeshar and Bethlehem Systems and also, to some extent, the Garof System of the Bay of Elat. The volcanic rocks of the Cover Basalt were also poured out over a rather mild relief (Schulman 1962) in northeastern Israel, indicating that no rift valley of any type was present in these times.

The Glacial Pleistocene lacustrine sequences of the three subbasins of the Jordan–Dead Sea Rift Valley represent similar paleoclimatic characteristics to each other. The Hula Group, the Jordan Group, and the Upper Dead Sea Group are seen as representing four successive pluvial phases. The uppermost, the Würm Pluvial, is represented by the Dan Travertine and the Ashmura Formation in the Hula and the Lisan Formation in the Central Jordan Valley and the Dead Sea Basin. The second, the Riss Pluvial, is represented by the Kefar Yuval Travertine, the Benot-Ya'akov, the Naharayim, and the Seif Formations, correspondingly. The third, the Mindel Pluvial, is represented by the Mishmar HaYarden and Ubeidiya Formations, by the third pluvial cycle penetrated within the Melech-Sedom I Borehole, and by the third raised lake beach of the Hazeva area. The fourth pluvial period, the Günz, is represented by the Gadot–Hazor Formations in the Hula Valley, the Erk el-Ahmar Formation in the Central Jordan Vlley, and by the fourth pluvial complex penetrated in the Melech-Sedom I Borehole in the Dead Sea Basin, probably corresponding to the fourth lake terrace at the Hazeva area. The Hula and Jordan Groups overlie the Cover Basalt over a taphrogenic relief, whereas the Upper Dead Sea Group most likely overlies the Ghor el-Qatar Series.

These four pluvial phases are also recorded in the mountainous backbone of the country, the Würm by the Nahshon Conglomerate and the Riss by the Baq'a Conglomerate, whereas the earlier two pluvial phases are not recorded by sediments but appear as benches in the topography that clearly designate climatic changes. These four benches and conglomerates cut into the erosive surfaces connected with the Bethlehem and HaMeshar Formations. A similar picture can be seen in the area surrounding the Bay of Elat and, especially, in the Timna erosion cirque. Therefore, correlation of the mountainous erosive sequences is suggested with the Jordan Valley pluvial lacustrine sediments. The same four pluvial phases are also recorded in the coastal plain, as paleosols. The Würm is recorded by the Netanya, Tel Barukh, and Nahsholim hamra beds within the Shefayim Member. The Riss is recorded by the Holon Hamra Member and the Mindel by the Dorot Hamra Member. The Günz is represented by the Hasi Member, which overlies the lateral, continental correlatives of the Ga'ash Formation. The four pluvial phases also appear as continental deposits separating the marine ingressions within the Haifa Bay buried Quaternary sequence.

The Western Galilee coastal plain Quaternary sequence is somewhat more problematic due to the subsidence of this area, but it seems that the pluvial phases could be recorded here as well. The Tyrrhenian, Monastirian, Late Monastirian, and Epi-Monastirian are represented by calcareous sandstone ridges. Of these, the Tyrrhenian ridge could easily be dated by the abundance of *Marginopora* at its seaward facing foot. Paleosols that are buried under this ridge are considered of Mindel age and appear as the lower pedogenic complex of the Evron Quarry. It should be noted that the pluvial sequences, both in the Jordan Valley and in the coastal plain, are characterized by similar artifact assemblages, except for the lowermost, presumably Günzian, cycle, for which only rare artifacts were found. The Mindel is characterized by the developed Oldowan Industry of Ubeidiya and the Dorot Hamra Member. The Rissian pluvial deposits are characterized all over the country by great abundance of Late Acheulian sites, and the Würmian is characterized by Mousterian through Epipaleolithic industries. Interfingering formations and beds of local significance, such as the various travertines and the volcanic rocks of the Central and Northern Jordan Valley, also correspond well with the suggested correlation pattern for the Glacial Pleistocene formations. Detailed analysis of these correlations is given in Horowitz (1974, 1975, 1976b).

6

Palynology

The present chapter is divided into two parts. The first deals with the Recent pollen spectra of Israel as representative of present-day vegetation, climatic conditions, and processes of transport and deposition. The second deals with Quaternary pollen spectra, reflecting paleoenvironments in various parts of the country and at various stages of the Quaternary. The first part deals both with airborne pollen and with pollen in Recent sediments. The study of airborne pollen was mainly conducted for allergiological and similar purposes, as well as for the study of movements of air masses over the area of Israel. Airborne pollen is of less importance for the study of Quaternary pollen assemblages, since airborne spectra differ considerably from pollen embedded in Recent sediments. There are two principal reasons for this: the mode and capability of preservation of various pollen grains and human influence, especially the extensive introduction of cultivated plants in recent decades in Israel. Therefore, pollen spectra representing Recent conditions or, in fact, somewhat sub-Recent conditions, were studied from sediments. These sediments were collected from all over the country, not from the surface, but from a few millimeters below the surface, in order to avoid the influence of cultivated plants and to overcome the rather slow processes of preservation and fossilization of pollen grains. Only in this way could Recent pollen spectra be utilized as a reference for arriving at the significance of Quaternary pollen spectra. The study of pollen spectra in Recent sediments from the soils and groundwater of the Mediterranean, the Jordan Valley, and the Bay of Elat has enabled the determination of processes of transport and deposition, biases in pollen spectra, and relationships between Recent pollen spectra and Recent vegetation. Quaternary pollen spectra are divided into two main groups. The first encompasses pollen spectra recovered from sediments dated by geological, stratigraphic, and radiometric methods. The other comprises pollen spectra recovered from prehistoric and archaeological sites, dated by archaeological and radiometric methods. With the help of palynology, prehistoric sites can be correlated with geological sequences of the Quaternary of Israel.

Palynological research in Israel has been carried out by three groups of workers. The first, who analyzed airborne pollen and spores for the most part, consisted of allergiologists assisted by botanists. This group lacked complete reference collections of spores and pollen grains of the present-day vegetation of the country, and, therefore, most of the identifications they made are general in nature.

The second was (Mrs.) M. Rossignol-Strick, who worked in the country for about 10 years from the late 1950s to the late 1960s. She set the basis for the palynological reference collection of the country by preparing slides of more than 700 species of plants, mostly collected from the herbarium of the Department of Botany, Hebrew University, Jerusalem. This collection was later enlarged by Horowitz and his students, and it is still in use. It is deposited at the Division of Paleontology, Geological Survey of Israel, Jerusalem. Most of the pollen grains that were studied by Rossignol, Horowitz, and other investigators have been identified to the generic level; only some were determined to a specific level. Some of the grains, however, could not be determined further than to family level, for example, some Compositae, Cruciferae, Gramineae, Cyperaceae, and others. In the case of the Centrospermae, even the family level cannot be determined, although, in some of the pollen diagrams and tables that were previously published, the group is designated as Chenopodiaceae. This is only a matter of convenience, since the Chenopodiaceae family forms a major part of the Centrospermae, but, in fact, the latter term includes all the superfamily. Detailed comparison (Horowitz 1968) with the reference collection shows that, in this particular case, no more accurate determinations could be made, even though great differences between some individuals appear to exist on first sight. It was found (Horowitz 1969a) that greater differences occur sometimes between grains taken from a single plant than among various genera of the superfamily.

Pollen grains of oaks were determined only at the generic level by Horowitz, and sometimes to species level by Rossignol. Although an analysis shows quite distinct differences among the various species (Horowitz and Baum 1967), it was thought better not to distinguish between species, especially in fossil material, as in many cases grains were damaged, distorted, or otherwise not well-preserved, which prevented specific identification; thus, any statistical conclusions would be misleading. Pollen grains of *Olea*, which are very distinctive, were determined to specific level, *Olea europaea*, on the assumption that other species of this genus do not occur in the region investigated. Otherwise, identification to species would have been very dubious. In the case of pollen grains of pistachio, no differentiation could be made, even in the reference collection (Horowitz and Baum 1967). "*Pistacia* spp." represents, therefore, the combined four species of this tree that grows in Israel, although Rossignol, especially in her study of the Recent pollen deposition of the Dead Sea (1969), distinguished the various species. The basis for this separation is not known.

Other arboreal pollen, such as *Ceratonia siliqua, Pinus halepensis,* and *Cedrus libani,* were very easy to determine. Pollen of Cupressaceae, on the other hand, are quite difficult to distinguish from each other, although quite distinct differences can be seen in the reference collection. The same problem as with the pollen of oaks occurs with that of the Cupressaceae. *Tamarix* pollen presents the same difficulty, although each of the 11 species of this tree that grows in Israel has specific grain characteristics. Pollen samples from sediments, even if only slightly damaged or distorted, do not display these characteristics clearly enough for identification of the species. Pollen of other stream-side trees, such as *Salix acmophylla, Populus euphratica,* and *Nerium oleander,* are readily recognizable. Pollen of the cultivated trees *Eucalyptus, Casuarina,* and *Washingtonia* were easy to identify, although this pertains only to the Recent sediments. The Rosaceous fruit trees were identified to family level without further distinction. This group presented some problems with identification, since the wild Rosaceous trees are not separable from cultivated trees on grounds of pollen morphology.

Most constituents of the nonarboreal pollen flora are quite well-defined, and no special problems arise concerning their identification. Still, only some could be identified generically, whereas most were identified to the family level. Specific identifications of nonarboreal pollen are quite rare. The main significance here is that the pollen spectra afford only a general picture of the vegetation in the area. Unidentified and damaged pollen grains form part of the pollen spectra of almost every sample that has been analyzed. Except for the preliminary study of Lorch (1959) in the Hula Valley, the values of these, taken together, do not exceed 5–6%, and it seems safe to disregard them. In the following discussion, this group of pollen grains will not be considered at all and will not appear in the described spectra, diagrams, and maps. Microphotographs and scanning electron microscope photographs of the more important Israeli pollen flora constituents are shown in Figures 6.12–6.16.

RECENT POLLEN SPECTRA

AIRBORNE POLLEN

M. Weinstein

Studies of airborne pollen and fungus spores were carried out in Israel in the 1950s and early 1960s by a group of allergiologists assisted by some botanists. These studies were initiated due to the increasing number of hay fever cases in the country and were conducted mainly by Barka'i-Golan and Glazer (1962), Feinbrum *et al.* (1959), Glazer and Barka'i-Golan (1961), Kessler (1953, 1954, 1958, 1958a), Parag *et al.* (1957), Tas (1966), Tas and Feinbrun (1962), and Tas and Rahat (1963). The health goals were to locate places that are not so much affected by allergenic pollen grains, as well as to reveal periods of the year in which one or another location is more pollen-free than elsewhere in the country. It was found that two pollen groups were mainly responsible for hay fever in Israel. Graminae are most important, and olives formed an allergenic group new to medicine (Kessler 1958). We shall not deal with fungus spores and molds in this context, since they do not seem to be of importance for the study of Quaternary paleoenvironments. They also seem to cause only a minor number of hay fever cases in Israel.

Studies for allergiological purposes took place only at a few localities in the country. A much more thorough study, summarized here, was carried out in 18 locations throughout the country in order to ascertain the monthly airborne pollen throughout the year. The purpose of the present study was to try to compare the monthly airborne pollen spectra throughout the country to pollen deposition and to the frequency of various pollen grains in Recent sediments. Most investigators trapped pollen grains by the gravity method, placing sticky slides in the area under study. Some of them counted the number of pollen grains per unit area, but, for the purpose of making comparisons of the airborne to the Recent pollen spectra, the percentages of the various constituents were calculated. The combined results of the investigators are given in Table 6.1, which summarizes the airborne pollen spectra in percentages of the total pollen identified and counted. This mode of calculation facilitated comparison between the airborne pollen spectra and the spectra of Recent sediments, which were calculated in the same way. Table 6.1 displays the average annual pollen spectra, since these are most important for comparison with spectra of Recent sediments and with fossil pollen spectra, which represent annual or multiannual averages rather than monthly peaks. Locations of the stations in which airborne pollen spectra were collected, as well as annual averages by the various investigators, are given in Figure 6.1. Figure 6.2 shows the monthly distribution of some selected pollen groups in certain locations, which make clear certain preferences within the pollen spectra for different areas of the country.

The most important difference between airborne pollen spectra and those collected from Recent sediments is the frequent appearance of pollen grains derived from cultivated and introduced plants in the former group. As

TABLE 6.1
Annual Averages of Airborne Pollen Spectra in Various Localities in Israel[a]

Pollen	Qiryat-Shemona	Zefat	Tiberias	Nazareth	Nahariyya	Haifa	Bet-She'an[b]	Afula	Pardes-Hannah	Netanya	Tel-Aviv	Jerusalem	Jericho	Hebron	Rehovot	Qiryat-Gat[c]	Ashqelon[d]	Be'er-Sheva[e]
Quercus	6.4	4.3	2.4	4.9	3.5	5.6	8.5	2.7	6.1	4.2	2.2	3.8	1.7	8	1.3	0.6	1.9	1.1
Pinus	2.6	4.2	2.8	20.2	6.4	7.5	1.6	9.5	8.5	7.8	5.6	8.7	1.4	3.9	25.2	3.0	2.8	2.6
Olea	8.0	17.0	2.9	6.9	6.2	5.4	15.0	3.9	9.8	9.2	8.3	7.4	2.6	3.3	2.1	4.6	9.0	1.8
Pistacia	0.4	0.3	0.2	0.8	0.8	1.0	0.2	0.3	0.6	0.1	0.1	0.1	0.1	0.2	0.4	—	0.1	0.3
Cupressus	6.3	12.7	1.7	4.1	5.0	9.3	1.1	8.5	3.9	2.0	11.0	1.3	9.7	0.1	9.2	0.5	0.8	0.2
Eucalyptus	9.0	9.0	34.5	14.9	20.5	20.0	11.6	19.7	7.1	24.9	12.8	5.0	0.8	3.6	13	12.8	14.1	23.5
Casuarina	4.6	0.7	4.6	4.2	11.4	8.0	2.4	4.6	6.6	4.0	4.9	5.3	9.6	6.9	9.5	19.5	13.0	17.2
Rosaceous trees	—	0.6	0.5	0.5	1.9	0.2	1.0	0.7	0.2	0.7	0.5	1.0	0.6	0.8	0.4	1.3	1.1	2.3
Other arboreal pollen	1.9	0.7	2.1	1.4	4.6	2.5	2.1	3.9	2.1	1.6	2.4	2.3	11.4	1.6	1.8	5.4	2.4	10.6
Total arboreal pollen	39.2	49.5	51.7	56.9	60.3	59.5	43.5	53.8	44.9	54.5	47.8	35	37.9	28.4	58.8	46.7	45.2	59.6
Cereals	2.5	1.5	2.4	0.7	1.6	0.7	3.3	1.4	0.9	0.7	0.9	2.9	0.7	3.5	1.7	2.9	0.6	0.8
Gramineae	13.9	12.9	11.1	8.5	10.7	13.3	17.1	10.5	13.4	10.1	11.2	15.2	7.6	16.2	7.7	15.9	12.9	8.2
Compositae	7.4	1.8	4.9	2.9	4.6	2.7	3.8	1.2	1.9	5.1	3.4	5.4	1.7	4.1	3.1	2.2	4.5	2.3
Cruciferae	2.3	1.5	0.5	2.0	0.9	0.7	0.7	2.1	9.1	1.0	1.4	3.6	2.5	2.6	1.4	2.9	0.4	1.4
Chenopodiaceae	6.2	3.5	5.5	7.8	2.7	8.0	15.4	6.2	12.1	12.3	10.3	11.6	25.7	8.7	6.7	7.9	10.1	11.1
Umbelliferae	2	2.9	1.8	0.6	2.7	0.9	7.5	5.3	0.5	0.4	1.8	3.0	0.6	0.1	0.8	2.0	3.1	0.3
Papilionaceae	2	0.9	3.9	1.9	1.7	1.0	0.9	0.9	1.8	1.0	1.9	2.0	2.2	1.8	1.3	1.5	1.3	0.5
Artemisia	14.3	14.5	7.2	5.9	3.9	6.8	0.6	3.8	8.0	8.6	8.5	9.7	12.9	16.9	11.5	9.3	13.4	2.9
Ephedra	0.1	0.2	0.1	0.8	0.3	0.1	0.2	0.3	0.1	0.6	0.1	0.4	0.1	0.4	1.5	0.1	5.0	0.1
Centaurea	0.9	1.4	0.3	0.9	0.9	0.2	1.6	0.6	1.1	1.1	2.9	0.9	0.2	0.1	0.6	1.1	1.8	1.0
Poterium	0.2	2.5	0.3	3.8	0.1	1.0	0.1	0.1	0.1	0.2	0.8	3.6	0.9	7.9	0.5	0.2	0.4	—
Other nonarboreal pollen	9	6.9	8.7	5.7	6.3	4.4	7.1	13.5	6.1	4.3	7.6	4.8	6.2	5.9	5.4	7.1	1.3	11.8
Total nonarboreal pollen	60.8	50.5	48.3	42.1	39.7	40.5	56.5	46.2	55.1	45.5	52.2	65	62.1	71.6	41.2	53.3	54.8	40.4

[a] Total counted pollen = 100%.
[b] March through August.
[c] April through January.
[d] April through December only.
[e] May through October only.

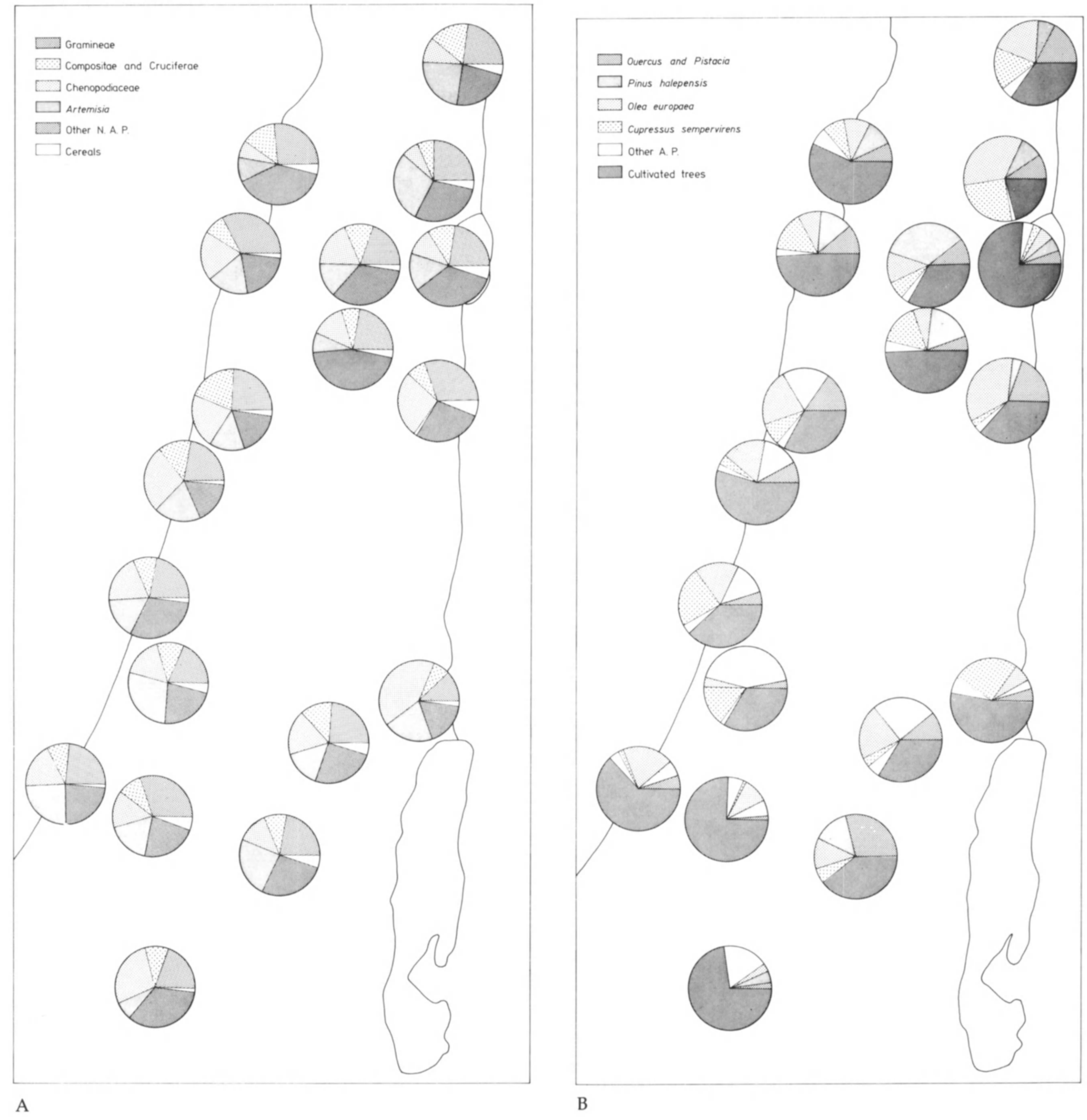


FIGURE 6.1. *Annual averages of airborne pollen spectra over Israel. (A) Arboreal pollen groups. (B) Nonarboreal pollen groups.*

already discussed, Recent sediments were collected in such a way as to minimize the inclusion of cultivated pollen grains in the spectra by collecting samples a few millimeters below the surface; thus, they do not represent the Recent but, rather, the proximate sub-Recent environment. The most important cultivated contributors of pollen grains are *Eucalyptus* and *Casuarina*, which may in certain cases contribute up to 40% of the total airborne pollen spectra—as in Tiberias, Be'er Sheva, and Qiryat Gat—whereas average annual values on the order of 15–30% for these elements are more common at most stations. Two important constituents of the arboreal pollen spectra present considerable problems. These are pine and olive pollen grains. Pines and olives comprised part of the natural vegetation of the country until not long ago, as will be apparent during analysis of the fossil pollen spectra discussed later. However, these two types of trees have been planted over considerable areas in recent decades and appear in the airborne pollen spectra in considerable percentages, up to 30% for each. It is

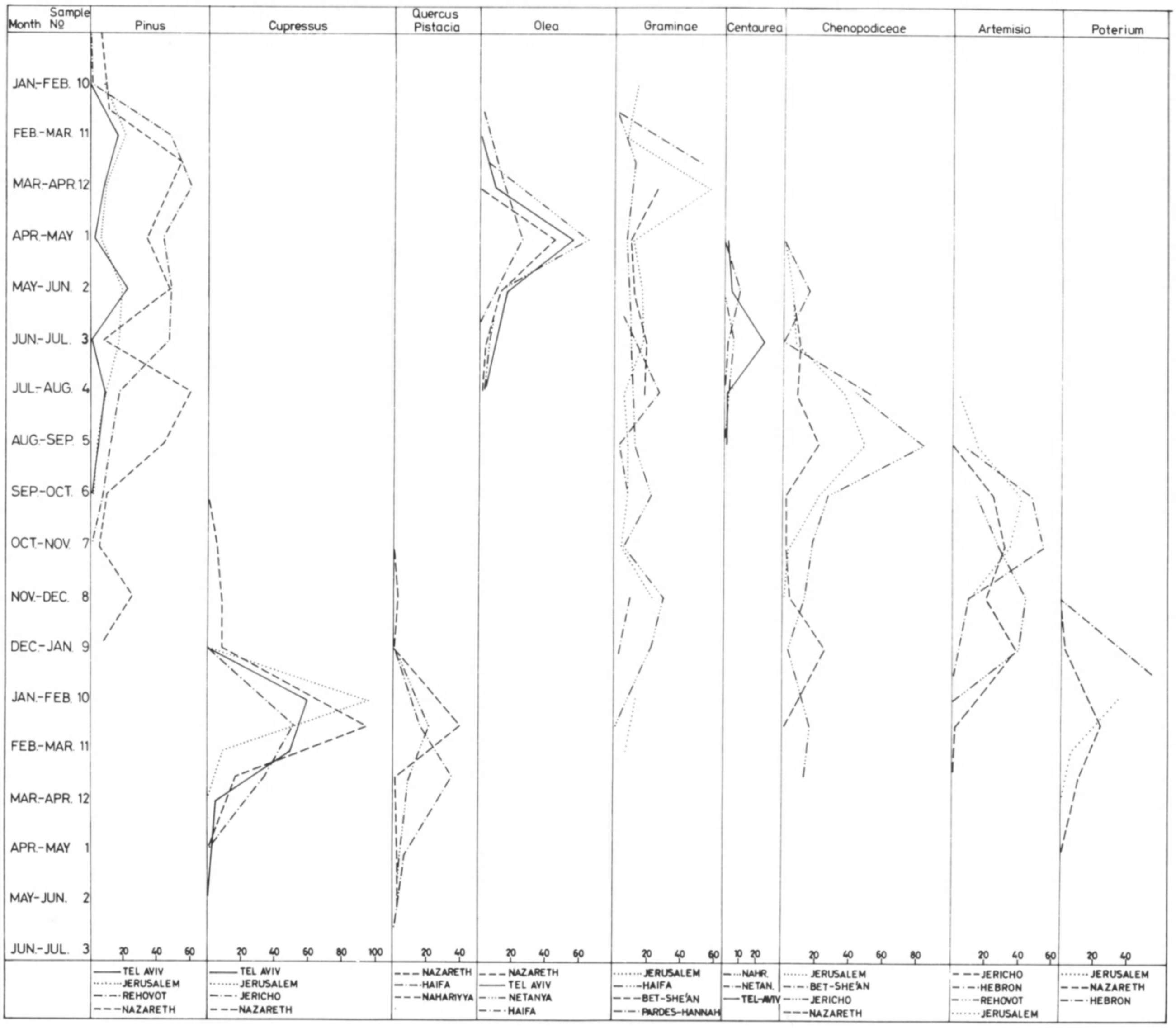


FIGURE 6.2. *Monthly distribution of the more important airborne pollen groups in Israel.*

impossible to say at this stage which part of the airborne pollen spectrum of the pine and the olive represents the natural and which part the cultivated constituents of these trees. The same holds for the cypress, which has also been planted throughout the country. Values of around 10% for cypress pollen are quite common.

Rosaceous fruit trees, which are planted all over the country, are mainly insect pollinated and, thus, appear in the airborne pollen spectra by no more than 1% as an annual average. Even during the climax of their flowering season in Jerusalem, when the pollen trap was standing some 20 meters from gardens of rosaceous trees, only 9% of their pollen was trapped; so, these trees apparently do not contribute substantially to any major contamination. The same, curious as it may sound, holds true for pollen of the cereals. They mostly represent about 1% of the spectrum and never exceed 2-3%. The pollen of cultivated trees, especially those of *Eucalyptus* and *Casuarina*, could be used to determine contaminations in pollen spectra or in samples collected for palynological analysis, since they are so widespread over the country. In fact, when analyzing samples collected from sampling sites, the nonexistence of *Eucalyptus* and *Casuarina* pollen in the spectra is regarded as a guarantee for their cleanliness. By careful calculations of the percentage of *Eucalyptus* and *Casuarina* pollen grains in spectra collected from ancient samples, the amount of contamination of the rest of the spectrum could also be deciphered. Hence, the sample could be regarded much more reliably than if the results were based on airborne pollen alone. Among the nonarboreal pollen group, except for low percentages of cereals, almost no pollen of cultivated and introduced plants were discerned, apparently for two reasons. First, they may belong to the same families as do some of the natural constituents of the pollen spectra; second, most of the introduced nonarboreal plants are, apparently, insect-pollinated.

It is clear, then, that discussion of ratios of arboreal to nonarboreal pollen within the airborne spectra will be misleading due to the great overrepresentation of introduced trees compared to an almost total absence of pollen from introduced nonarboreal plants. Among the airborne arboreal pollen, only two genera can be considered as representative of natural vegetation, namely, that of pistachio and oak. Pollen produced by pistachio, as already noted by many investigators (as summarized later), is underrepresented; the same picture can be seen also in the airborne pollen spectra, in which values for pistachio do not exceed an order of tenths of a percent. Only in Haifa do they attain 1%; however, it should be noted that the area of Haifa is thickly surrounded by pistachio bushes, and this tree should thus, actually, have had a higher frequency. Oaks seem to be well-represented by their pollen grains and seem to us to be the best indicators for the presence of natural vegetation or for coverage of the country by the Mediterranean maquis. Generally, the percentage of oak pollen grains in airborne pollen spectra is somewhat higher in the mountainous areas of the country, somewhat lower to the east in the Jordan Valley and to the west in the coastal plain, and also diminishes toward the south, in the Be'er Sheva area. One sample seems somewhat exceptional, comprising 8.5% of oak pollen in the Bet She'an area, but, apparently, this is the result of very low values of cypress, *Eucalyptus* and *Casuarina*, which, had these been represented in the normal percentage range as recorded all over the country, the relative percentage of oak pollen in Bet She'an would drop to about 4%, the expected figure for this area.

Noteworthy among the nonarboreal airborne pollen are the rather constant values of most constituents in many of the pollen spectra throughout the country, which, overall, give a rather uniform picture everywhere. However, some minor differences characteristic of certain regions should be noted. The wider valleys are characterized by somewhat higher percentages of Gramineae, as in the samples collected at Bet She'an and those from Qiryat Gat. Compositae and Crucifereae do not show distinct variation at any locale, whereas Chenopodiaceae are definitely more abundant in the Jordan Valley, as in the samples collected at Bet She'an and, particularly, the sample collected at Jericho. The Chenopodiaceae seem to appear in two environments. The first is a halophytic environment, thus the very high percentages around the Dead Sea. The other is a *ruderal* environment (plants that accompany human habitation and soil cultivation); thus, these pollen grains are found in almost every airborne spectrum collected in modern settled environments. Comparing the airborne spectra with spectra collected from Recent sediments, it can be seen that the latter have somewhat lower percentages of Chenopodiaceae in areas that are not saline. Apparently, this is due to the influence of human settlement, which promotes ruderal vegetation. Umbelliferae apparently favor the inner valleys of the country but are not so much associated with a halophytic environment and are more abundant at Bet She'an and in the Valley of Yizre'el, judging by the sample collected at Afula, than in most other localities.

Papilionaceae, *Ephedra*, and *Centaurea* pollen do not show great variations in their distribution throughout Israel. On the other hand, pollen produced by *Artemisia* presents a considerable problem, since no certain connection between its relative percentage and its environment could be found. This had been observed in the Recent sediments of Lake Kinneret (Horowitz, 1969a) and can be seen as well in the airborne pollen spectra. The highest values were recorded in Hebron, which makes no sense, as this area is far from being the ideal environment for *Artemisia*. Apparently, the distribution of *Artemisia* pollen grains is much more dependent on the direction and concentration of winds, the grains being very susceptible to wind transport. Any further conclusions based on the distribution or the relative distribution of pollen grains derived from *Artemisia* should be made with great care. In fact, any such conclusions should be strengthened by the distribution of other pollen grains, based on their dispersion both in airborne spectra and in spectra derived from Recent sediments. *Poterium spinosum,* which is an important constituent of the *batha* (low undergrowth and border vegetation of the maquis margins) vegetation of the country, is encountered only in fractions of a percentage in most areas; in the mountainous areas, in samples collected from Zefat, Nazareth, Jerusalem, and particularly Hebron, they amount to several percent of the airborne spectrum. It should be noted that the influence of local elements growing in the vicinity of the pollen trap is not so much felt in the airborne spectra, which seems to indicate that the mixing effects of the wind are quite considerable. More influence of local elements can be seen in places that are poor in vegetation. An airborne pollen spectrum collected by Tas and Rahat (1963) from En Bokeq on the western side of the Dead Sea showed up to 50% of pollen grains derived from *Forskahlea,* which is a typical local element belonging to the Urticaceae family. It should also be noted that, besides the presence of local elements, the rest of the En Bokeq spectrum displays more or less the same overall picture obtained from other regions of the country. The influence of local elements on the pollen spectrum, even when it is considerable, could, thus, be eliminated by rather simple calculations based on the uniformity of pollen spectra throughout the country.

Seasonal variations of the airborne pollen spectra (Figure 6.2) are considerable and may amount to more than an order of magnitude. Such variations are quite important in analyzing the frequencies of pine and oak pollen, of Gramineae, and of almost all the remaining nonarboreal plants. Both pine and Gramineae generally show peaks in their monthly distribution from March through May, whereas most of the other plants of the country, the nonarboreal and the oaks, flower before that, with peaks in January, February, and the beginning of March. Spring is the season in Israel of easterly winds called Hamsin, which transport most of the pine and Gramineae pollen westward toward the coastal plain. Winter is the season of northwesterly and westerly winds, which transport the oak and most of the nonarboreal pollen eastward toward the Jordan Valley. Consequently, oak and nonarboreal pollen (excluding Gramineae) are more frequent in the Jordan Valley than in the coastal plain, where pine and Gramineae are major constituents of the pollen spectra. This is, apparently, also exhibited in some of the fossil spectra, as will be discussed later. This preference should be taken into account when analyzing or comparing pollen spectra from the Jordan Valley with those obtained from the coastal plain. Percentages cannot be compared directly but should be recalculated in view of the effect of the prevailing winds during the flowering season of each of these constituents.

Two main differences can be observed when comparing the airborne pollen spectra and those obtained from sub-Recent sediments. First, naturally, is the rarity of pollen grains derived from cultivated and introduced plants in the sub-Recent samples. The other is some increase in elements such as oak, Gramineae, and *Artemisia* while the other, mostly nonarboreal pollen, are somewhat less represented. This most probably results from differential preservation of some of the pollen grains, especially from the nonarboreal group. It seems that the proportions within the arboreal pollen group in the sub-Recent samples are almost the same as those obtained from the airborne spectra, whereas, within the nonarboreal pollen group, in both sub-Recent sediments and in fossil samples, pollen grains of groups such as Gramineae, Compositae, Crucifereae, Chenopodiaceae, Umbelliferae, Papilionaceae, *Artemisia, Ephedra, Centaurea,* and *Poterium* are more frequent than those derived from other plants. This is expressed by lower values of the other constituents of the NAP group in the sub-Recent sediments than in the airborne spectra.

The principal conclusions obtained from the analysis of the airborne pollen spectra are as follows. The airborne spectra of the natural vegetation are more or less comparable with those obtained from sub-Recent sediments, except for some minor differences resulting from differential susceptibility to destruction of various pollen grains. The second conclusion considers preferences of some pollen groups for certain areas of the country; some pollen groups are strongly represented as a consequence of prevailing wind directions at the time of their flowering. Thus, pine and Gramineae assemblages predominate in the coastal plain, whereas oak and other nonarboreal plants are conspicuous in the eastern parts of the country, especially the Jordan Valley.

POLLEN CARRIED BY DUST STORMS

A study of pollen spectra in dust brought to Israel by dust storms was carried out by Horowitz *et al.* (1975). Samples were collected in Jerusalem and Tel Aviv during dust storms, using dust traps placed on high buildings. The dust traps were of the usual type used for collection of airborne pollen by almost all investigators and consisted sisted of a sheltered glass or metal plate covered with glycerine jelly. The mineral fraction of the dust (Yaalon and Ganor 1973) generally indicates a bimodal distribution with a large peak in the silt fraction, about 65%, and a second peak in the clay fraction, about 30%, as opposed to dust washed out by rainfall, which contains about 65% clay. Most of the dust samples were collected in Jerusalem; samples of one dust storm were collected both in Jerusalem and in Tel Aviv—the dust storm of April 29, 1972. Figure 6.3 shows the directions of air masses that passed over Israel during westerly dust storms, and Figure 6.4 is a synoptic map of an easterly dust storm of May 7, 1973. The results of pollen analyses of the dust storms are summed up in Table 6.2 as percentages of the pollen brought to Israel by these storms. Figure 6.5 sums up the provenances of the main pollen groups reaching Jerusalem during dust storms.

According to meteorological data, the dust storm of January 9, 1968, originated in northeast Africa and reached Israel through northern Sinai and the Negev, from a south–southwest direction. The pollen spectrum is characterized by a relatively high proportion of cereals (33%), Graminae and Cyperaceae (17%), cypress (11%), olive (11%), and oak (8%). The storm of March 31, 1969, also came from the south–southwest and is characterized by a pollen spectrum that is particularly rich in grasses and sedges (37%) and oak (15%), together with considerable amounts of Chenopodiaceae (10%) and cypress (9%). The storm of April 29, 1972, originated from the same provenance and also carried high percentages of grasses and sedges (31%), cypress (11%), and Chenopodiaceae (10%), with a relatively high amount of Cruciferae (10%). The same storm, checked by samples collected at Tel Aviv, showed an exceptionally high proportion of cypress (65%) and *Poterium spinosum* (14%). Two storms came from the southwest, having originated in northeast Africa, and arrived in Israel through the northern coastal plains of Egypt and Sinai. The storm of March 12, 1968, carried a pollen spectrum rich in grasses and sedges (30%), cereals (16%), olive (14%), and *Plantago* (12%), whereas in the storm of March 29, 1971, Chenopodiaceae (34%), grasses and sedges (27%), and Compositae (10%) prevailed. Quite high amounts of *Artemisia* (7%) and Papilionaceae (7%) were noted in this storm. The storm of January 13, 1968, came from the west and carried a great number of pollen grains, with a high amount of *Poterium spinosum* (29%), cypress (18%), *Artemisia* (14%), and *Eucalyptus* (9%), and the storm of November 25, 1968, which originated in Saudi Arabia and arrived at Jerusalem through Jordan, the Arava, and the Judean Desert, was especially rich in Chenopodiaceae (47%) and Compositae (11%). Two dust storms, of May 7, 1973, and January 17, 1969, were especially interesting, since they arrived at Jerusalem from the east by a circular

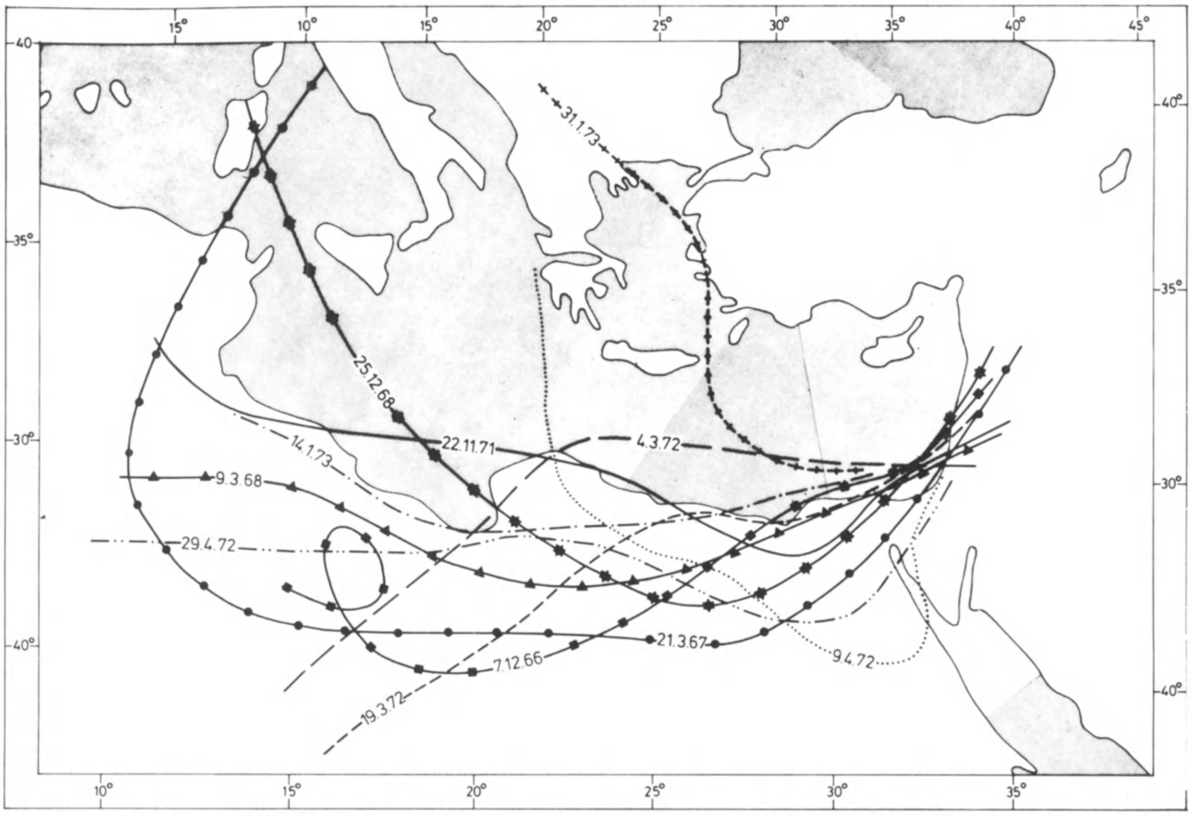


FIGURE 6.3. *Paths of westerly dust storms arriving in Israel, from which the pollen spectra have been studied. (From Horowitz* et al. *1975.)*

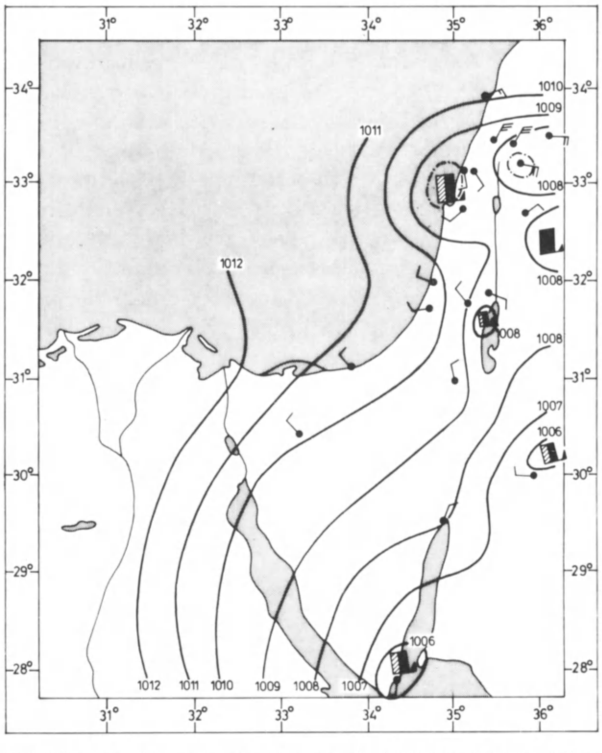


FIGURE 6.4. *Synoptic map of an easterly dust storm that was palynologically studied. (From Horowitz* et al. *1975.)*

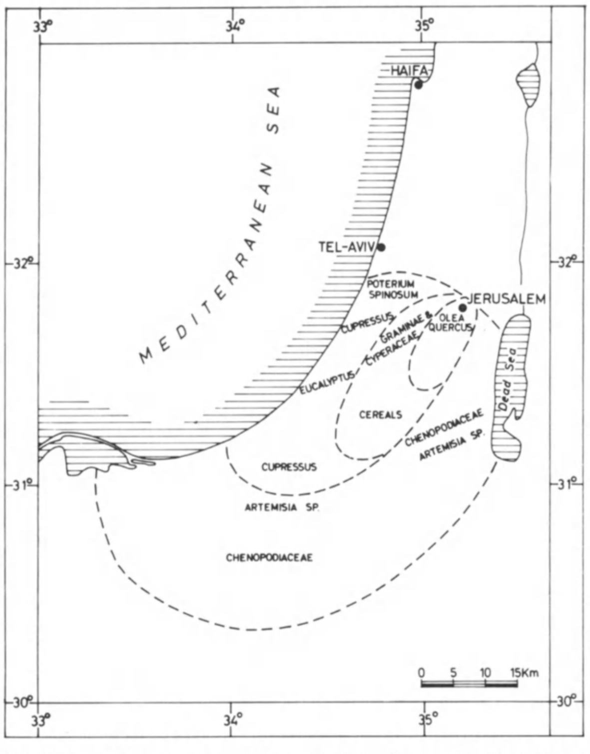


FIGURE 6.5. *Provenances of the more important palynological elements arriving in Jerusalem with dust storms. (From Horowitz* et al. *1975.)*

TABLE 6.2
Pollen Spectra of Different Dust Samples Collected in Jerusalem and Tel Aviv[a]

Pollen	9 January 1968	31 March 1969	29 April 1972	29 April 1972[b]	12 March 1968	29 March 1971	13 January 1968	25 November 1968	7 May 1973	17 January 1969
Arboreal pollen										
Quercus spp.	8	15	2	1	3	—	2	3	15	18
Olea europaea	11	1	3	1	14	2	3	5	11	26
Eucalyptus	3	2	1	1	1	3	9	4	1	1
Cupressus sempervirens	11	9	11	75	3	—	18	0.5	4	2
Pinus halepensis	2	1	1	1	1	—	2	2	1	2
Pinus pinea	—	—	2	1	—	—	—	—	—	—
Acacia farnesiana	1	—	—	—	—	—	—	—	—	—
Populus	—	1	—	1	—	—	—	0.5	—	—
Juglans	—	1	0.5	—	—	—	—	—	—	0.5
Prunus	—	1	—	—	1	1	—	0.5	0.5	2
Pistacia	—	—	3	1	—	1	—	—	1	0.5
Casuarina	—	—	1	1	—	—	3	—	—	—
Nerium oleander	—	—	—	1	—	—	—	—	—	—
Carya	—	—	—	—	1	—	—	—	—	—
Ceratonia siliqua	—	—	—	—	1	—	—	2	—	—
Rhamnus	—	—	—	—	—	—	0.5	0.5	—	—
Zizyphus	—	—	—	—	—	—	0.5	0.5	—	—
Tamarix	—	—	—	—	—	—	2	2	—	—
Salix acmophyla	—	—	—	—	—	—	—	—	0.5	—
Nonarboreal pollen										
Gramineae and Cyperaceae	17	37	31	3	30	27	2	5	12	28
Cereals	33	1	0.5	1	16	1	3	9	4	10
Plantago	1	1	6	—	12	2	—	0.5	1	2
Chenopodiaceae	2	10	10	1	9	34	7	47	21	1
Umbelliferae	1	1	1	1	2	1	—	1	2	1
Compositae	2	3	2	3	2	10	2	11	6	2
Artemisia	2	4	2	1	1	7	14	—	9	—
Cruciferae	1	1	16	1	1	4	2	5	2	2
Ephedra	—	—	1	—	—	3	—	—	1	0.5
Polygonum equisetiforme	—	—	—	—	1	—	—	—	—	—
Papilionaceae	—	1	—	—	—	7	1	—	0.5	0.5
Labiatae	—	1	1	1	—	—	—	0.5	0.5	—
Poterium spinosum	2	1	2	14	—	—	29	—	—	0.5
Mercurialis annua	—	—	2	—	—	—	—	—	—	—
Trifolium	—	—	2	—	—	—	—	—	—	—
Liliaceae	—	1	1	—	—	—	0.5	—	—	—
Rubus sanctus	2	3	—	—	—	—	—	—	1	0.5
Scabiosa prolifera	—	1	—	—	—	—	—	—	0.5	—
Urtica	—	1	—	—	—	—	—	—	—	—
Typha	—	—	—	—	—	—	—	—	5	—
Euphorbiaceae	—	—	—	—	—	—	—	—	1	—
Solanaceae	—	—	—	—	—	—	—	—	0.5	0.5
Centaurea	—	—	—	—	—	—	—	—	—	0.5
Cistus	—	—	—	—	—	—	—	—	—	0.5
Total counted	200	200	254	545	200	131	177	188	210	255

[a] From Horowitz *et al.* (1975).
[b] Collected in Tel Aviv.

path, passing through other western and southern parts of the country (Figure 6.4). Both were rich in oak (15 and 18%), olive (11 and 26%), and grasses and sedges (12 and 28%). The storm of May 7, 1973, was further characterized by a high percentage of Chenopodiaceae (21%).

It seems that the pollen spectra of dust storms arriving in Jerusalem from various sources differ quite markedly (Figure 6.5). Pollen spectra of storms coming from the southwest are characterized by high percentages of cereals, mainly cultivated in the Western Negev; cypress, a typical coastal plain tree in Israel; and grasses and sedges that accompany all the Israeli vegetational formations but are mainly typical of open fields and are widespread in the Shefela foothills. Olive trees, also common in the Shefela region, contribute to the southwestern spectra. A southern provenance for storms arriving in Jerusalem is indicated by high percentages of oak pollen, produced by trees that grow in the Judean hills and are quite common in the Hebron area, south of Jerusalem. A western source is indicated by high percentages of *Poterium spinosum*, a batha plant common to the western flanks of the mountains and to the higher Shefela. The velocities of the dust storms could also be detected up to a certain limit and are reflected by their pollen spectra. Higher velocities of southwestern storms result in higher levels of Chenopodiaceae and *Artemisia*, both of which originate in the Negev and in the coastal plains of northern Sinai and southern Israel. Higher percentages of *Plantago* and Papilionaceae may indicate either seasonal or local variations. An eastern source of dust storms is characterized by high percentages of Chenopodiaceae, together, occasionally, with higher percentages of *Artemisia* and other Compositae. Regional differentiation was encountered when spectra of the same storm, of April 29, 1972, were analyzed from samples collected both in Jerusalem and Tel Aviv. Local influence is felt in both and is even stronger in Tel Aviv, with exceptionally high percentages of cypress and *Poterium spinosum*. Grasses and sedges, Cruciferae, cypress, and Chenopodiaceae are the dominant components in the Jerusalem spectrum. Thus, it seems that differences in pollen spectra of storms originating in different areas, as observed in samples collected at a certain location, are diagnostic enough to determine the direction from which the storms derived.

Concerning the influence of dust storms on the average Recent pollen spectrum, it seems that most pollen grains are carried from adjacent areas, although it is not uncommon to find some that have been transported 100–150 kilometers or more. Naturally, the storm velocities have some influence on the distances over which the pollen could have traveled. Seasonal variations are sometimes evident but usually have little influence, probably because the dust was accumulated during a period longer than one season, so that variations observed are annual or cover even longer periods. The dust storms, apparently, carry and contain an average pollen spectrum of the area in which they originated, and especially of those over which they have traveled. Dust storms are quite frequent in the Middle East; it is, therefore, important to note the influence of those pollen grains carried by these storms on the spectrum. It seems that dust storms do affect the Recent pollen spectra and, most likely, have also affected the Quaternary pollen spectra in preserving pollen elements from areas over which the storms have passed. This point should, of course, be taken into account when analyzing pollen spectra from sediments of a particular location.

POLLEN SPECTRA IN RECENT SEDIMENTS

Mediterranean Offshore

Recent pollen deposition in the Mediterranean offshore of Israel was studied by Rossignol. The preliminary stage of the study dealt with the southern sector of the offshore Mediterranean and was published in 1961, and a more comprehensive study of the entire offshore Mediterranean along Israel's coast was published in 1969. The present account is chiefly based on the latter publication. Samples for the study were collected using a Patterson grab, which penetrated the upper 30–40 cm of the sea bottom sediment. As distant as 3 km offshore, most of the sediments brought up were sandy and rather poor in pollen grains, whereas further offshore most of the sediments comprised gray to bluish clays and silts for which the pollen yields were productive. Samples were collected along several east-west bearings, opposite the following points along the Israeli coast: Ashqelon, Ashdod, Tel Aviv, Herzeliya, Netanya, Dor, Atlit, Tira, and Nahariyya, from water depths ranging from several to about 100 fathoms. Most of the samples yielded pollen spectra in the range of 100–200 pollen grains per sample. Several samples were rather poor, and only in rare cases were more than 200 grains identified and counted. The spectra comprised three groups: pollen grains, cryptogamous spores, and hystrichospheres. Detailed results are given by Rossignol (1961) only for the southern sector of the Mediterranean offshore, whereas for the rest of the samples only maps representing the relative and absolute frequencies of pollen grains, spores, and hystrichospheres are given in the 1969 publication. It seems, however, that most of the pollen spectra, regardless of their distance from the shore, water depth, lithology of the sample from which they were recovered, and their position along the north–south line parallel to the coastline of Israel, are very similar and could, in fact, be treated as a single representative pollen spectrum for Israel's offshore during Recent times.

The absolute frequencies of pollen grains in the Mediterranean offshore samples are higher opposite the main wadis, or main rivers, which provide water to the Mediterranean. In the south, a peak can be seen (Figure 6.6) opposite the outlets of Nahal Lakhish and Nahal Soreq. Peaks in the central part of the country can be seen opposite Nahal Poleg and Nahal Alexander, and there are also two peaks in the north, one of them opposite Nahal Kishon and the other opposite Nahal Keziv. The absolute frequencies of pollen grains are highest along an area parallel to the coastline and situated about 10 km seaward. The absolute frequency of pollen grains diminishes toward the coast, most probably as a result of the sandy type of sediment, and they diminish still farther seaward as a result of the loss of energy of the transporting agents. This picture seems to point toward the importance of water as a transporting agent, as indicated by the peaks opposite river outlets. Relative frequencies of the most important constituents of the pollen spectra along the Mediterranean offshore are shown in Figure 6.7. (The relative frequencies of the more important pollen and spore groups of the Mediterranean offshore, calculated on the basis of total counted pollen and spores, equals

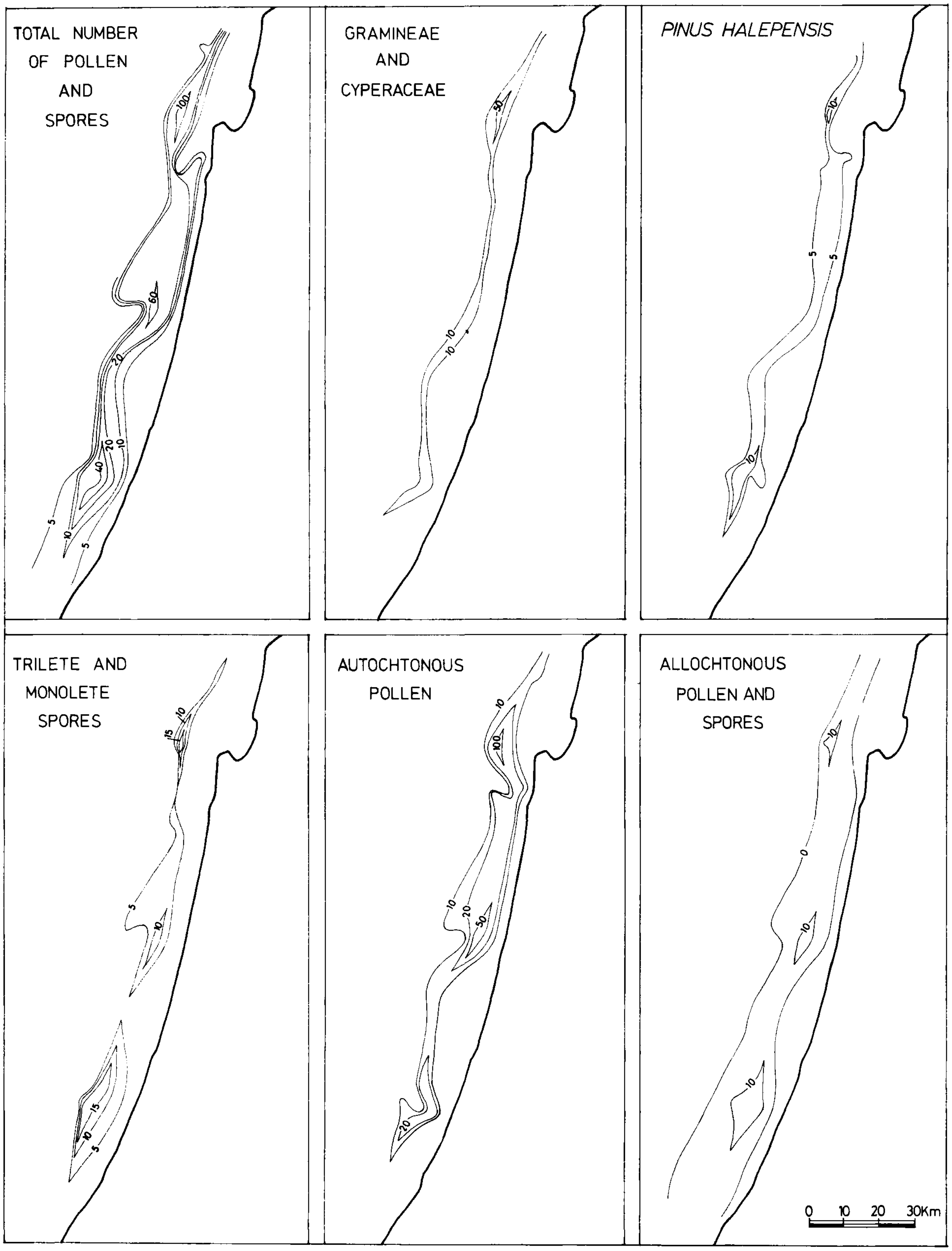


FIGURE 6.6. *Absolute frequencies of the more important palynomorph groups along the Mediterranean offshore. (From Rossignol 1969.)*

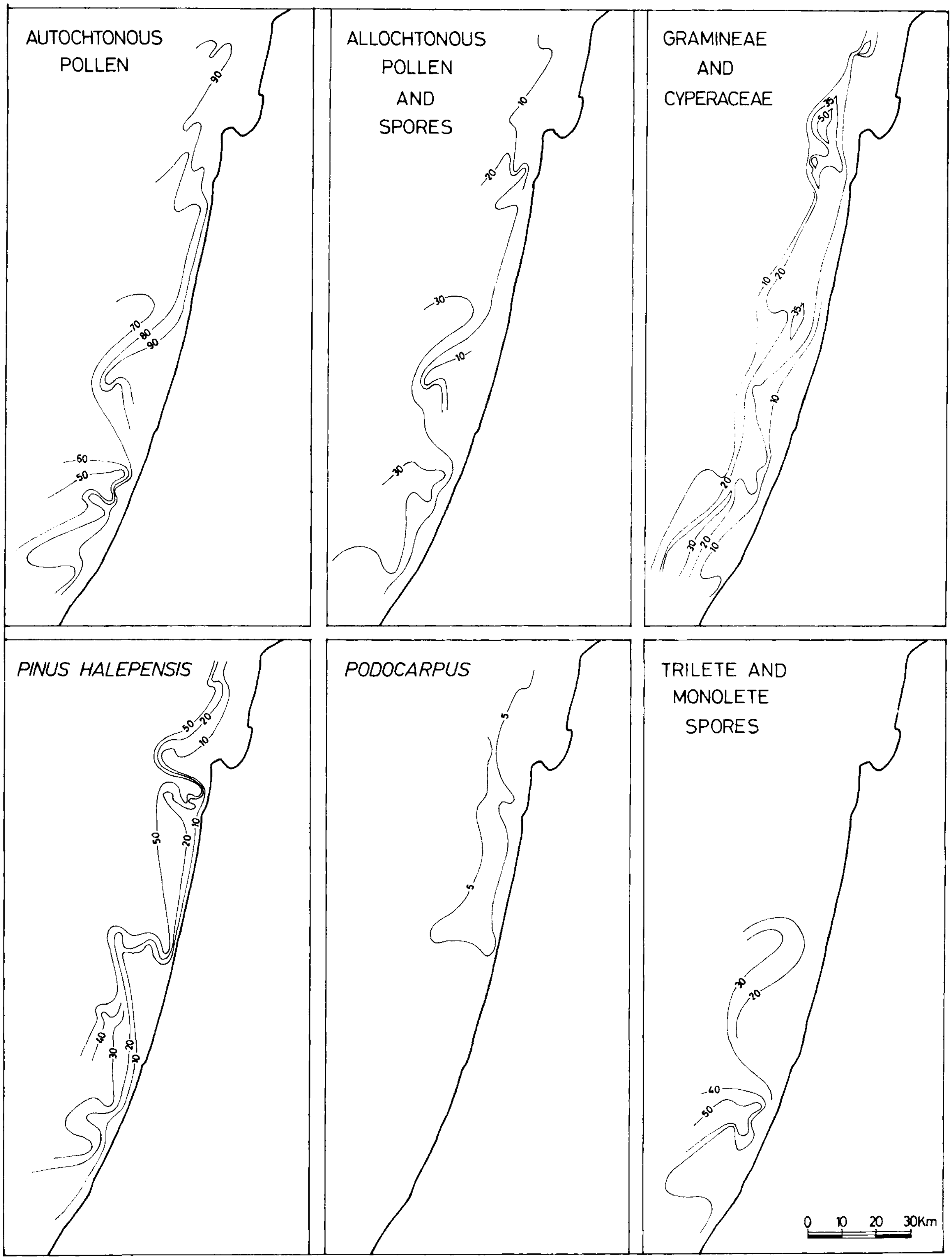


FIGURE 6.7. *Relative distribution of the more important palynomorph groups along the Mediterranean offshore. (From Rossignol 1969.)*

100%.) Gramineae and Cyperaceae dominate the pollen spectra of Recent samples for the Mediterranean offshore all along the coastline of Israel. Sometimes these are accompanied by pollen grains of *Sparganium;* all grow together in the littoral environment. The second most common group comprises pollen grains of conifers, of which *Pinus halensis* is the dominant element. Some grains of *Cedrus libani* also appear but are quite rare and were most probably carried offshore by winds from Lebanon. Another conifer that is quite abundant, somewhat more in northern locations, is *Podocarpus gracilior.* Pollen grains of *Cupressus* are quite rare and are suspected to be a result of contamination during preparation of the slides.

Next in frequency are pollen grains of Compositae, from which Liguliflorae form a major part. Among Tubuliflorae, *Artemisia* is rare, and *Centaurea* appears occasionally. Pollen grains of *Asphodelus microcarpus* sometimes accompany Compositae. Pollen grains of Chenopodiaceae and *Ephedra* are very rare; only a few were encountered in these samples. A group that seems to be quite abundant among the Recent pollen spectra of the offshore Mediterranean comprises spores of cryptogamous plants. Of these, more than 50 species were encountered in the various samples, representing mainly such families as the Gleicheniaceae, Cyatheaceae, Anthocerotaceae, Polypodiaceae, Lycopodiaceae, Osmundaceae, Schizaeaceae, and others (Figure 6.16). Among the rest of the pollen grains, which form together only a minor part of the spectra, appear some pollens derived from the Acanthaceae, such as *Blepharis edulis,* which grows in Israel, and *Haplanthera,* which grows only in Ethiopia. Others are Caryophyllaceae, *Ceratonia siliqua,* Cistaceae, among which *Helianthemum* is quite common; *Colchicum, Convolvulus,* Cruciferae, *Cynocrambe,* and Dipsaceae, of which *Pterocephalus,* and *Scabiosa* are the main elements; Ericaceae, *Eucalyptus,* Malvaceae, *Olea europaea,* Umbelliferae, the palm *Hyphaene thebaica,* Pedaliaceae, *Pistacia, Plantago,* Plumbaginaceae, and Polygonaceae, of which both *Polygonum* and *Rumex* were identified; *Poterium spinosum, Quercus calliprinos, Quercus ithaburensis, Rhus coraria, Gallium,* Solanaceae, and Thymeleaceae, of which *T. hirsuta* is the main element; and some triporate pollen grains derived from *Casuarina,* which is cultivated in Israel. It is surprising that the frequency of pollen grains of *Artemisia* is rather low, because *Artemisia monosperma* comprises a major part of the coastal vegetation of Israel, together with *Ammophila arenaria.* Rossignol also notes the rarity or absence of pollen grains of certain plants that are prominent in the Recent vegetation, including *Ceratonia siliqua* and *Pistacia lentiscus,* which together form a very important vegetational formation, especially in the dunes of the central coastal plain. Rare also are pollen of Papilionaceae, among which *Retama roetam* and *Lotus creticus* are very common in the coastal plain. Pollen grains of cultivated plants are also quite rare in Recent sediments of the Mediterranean offshore; the main reason, apparently, is that the Patterson grab penetrated and brought upward sub-Recent material not much contaminated by the pollen of cultivated and introduced plants, which had been brought to the country only in recent decades.

Many plants just cited as comprising the Recent pollen spectra of the Mediterranean offshore adjacent to Israel do not presently grow in the country, and their pollen grains are brought to the Mediterranean from a remote source. Allochtonous pollen sometimes comprises up to 80% of the Recent pollen spectrum. The most important pollen comprising the group of allochtonous sporomorphs are the cryptogamous spores, *Podocarpus,* Acanthaceae, Dom Palms, and the Ericaceae. Pollen from these plants is brought to the eastern Mediterranean basin by the Nile; this was proved by Rossignol while analyzing Recent sediments of the Nile collected near Abu-Simbel, quite far landward. The allochtonous pollen grains are derived from plants that comprise quite an important part of the Ethiopian highland vegetation at the source of the Nile and, especially, the Blue Nile. These allochtonous pollen and spores are, apparently, quite resistant to the destructive influence of transporting agents and can travel the Nile downstream a distance of several thousand kilometers, thus appearing within the Recent pollen spectra of the Mediterranean. It is worthwhile noting that the allochtonous pollen grains and spores appear in the eastern Mediterranean basin at the time when the activity of the Nile began, at the onset of the Pliocene period (Horowitz 1974), and are known throughout the Pliocene (Horowitz 1974b) and the Pleistocene (Rossignol 1962, 1969).

Rossignol regards all pollen derived from plants that grow in Israel as autochtonous, but a comparison of the airborne and Recent pollen spectra off the Mediterranean coast indicates that Gramineae and Cyperaceae, for example, the most common group in the Recent sediments, cannot surely be regarded as completely autochtonous. In the airborne spectra collected at the coastal plain (see discussion earlier), Cyperaceae are very rare; in fact, they do not appear at all in most of the samples, whereas Gramineae are quite common. It seems, therefore, that most Cyperaceae and some Gramineae are also allochtonous, having been brought by the Nile, and this is one reason for their overrepresentation in the Mediterranean Recent sediments as compared with Recent sediments collected in other locations of the country. Most of the minor elements mentioned are probably of local origin. Among the local trees, only *Pinus halepensis* is well represented in the Recent Mediterranean offshore sediments, whereas trees such as *Quercus calliprinos, Quercus ithaburensis, Pistacia, Ceratonia,* and *Olea* are underrepresented when the offshore spectra are compared with Recent spectra collected elsewhere in the country. It seems that the main reason for this is that the wind direction during the time of pine flowering is mainly easterly, whereas the prevailing westerly and northwesterly winds during flowering seasons of the remaining trees account for their underrepresentation. Further, as expected, *Ceratonia* and *Pistacia* are underrepresented, *Ceratonia* probably because it is, at least to some extent, insect pollinated, whereas with *Pistacia* the irresistibility of its pollen grains to oxidation and to preservation processes is the probable cause.

The Gramineae and Cyperaceae are quite abundant in the offshore spectra, from 20% to 58%. Both are somewhat more abundant to the north than to the south. The average percentages are about 27% south of Netanya and 42% north of it. *Pinus halensis*, with a maximum of 77% at Atlit, displays more or less the same picture of higher frequencies in the north than in the south, and the same is true for pollen grains of *Podocarpus*. The cryptogamous spores show the opposite picture. They are quite abundant in the south, 16% opposite Ashdod, and diminish northward. The relative frequencies of the autochtonous and allochtonous groups are also shown in Figure 6.7 as calculated by Rossignol, but it should be noted that the entire group of the Gramineae and Cyperaceae is included within the autochtonous group, which seems unjustified. Dinoflagellate cysts in the form of hystrichospheres are quite common offshore along the Israeli coast and are dealt with in detail by Rossignol (1964a, 1969). They were found to be somewhat more abundant in the southern area, along a strip that is about 10 km offshore, parallel to the coastline. These microfossils do not seem to be of great importance for the stratigraphy of Quaternary sediments of the coastal plain of Israel and will not be dealt with in detail here. Other organic-walled microfossils mentioned by Rossignol for Recent Mediterranean offshore sediments comprise some foraminifera and unicellular algae, which seem to be of little importance. An average pollen spectrum for Recent sediments collected offshore Ashdod in the southern coastal plain comprises 20% Gramineae and Cyperaceae, 2% Compositae and *Asphodelus*, 1% Chenopodiaceae and *Ephedra*, 26% *Pinus halepensis*, and 3% of other pollen grains, altogether 52% autochtonous pollen grains. The allochtonous group comprises 48%.

Jordan Valley Lakes

Studies of Recent pollen deposition have been carried out in the three subbasins of the Jordan Valley, presently occupied by lakes: the Hula Basin in the north (Horowitz 1971), Lake Kinneret in the Central Jordan Valley (Horowitz 1969a), and the Dead Sea in the Southern Jordan Valley (Rossignol 1969a). Of these, Lake Kinneret and its surroundings were chosen for more detailed study in order to determine and understand the various mechanisms by which pollen and spores are brought to it and deposited in the continental basins of the Northern and Central Jordan Valley, and to establish a regional model of pollen sedimentation that would represent the Recent conditions of semiarid climate, vegetation, and present-day topography and hydrography.

Lake Kinneret Lake Kinneret (the Sea of Galilee) is located in the northern part of the Central Jordan Valley. It is a rather large lake, about 170 km^2, and lessens the influence of bank vegetation on the pollen spectra of the area (cf. Faegri and Iversen 1964; Tauber 1965, 1967), thus giving a more reliable picture of regional conditions than other locations. The sediments are generally fine, gray to black silts and clays poor in carbonates, in which pollen grains are very well preserved (Nir, 1963). In order to obtain a clear picture of pollen transport and deposition, a comparison was made between the composition of the actual vegetation and the pollen and spore spectra recovered from the lake's surface sediments (Horowitz 1971). Samples of Recent sediments from Lake Kinneret were collected from the lake's bottom by a Patterson grab operated from a motorboat deck. The grab penetrated only a few centimeters into the bottom mud, thus bringing up almost only Recent material. The mixing of samples of the uppermost centimeters of the bottom mud has diminished to a certain extent the influence of the cultivated plants on the pollen spectrum, since pollen of the plants are present only in the uppermost millimeter or two of the bottom mud. At least 200–250 pollen grains were counted in each slide. Lake Kinneret obtains most of its water supply from three sources: the Jordan River to the north, passing through the Hula Valley; some small streams to the northeast and northwest, such as Nahal Amud, Nahal Zalmon, and a series of wadis coming through the Buteiha; and a number of springs, most of them saline, issuing near the shore or from the lake's bottom. Lake Kinneret is an intermediate lake, being drained southward by the Jordan River flowing down to the Dead Sea.

Climatic conditions in the northern part of the Jordan Valley are semiarid but locally become almost tropical wherever enough water is available. The average annual rainfall is about 400–500 mm. Rain falls only during 5 winter months, and the summer is hot and dry. Temperatures are rather high during the day, decreasing at night, and the relative humidity is low during the day, increasing somewhat with the drop in temperature. The mean annual temperature is about 23°C, with a daytime average of about 14°C in January and an average of 30°C in July. Winds are mostly strong, changing their direction during the day; the most abundant are northern and northwestern winds. Eastern winds, mostly occurring during the spring and the fall, sometimes affect the Northern Jordan Valley. The Central and Northern Jordan Valley is flanked by mountains in which the climate is Mediterranean. Annual winter rains of 600–1500 mm, depending on the elevation of the mountains, are quite typical.

The soils are of three main types: alluvial soils that cover the outwash plains of Nahal Amud, Nahal Zalmon, Ginnosar Plain, and the Buteiha; the most common soil of the surrounding mountains is terra rossa, derived either from carbonate rocks or from basalts. The mountainous vegetation consists of several variants of Mediterranean maquis and batha, *Quercetea calliprini* (Zohary 1959). This class is subdivided into many associations, of which the most important trees are *Pinus halepensis, Cupressus sempervirens, Quercus ithaburensis, Quercus calliprinos, Styrax officinalis, Pistacia atlantica, Pistacia palaestina, Pistacia lentiscus, Crataegus azarolus, Prunus amygdalus,* and *Ceratonia siliqua.* The most important batha plants are *Calycotome villosa, Cistus villosus, Poterium spinosum, Salvia triloba, Satureja timbra, Phlomis viscosa, Thymelea hirsuta, Thymus capitatus, Ballota undullata,* and *Asphodelus microcarpus,* among many other species. The undergrowth of the maquis comprises most of the typical batha plants, together with some species of *Ephedra,* Liliaceae, *Hypericum serpyllifolium,* and others. The prevalence of northern and northwestern winds in the area should direct attention also to the composition of the faraway Lebanese and Syrian maquis and forests, which have to some extent influenced the area under study. The principal elements are some species of oak, especially *Quercus libani,* and of cedar, *Cedrus libani,* which remain today only as relics but which are known from historical documents to have occupied considerable areas in the Lebanese mountains. In the Jordan Valley itself, the maquis is completely replaced by ruderal vegetation, which consists of Chenopodiaceae, Umbelliferae, Compositae, Cruciferae, *Artemisia, Scabiosa, Centaurea,* and many other taxa. The hydrophil plants of the Jordan Valley, growing mainly in the Hula Basin, form a rich variety of associations. The bank trees of the Jordan River and some other small rivers are mostly *Populus euphratica, Tamarix scebelensis, Salix acmophylla, Nerium oleander, Vitex angus-castus,* and some *Platanus orientalis* and *Fraxinus syriaca.* The swamp vegetation, which is very well-developed in the Hula Basin, consists of *Cyperus papyrus, Polygonum acuminatum, Phragmites communis, Sparganium neglectum, Rubus sanctus, Lythrum salicaria, Inula viscosa, Juncus acutus,* and others. Aqueous plants are common in the Hula. The most important are *Nuphar luteum, Ceratophyllum demersum, Potamogeton lucens, Potamogeton pectinatum, Potamogeton nodosus, Myriophyllum spicatum,* and various species of *Lemna.* These water plants are quite rare in Lake Kinneret because of the steepness of the shore and the scarcity of marshes. The only fern that is abundant in the Hula is *Thelypteris palustris,* which grows on the border of the marsh and the lake, producing typical, resistant spores.

Cultivated plants must also be taken into consideration, since they affect the pollen spectrum of the Recent sediments and can be taken as indicators of wind and stream directions, which might have influenced the spectrum in certain ways. Three main groups contribute to this element: the cereals, which occupy mainly the fields on the southwestern margins of Lake Kinneret; the fruit trees, especially those of the Rosaceae, cultivated in the valley and on the mountain slopes, and other trees like *Eucalyptus* and *Casuarina,* planted, for beautification purposes, mainly on the lake shore. One of the most important is the olive tree, *Olea europaea.* It is quite clear that olives grew wild in Israel long before their introduction as a tree cultivated by man; in fact, most of the Quaternary pollen spectra contain olive pollen grains. The period of transition or the mode of transition between wild growth and the cultivated tree is unknown, and no difference is observed between the pollen grains of the cultivated and the wild olive. It should be noted that, on the margins of the Jordan Valley in the north, there are still some stands of wild olives. It also seems that the cultivated olives now occupy more or less the same ecological niche as the wild olive; therefore, they can be counted as part of the natural vegetation and not so much as an influence of human interference (Horowitz 1968).

From the botanical point of view, the greater part of the Northern Jordan Valley and the northern part of the Central Jordan Valley belong to the Mediterranean belt. The remainder of the Central Jordan Valley belongs to the Irano-Turanian belt and the Southern Jordan Valley to the Saharo-Sindian belt. Some Sudano-Deccanian relics are scattered through several localities and are found especially around springs. The influence of the Irano-Turanian belt, which reaches the southern shores of Lake Kinneret, can be seen in small areas in which Chenopodiaceae and *Artemisia* are very abundant; these occur principally in the vicinity of En Gev on the eastern shore of the lake. Detailed accounts of the vegetation of the area are given in Eig (1946), Zohary (1959, 1962), Zohary and Orshanski (1947), and several others. The plants represented by pollen spectra were divided by Horowitz (1969a) into six groups, according to ecological and plant-sociological significance:

1. Trees of the maquis, mainly various species of oak, various species of *Pistacia, Pinus halepensis,* and Cupressaceae. *Olea europaea,* although in the present usually a cultivated tree, was included in this group for reasons mentioned earlier. Some elements of relatively minor importance in the pollen spectra, like cedars and *Ceratonia siliqua,* are also included in this group.
2. Hydrophil plants, including trees and nonarboreal plants. The trees include mainly various species of *Tamarix, Nerium oleander, Salix acmophylla, Populus euphratica,* and others; the nonarboreal group comprises a great variety of plants, among which Gramineae, Cyperaceae, *Typha angustata, Rubus sanctus, Plantago,* Labiatae, and the fern *Thelypteris palustris* are included.

3. Cultivated plants, further divided into trees including *Eucalyptus, Casuarina,* and rosaceaous fruit trees like *Prunus* and *Pyrus,* and nonarboreal plants, which are almost entirely cereals.
4. Plants of the batha. These are herbs and small shrubs making up a steppe-like vegetation, which, in most cases, replaces the former maquis but sometimes comprises part of its undergrowth. The main element of this vegetational formation in the pollen spectra is *Poterium spinosum,* together with *Asphodelus, Ephedra,* and some other plants that are relatively rare in the pollen spectra.
5. Ruderal plants, which replace the natural vegetation following human activitiy. These plants sometimes contribute a considerable part of the Recent pollen spectra and include some families of the Centrospermae, mainly the Chenopodiaceae and the Amaranthaceae, various Umbelliferae, Compositae, Cruciferae, *Scabiosa prolifera, Artemisia,* and *Centaurea,* among others.
6. Water plants, growing in lakes and marshes and always submerged. The water lilies, *Nuphar luteum, Potamogeton* spp., *Myriophyllum spicatum,* and others, contribute to this palynological association.

Locations of the Recent sediment samples are shown in Figure 6.8. Results of analyses of Recent sediments from Lake Kinneret are presented in Table 6.3 as percentages of the various constituents of the Recent pollen spectra. The table is arranged according to the plant groups described earlier. Calculations are based on the total sum of counted grains. Figure 6.9 shows the relationship between the main ecological groups over the lake's surface. These are as follows: pollen of maquis and batha plants, taken as one group because of their natural affiliation and the low percentage of batha elements, which does not justify independent representation; pollen of ruderal plants; pollen of hydrophil and water plants, which are dealt with together for the same reasons as the maquis and batha elements; and pollen of cultivated plants, with trees and cereals taken together. Figure 6.10 shows the relation of the arboreal to nonarboreal pollen ratios over the lake's area, and Figure 6.11 shows the relative distribution of some of the main constituents of the pollen spectra over the lake's surface. The pi diagrams are proportional to the frequency of each group. The distribution of four maquis representatives is shown: oak, olive, pine, and the Cupressaceae. Pollen of the hydrophil trees are shown together with the spores of *Thelypteris palustris,* because both are good representations of material supplied to Lake Kinneret mainly by the Jordan River. From the batha plants, only *Poterium spinosum* is represented. The reason is the relative poverty of pollen grains from the other batha plants. Distribution of pollen grains of the ruderal plants are given for five groups: Centrospermae, Umbelliferae, Cruciferae, Compositae (except for *Artemisia* and *Centaurea*), and Gramineae and Cyperaceae, which belong for the most part to the nonarboreal hydrophil plants and are combined in one group. The distribution of pollen grains of *Rubus sanctus* is shown separately. The distribution of cultivated plants is given for the cereals, *Eucalyptus* and *Casuarina.*

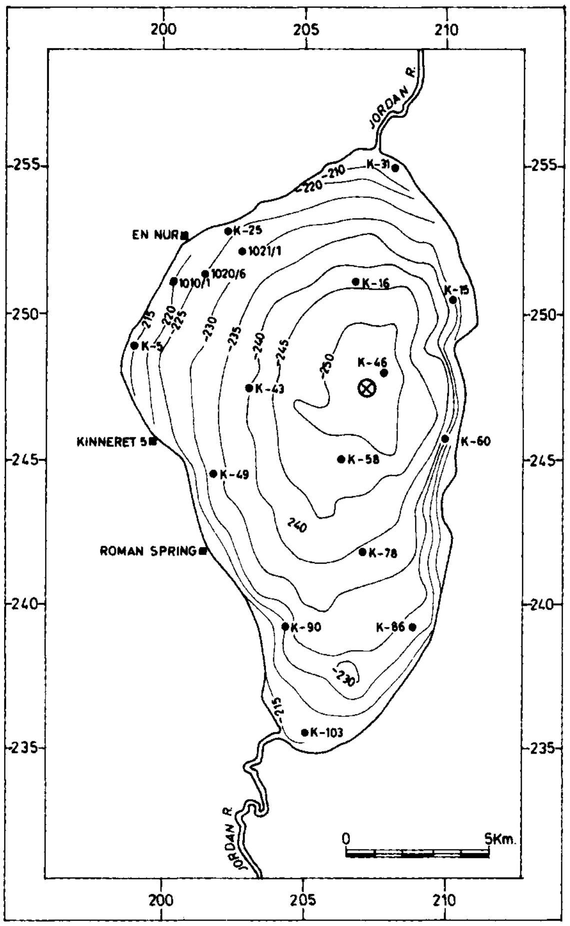


FIGURE 6.8. *Lake Kinneret. Contour map of lake bottom (m below mean sea level), showing locations of samples of Recent sediments and saline water sources.*

To conclude from Figure 6.9, it seems that, on the whole, there are no great or essential differences among the spectra. There are some variations, but none are especially marked. Generally, the percentages of maquis and batha constituents are higher in sumples taken far from the shore, like K-16, K-46, K-43, K-58, and K-78, than in most of the near-shore samples. Two near-shore samples show higher proportions of maquis and batha pollen: K-25, which yielded higher percentages of pollen of olive and batha plants; and K-26, with higher percentages of olive. Pollen of ruderal plants are very common near the shore, as can be seen from almost all the samples.

TABLE 6.3
Pollen Spectra of Recent Sediments, Lake Kinneret[a]

	Sample number													
Pollen	K-31	K-25	K-16	K-13	K-5	K-46	K-43	K-60	K-58	K-49	K-78	K-86	K-90	K-103
Arboreal pollen grains														
Maquis trees														
Quercus sp.	14	12	23	6	6	20	15.5	13.5	18	9	16	15	6	7
Olea europaea	0.5	7	7	4	2	6	6	6	10	5	8	11	5	6
Pistacia sp.	—	1	—	0.5	—	0.5	2	—	5	—	2	1	2	0.5
Ceratonia siliqua	0.5	—	0.5	—	—	—	—	—	—	—	—	—	—	—
Pinus halepensis	1	2	1	3	5	—	1	1	3	2	—	4	3	7
Cupressaceae	2	—	—	1	1	0.5	1	1	2	5	0.5	2	3	0.5
Cedrus libani	—	—	0.5	—	—	—	1	—	0.5	—	—	—	—	—
Total	18	22	32	14.5	14	27	26.5	21.5	38.5	21	26.5	33	19	21
Hydrophil trees														
Salix aomophylla	0.5	—	—	—	—	—	—	—	—	—	—	—	—	—
Tamarix sp.	—	1	4	0.5	1	0.5	—	—	—	—	—	—	—	—
Nerium oleander	—	—	—	0.5	—	—	—	—	—	0.5	—	—	—	—
Total	0.5	1	4	1	1	0.5	—	—	—	0.5	—	—	—	—
Cultivated trees														
Eucalyptus sp.	3	1	2	—	3	—	0.5	0.5	1	—	2	0.5	—	0.5
Casuarina sp.	1	1	0.5	0.5	—	1	1	2	3	—	2	0.5	—	4
Acacia farnesiana	—	—	—	0.5	—	—	—	—	—	—	—	—	—	—
Washingtonia sp.	2	—	—	—	1	—	—	—	—	—	—	—	—	—
Rosaceae (*Prunus & Pyrus*)	—	—	—	4	0.5	—	1	—	1	3	4	1	0.5	0.5
Total	6	2	2.5	5	4.5	1	2.5	2.5	5	3	8	2	0.5	5
Total arboreal pollen	24.5	25.0	38.5	20.5	19.5	28.5	29	24	43.5	24.5	34.5	33	19.3	26
Nonarboreal pollen grains and spores														
Batha plants														
Poterium spinosum	3	3	1	1	1	4	5	3	6	2	3	3	0.5	1
Asphodelus sp.	—	—	2	—	1	0.5	0.5	—	—	—	—	—	—	0.5
Ephedra sp.	—	2	—	1	1	—	—	0.5	—	0.5	0.5	—	—	—
Cistus sp.	—	—	—	—	—	0.5	—	—	—	—	—	—	—	—
Phlomis type	2	2	1	1	—	0.5	—	0.5	0.5	—	—	—	—	—
Liliaceae	3	0.5	1	1	1	1	0.5	—	—	—	—	1	—	0.5
Capparidaceae	1	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	9	7.5	5	4	4	6.5	6	4	6.5	2.5	3.5	4	0.5	2
Ruderal plants														
Centrospermae	6.5	6	8	11	8	10	6	10	2	1	7	12	4	8
Umbelliferae	5	10	4	6	5	3	5	12	3	8	6	4	3	1
Compositae (tubuliflorae)	6	7	0.5	13	10	1	4	16	2	17	4	9	5	4
Compositae (liguliflorae)	—	—	—	4	1	—	1	1	0.5	6	0.5	2	7	1
Cruciferae	7	15	7	12	15	3	7	9	4	5	6	8	13	4
Artemisia sp.	3	5	7	6	3	8	17	7	9	3	26	5	2	3
Scabiosa prolifera	0.5	1	—	2	6	—	—	1	—	—	—	1	1	0.5
Centaurea sp.	—	—	—	6	—	—	0.5	—	—	—	0.5	—	—	—
Polygonum equisetiforme	—	—	—	—	—	—	—	—	—	—	—	—	—	0.5
Adonis type	0.5	—	0.5	1	0.5	—	—	—	—	—	0.5	—	—	—
Papilionaceae	3	1	1	1	0.5	1	—	—	—	—	—	—	—	—
Convolvulaceae	—	—	—	1	—	—	—	—	—	—	—	—	—	—
Aizoaceae	—	—	—	0.5	—	—	—	—	—	—	—	—	—	—
Total	31.5	45	28	63.5	49	26	40.5	56	20.5	40	50.5	41	35	22
Hydrophil plants														
Gramineae <60 μm	7	4	5	2	6	15	7	3	11	15	2	6	10	20
Cyperaceae	5	6	3	1	6	4	2	4	8	8	—	5	6	3
Typha angustata	5	6	4	2	6	0.5	3	1	—	—	—	0.5	—	1
Polygonus acuminatum	1	—	—	—	—	—	—	—	—	—	—	—	—	—
Rubus sanctus	2	2	7	4	1	6	4	5	3	4	6	6	1	3
Plantago sp.	—	0.5	4	—	1	3	1	0.5	1	3	1	0.5	—	1
Rumex sp.	—	—	—	—	—	—	1	—	0.5	—	2	0.5	—	—
Urticaceae	—	—	—	—	—	—	—	—	—	—	—	—	0.5	—
Mentha type	3	0.5	1	1	—	—	0.5	—	—	—	0.5	—	—	—
Geraniaceae	—	—	—	0.5	0.5	—	—	—	—	0.5	—	—	—	—
Vitex agnus—castus	2	—	1	1	—	—	—	—	—	—	—	—	—	—
Thelypteris palustria	12	0.5	—	2	1	—	—	—	—	—	0.5	—	—	—
Dryopteris rigida	—	—	—	—	0.5	—	—	—	—	—	—	—	—	—
Total	37	19.5	25	13.5	22	26.5	18.5	13.5	23.5	30.5	12.5	18.5	18.5	28
Water plants														
Nuphar luteum	—	—	—	—	—	—	—	—	—	—	—	0.5	0.5	—
Potamogeton sp.	—	—	—	—	2	—	—	—	0.5	0.5	—	0.5	—	—
Myriophyllum spicatum	—	0.5	1	—	—	—	—	—	—	—	0.5	—	—	—
Ranunculus aquatilis	—	—	—	—	—	—	—	—	—	0.5	—	—	—	—
Jussiaea repens	0.5	—	—	—	—	—	—	—	—	—	—	—	—	—
Marsilia diffusa	0.5	—	—	—	—	—	—	—	—	—	—	0.5	—	—
Total	1	0.5	1	2	2	0	0	0	0.5	1	0.5	1.5	0.5	0
Cultivated plants														
Gramineae >60 μm	—	2	3	—	3	8	3	1	6	3	1	3	26	22
Total nonarboreal pollen	78.5	72.5	62	81	80	69	68	75	57	77	67.5	68	80.5	74

[a] From Horowitz (1969a).

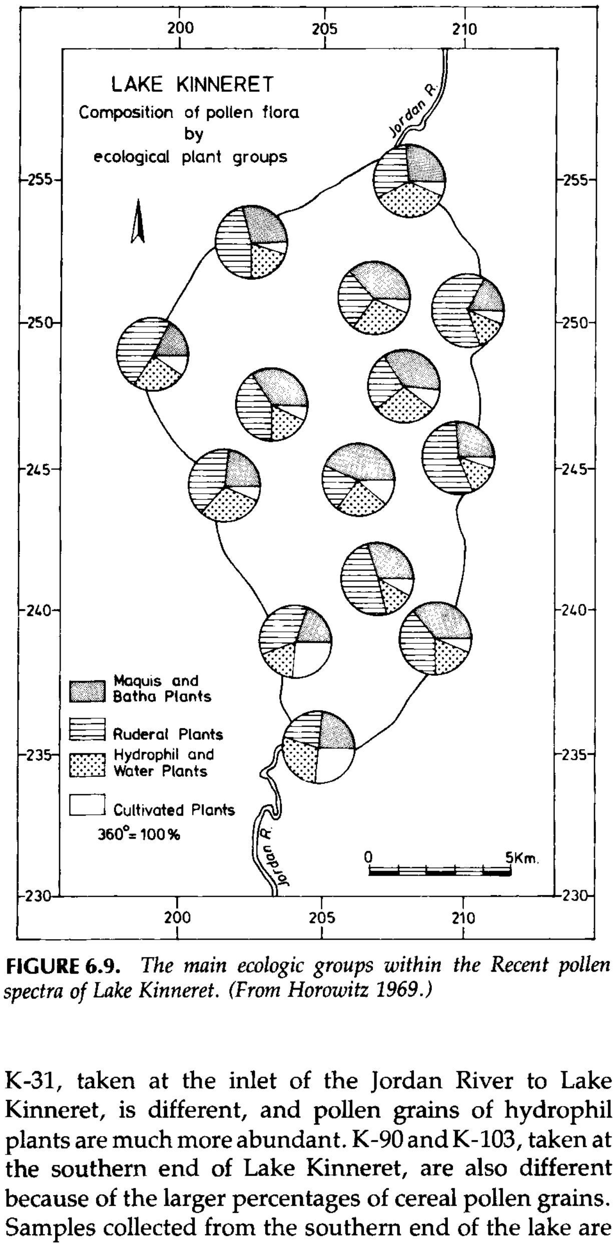


FIGURE 6.9. *The main ecologic groups within the Recent pollen spectra of Lake Kinneret. (From Horowitz 1969.)*

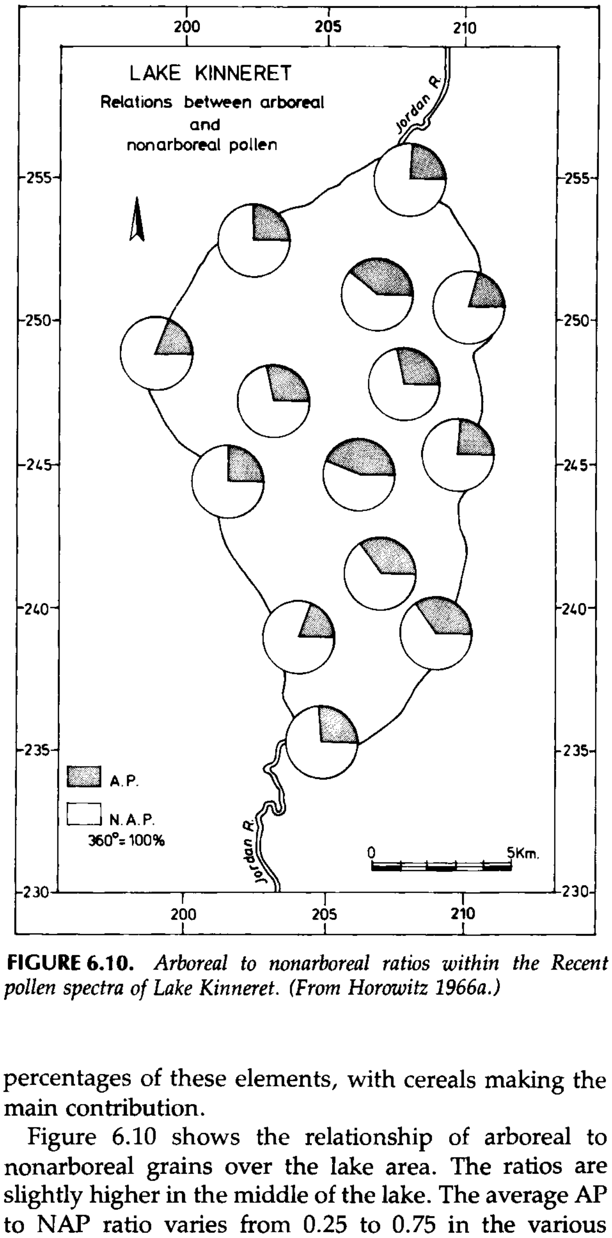


FIGURE 6.10. *Arboreal to nonarboreal ratios within the Recent pollen spectra of Lake Kinneret. (From Horowitz 1966a.)*

K-31, taken at the inlet of the Jordan River to Lake Kinneret, is different, and pollen grains of hydrophil plants are much more abundant. K-90 and K-103, taken at the southern end of Lake Kinneret, are also different because of the larger percentages of cereal pollen grains. Samples collected from the southern end of the lake are poor in pollen grains of hydrophil vegetation. Sample K-78, though taken far from the shore, is rich in pollen grains of ruderal vegetation. Pollen grains of hydrophil and water plants are more abundant in samples collected near the northern and northwestern shores than near the eastern shore, having intermediate values in samples collected from the central part of the lake. K-103, taken near the outlet of the Jordan River from Lake Kinneret, is rich in pollen grains of hydrophil plants. Pollen grains of cultivated plants, except for cereals, appear at almost constant values in all of the samples. In samples taken near the eastern shore, like K-60 and K-86, slightly lower percentages occur, whereas those taken near the southern end of the lake, like K-90 and K-103, show very high percentages of these elements, with cereals making the main contribution.

Figure 6.10 shows the relationship of arboreal to nonarboreal grains over the lake area. The ratios are slightly higher in the middle of the lake. The average AP to NAP ratio varies from 0.25 to 0.75 in the various samples but is mostly around 0.3–0.4. The average ratio is 0.4. The distribution of oak grains over the lake area is not uniform (Figure 6.11). Oak pollen are more abundant in the central part of the lake than near the shores. This may be compared with the distribution of pollen grains of olive, which is quite uniform over the lake area, except near the Jordan inlet (sample K-31), where the pollen is practically absent. The ratios of oak to olive pollen, which are both common in the analyzed samples, are between 1:2 and 3:3, but the average ratio is about 2:1. Pollen grains of other trees, such us *Pinus halepensis*, Cupressaceae, *Eucalyptus*, and *Casuarina*, are quite evenly distributed over the lake surface. Pollen of *Tamarix*, probably *T. scebelensis*, appears in sample K-16, taken south of the

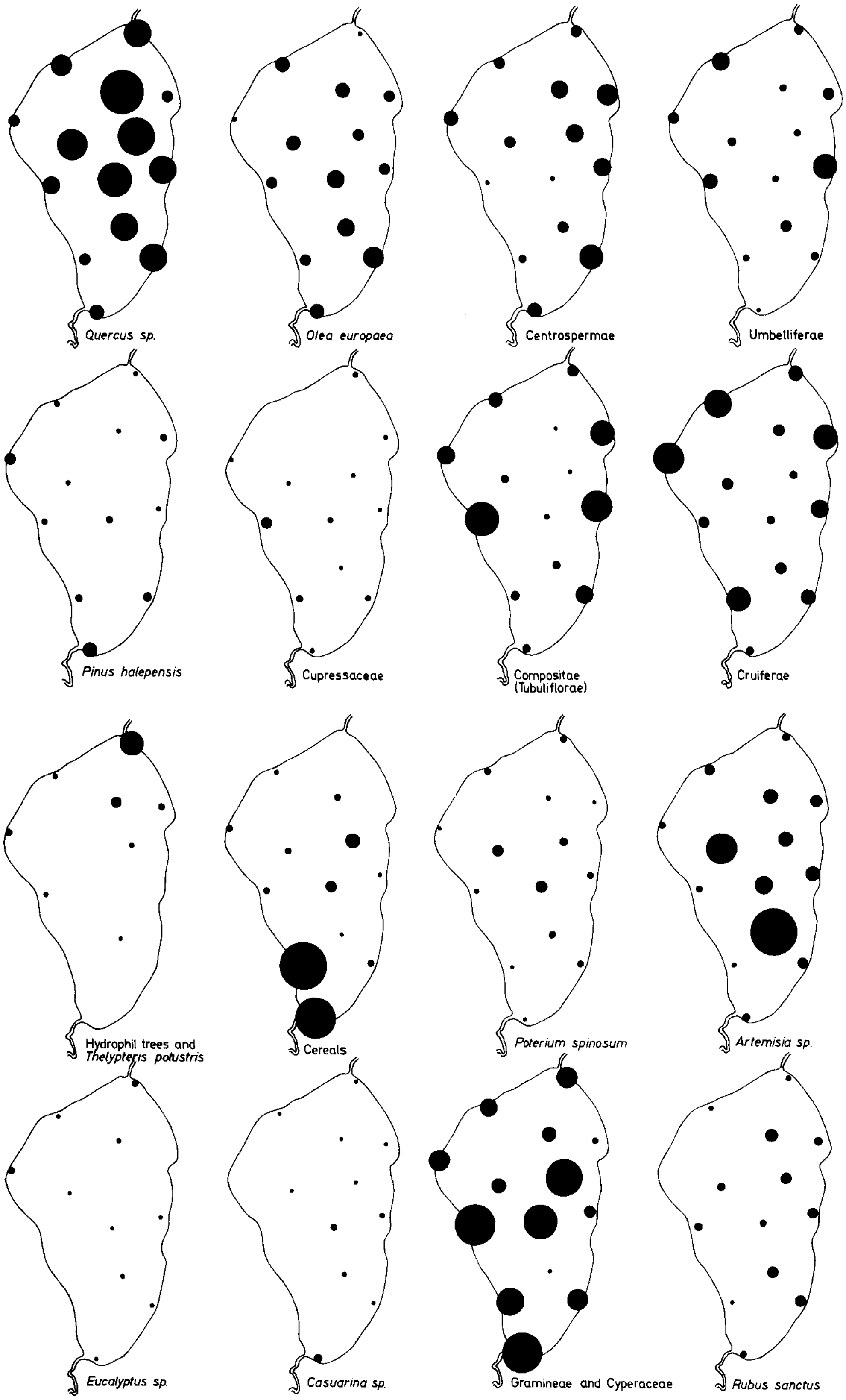


FIGURE 6.11. *Relative frequencies of various pollen grains in Recent sediments of Lake Kinneret. (From Horowitz 1969a.)*

Jordan River inlet in the north of Lake Kinneret, and is quite rare in the other samples. Pollen grains that represent Centrospermae, a group to which Chenopodiaceae contributes the major part, show greater abundance near the eastern shore of Lake Kinneret. This group was classified with the ruderal plants, but it also forms part of the Irano-Turanian steppe vegetation. Pollen grains of Umbelliferae show a rather even distribution except at three locations: near Tiberias (K-49), near Tabgha (K-25), and near En Gev (K-60). No pollen of this group were recorded at the southern end of the lake, in sample K-103. The association of pollen grains of Compositae (except *Artemisia* and *Centaurea*) displays a pronounced affinity to the shore. Differences in frequency are quite high, ranging from 1% at the center of the lake to 17% of the total sum of counted grains near the shore. Pollen grains of the Cruciferae show the same pattern as those of the Compositae; the only difference is the higher percentages near the western shore relative to the eastern. The combined frequencies of Compositae and Cruciferae pollen give a constant value in samples taken near the shore. The number of pollen grains of *Poterium spinosum* is rather small but shows a tendency to increase toward the center of the lake. It is, however, not very significant.

The distribution pattern displayed by pollen grains of *Artemisia* is somewhat peculiar. Although most of the samples show quite constant values of this pollen, samples K-43 and K-78 are completely different; these yielded a great number of *Artemisia* pollen grains, several times the quantity in adjacent samples. Except for these two samples, the pattern is quite similar to that of the Centrospermae: higher percentages in the vicinity of the eastern shore and lower near the western, with no noticeable effect of the distance from shore. The distribution pattern of the Cyperaceae and Graminae pollen is also peculiar. Most of the samples yielded approximately similar percentages, slightly decreasing toward the eastern shore. Sample K-78, which is so rich in *Artemisia* grains, is quite poor in pollen of these two families. Samples K-16 and K-43, taken far from the shore, are also poor in these grains, and so are K-13 and K-16, taken close to the eastern shore. Pollen grains of the wild raspberry *Rubus sanctus*, which grows on the shores around the lake and along the rivers and wadis, are prominent in samples taken from the center of the lake and its eastern shore and also appear in some of those taken near the western shore. The total number of these grains is not great, and the differences are not very significant. Pollen grains of cereals are most common at the southernmost end of the lake. In other samples, they appear in constant, but low frequency. It should be noted that in the south, and especially southwest of Lake Kinneret, these plants are cultivated over a large area. The most important conclusion resulting from this study is the relative uniformity of pollen spectra over all the lake area. It is suggested that this even distribution of the major pollen assemblages can be used as a basis for interpreting pollen diagrams from borehole samples taken elsewhere in the region.

The influence of ruderal vegetation is accentuated near the shore, but there are set limits to this variation. The small variations in distribution of various pollen is attributed to two factors: the influence of transporting agents, and local conditions that favor growth of a certain plant or plant association. The most important variations in the distribution of pollen of the four major ecological plant groups (Figure 6.9) are evidently due to transportation. Pollen of maquis and batha plants, which derive from higher regions, are carried by wind over great distances and are dispersed evenly over the surface of the lake. Pollen grains of open field vegetation growing in low regions are not carried great distances and are deposited near the shores. The inflow of the Jordan River into Lake Kinneret has a pronounced influence on the pollen spectra. Sample K-31, taken close to the inlet, is very rich in pollen from hydrophil plants. It is especially rich in spores of the fern *Thelypteris palustris*, which grows only in the Hula swamps. Spores of this fern are relatively heavy and are, thus, deposited immediately on reaching the lake, whereupon the energy of the Jordan River waters is considerably diminished. Pollen grains of *Tamarix*, growing along the Jordan River gorge, are much lighter and, thus, are carried farther southward, forming a peak in sample K-16. The course of the Jordan waters in Lake Kinneret can thereby be partly traced by pollen grains that are brought by the river. The water flows southward for about 2 km, changing direction westward, more or less toward Tiberias. South of Tiberias, no further influence of the Jordan waters can be followed. These conclusions were compared by Horowitz (1969a) with observations made on the movement of suspended mud occasionally carried by the Jordan (Slik 1964), which behaves in exactly the same way. It could be also used for calculating the energy dissipation of the Jordan River waters.

The increased percentages of hydrophil vegetation pollen in sample K-103 at the southern end of the lake are attributed to the rich hydrophil vegetation that follows the Jordan on leaving the lake. The pollen are probably carried to the lake by winds. Pollen of cultivated trees, *Eucalyptus*, *Casuarina*, and Rosaceous fruit trees, are distributed quite evenly over the lake area, probably due to their arboreal origin. The influence of grain fields, mainly in the area southwest of Lake Kinneret, is felt only in samples taken at the southern end of the lake and does not extend far north. The oak to olive pollen ratios are fairly constant over the lake, except in sample K-31, taken near the inlet of the Jordan River. It was suggested that pollen grains of olive, growing in the vicinity of Lake Kinneret but much less in the Hula Valley, are probably brought to the lake only by winds, whereas pollen of oak, which is much more abundant in the northern part of the country, is, at least in part, brought by the Jordan River. Pollen grains of Centrospermae are recorded in greater numbers in samples taken near the eastern shore, which seems to be due to some remnants of the Irano-Turanian steppe vegetation, rich in Chenopodiaceae, that grows on the eastern shore of Lake Kinneret. Pollen grains of Umbelliferae, Compositae, and Cruciferae, produced by a rather low, open-field vegetation growing all around the lake, are much more abundant near the shore than in the central area of the lake. *Poterium spinosum*, on the other hand, growing on the hills, is better represented by its pollen at the center of the lake, since it is carried over longer distances by wind. Pollen distribution of *Artemisia* raises some difficulties in interpretation. Disregarding samples K-43 and K-78, in which this pollen is very abundant, it displays the same behavior as does the pollen of Centrospermae. This is as expected, because *Artemisia* comprises an important part of the Irano-Turanian type steppe vegetation. The reason for the high frequency of *Artemisia* in the above-mentioned two samples is as yet obscure. The pollen of Graminae and Cyperaceae are more common in samples collected from the southern part of the lake, because these plants comprise a great part of the open field vegetation in that area. Pollen grains of *Rubus sanctus* are slightly more abundant in the eastern and central parts of the lake, but differences are not sufficient to reach any firm conclusions.

The following conclusions have been drawn from palynological investigation of Recent sediments from Lake Kinneret and are regarded as representative of conditions prevailing in northeastern Israel. The uniformity of pollen spectra in samples taken from all over the lake permits us to rely on the data from palynological investigations of core samples, also, pollen diagrams recorded from boreholes may be considered as representative of particular times in the past. The ratio of arboreal to nonarboreal pollen in these samples is also quite uniform. The only noticeable variations are the slightly smaller nearshore ratios, which may, in a series of isochronous samples, be utilized to determine the location of ancient shorelines. Approximate outlines of transport routes by wind and by water may be traced according to these pollen spectra. This was done in an attempt to trace the Jordan's water course through Lake Kinneret. Pollen grains of cereals, although very commonly grown in high places, are not transported over long distances in this area.

The Hula Basin The Hula Basin, north of Lake Kinneret, is separated from the latter by a basaltic barrier, through which the Jordan River cuts its way. The Hula is presently about 70 m above sea level, and Lake Kinneret is about 200 m below sea level. The Basin is narrow and elongated and is flanked by the Naftali Mountains on the west and the Golan Plateau on the east, rising to about 800–1000 m elevation. To the north, the Hermon range towers up to 2800 m. The Hula Basin floor is rather shallow and was occupied by a shallow lake (Hula Lake) until 1955, when it was artificially drained. Its depth did not exceed 3–4 m. The Basin was roughly divided into three parts: the southern area, which was occupied by Hula Lake; the central area, which was occupied by widespread marshes; and the northern area, which was somewhat higher than the other two sectors and covered by alluvial soils. Recent pollen deposition in the area was studied by Horowitz (1968, 1971), who, in order to avoid the influence of cultivated plants, took samples from only a few centimeters below the surface. This was successful in that no cultivated plants appear in the pollen spectra.

A number of samples were collected, both from the lake and from the marshes, and each group of samples seems to be similar overall, so they have been combined into a single, composite spectrum. The Recent pollen spectrum for the lake sediments comprises 19% arboreal pollen, 25% open field vegetation, and 56% marsh vegetation. Of the arboreal pollen, the major part, 11%, is shared by *Quercus*, mainly *Q. calliprinos*, 3% *Olea*, 2% pine, 1% *Pistacia*, 2% bank trees, mainly *Populus* and *Salix*, and .5% Cupressaceae. The pollen representative of marsh vegetation comprises mainly Graminae and Cyperaceae (45%), some *Typha* (3%), some *Rubus sanctus* (2%), and spores of the fern *Thelypteris palustris* (6%). It should be noted that Graminae also form part of the open field vegetation, but, as they are much more prevalent in the marshes, especially *Phragmites communis*, it seems justified to include the Graminae pollen in the marsh vegetation sector. Of the open field plants, Chenopodiaceae contribute 2%, Compositae 7%, Umbelliferae 5%, *Artemisia* 2%, and others 9%. The combined average pollen spectrum for the marsh area shows a much lower percentage of arboreal pollen (only about 4%) than for the lake. Open field vegetation also comprises only 4% of the spectrum, whereas marsh vegetation comprises all the rest, about 92%. Of the arboreal pollen, oak forms 2.5%, olive .5%, Cupressaceae .5%, and cedars .5%. The open field vegetation spectrum is shared almost equally among Chenopodiaceae, Cruciferae, Papilionaceae, and *Artemisia*. In the marsh vegetation spectrum, once more Gramineae and Cyperaceae form the major part, 78%, *Rubus sanctus* forms 2%, *Lythrum salicaria* another 2%, *Typha angustata* 4%, and the fern *Thelypteris palustris* 6%. It is quite clear, when comparing the pollen spectrum from Lake Kinneret and that from the Hula, that the influence of marsh vegetation is much greater in the Hula Valley than in Kinneret. This is also a consequence of the topography of these two lakes, the Kinneret being rather steep, whereas the Hula is rather shallow.

Pollen grains deposited in the Hula Basin originate from three main sources: marsh vegetation, maquis, and open field vegetation. Marshes are developed mainly north of the lake. Maquis is developed on the mountains and mountain slopes, mainly east, west, and north of the Basin, but it seems that some maquis vegetation was present not long ago in the valley itself, as witnessed by a number of relics that have survived human deforestation, especially in sacred places like sheikhs' tombs, etc. The open field vegetation forms a belt around the marsh, sometimes extending to the mountain slopes. Naturally, some of the undergrowth of the maquis is recorded in the pollen spectra as open field vegetation. It should be noted, though, that almost no batha elements were recorded in the Hula Valley Recent pollen spectra. Pollen grains are, apparently, carried down to the Basin by winds and streams for the most part. The streams flow mainly in a southward direction, and the three main streams that bring water to the Hula Valley, the Dan, the Snir, and the Hasbani, originate in the Lebanese mountains and in the Hermon range. The main wind directions are north and northwest, and it seems that these two agents are responsible for a certain preference for northern elements (such as cedars) in the pollen spectra.

The Dead Sea The Dead Sea Basin is the southernmost and largest of the inland water bodies of the Jordan Valley. It is elongate, about 80 km in length, and consists of two subbasins (Neev and Emery 1967). The northern subbasin contains a fossil water body and is about 400 m deep. The southern subbasin is only 3-6 m deep. The Dead Sea receives its water from the Jordan to the north and from several small rivers flowing mainly from the Transjordan Plateau. Most of these rivers flow into the northern basin, but one or two flow to the southern. From the west there are no rivers that bring water to the Dead Sea, except for some occasional seasonal floods. The drainage area of the Dead Sea basin also extends far south and incorporates about half of the Negev and the Arava. According to Zohary (1959, 1962), the Dead Sea lies in the Saharo-Sindic vegetational belt, with some Sudano-Deccanian enclaves that surround it, especially where fresh water is available. The Saharo-Sindic vegetational belt is especially developed east, west, and south of the Dead Sea, as well as in the south of the Transjordanian desert. This vegetational formation grows mainly over desert hammada and is dominated by Chenopodiaceae such as *Anabasis articulata, Chenolea arabica, Suaeda asphaltica,* and Zygophyllaceae, mainly *Zygophyllum dumosum*. The sebkhas bordering the southern edge of the Dead Sea are occupied by an association of *Arthrocnemum glaucum, Tamarix tetragyna,* and *Nitraria retusa,* accompanied by *Anabasis articulata* and *Acacia tortillis.*

The Arava, south of the Dead Sea, of which the northern part is drained through Nahal Ha'Arava to the Dead Sea, is mainly a sandy hammada, with *Haloxylon salicornicum* and *H. persicum.* The Irano-Turanian vegetation belt, which envelops the Saharo-Sindic belt here (see also Figure 2.45), is mainly occupied by steppe-like elements dominated by *Artemisia herba-alba.* Farther north is the Mediterranean belt with the typical batha vegetation of border type, with *Ononis natrix, Echinops viscosus, Carlina corymbosa,* and some Labiatae, and scattered trees such as *Amygdalus communis, Crataegus azarolus, Quercus calliprinos,* and *Juniperus oxycedrus,* especially on the Transjordanian plateau. North of the Dead Sea, the delta of the Jordan maintains more or less the same kind of vegetation as the sebkhas at the southern end of the Dead Sea. Farther north, the Zor, which is the alluvial plain of the Jordan River, maintains typical bank vegetation of *Populus euphratica* and *Tamarix jordanis,* accompanied by *Lycium europaeum, Atriplex halimus, Glycyrrhiza glabra, Asparagus palaestinus,* and *Prosopis farcata.* The Irano-Turanian steppes north of the Dead Sea are characterized for the most part by a steppe-like vegetation, including *Retama roetam* as a major component, in the valleys farther north the steppe includes also *Zyziphus lotus.* In Transjordan, the typical batha Mediterranean elements, such as *Poterium spinosum, Thymus capitatus, Calycotome villosa, Cistus salvifolius,* and others, are abundant. These elements grade upward to a Mediterranean maquis, consisting of *Quercus calliprinos* and *Pistacia palaestina* or *Pinus halepensis–Hypericum serpyllifolium* associations, sometimes also a *Quercus ithaburensis–Styrax officinalis* association. On the Israeli side, the same batha grades to a *Pistacia lentiscus–Ceratonia siliqua* association, especially when coming north towards Lake Kinneret, accompanied by some *Zyziphus lotus,* and toward the Mediterranean is the climax of the *Quercus ithaburensis–Pistacia atlantica* association.

Pollen spectra of Recent sediments in the Dead Sea were analyzed by Rossignol (1969a) and form the basis for the following discussion. Samples were collected from six localities, three from the deep northern basin and three from the shallow southern basin, the sediments being fine, gray-to-black clays. At station 114 of the northern basin, a surface sample was analyzed together with a subsurface sample collected 15–30 cm below the surface, for comparison. It seems that water depth does not influence the quantity of pollen in the sediments very much, as was also observed for the Bay of Elat (Horowitz 1966) and for the Mediterranean (Horowitz 1974d), and a sufficient number of pollen could be identified and counted in each of the slides. At least 200 pollen grains were counted in each of the slides, except for one sample, No. 75, which proved to be quite poor and was probably contaminated. The results are summed up in Table 6.4 as percentages of the most important constituents of the pollen spectra. The vegetation surrounding the Dead Sea mainly exhibits high percentages of Chenopodiaceae in the spectra, especially in those collected from the southern basin. These apparently represent the Saharo-Sindic and halophil

TABLE 6.4
Pollen Spectra of Recent Sediments from the Dead Sea[a]

	Northern basin				Southern basin		
Pollen / Depth	No. 114 surf. 326 m	No. 114 (15–30 cm) 326 m	No. 75 325 m	No. 22 350 m	No. 6 3.3 m	No. 7 5 m	No. 131 3.8 m
Quercus spp.	2	2	—	2	2	1	5
Olea europaea	5	5	—	5	4	—	4
Pistacia spp.	4	3	—	1	2	—	0.5
Pinus halepensis	5	1	45	4	3	11	9
Cupressaceae	2	1	—	2	0.5	—	0.5
Other trees	1	1	1	1	1	1	1
Total arboreal pollen	19	12	46	13	12.5	13	20
Gramineae	19	17	9	15	5	6	13
Cyperaceae	3	1	—	1	0.5	2	1
Compositae	6	6	21	7	13	11	9
Chenopodiaceae	17	25	10	28	32	56	22
Cruciferae	2	3	—	1	2	1	3
Caryophyllaceae	0.5	1	—	1	2	0.5	1
Labiatae	1	—	—	1	0.5	—	0.5
Umbelliferae	2	2	—	2	1	1	2
Artemisia	11	15	—	10	15	—	16
Plantago	10	8	—	10	5	1	3
Poterium spinosum	6	6	1	6	2	1	4
Ephedra	0.5	1	4	1	2	1	2
Asphodelus	—	—	4	0.5	0.5	0.5	—
Rumex	—	0.5	—	1	—	—	1
Sparganium	1	0.5	—	1	—	—	—
Others	3	3	4	5	8	4	4
Total nonarboreal pollen	81	88	54	87	87	87	80
Reworked Sporomorphs	1	—	2	0.5	—	2	0.5
Total counted	243	267	92	334	424	287	293

[a] Generalized after Rossignol (1969a).

vegetation. The second most abundant element in the spectra is *Artemisia*, most probably *A. herba-alba*. It is represented by more or less the same percentages in the southern and northern basins and is taken by Rossignol to represent the Irano-Turanian steppe. Gramineae are also quite abundant, but more so in the northern than in the southern basin. Many Gramineae are found to grow around the Dead Sea, such as *Stipa tortillis, Bromus aulerosus,* and others, and Gramineae also form a large part of the Irano-Turanian, Saharo-Sindic, and Mediterranean vegetation, and their grains were apparently carried by winds to the Dead Sea. Compositae are also quite abundant, sometimes even more so than Gramineae. Most of the recorded Compositae grains are derived from Tubuliflorae, and only a minor part from Liguliflorae. In Table 6.4, these are combined. This group does not contain the pollen of *Artemisia* and *Centaurea,* which are quite easy to determine and were treated separately. Some Compositae, and especially *Inula,* are very abundant among the plants growing in the sebkhas, as well as in the hammadas of the Saharo-Sindic region.

Many Cruciferae also grow in these hammadas and are represented in the pollen spectra, but they do not exceed 2 or 3%. *Plantago,* which is not so common among the vegetation, is quite well-represented in the pollen spectra, 7–9% in the northern basin and 1–4% in the southern. It seems that the reason for this is the high amount of pollen grains produced by *Plantago*. Nine species of the plant are known to grow around the Dead Sea. The Zygophyllaceae, which comprise a considerable part of the halophil and Saharo-Sindic vegetation, are hardly represented at all in the pollen spectra, except for some rare specimens of *Zygophyllum, Nitraria,* and *Fagonia*. The same holds for the Plumbaginaceae, of which *Limonium* (or *Statice*) is quite common, especially around En Gedi and Mt. Sedom. Some other common plants that are rarely represented in the pollen spectra are *Capparis cartilaginea, Cleome, Thymelea hirsuta, Haplophyllum, Ephedra, Centaurea, Asphodelus,* and *Phoenix dactilifera*. Most of these are grouped in Table 6.4 under "Other Trees" or "Others," since they do not constitute any considerable part of the pollen spectra. It was also noted by Rossignol that elements that grow in the Sudano-Deccanian enclaves are hardly represented in the Recent sediment of the Dead Sea. Neither *Acacia* nor Asclepiaceae, which are quite common in the area, are represented in the pollen spectra. The same scarcity of *Acacia* was also found in the sediments of the Bay of Elat (Horowitz 1966). Some rather common elements of the Irano-Turanian steppes, such as *Retama roetam,* are also quite underrepresented in the pollen spectra of the Dead Sea. The same holds also for *Pistacia atlantica* and *Prosopis farcata,* which are quite common in the mountains surrounding the Dead Sea, particularly around Jerusalem.

Some Mediterranean elements are present in the spectra: *Poterium spinosum* and various species of *Pistacia, Olea europaea, Quercus calliprinos, Q. ithaburensis, Pinus halepensis, Cupressus sempervirens, Asphodelus microcarpus, Calycotome villosa, Phillyrea media, Ceratonia siliqua, Cistus villosus,* and *Rhamnus.* Rossignol concludes that aquatic transport predominates among the transporting agents of pollen grains, and, therefore, these Mediterranean elements should apparently have been carried out from Transjordan rather than Israel. On the other hand, she does not exclude the possibility of pollen grains, especially those of *Pinus halepensis* and perhaps others, coming from the west by the dominant west winds. In this case, the source area for these pollen grains should be Judea and Samaria. The percentage of Mediterranean elements in the pollen spectrum is much higher in the northern basin, about 24%, than in the southern basin, about 15%, which Rossignol concluded to be a result of different sources for water, the northern basin getting its water from Jordan and the southern basin from the Arnon. She takes this as supplementary evidence for the transport of pollen of Mediterranean elements by water courses.

The rest of the elements recorded in the pollen spectra, such as Umbelliferae, Urticaceae, Labiatae, Caryophyllaceae, Papaveraceae, Solanaceae, *Rumex, Convolvulus,* and others, have no particular connection with any of the vegetational belts, and plants belonging to these families grow in each of them. Another group of pollen and spores that should be mentioned is that of reworked sporomorphs, which comprise mainly fern spores and pollen of some exotic trees. This group characterizes the Pliocene sediments of Israel (Horowitz 1974b) and is, apparently, reworked by the dissolution of Pliocene salt of the Sedom Formation, which is pushed upward and dissolved in the Dead Sea waters. Rossignol also compares the two samples from station No. 114, the one taken from the surface and the one taken from 15–30 cm below the surface. Allowing for rate of sedimentation given by Neev and Emery (1967), she concludes that within the last 300 years there was little climatic change. It seems, however, that the higher percentages of pine at the surface are due to reforestation by humans of the Judea area, and the somewhat lower values of Chenopodiaceae and *Artemisia* toward the surface could be attributed to the influence of irrigation that has taken place throughout the country over the years. The arboreal pollen share of the spectra is between 12 and 20%, which is quite high considering the environment surrounding the Dead Sea, in which almost no trees grow at all. This, in my opinion, is a result of transport, mainly by winds and not so much by running water, of these pollen grains. Transport by winds was found to be important from analysis of the sediments of the Bay of Elat, where arboreal pollen grains of the Mediterranean maquis are quite abundant (Horowitz 1966). No running waters at all come to the Bay. The final conclusions follow those reached for the Kinneret Basin. The pollen spectra are more or less uniform over the Dead Sea surface, and a borehole, especially one drilled in the center of the basin, if analyzed, would reflect the vegetational constitution quite reliably, without considerable influence by local elements. This is mainly due to wind transportation and mixing of various elements before deposition.

Bay of Elat

A study of pollen spectra was carried out by Horowitz (1966) at the Bay of Elat to determine the mechanism by which spores and pollen grains are brought to the Bay and to examine the influence of water depth on their sedimentation and preservation. Twelve samples were collected by a Patterson grab from various depths off the coast of Elat in the northernmost corner of the Bay, at water depths ranging from 100 to 700 m, as determined by the boat's echo sounder. The grab penetrated only about 10–20 cm into the sea floor mud, therefore bringing up only Recent material. The samples yielded rich pollen and spore spectra, all of which were very similar in composition. Four groups were distinguished by frequency:

1. Very Abundant. Chenopodiaceae, Zygophyllaceae, Cruciferae, *Ephedra, Artemisia,* and some fern spores, especially those derived from Cyatheaceae, *Lygodium,* Polypodiaceae, Vittariaceae, *Pteris, Actiniopteris, Onychium,* and Hymenophyllaceae.
2. Quite Abundant. Pollen grains of Caryophyllaceae, Capparidaceae, Guttiferae, Compositae, *Pinus halepensis,* and *Cedrus libani.*
3. Scarce; not found in all the samples. Umbelliferae, Geraniaceae, Gramineae, Leguminosae, Cyperaceae, Combretaceae, Rosaceae, *Asphodelus, Plantago, Typha, Acacia, Salix, Quercus calliprinos, Pistacia,* and *Podocarpus.*
4. Very rare. *Isoëtes, Cheilantes, Marattia, Asplenium, Thelypteris, Dryopteris, Lycopodium, Pteris,* and others that could not be determined due to lack of an adequate reference collection of tropical flora.

Most of the fern spores were identified by (Miss) D. Wellman of the Palynological Laboratory, University of the Orange Free State, South Africa. Some of them were determined according to Erdtman (1957), van der Hammen and Gonzalez (1960), and Woodhouse (1959).

The Bay of Elat is surrounded far and wide by deserts in which the vegetation is very poor. North of the Bay is the Arava Rift Valley, whose playa vegetation (Zohary 1959) contributes considerably to the pollen spectra. Grains of xerophytic and halophytic plants like Chenopodiaceae, Caryophyllaceae, Zygophyllaceae, Capparidaceae, Guttiferae, Compositae, Cruciferae, *Ephedra*, *Artemisia*, and others are very abundant. Some grains of Umbelliferae, Geraniaceae, Leguminosae, *Asphodelus*, *Plantago*, and *Typha* are present in every sample, whereas pollen grains of Gramineae, Cyperaceae, and *Acacia* occur only rarely. The last three are remarkably rare. The plants are, however, very abundant in the close vicinity: Cyperaceae and Gramineae in the playas and *Acacia* in practically every wadi. Large groups of *Acacia* trees grow in the Arava, over a distance of hundreds of kilometers. They extend north to the Jordan Valley, into the path of the prevailing strong northern winds (Ashbel 1950). A possible explanation for the scarcity of *Acacia* grains in the samples is that, being polyads consisting of 16 units, they are too heavy to be carried long distances by normal winds. The rarity of pollen grains produced by the other two families has, so far, no explanation. It should be noted that the rarity of *Acacia* was also noted in Recent Dead Sea sediments (Rossignol 1969a), even though the Dead Sea is surrounded by wadis in which *Acacia* is quite a common tree.

About 20% of the pollen spectrum of each sample is made up of grains that should have been brought to the site by winds coming from the Northern Jordan Valley and the surrounding mountains. These comprise mainly winged conifer grains such as *Pinus halepensis* and *Cedrus libani*. Pollen grains of *Quercus calliprinos*, *Salix*, *Pistacia*, and Rosaceous trees are also brought occasionally by these winds. Northern winds are most common in the region. They blow continuously from Lebanon down to the Red Sea almost daily the year round, at times reaching even storm velocity. Their capacity can be judged by the finding that pollen grains of cedars, which in this region grow only in Lebanon today, about 500 km north of the Bay of Elat, are found in the Recent sediment of the Bay. Pollen grains comprising 5–10% of the palynological spectrum must have traveled by sea currents thousands of kilometers from the tropical region, northward to the Bay of Elat. These are especially pollens of Combretaceae and *Podocarpus* and spores of some species of ferns, mentioned earlier. No other source from which these spores could have reached the Bay of Elat seems possible, since fern species producing these spores do not grow in the Near East. Sea currents from the south were measured at many localities along the Red Sea, and a surface current of 3 knots is known to pass northward through the Straits of Tiran (Red Sea Charts 1848). It seems probable that the grains are carried northward by these surface currents. They are deposited on the bottom when the currents change their direction on reaching Elat and flow back as deep currents that are considerably slower than the surface currents. This is also supported by findings that relatively high amounts of oxygen are present in all the sediments down to a depth of 700 m (analysis by F. D. Por, Department of Zoology, Hebrew University, Jerusalem, at the time of collection of the samples). It should be noted that spores and pollen grains of tropical flora were reported from the Mediterranean Recent sediment (Rossignol 1961), brought to these locales by the Nile.

No significant relationship was found between water depth and either grain shape or spectrum composition. Even in samples taken from a depth of 700 m, no distortion of shapes was observed, as might be expected at high hydrostatic pressure. The spectrum is essentially identical in all the samples analyzed. This, once more, is in accordance with the results of Rossignol from the Dead Sea (1969a) and Horowitz from the Mediterranean (1974d). It seems, therefore, that the palynological spectrum of Recent sediments in the Bay of Elat is influenced mainly by the capacity of transporting agents and much less by the actual floral composition of the adjacent mainland.

Birket Ram

Birket Ram is a small crater lake situated at the northwestern corner of the Golan Plateau. The lake, almost circular (600 by 800 m), occupies an explosion crater that was formed approximately 70,000 years ago (Mor 1973) and is presently filled by water and sediments. The crater is situated about 12 km (as the crow flies) from the northeastern corner of the Hula Basin, at the foothills of the Hermon range, at an elevation of 940 m above sea level. Most of the water is collected by the lake from runoff, but some groundwater also enters through a number of small springs that are situated at an outcrop of Cenomanian limestone at the southeastern corner of the lake. The water depth is around 8–9 m and does not exceed 12 m. The annual fluctuations are on the order of 2–3 m. The shape and location of this small lake makes it an almost ideal trap for pollen grains, and a thorough study of the palynology of the surface sediments and of a core drilled in the center of the lake was carried out by Weinstein (1976). Phytogeographically, Birket Ram is situated at the margin of the Mediterranean region and is influenced by the Irano-Turanian steppes of the southern and eastern slopes of the Hermon range and of the Damascus basin farther east. On the other hand, the tragacanthic vegetation of the Hermon should be also represented within the pollen spectra. Being situated in a marginal zone, this area is quite vulnerable to climatic changes and should have recorded them with a rather high resolution.

The climate of the northern part of the Golan Plateau is humid or semihumid and gets drier as the elevation decreases and one proceeds southward. The annual rainfall is more than 800 mm around Birket Ram and increases with elevation on the slopes on the Hermon range until it reaches about 1300 mm. Rain and snow fall in the area only in the winter, snow being a very common phenomenon, occuring annually, in contrast to Israel, where it occurs only once in a couple of years and, then, only for a few days. The average temperature for January is 3.1°C, and the temperature for August is 29.4°C. However, in the winter, temperatures below the freezing point are quite common, especially at night. Winds are quite strong in the area, and western winds prevail. Northwestern winds occur mainly in the summer, and in the winter some eastern and northeastern winds have been recorded. Soils in the area are mainly deep brown basaltic, but on the Hermon range, wherever sandstone outcrops occur, hamra-type soils are developed, such as on the Lower Cretaceous outcrops, whereas on the Jurassic limestone terra rossa is developed. Natural vegetation of the Birket Ram area is typified by a maquis or forest of *Quercus ithaburensis* and *Q. infectoria.* It seems that this type of forest covered the entire area of the northern Golan Plateau, but, since most of the area is now cultivated, it has been cut down. Quite large relics of this type of forest can still be seen in the Plateau, such as the forest reserve near the village of Mas'ada and other, principally sacred, places.

Important components of these forests are *Quercus calliprinos* and *Quercus boissierii,* accompanied by *Crataegus aharonii, Prunus ursina, Pyrus syriaca, Styrax officinalis,* and *Pistacia atlantica. Sportium junceum* and *Crataegus monogyna* are also quite common. Climbing plants are quite common in this type of forest, such as *Lonicera etrusca, Rubia olivierii, Smilax aspera, Asparagus stipularis, Rosa canina, Rubus tomentosus,* and others. Batha plants are very rare, and the undergrowth of the forest is mainly composed of annual plants and geophytes, such as *Helleborine latifolia, Cephalanthera latifolia, Cyclamen coum, Iris histria, Lecokia cretica, Dianthus polyanda, Vicia dasycarpa,* and others. Many Gramineae grow in the forest clearings. Some species of ferns also occur in this type of forest but are quite rare, among which *Dryopteris rigida, Polypodium vulgare, Ceterah officinarum,* and some others occur. The ruderal vegetation in this area, which mainly follows deforestation, comprises plants like *Hordeum bulbosum, Scolymus hispanicus, Echium italicum, Eryngium glomeratum,* and others. This is, in fact, the easternmost area of the *Quercus calliprinos* association in the Mediterranean region, except for some small enclaves in the Jebel Druze. Eastward the typical *Pistacia atlantica* stands of the Irano-Turanian region are developed. The basaltic substrate of the Golan Plateau seems to be responsible for the lack of a number of typical Mediterranean trees and plants, such as *Laurus nobilis, Phillyrea media, Pistacia lentiseus, Viburnum tinus, Arbutus andrachne,* and *Rhamnus,* which usually occur with this type of forest. For instance, these trees do appear on limestone substrated forest of the same type, over which terra rossa is developed. Typical batha plants like *Poterium spinosum* and Cistaceae do not appear in this area, probably for the same reason. Most of the trees comprising this type of forest, except for *Quercus calliprinos,* are deciduous, thought to be a result of the cold winters on the Golan Plateau.

To the north, Birket Ram is faced by the Hermon range, in which three vegetational belts are very conspicuous: the *Quercus calliprinos* maquis belt, at an elevation up to 1400 m; the mountainous forest belt, at an elevation of 1400–1800 m; and the tragacanthic forest belt, at an elevation that exceeds 1800 m. The *Q. calliprinos* forest belt is developed at the Hermon foothills, and the belt that faces Birket Ram is approximately the same type as that found in Israel. In the northern and western foothills, however, where the rainfall is higher, northern elements enter this formation, of which the most typical are *Cedrus libani* and *Quercus libani.* The only typical appearance of the batha vegetational formation in this area is near Majdal Shams, north of the lake, where it is developed on red, hamra-like soil that originated from the Lower Cretaceous sandstone at an elevation of 850–1050 m. *Poterium spinosum, Cistus villosus,* and *Lavandula stoechas* are the typical plants of the batha in this area. The higher, mountainous forest belt in the Hermon is a type of park forest, mainly comprising underdeveloped specimens of trees such as Juniper, *Quercus look, Acer microphyllum, Quercus boissierii, Styrax officinalis, Crataegus azarolus,* and *Pyrus syriaca.* The undergrowth and open areas are mainly occupied by gramineae, but other annual plants are also common. The tragacanthic batha, at an elevation exceeding 1800 m, is typified by small, spiny shrubs, mainly of *Astragalus, Onobrychis,* and *Acantholimon,* which can bear the low temperatures, the snow, and the wind. These occur up to the peak of the Hermon. Of the bank vegetation, *Populus* and *Salix* appear on the banks of Birket Ram, but it seems that some of them were planted. Of the submerged water plants, *Myriophyllum spicatum, Ceratophyllum demersum, Potamogeton perfoliatus,* and *P. crispus* are the most common. Some species of *Lemna* also occur. The cultivated trees mainly comprise Rosaceous fruit trees, with some olive and cypress. Vines are also quite common in the area.

Recent pollen spectra were analyzed from three samples collected along an east–west line, from distances of 30, 90, and 150 m from the lake shore. The three spectra were quite identical and were, therefore, combined to form one spectrum, including 944 pollen grains. The total arboreal pollen comprises 33% of the spectrum, divided between oak (10%), olive (8%), *Pistacia* (4%), pine (1%), Rosaceae (3%), *Ceratonia siliqua* (.5%), *Cedrus libani* (2%), willow (1%), *Tamarix* (1%), *Populus euphratica* (2%), and *Nerium oleander* (.5%). The nonarboreal pollen comprises 67%, of *Poterium spinosum* (4%), *Ephedra* (1%), *Phlomis* (2%), Liliaceae (1%), Malvaceae (.5%), Centrospermae

(11%), *Artemisia* (7%), Umbelliferae (3%), Compositae (7%), Acanthaceae (.5%), Cruciferae (1%), *Scabiosa prolifera* (.5%), *Adonis* type (.5%), *Polygonum equisetiforme* (.5%), Papilionaceae (3%), Gramineae and Cyperaceae (20%), *Typha angustata* (.5%), *Rubus sanctus* (4%), and Labiatae (11%). Weinstein (1976) divided the pollen of the spectrum into seven main ecological groups:

1. Forest and maquis trees. These were subdivided into two subgroups: first, the Mediterranean forest and maquis trees such as *Quercus, Pistacia,* and olive, with Cupressaceae and Rosaceae; and, second, the higher and northern elements, of which *Cedrus* is the only element in the Recent pollen spectrum.
2. Batha vegetation, also including two groups. The first comprises mainly Gramineae, Umbelliferae, and others that are quite difficult to distinguish from ruderal and hydrophil vegetation, which also include plants of these families. The second is the typical Mediterranean batha, including *Poterium spinosum, Asphodelus, Ephedra,* and others, which are quite distinguishable.
3. Ruderal vegetation, including mainly families such as Chenopodiaceae, Umbelliferae, Compositae, Cruciferae, and genera like *Artemisia* and *Centaurea.* Some of these plants, and especially Chenopodiaceae and *Artemisia,* are also typical for the Irano-Turanian dry steppe vegetation.
4. Gramineae and Cyperaceae. These were treated separately because of their considerable part in the spectrum and because it was impossible to relate them to another group, since they take part in most of the ecologic divisions.
5. Hydrophil plants. These are from the trees *Populus, Salix, Tamarix,* and *Fraxinus,* which are quite common, and from the nonarboreal vegetation of which *Typha angustata, Rubus sanctus, Plantago,* and Labiatae form a considerable part.
6. Cultivated plants. This group comprises only the pollen grains of cereals. Those of the Rosaceous fruit trees were included in the maquis group because it is impossible to differentiate between them and wild Rosaceous trees and also because of their very small part in the spectrum, which does not justify special treatment. Pollen grains of the olive were also included with the natural maquis vegetation because, although today they are almost entirely a cultivated plant, in the past they were apparently part of the natural maquis as discussed earlier for the Hula Basin.
7. The submerged water plants, such as *Myriophyllum, Potamogeton,* and others. Pollen grains of this group were excluded from the total pollen spectrum, since they merely indicate the existence of a water body, and their large numbers might distort the results of the pollen analysis.

Pollen grains that were excluded from the Recent pollen spectrum are those known only as cultivated plants, such as *Juglans,* cereals, and Cupressaceae, *Cupressus* being planted on the rim of the lake and contributing a considerable number of pollen to the spectrum.

Pollen grains of oak were most probably contributed by the nearby Mas'ada forest, although some of them might have been carried by northwestern winds from the Hermon slopes. The high percentage of olive pollen grains is probably a result of the cultivation of these trees not far from the lake. Although the olives are pollinated by insects, they produce quite a large number of pollen grains, which are carried by winds. This is in contrast to the pollen grains of Rosaceous fruit trees, which were probably derived, at least in part, from the plantations in the area, but, since they are insect pollinated and do not discharge a great number of pollen into the air, they are underrepresented. The pollen grains of cedar that appear in the spectrum probably indicate transportation, especially by northwestern winds. About half of the nonarboreal pollen spectrum comprises Gramineae and Cyperaceae. These plants grow almost everywhere in the region and comprise a major part of the field vegetation, of the herbaceous batha, forest clearings, and lake banks. Their provenance is most probably in the nearby vicinity. The appearance of batha pollen, especially *Poterium spinosum,* is probably a result of the occurrence of this vegetational formation in sandstone areas north of the lake. *Artemisia* and Chenopodiaceae, although some of them are most probably of ruderal origin, are, at least in part, derived from the Irano-Turanian batha areas of the Hermon foothills. The contribution of the higher areas of the Hermon to the pollen spectrum is very slight, most probably because of the scarce and poorly developed plants and their very short blossoming period. The bank vegetation pollen probably arrives from the lake shore, since there are no streams in the nearby vicinity that might have contributed to this part of the spectrum. These comprise mainly *Populus, Salix,* and *Tamarix.* Some Cyperaceae, Gramineae, and, most probably, Compositae, accompany this group. It seems, therefore, that most of the vegetational formations occurring in the vicinity of Birket Ram are represented in the sediments, and it is clear that they have been deposited by winds.

Terrestrial Sediments

Pollen analyses of Recent soils and other terrestrial sediments are rarely available in Israel. This is mainly the result of the high oxidation potential of these sediments, which has prevented the conservation of organic materials comprising the pollen grains. Various investigators have tried to analyze samples of these sediments, but results were mostly nil, and the samples proved to be totally barren. The composition of pollen spectra in these areas is better studied, therefore, from airborne pollen, which have not yet been oxidized. Comparison of airborne spectra with those from sediments can sometimes be helpful as well. A Recent pollen spectrum from the soils and marshes of the Sharon, somewhat north of Tel Aviv, has resulted in the following average results: arboreal pollen, 9%, divided among *Quercus calliprinos* (3%), *Olea europaea* (1%), *Populus euphratica* (2%), and *Salix acmophylla* (3%). The 91% of the nonarboreal pollen was made up of Compositae (84%), Gramineae and Cyperaceae (5%), and Umbelliferae (2%). Cultivated plants have been omitted from these spectra, but, due to the extensive cultivation of this area and deforestation, which took place long ago, it seems that these results should be taken cautiously if regarded as representing Recent conditions.

More reliable pollen spectra have been obtained for the drier areas of Israel, especially the Negev and the Judean Desert, where conditions are much more favorable for the preservation of pollen grains. Three samples were studied from the Fatza'el area, north of the Dead Sea, by Alon (1976), and the average pollen spectrum is as follows: Arboreal pollen makes up 5%, of which 1% is *Quercus*, 2% *Pinus halepensis*, and 2% *Olea europaea*. Nonarboreal pollen, which comprised the majority of the spectrum, 95%, comprises Gramineae (43%), Compositae (37%), Chenopodiaceae (7%), Cruciferae (3%), cereals (3%), *Poterium spinosum* (1%), Liliaceae (5%), and Umbelliferae (.5%). The arboreal pollen share, in this sample, is noticeably lower than that of the samples collected from Recent sediments of the Dead Sea, discussed earlier, which is probably the result of some sheltering of the Wadi Fatza'el from the prevailing northern winds that carried pollen down to the Dead Sea. It is, therefore, assumed that the Recent pollen spectra from Fatza'el really reflect local conditions, rather than the transporting agents that cause northern preferences at the Dead Sea sediments.

Several samples, mainly of Recent wadi muds, were analyzed by Horowitz (1976a) from the Nahal Zin area of the Central Negev. The vegetation of the area was discussed in detail by Danin (1970). Most of the vegetation is restricted to the nahal (wadi) floor and around rare springs, comprising mainly Chenopodiaceae, of which *Atriplex* is the most abundant, Gramineae and Cyperaceae, less frequent amounts of Compositae, and others. An interesting group of plants, comprising trees such as *Pistacia atlantica*, *Amygdalus korschinskyi*, *Rhamnus disperma*, and *Rhus tripartita*, together with some shrubs and herbs, are thought by Danin (1972) and Danin and Orshan (1970) as being relics of a former Mediterranean vegetation in the area. These are, however, quite rare and restricted to the wadi floors, in which some water is available due to a relatively high groundwater table, especially in places where the substratum is built of Paleocene Taqiya shales. The average Recent pollen spectrum of the area includes Chenopodiaceae (77%), Gramineae and Cyperaceae (19%), Umbelliferae (1%), *Retama roetam* (1%), and *Olea europaea* (2%). This pollen spectrum, which is dominated by the Chenopodiaceae, with some Gramineae and Cyperaceae, seems to be typical of the desert environment. No naturally occurring arboreal pollens are recorded, and the few isolated trees that grow in the area did not significantly contribute to the spectrum. The closest stands of trees that might have contributed pollen are on the Hebron mountains, but their influence was not observed. The influence of trees such as olives, which were planted in the Sede Boqer area quite close to Nahal Zin, where the samples were collected, can only be seen in samples collected very close to the settlement. Samples that were collected south of Nahal Zin contained only 1–2% of olive pollen, and it is quite clear that these grains came from the plantations around Sede Boqer and were not carried by the winds from the natural stands of these trees, about 100 km north.

The Western Negev highlands are of the same type as the Central Negev, but water occurrences are much rarer. As a result, *Atriplex* is much less frequent, and the very poor vegetation that covers the area, which is mainly restricted to the wadi courses, comprises Gramineae, with some very rare Mediterranean relics, such as those mentioned earlier. Samples of Recent sediments, comprising mostly windblown dust that was trapped in the vegetation and deposits of Recent wadi floods, were analyzed by Horowitz (in press), and the Recent pollen spectrum comprises Gramineae and Cyperaceae (91%), Chenopododiaceae (6%), and Papilionaceae (2%), with some rare occurrences of *Artemisia*, *Zygophyllum*, and Compositae that together form about 1%. No arboreal pollen were encountered in any of the four samples analyzed, in which more than 200 pollen grains were counted. This pollen spectrum looks almost identical in nature to the spectrum obtained from Recent sediments in the Central Negev, save for the substitution of Chenopodiaceae by Gramineae, due to the lack of running water.

Groundwater

Water samples, about 100 liters each, were palynologically analyzed from six springs around Lake Kinneret (Horowitz 1970c). Five of these springs are saline, and the sixth, of freshwater, was taken for comparison. The aims of this study were to see whether groundwater emerging as springs contributes to Recent pollen deposition in Lake Kinneret and to see whether the saline solutions carried up by these springs carry pollen grains that are also deposited and included in the Recent sediments. It was also thought that the age of these saline solutions could be suggested by the pollen spectra of the water. Locations of the springs are shown in Figure 6.8. The results of these analyses are summarized in Table 6.5 as percentages of

TABLE 6.5
Pollen Spectra of Saline Sources around Lake Kinneret

	Sample					
Pollen	Roman Spring	Kinneret 5	En Nur	1020/6	1021/1	1018/1
Arboreal pollen						
Quercus spp.	8	—	3	4	8	3
Olea europaea	2	5	—	5	—	5
Pistacia spp.	2	—	—	2	—	2
Ceratonia siliqua	2	—	—	2	—	1
Pinus halepensis	2	5	14	10	16	47
Zizyphus spina-christi	—	5	—	—	—	2
Nerium oleander	—	—	—	2	—	—
Cupressaceae	—	—	7	—	8	2
Cedrus libani	—	—	—	—	4	2
Populus euphratica	—	—	—	—	4	—
Eucalyptus spp.	6	—	10	1	—	—
Casuarina spp.	—	—	10	16	16	8
Citrus aurantium	—	—	3	—	—	—
Total arboreal pollen	22	15	47	42	64	72
Nonarboreal pollen						
Poterium spinosum	—	—	—	1	—	—
Ephedra spp.	2	5	—	—	4	—
Labiatae	—	—	—	1	—	1
Centrospermae	—	—	24	10	4	7
Umbelliferae	—	—	3	2	—	—
Compositae	4	—	—	7	—	2
Cruciferae	—	—	3	—	—	2
Artemisia spp.	2	—	—	9	—	2
Polygonum equisetiforme	—	—	—	1	—	—
Ranunculaceae	2	—	—	—	—	—
Papilionaceae	—	—	—	—	—	1
Linum spp.	—	—	—	—	—	2
Gramineae	46	27	14	23	20	6
Cyperaceae	11	—	—	—	4	—
Plantago spp.	2	9	7	5	—	1
Rumex spp.	—	—	—	—	4	—
Urticaceae	—	—	—	1	—	6
Total nonarboreal pollen	69	41	51	60	36	30
Fern spores	10	45	—	?	—	—
Arboreal–nonarboreal ratio	0.31	0.33	0.93	0.71	1.78	2.47
Salinity (mg Cl$^-$ per liter)	18200	5930	3000	3150	3000	130

the various constituents of the spectra, based on the total sum of counted pollen and spores. The spectrum was divided into three groups: arboreal pollen, nonarboreal pollen, and fern spores. The most common arboreal pollen, except in the samples from the most saline Roman Spring and Kinneret 5 Spring, is *Pinus halepensis.* This is quite different from the results obtained by analysis of Recent sediments of Lake Kinneret as discussed earlier. *Eucalyptus* pollen are also abundant, and the other arboreal pollen show generally the same distribution as in Recent sediments. In the nonarboreal pollen spectrum, Centrospermae, *Plantago,* and Gramineae are much more abundant than in the Recent samples. In the two samples collected at the Roman Spring and the Kinneret 5, some fern spores were found. These were not identified taxonomically but were seen to be identical to some of the taxa that were recovered from rock salt of Pliocene age (Horowitz and Zak 1968) of the Sedom Formation and to fern spores recovered from the Pliocene rocks of the coastal plain of Israel (Horowitz 1974b). The arboreal to nonarboreal pollen ratio increases as the salinity of the source decreases. In the freshwater source that was taken for comparison, 1018/1, it is as high as 2.47, whereas in the most saline Roman Spring it is only .31. There is no way as yet to distinguish between pollen grains of the same taxa that appear both in the Pliocene and in the Recent assemblages, so these could not be taken as guides.

The pollen and spores found in the water samples have been divided into three categories: those produced by plants growing in the region only today, especially the cultivated trees; those that are exclusively fossil; and those appearing in both Recent and Pliocene sediments. The first category includes pollen of *Eucalyptus, Casuarina,* and oranges (*Citrus aurantium*), which were introduced to the country in recent decades. It seems that some of the pine pollen also belong to this group, pine being planted quite extensively, especially in the Galilee. To the second category, only the fern spores could be attributed with certainty. No fern producing such spores is known to grow in the Near East today. The influence of the mixing of Recent groundwater with the fossil saline solution seemingly of Pliocene age, is quite conspicuous in the arboreal to nonarboreal ratio. In the freshwater spring, this ratio, 2:5, is much higher than the ratio in the Recent sediments of Lake Kinneret, which is around .4. The main reason for this is probably because the water intake area of the aquifer lies in the mountainous area of the Galilee, which is quite well-forested, especially by plantations of pine. When compared with the sources of the saline palynological spectra, it seems that at least part of the nonarboreal pollen of these samples belongs to the brine assemblages, probably pollen of Gramineae and Centrospermae for the most part, which are very abundant in the rock salt of the Sedom Formation, representing a dry climate and saline environment around the lagoon in which these rocks were deposited.

CONCLUSIONS

Analyses of the distribution of the natural constituents of Recent pollen spectra over Israel give a rather consistent picture. The arboreal pollen share at the north of the country is dominated by oak, with occurrences of other Mediterranean trees such as cypress, pistachio, and olive. The arboreal pollen percentage decreases gradually over the country southward until, in the Negev, no arboreal pollens are encountered at all. This picture changes somewhat in the Jordan Valley. Arboreal pollen shares are about 15% in the north and show considerable increase to the south, up to 25% in the Dead Sea area. The composition of the arboreal pollen spectrum remains, however, more or less constant, with oak as the prevailing element. The main reason for the increasing percentage of arboreal pollen to the south is the prevailing northern winds in the Jordan–Arava Rift Valley. Arboreal pollen grains are more easily carried by the winds, and, though nonarboreal pollen production decreases to the south, the winds still carry almost the same amount of arboreal pollen as in the north, therefore increasing the percentage of arboreal versus nonarboreal pollen. Effects of prevailing winds can also be seen in the ratio of pine to oak, which is much higher in the coastal plain to the west than in the Jordan Valley to the east. This is probably due to the eastern winds, which are common in the country mainly during the flowering season of the pines. Throughout the rest of the year, western winds prevail, which carry the oak grains to the east, depositing them in the Jordan Valley basins. Occasional dust storms bring considerable amounts of pollen from the southern areas, mainly Chenopodiaceae and *Artemisia,* depositing them all around the country. This factor helps to decrease the arboreal pollen percentage, but it seems that the decrease is proportional throughout the country.

Allochtonous contributions to the Recent pollen spectra are known from the Mediterranean coastal and marine sediments, where pollen grains and spores brought by the Nile from tropical Africa are encountered in the sediments. These might comprise up to 15–20% of the pollen spectra. Apparently, some of the Gramineae and Cyperaceae pollen encountered in the Mediterranean sediments are also allochtonous, their provenance being mainly the Nile delta. The Bay of Elat also receives considerable contributions of allochtonous pollen and spores. These come from two sources. One is the sea currents that bring pollen and spores from tropical Africa up to the Bay of Elat, and the other is the prevailing northern winds, which carry pollen grains from the Lebanon through the entire Jordan Valley and the Arava, to be deposited in the Bay of Elat and encountered in its sediments. Redeposited pollen and spores are quite rare in the Recent pollen spectra of Israel and mostly appear in negligible quantities. Only at one locality, in Lake Kinneret, near the saline sources, do redeposited grains appear in some quantities. Redeposited pollens, mostly of Pliocene age, are carried out in saline solution and are encountered in the Recent sediments of Lake Kinneret, close to the saline springs. The percentages of these sporomorphs are not high, however, and do not usually exceed 5% of the total Recent pollen spectrum, even very close to a saline source. Differences in the Recent pollen spectra encountered from one locality to the other are gradual, except for the difference between the mountainous backbone and the Jordan–Arava Rift Valley, which is quite considerable. It is, therefore, necessary to have a Recent pollen spectrum at hand for any analysis and comparison with Quaternary sediments.

It seems that, when analyzing sediments, the arboreal pollen group and, especially, oak, is the most reliable indicator in the northern part of the country and the Jordan Valley, whereas to the south nonarboreal pollen should be used when studying paleoenvironments. Conclusions based on the composition of nonarboreal pollen, however, should be drawn with some care. The main reason is that most of the nonarboreal pollens cannot be defined to more than the family level. Different groups of the same family may favor different environmental and climatic conditions. Such is, for instance, the case with the relations between Gramineae and Compositae. The Recent pollen spectra of the Central Negev are rich in Gramineae, whereas the Northern Negev and the Shefela regions are quite rich in Compositae. Moving north, the northern coastal plain, the Kinneret, Hula, and Galilee are once more richer in Gramineae, naturally of different genera and species than those to the south. The Chenopodiaceae should also be considered with some care. These are most abundant in two environments: saline environments, such as sebkhas and playas, in which they prevail, and in environments connected with human occupation, in which organic material is quite abundant. Peaks in the Chenopodiaceae might, therefore, point either to more saline conditions or to some settlement phase in the analyzed sediments. Special care must be taken with this point when analyzing sediments of archaeologic and prehistoric sites. When analyzing sediments connected with these sites, some care should be taken also to differentiate cultivated plants from natural ones. It is known that people cultivated olives, almonds, and cypress in many places, but higher arboreal pollen percentages based on these may be misleading. This is another reason why the oak is a much better indicator than the rest of the trees. The Recent pollen spectra show a high degree of uniformity in any determined environment or basin of deposition. This fact is considered as a good basis for drawing paleoenvironmental conclusions based on samples collected from even a single section or a single borehole within a given area. The consistency of results obtained from various sites, sections, and boreholes have proved the validity of this assumption.

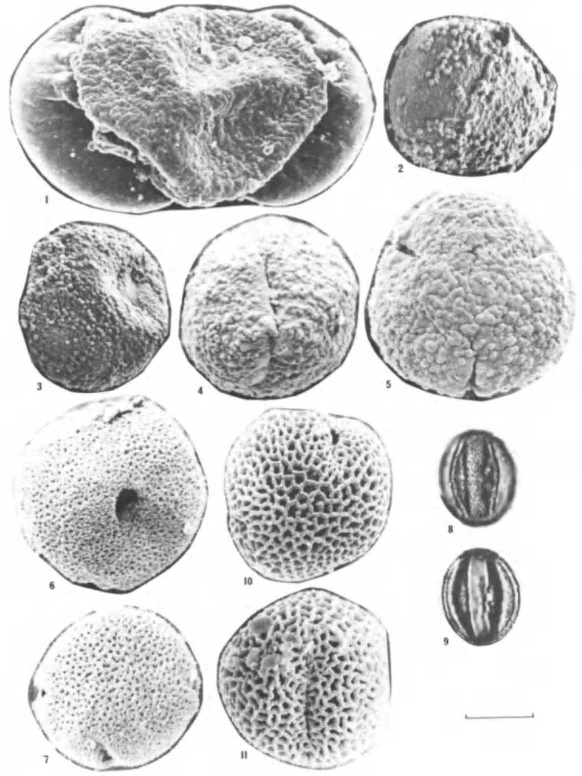


FIGURE 6.12. *Recent arboreal pollen from Israel (SEM photographs by M. Dvorachek, Geological Survey of Israel). Scales: 1–7, 10 μm; 8,9, 25 μm (LM); 10,11, 4 μm. 1,* Pinus halepensis. *2,* Cupressus sempervirens. *3,* Juniperus oxycedrus. *4,5,* Quercus infectoria. *6,* Pistacia atlantica. *7,* P. palaestina. *8,9,* Quercus calliprinos. *10,11* Olea europaea.

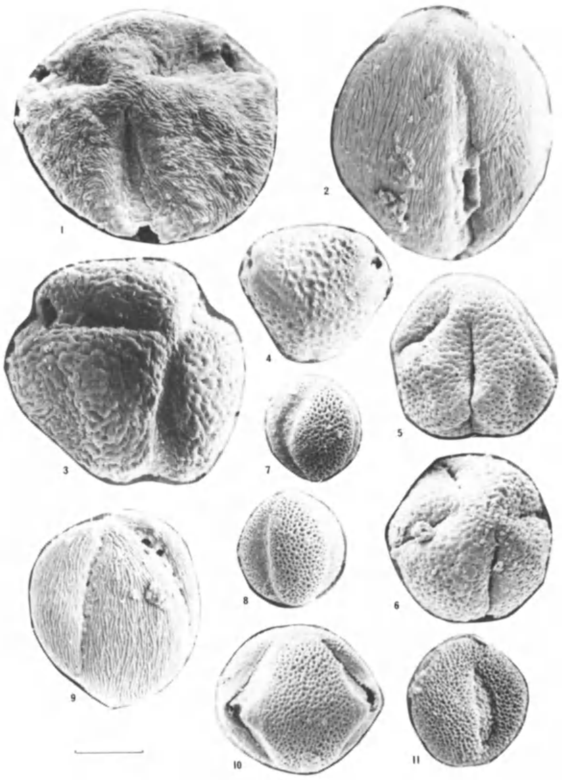


FIGURE 6.13. *Recent arboreal pollen from Israel (SEM photographs by M. Dvorachek, Geological Survey of Israel). Scale 10 μm. 1,* Amygdalus communis. *2,* Prunus ursina. *3,* Crataegus azarolus. *4,* Rhamnus alaternus. *5,6,* Ceratonia siliqua. *7,8,* Tamarix *spp. 9,* Acer obtusifolium. *10,* Cercis siliquastrum. *11,* Platanus orientalis.

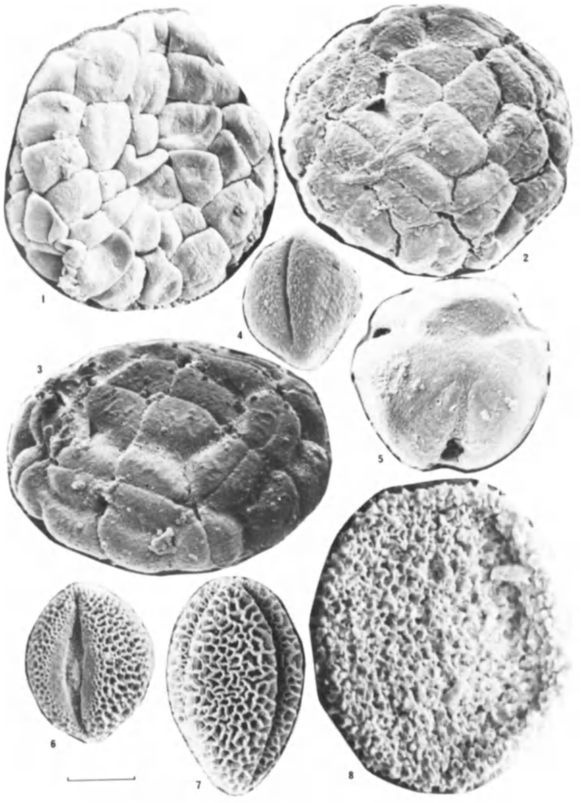


FIGURE 6.14. *(Above, left) Recent arboreal pollen from Israel (SEM photographs by M. Dvorachek, Geological Survey of Israel). Scales: 1, 20 μm; 2-7, 10 μm; 8, 4 μm. 1,* Acacia albida. *2,3,* A. Negevensis. *4,* Maerua crassifolia. *5,* Moringa aptera. *6,* Salix acmophylla. *7,* Viburnum tinus. *8,* Populus euphratica.

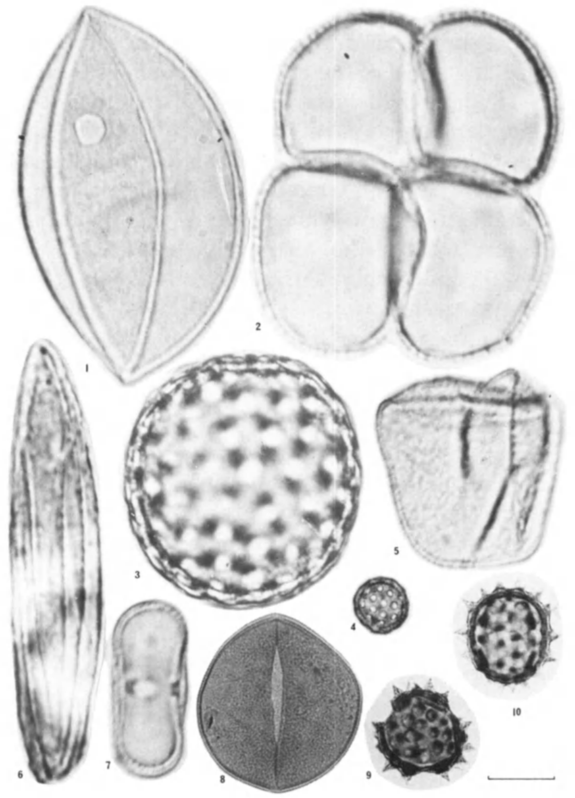


FIGURE 6.15. *(Above right) Recent nonarboreal pollen from Israel (LM). Scales: 1-3, 10 μm; 4,9,10, 25 μm; 5-8, 10 μm. 1, Gramineae (cereal). 2,* Typha angustata. *3, Chenopodiaceae (*Chenopodium *type). 4, Chenopodiaceae (*Atriplex *type). 5, Cyperaceae. 6,* Ephedra *sp. 7, Umbelliferae. 8,* Asphodelus microcarpa. *9,10, Compositae (Tubuliflorae).*

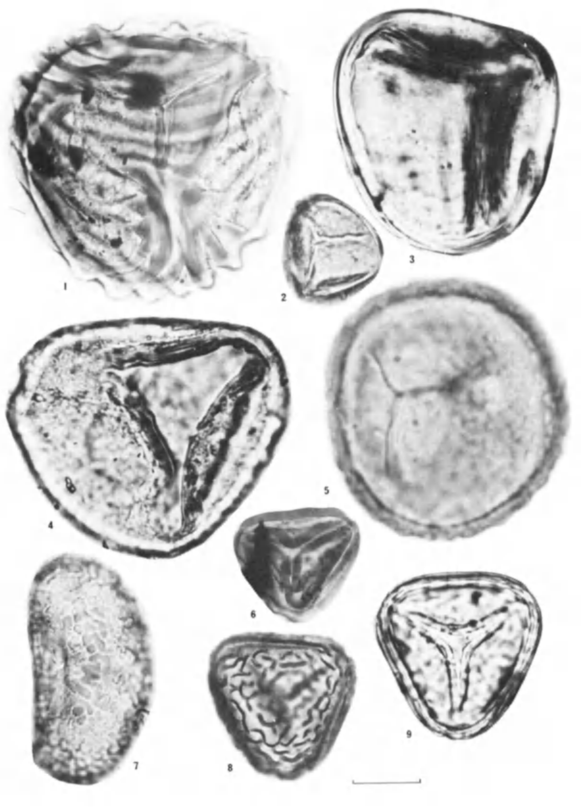


FIGURE 6.16. *(Opposite) Allochtonous spores of tropical origin, recovered from Recent sediments of the Bay of Elat and the Mediterranean offshore. Scale 10 μm. Identified by D. Welman, University of the Orange Free State. 1, Polypodiaceae. 2, Hymenophyllaceae. 3, Cyatheaceae. 4,* Lygodiuim *sp. 5, Vittariaceae? 6, Polypodiaceae? 7, Polypodiaceae. 8,9,* Pteris? *(or* Lycopodium*).*

QUATERNARY POLLEN SPECTRA

No outcrop of a complete, continuous sequence of Quaternary sediments can be seen anywhere in Israel. A complete sequence was, however, recovered by drilling in at least two basins of deposition, the Mediterranean coastal plain and the Dead Sea. Pollen diagrams of these sediments are not complete, for several reasons. In the Mediterranean coastal plain, boreholes penetrated mainly sediments of transgressive cycles, whereas regressions are either represented by sandstone and paleosol horizons devoid of pollen or by erosional surfaces over which not only were none of the regressive sediments preserved, but the underlying sediments of transgressive cycles were also eroded to some extent. Several boreholes have been drilled offshore during oil exploration, but, for this reason, their Quaternary sequences, although complete, were only sparsely sampled. These boreholes were not analyzed palynologically. In the Dead Sea Basin, where the complete sequence is preserved, poor sampling, rather widely spaced at the time of drilling, did not allow drawing of complete pollen diagrams for this area but, rather, gave a number of points from which only the general scheme could be concluded. No drillings were carried out in the Bay of Elat. In the Central and Northern Jordan Valley, more boreholes were drilled, which are better sampled, but most of the sequences encompass only the late–middle and upper parts of the Quaternary sequence. In the Lake Kinneret Basin, only the uppermost Pleistocene and the Holocene sequences were deposited, since this lake was tectonically formed only about 18,000 years ago. The Hula Basin seemed to be the area that produced the best palynological results. Unfortunately also here, sampling of a borehole that was drilled down to 450 m in the center of the Basin is widely spaced, and only a general picture could be drawn, whereas another borehole at the north of the Hula Valley, which penetrated the entire Quarternary sequence, was drilled mainly within the marginal facies of the Basin, encompassing generally conglomerates and paleosols, which yielded almost no pollen. The upper 120 m of the Hula Basin sediments were much better sampled, and a number of investigators have analyzed these sediments palynologically. The results give quite a clear picture of the Riss–Würm Interpluvial, the Würm Pluvial, and the Holocene history of this area.

Another late Quaternary sequence, encompassing more or less the same period as the Hula boreholes, was drilled and analyzed palynologically at Birket Ram, in the northern Golan Plateau, and also serves as a good source of information for this period. The older Quaternary formations, which are exposed in the southern Hula Basin and in the Central Jordan Valley Basin, were palynologically analyzed, but samples are not sufficiently closely spaced or numerous enough to enable drawing of pollen diagrams. Once more, only the general characteristics of these formations could be drawn. The Mediterranean coastal plain sediments have been analyzed by Rossignol (1962, 1964, 1969). The late Quaternary sequence of the Hula Basin was studied by Brotzen (in Picard 1952), by Horowitz (1968, 1970b, 1971, 1973), by Lorch (1959), and by Remy (in Picard 1963). Sequences of sediments from the Dead Sea were analyzed by Horowitz (1966a, 1968b) and by Rossignol (1969b). Sediments of the sequence penetrated in Birket Ram were analyzed by Weinstein (1976), and pollen spectra for the earlier Quaternary formations of the Central and Northern Jordan Valley were obtained by Horowitz (1973, in Bar-Yosef and Tchernov 1972, and unpublished data). The sequence from Lake Kinneret, of the Tabgha Formation, was analyzed by Horowitz (1971). Sediments of the Sedom Formation, thought at that time to be of Quaternary age, were analyzed by Klaus (1965), who gives pollen spectra of several samples from the sequence, including *Pterocarya* pollen grains. Since these sediments are not considered presently (Horowitz 1974) to be of Pleistocene but of Pliocene age, these spectra will not be included in the discussion.

MEDITERRANEAN COASTAL PLAIN

The Quaternary marine sequence of the coastal plain of Israel was palynologically studied by Rossignol (1962, 1964, 1969), who analyzed several boreholes from Ashdod in the south up to Haifa Bay in the north (Figure 6.17). Most of these boreholes yielded only fragmentary information on the sequence due to sampling problems, and, therefore, two composite sequences were proposed by Rossignol (1969) for the southern coastal plain, mainly based on borehole Ashdod 15-0 as a type section and another composite section for the Haifa Bay boreholes, based principally on the Refinery borehole. Almost all the boreholes that penetrated Quaternary sediments of the coastal plain of Israel comprise an alternation of sandy and clayey deposits. Generally, the sandy deposits represent regressive phases of the Mediterranean, whereas the transgressions are represented by rather thin gray-to-blue, sometimes black, clays and silts, deposited either in the sea or in coastal marshes and restricted lagoons that have developed as a result of the rising sea level. It should be clear, therefore, that the coastal plain sequence analyzed by Rossignol represents only transgressive phases of the Mediterranean, which deposited sediments containing pollen, whereas regressive phases, which are mainly represented by sandstones, did not yield pollen. Therefore, the sequence represents a series of superimposed successive transgressive cycles, whereas there is

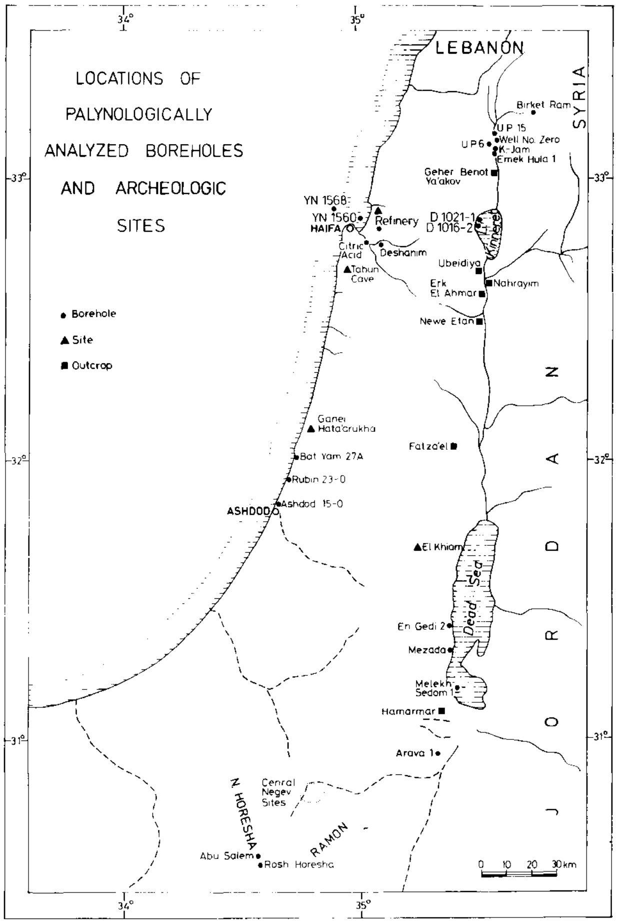


FIGURE 6.17. *Location map of palynologically analyzed sites and sequences.*

almost no information on pollen spectra of the regressive cycles. In general, it could be seen, and had already been noted by Rossignol in 1962, that most of the pollen spectra obtained from Quaternary transgressive sediments resemble average pollen spectra of Recent sediments of the offshore Mediterranean and, therefore, represent more or less the same type of vegetation as exists at present. No significant climatic changes are recorded on the composite pollen diagram for the Quaternary of the coastal plain of Israel because information is fragmentary. The only conclusion drawn by Rossignol was that, during transgressions, the vegetation was of Mediterranean type, more or less of the same character as the present-day vegetation, therefore also implying that the climate was about the same throughout the Quaternary transgressive cycles.

The Quaternary sequence at Ashdod 15-0 borehole, which was the best-sampled and palynologically studied in most detail, together with some sectors from borehole Rubin 23-0 and Bat Yam 27-A, serves as a type section for the palynostratigraphy of the southern coastal plain of Israel. The sequence was divided by Rossignol into five zones. Each of the zones is based on an association that dominates the pollen spectrum and represents a complete cycle, during which a dry or halophil vegetation was followed by a more humid type of plant community. In the secondary division, A denotes the drier associations, and B denotes the more humid ones. The third subdivision of the sequence, denoted by arabic numerals, indicates variations in the pollen spectra of rather short duration within the dominant associations. This composite palynostratigraphy is displayed in Table 6.6, which shows that no extreme variations within the pollen spectra took place throughout the Quaternary, when only transgressive cycles are included. The composite diagram, naturally, gives the average pollen spectra for each of the levels. Zone 1, from a depth of 189 m to 165 m, is characterized by rather high percentages of Compositae, Chenopodiaceae, and *Pinus halepensis*, together with some cryptogamous spores that are quite abundant in certain levels. Medium values of Gramineae and Cyperaceae are also recorded in this zone. Zone 2, from 157.5 m to 120 m, is characterized by higher percentages of Chenopodiaceae and *Ephedra* in the lower part, whereas the upper part is characterized by much higher percentages of Gramineae and Cyperaceae. *Pinus* is almost absent in the lower part but somewhat increases toward the upper part. *Artemisia*, which was almost absent in Zone 1 and along almost all of Zone 2, appears in values of about 10% in the upper part of Zone 2. Zone 3, from 107 to 80 m, is characterized once more by medium ratios of Gramineae and Cyperaceae, very high percentages of Compositae, *Artemisia*, and Chenopodiaceae, and medium percentages of pine. Spores are almost absent in Zone 3. Zone 4, which was taken from Rubin 23-0 borehole, from a depth of 63–15 m, is characterized by an increase of Gramineae and Cyperaceae, which are quite low, about 10% together in the lower part, increasing up to 75% together in the upper part. Compositae are very abundant, up to 60% in the lower part, but totally absent in the upper part, whereas *Pinus* is also more abundant, about 20% in the lower part, and diminishes toward the top of this zone. *Artemisia*, Chenopodiaceae, and *Ephedra*, together with fern spores, are quite rare in this zone. Zone 5 was taken from Bat Yam 27-A borehole at a depth of 7–5 m and is characterized by very high percentages, up to 93%, of Compositae, some Gramineae, and minor amounts of spores, with almost nothing else.

The entire sequence penetrated by the Haifa Bay boreholes (Table 6.7)—and it should be noted once more that only the transgressive sediments were analyzed (Rossignol 1964, 1969)—displays rather uniform pollen spectra, with shares of Gramineae and Cyperaceae in the order of 20–40%. Compositae and *Asphodelus* are the dominant associations, amounting up to 60–80%, whereas Chenopodiaceae, *Pinus*, spores, and other pollens do not occupy more than 20% of the total spectrum.

TABLE 6.6
Composite Palynostratigraphy of the Mediterranean Quaternary Sediments, Based on Data by Rossignol (1969), Showing Average Pollen Spectra for Each of the Horizons

Type borehole	Depth (m)	Palyno-stratig-raphy			Gramineae	Cyperaceae	Compositae	*Asphodelus*	*Artemisia*	Chenopodiaceae	*Ephedra*	*Pinus halepensis*	Spores	Various pollen	Total counted
Bat Yam 27–A	5–7	V	A		6	—	91	—	—	—	—	—	2	1	108
Rubin 23–0	15–19	IV	B		60	18	—	—	—	—	—	7	10	5	53
	49–63		A		5	5	58	—	2	6	1	18	2	3	253
Ashod 15–0	80–93.5	III	B	2	21	5	24	4	7	8	2	2	2	25	2385
	93.5–103.5			1	21	8	26	1	7	15	3	7	1	11	1425
	103.5–107		A		12	4	60	1	1	16	2	2	1	1	619
	120–131	II	B	3	46	5	6	—	9	8	2	5	8	11	566
	131–137.5			2	60	9	2	1	1	5	1	3	7	11	768
	137.5–146			1	44	4	2	1	1	5	1	10	25	7	1652
	146–151		A	2	10	2	10	—	2	50	8	2	1	15	799
	151–157.5			1	15	4	20	1	3	25	4	2	1	25	368
	165–169.5	I	B	4	24	8	3	1	1	6	2	13	34	8	709
	169.5–172			3	12	3	22	1	1	32	3	6	3	17	287
	172–176.5			2	25	5	6	1	1	13	2	7	25	15	372
	176.5–177.5			1	5	—	47	23	—	18	1	4	—	2	80
	177.5–188.5		A		8	3	14	3	2	30	13	11	2	14	1144

TABLE 6.7
Composite Palynostratigraphy of the Haifa Bay Boreholes, after Rossignol (1969), Showing Percentages of the More Important Components of the Pollen Spectra at Each Analyzed Level[a]

Borehole	Depth (m)	Stage	Gramineae	Cyperaceae	Compositae	*Asphodelus*	Chenopodiaceae	*Pinus halepensis*	Spores	Various pollen	Total counted
Refinery	0.90	V4	10	2	66	—	—	4	—	18	107
Refinery	3.50		30	15	16	—	8	4	—	29	111
Deshanim	1.50	V3	5	—	78	—	5	4	—	8	101
Refinery	11.50		6	—	85	—	3	4	—	2	111
Citric acid	13.50		9	2	80	1	—	4	4	—	123
Refinery	29	V2	5	—	80	2	8	—	3	2	135
Refinery	38.50		10	3	71	2	6	4	—	4	113
Deshanim	57	V1	35	5	7	—	21	—	—	32	153
Deshanim	65		41	—	42	2	3	—	—	12	141

[a] Stratigraphy of boreholes after Slatkine and Rohrlich (1964).

To conclude, therefore, pollen spectra obtained from the Quaternary transgressive sediments of the Mediterranean coastal plain are within the limits of the Recent pollen spectra of this domain and, apparently, indicate vegetation and climate of the eastern Mediterranean type, which did not vary considerably from present-day conditions, regarded by Horowitz (1971) as typical for interpluvials in the country. The most important paleoclimatic conclusion based on the palynological investigations by Rossignol (1962, 1964, 1969) is that transgressive cycles of the Mediterranean during the Quaternary occurred in the country during interpluvial climatic times. Since the same transgressive cycles of the Mediterranean occurred in southern Europe during interglacial times, this points to a correlation between the European interglacials and interpluvial climates in Israel.

Two cores of bottom sediments were collected by Y. Nir, Geological Survey of Israel, in offshore Haifa Bay. Y. N. 1560 is 160 cm long, collected under 44 m of seawater, whereas Y. N. 1568 is 180 cm long, collected under 1160 m of seawater. The sequences penetrated by the two cores were dated (Horowitz 1974d) by comparing the arboreal to nonarboreal pollen ratios with those obtained from a radiocarbon dated borehole in the Hula Valley, U. P. 15, discussed later. The sequence of Y. N. 1560 represents approximately the last 1600–1700 years, whereas the one penetrated by Y. N. 1568, due to a much lower rate of deposition in the deeper sea, represents the second half of the Holocene, from the Atlantic through the present. The pollen diagram for this core (Figure 6.18) is given here. The conclusions presented for the core have been correlated with those obtained for the Hula boreholes; therefore, they are quite general, reliably dating the climate and vegetation for the entire period. Several pollen spectra of samples collected from archaeologic sites were also analyzed by Horowitz (1974d) in order to check the radiocarbon datings against the archaeologic ones. The pollen spectra of these archaeologic sites are discussed later. The conclusions arrived at are based on comparison of these pollen spectra with those characterizing Recent sediments. The Recent spectra for northern Israel comprise about 10–15% arboreal pollen, shared almost equally between oak, pistachio, olive, and pines. The nonarboreal spectra comprise a mixture of elements, of which Compositae, Cruciferae, Gramineae, and Chenopodiaceae prevail, whereas others appear in smaller percentages.

Some zones along the diagram differ from others in their arboreal pollen share and composition. Two types of pollen assemblages occur in the sequence, those that are more or less comparable to the Recent, and others that are characterized by considerably higher percentages of arboreal pollen, especially oaks and olives. The latter can be seen for the parts of the sequence representing the years from the bottom of the section up to about 2400–2300 BC, from about 2100 to about 1100 BC, and a less pronounced one from 700–600 BC up to AD 800–900. These periods are separated by shorter ones in which the pollen spectra and, evidently, the corresponding vegetation, show a considerable drop in arboreal share. These lows are around 2250 and 950 BC, after which the arboreal pollen curve remains low up to the present day. The peaks of arboreal pollen seem to indicate periods in which the vegetation was richer than at present, whereas the lows represent drier periods. It seems that water availability for plant life increased by a rate of 10–15%, but no temperature drop is known for these times in the country, as concluded from oxygen isotope analyses in the Hula Basin (Horowitz 1971). The higher water availability might be a result of higher precipitation, probably distributed more evenly throughout the year. The possibility of some summer rains should not be excluded, as pointed out by Y. Itzhaki (Institute of Archaeology, Tel Aviv University, personal communication, 1972).

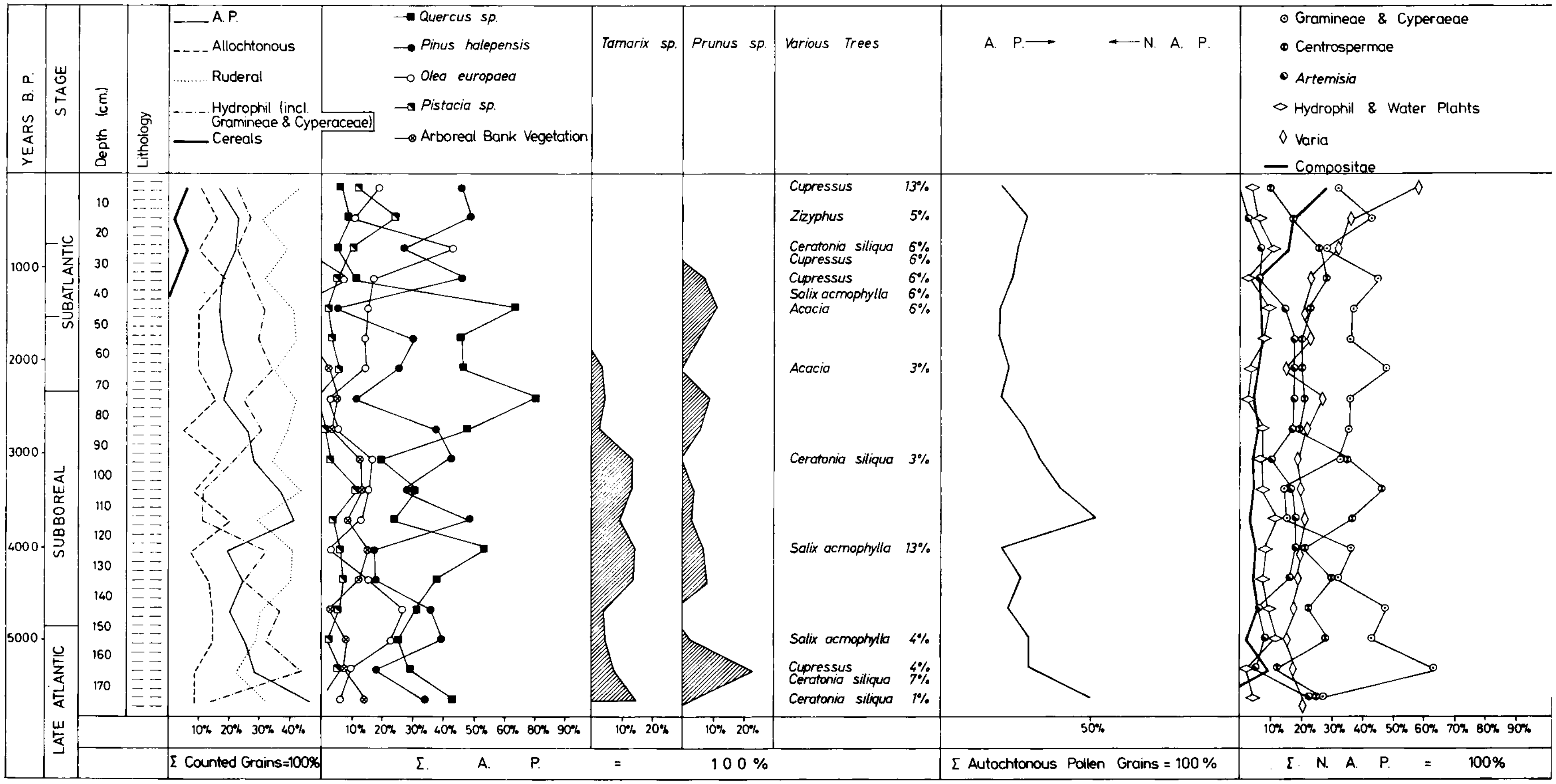


FIGURE 6.18. *Pollen diagram of sea bottom core Y.N. 1568, collected off Haifa Bay under 1116 m of seawater.*

HULA BASIN

The Hula Basin has existed as a taphrogenic depression since Pliocene times (Horowitz 1973). During the Pliocene, it was a rather shallow basin, and a subsidence on the order of a couple of hundred meters took place throughout the entire period, during which the Kefar Gil'adi Group was accumulated in this area. Flows of the Cover Basalt inundated the area in Preglacial Pleistocene times, from approximately 2.8 up to 1.7 million years ago (Siedner and Horowitz 1974). A renewed tectonic activity at the commencement of the Glacial Pleistocene, about 1.6 million years ago, separated the Hula Basin from neighboring areas to the south and the north and resulted in the formation of the Hula Valley, more or less in its present-day shape. A further subsidence followed by sedimentation of the floor of the basin resulted in the accumulation of some 1700 m of sediments during the Glacial Pleistocene (Yuval 1967), which have continued to accumulate up to the present and are designated as the Hula Group (Horowitz 1973). Some complicated tectonic movements in the south of the Basin, in the Gesher Benot Ya'akov area, have uncovered the lateral facies of the formations accumulated in the center of the Basin; thus, most of the formations that accumulated under conditions of a lake that occupied a larger area than the present-day lake could be sampled and analyzed from outcrops. A summary of the sequence is given by Horowitz (1973).

The earliest of the lacustrine formations exposed in the southern basin is the Gadot Formation, of Günzian age. It is covered by a paleosol, apparently of Günz–Mindel age, which is, in turn, covered by the lacustrine Mishmar HaYarden Formation of Mindelian age. This formation is covered at the Benot Ya'akov area by a sheet of the Yarda Basalt, which yielded ages of about 690,000 years (Horowitz *et al.* 1973). The Ayyelet HaShahar Formation, of Mindel–Riss age, is not known from outcrops but was penetrated by Emek Hula 1 Borehole. It is covered by the Benot Ya'akov Formation, of Rissian age, which at the Benot Ya'akov area overlies the Mishmar HaYarden Formation over a pronounced angular unconformity. The Hulata Formation of Riss–Würm age is also known only from boreholes, but was penetrated by quite a few. It comprises mainly peats with some organic clays. It is overlain by the Ashmura Formation, of Würmian age. This formation continued to be deposited until recently, when the Hula Lake was drained artificially, but, following the desiccation of the lake in post-Würmian times, the Mallaha Formation peats began to be formed during the Holocene in the northern part of the Hula Valley. Two travertine formations are known from the northern margins of the Hula Valley, the Kefar Yuval Travertine, apparently of Rissian age, and the Dan Travertine, apparently of Würmian age. They are separated by the Hasbani Basalt sheet, that yielded radiogenic ages of around 70,000–80,000 years (Siedner and Horowitz 1974).

Outcrops of the Hula Group

Samples collected from the Gadot Formation were quite poor in pollen grains, probably due to the high carbonate content of the sediments, being mostly marls, poor in organic material. The average pollen spectrum for five samples includes: *Quercus* (35%), *Cedrus* (2%), *Populus* (1%), *Salix* (1%), a total of 39% arboreal pollen. Gramineae and Cyperaceae form about 20%, Chenopodiaceae 15%, Umbelliferae 8%, Compositae 5%, *Artemisia* 3%, Liliaceae 2%, *Ephedra* 3%, Papilionaceae 3%, and Labiatae 2%. This pollen spectrum probably represents a pluvial phase, because of the rather high arboreal pollen share in which oak forms almost the only constituent. This was interpreted by Horowitz (1971) as indicative of pluvial climatic conditions. Most of the other plants represent open field vegetation. Marshes were apparently not so widespread, since Gramineae and Cyperaceae form only 20% of the spectrum, but some salinity was present, as can be seen by the relatively high percentage of Chenopodiaceae. This might reflect that during deposition of the Gadot Formation the Hula Basin was a closed lake, with some influence of slightly salty marshes forming on its margins. The paleosol separating the Gadot and the Mishmar HaYarden Formations did not yield any pollen, probably due to oxidation.

Two distinct facies comprise the Mishmar HaYarden Formation at the Benot Ya'akov outcrop. The lower part comprises a lacustrine gray marl, very rich in fossil mollusks with some bones, mostly *Hippopotamus*, and the upper part comprises mainly paludine peat. An average pollen spectrum of the lacustrine marls is as follows: arboreal pollen 38%, of which *Quercus* forms 34%, and the rest is shared by *Populus* and *Salix*. The nonarboreal spectrum comprises Gramineae and Cyperaeae (17%), *Artemisia* (13%), Umbelliferae (10%), Chenopodiaceae (1%), Compositae (12%), Liliaceae (3%), Cruciferae (1%), *Typha* (2%), *Plantago* (1%), fern spores (1%), Acanthaceae (0.5%), and Labiatae (0.5%). This pollen spectrum, which is quite similar to the one obtained from the Gadot Formation, once more represents pluvial conditions during deposition of this formation. The relatively high percentages of *Artemisia* and Umbelliferae might point out the proximity of the Irano-Turanian belt, most likely in the highlands on the east, which could have influenced to some extent the pollen spectrum of the Mishmar HaYarden Formation. The pollen spectra for the peat layers within the Mishmar HaYarden Formation are even more surprising, since the arboreal pollen share is as high as 76%, comprising only 1% of Cupressaceae and 75% of oak grains. Gramineae and Cyperaceae form 21%, Compositae 1%, *Typha* 1%, Umbelliferae 1%, Chenopodiaceae 1%, and *Rubus sanctus* 0.5%. This spectrum definitely points to pluvial conditions, but apparently the Mishmar HaYarden lake somewhat shrank as compared with the previous period, in which lacustrine chalks were deposited, and the oak forest, which then grew up to the lake shore, propagated toward the place in which marshes were formed and peat was deposited. This is probably the reason for the very high percentage of oak pollen grains, which is relatively high even when compared with pluvial pollen spectra of other layers in the Basin. For comparison it must be remembered that oak percentages for Recent sediments in the lake are about 7%, while the oak percentage for the peat, forming presently in the marshes north of the Hula Lake, is only 3%.

Pollen spectra for the lacustrine sediments of the Rissian Benot Ya'akov Formation that crop out at the Gesher Benot Ya'akov area average as follows: arboreal pollen grains 49%, of which *Quercus* is the major component (41%), while *Fagus* (3%), *Rhamnus* (1%), and the bank trees *Populus* (3%) and *Salix* (1%) also appear. Gramineae and Cyperaceae form 29% of the spectrum, Umbelliferae 4%, Chenopodiaceae 1%, Labiatae 2%, Papilionaceae 2%, *Typha* 2%, Compositae 3%, and 1% of each of the following: *Artemisia, Myriophyllum,* Malvaceae, and trilete spores. This, once more, is a typical pollen assemblage of pluvial character for the Hula Basin, and the occurrence of several pollen grains of *Fagus* should be noted. It will be seen later that almost every pollen assemblage for the Rissian sediments of the Jordan Valley contains some *Fagus* pollen grains, and they seem to be a good marker for this period in the Jordan Valley.

Results from Boreholes in the Hula Lake

The first attempt to analyze sediments of the Hula Valley palynologically was carried out by F. Brotzen and G. Erdtman in Stockholm (in Picard 1952). Three samples were submitted for their analysis from a borehole drilled to about 120 m depth in the northern part of the Hula Lake. Two samples consisted of peat, derived from depths of 31 and 80 m, and the third was a limnic clay, characteristic of what was defined by Picard as "sterile, peat-free layers," from a depth of 120 m. The sample of peat collected from 31 m yielded pollen grains of *Typha, Artemisia,* Gramineae, Cyperaceae, Chenopodiaceae, *Myriophyllum, Lythrum, Nymphaea,* and pine. The peat sample at 80 m contained oak grains, fern spores, and a conifer, apparently *Cedrus,* while clay from 120 m contained *Quercus,* Gramineae, *Cupressus,* and Compositae. Picard (1952) believed that although they were of a generic and provisional character, these determinations revealed only endemic floral elements growing at present in the country. Picard ascribed the penetrated sequence to the entire Quaternary, and therefore concluded that the persistence of Quaternary climate, implying no climatic changes, is strengthened by the evidence gathered from the floral ecology. It must be noted though that no countings were carried out during this study, so that no pollen spectra could be given, and in fact no valid conclusions about climate could have been drawn. Since the penetrated sequence represents only part of the late Quaternary and not the entire period, the conclusions presented by Picard in 1952 seem to be invalid.

The series of boreholes drilled in the Hula Valley for a survey of peat in 1951, of which a preliminary analysis was carried out by Brotzen and Erdtman (as mentioned) were studied in more detail by Lorch (1959), by Remy (in Picard 1963), and by Horowitz (1971). These boreholes penetrated mainly the Ashmura and the Hulata Formations, but some of them, especially those drilled in the north of the Basin where the sedimentary fill is somewhat less developed than at the center, also penetrated the upper part of the Benot Ya'akov Formation. Lorch (1959) had studied borehole samples taken from the swamp area, at coordinates 20640–27914 of the Israeli grid. Samples were removed at irregular intervals to a total depth of 120 m. The reference collection used by Lorch was far from complete, and although all the members of the arboreal flora listed by Zohary (1951) as well as aquatic plants and other leading plants of the region were included, the number of undetermined grains in his analysis is still large. The results are summed up in Table 6.8 as percentages of the various constituents of the pollen spectra. At most levels more than 150 grains were counted. At others, due to the extreme paucity of grains, the number counted was smaller, as few as 70. Lorch found that Gramineae among the families and *Quercus* among the genera are the most strongly represented. At two levels, though, Centrospermae become the dominant group, while among the individual genera at 18.5 m, *Sparganium, Nymphaea,* and *Artemisia* approach values of 10%. Conifers were poorly represented at all but two levels, sometimes by fractured grains. Monolete spores of *Thelypteris palustris* at some levels, such as at 53 m, reach quite high percentages, while at other levels they are rare or absent. Lorch notes two major findings from his investigation: the extreme scarcity of pollen grains and the low percentages of tree pollen. He maintains that in the Lake Hula region, trees generally and anemophilous trees in particular may never have formed a complete cover. For this reason, he computes the pollen spectra on the basis of the total number of grains counted and not on the total arboreal pollen, since at some levels arboreal pollen is almost completely absent. Lorch did not draw any pollen diagrams because the vertical distances between the samples were considerable, and although he indicates certain trends, a diagram, in his opinion, might be misleading. As a consequence of his findings, Lorch did not draw either paleoclimatic or paleoecologic conclusions. Moreover, he stated that classical methods of pollen analysis are not suited to the Hula deposits, a statement opposed by almost all workers who have done any palynological research in the Near East.

Picard (1963) divided the sequence penetrated by this series of boreholes down to 120 m into a "Recent or Surface Peat," presently known as the Mallaha Formation, the "Upper Lacustrine Beds," presently known as

TABLE 6.8
Pollen Spectra of a Borehole Analyzed by Lorch (1959) from the Hula Valley (Coord. 20640/27914)

Depth (m)	Sediment	Total counted	Not determined	Damaged	Centrospermae	Compositae	Coniferae	Cyperaceae	Geraniaceae	Gramineae	Plumbaginaceae	Pteridophyta	Umbelliferae	*Artemisia*	*Butomus*
Würm-recent Stage															
Ashmura Formation															
2–3	Grey calc. siltstone	48	14	8	4	10	4	4	—	4	—	—	2	4	—
18	Grey siltstone	69	12	24	12	10	2	—	—	46	—	—	10	11	3
31	Dark grey calc. siltstone	180	12	24	7	5	1	—	—	26	—	—	6	6	—
Riss-Würm Stage															
Hulata Formation															
43	Black peat	174	11	21	2	2	3	—	—	43	—	4	—	3	—
49	Black peat	140	19	9	16	2	2	1	—	6	—	—	3	9	1
53	Dark-grey-black peat	161	11	13	26	3	2	—	—	10	—	16	—	4	—
57	Dark-grey siltstone	173	12	11	4	2	1	5	—	50	1	—	—	1	—
62	Grey, calc. bituminous siltstone	83	14	6	8	4	7	1	—	14	—	—	1	—	—
65	Grey, calc. bituminous siltstone	144	21	6	4	4	1	1	—	26	—	—	—	—	—
71	Brown-black finegrained peat	215	14	20	7	1	1	—	—	17	13	—	1	3	—
82	Fine cuttings of black peat	90	12	18	9	1	1	1	—	23	—	—	—	—	—
85	Black peat	127	12	13	—	2	6	—	—	10	—	1	2	11	—
Riss Stage															
Ayyelet Hashahar Formation															
91	Light-grey argillaceous siltstone	186	4	8	4	16	—	1	3	24	—	—	3	3	—
93	Light-grey argillaceous siltstone	159	13	16	14	2	—	1	—	21	—	—	5	1	—
96	Light-grey argillaceous siltstone	246	11	16	11	12	1	6	—	26	—	—	3	1	1
100	Light-grey argillaceous siltstone	168	18	5	5	4	1	—	—	25	—	5	2	2	—
107	Light-grey argillaceous siltstone	174	18	10	28	8	8	3	—	11	—	—	2	2	—
113	Light-grey argillaceous siltstone	81	6	10	1	3	1	1	—	53	—	12	—	3	—
118	Light-grey argillaceous siltstone	178	20	7	3	2	12	1	—	13	1	1	2	1	—

Depth (m)	Sediment	*Ceratophyllum*	*Ephedra*	*Lemna*	*Lythrum*	*Myriophyllum*	*Nuphar*	*Nymphaea*	*Olea*	*Polygonum*	*Potamogeton*	*Poterium*	*Quercus*	*Salix*	*Sparganium*	*Typha*
Würm-recent Stage																
Ashmura Formation																
2–3	Grey calc. siltstone	—	—	—	—	—	—	—	2	34	—	—	4	2	—	—
18	Grey siltstone	—	—	—	—	—	—	1	16	—	—	—	22	—	—	1
31	Dark grey calc. siltstone	—	—	—	—	—	—	1	—	—	—	—	3	4	14	2
Riss-Würm Stage																
Hulata Formation																
43	Black peat	—	—	—	—	—	—	1	—	—	—	—	6	8	26	3
49	Black peat	—	—	—	—	5	—	15	—	—	—	—	10	—	2	—
53	Dark-grey-black peat	—	—	1	—	4	—	9	—	—	—	—	—	—	—	1
57	Dark-grey siltstone	—	—	—	—	6	—	3	2	—	—	—	2	—	—	1
62	Grey, calc. bituminous siltstone	—	—	—	—	—	21	—	—	—	—	1	40	—	—	—
65	Grey, calc. bituminous siltstone	—	2	1	1	2	—	10	11	—	—	—	11	—	—	1
71	Brown-black finegrained peat	—	—	4	—	2	—	1	2	—	—	1	1	—	—	—
82	Fine cuttings of black peat	—	—	2	—	—	2	2	3	—	1	—	21	—	—	—
85	Black peat	1	—	—	—	—	—	4	—	—	—	—	40	1	—	—
Riss Stage																
Ayyelet Hashahar Formation																
91	Light-grey argillaceous siltstone	5	—	—	—	—	1	—	—	—	—	—	—	5	1	1
93	Light-grey argillaceous siltstone	—	—	—	—	—	—	1	—	—	—	—	19	—	—	1
96	Light-grey argillaceous siltstone	—	—	—	—	—	—	—	2	—	1	—	10	—	1	—
100	Light-grey argillaceous siltstone	—	—	—	—	1	—	1	—	—	—	—	29	3	—	—
107	Light-grey argillaceous siltstone	—	—	—	—	—	—	—	—	—	2	—	6	—	1	—
113	Light-grey argillaceous siltstone	—	—	—	—	—	—	—	—	—	—	—	—	6	—	1
118	Light-grey argillaceous siltstone	—	—	—	—	—	2	—	1	—	—	—	35	1	—	—

the Ashmura Formation, the "Main Peat layers," known as the Hulata Formation, and the "Lower Lacustrine Beds," known today as the Benot Ya'akov Formation. A series of samples from well No. 0, situated 1 km north of the Jordan River inlet to the lake, about 70 m above sea level at coordinates 2780-2072, was sent for palynological study to J. M. Remy of the Department of Geology of Bonn University, in 1959. Unfortunately, the details of Remy's investigation have never been published and no data or pollen diagrams are available. Picard (1963) summarized the results obtained by Remy as follows (Table 6.9). Remy distinguished three floral zones, roughly corresponding to Picard's lithostratigraphic divisions. Zone A, from the surface down to 31 m depth, represents mainly the limnic chalk of the Upper Lacustrine member with a thin capping layer of Recent to sub-Recent Surface Peat. This zone is rich in *Quercus* pollen but devoid of *Cedrus*. Zone B, from 31 to 85 m, comprises mainly the Main Peat horizons with very thin intercalated beds of freshwater chalk occurring at a depth of 50–65 m; *Cupressus* is the dominant pollen. Zone C represents the lake chalk of the Lower Lacustrine member, and is rich in *Cedrus* pollen grains.

Following Remy's climatic interpretation (Table 6.9), the driest period would thus correspond to the deposition of the Main Peat horizons, or the Hulata Formation, Zone B. The Upper and Lower Lacustrine members, Zones A and C (Benot Ya'akov and Ashmura Formations), would coincide with a more humid, though still warm, climate. One of the deepest layers, sampled at 118 m depth, is believed by Remy to represent the climatic optimum of the investigated section. The change from the more humid conditions of the Lacustrine members to drier conditions during the Main Peat deposition in Zone B is apparently sharper at the beginning of the Upper Lacustrine period, Zone A, than at the transition period from Lower Lacustrine times, Zone C, to the Main Peat sedimentation. The most recent development of surface peat may well point to a renewal of dry climatic conditions, according to Picard. In 1963, Picard still assumed that the 120-m sequence represents approximately the entire Quaternary period, and therefore concluded that during the Quaternary or the depositional time of the Hula Series, "there existed a climate no different in substance from the present" and returns to his conclusion from 1937: "The present day climatic zones of Palestine, were, except for insignificant fluctuations, as regards time and place, already developed in the Pleistocene." Zone B, according to Picard (1963), the Hulata Formation peat, might indeed reflect such a fluctuation, i.e., a phase of diminishing rainfall resulting in insufficient drainage of the Hula depression and therefore larger peat accumulation. Considering Remy's results, it is quite clear that basically the composition of the flora was the same as it is

TABLE 6.9
Conclusions Arrived at by Remy (*in* Picard, 1963) from the Pollen Analysis of Borehole "No. 0 First Test," Hula Valley

Stage	Formation	Depth (m)		
	Mallaha (Upper Peat)	6	A	4. "Humid–warm" 3. "Dry" (at 22 m depth): slight maximum of Compositae with Oleaceae of short duration 2. "Humid–warm": *Quercus* maximum 1. ?
Würm–Recent	Ashmura (Upper Lacustrine)	31		
Riss–Würm	Hulata (Main Peat)	85	B	4. Again "dry": Compositae maximum. No Oleaceae 3. Less "dry": more *Cedrus*, some *Picea*, Graminae max., frequent Oleaceae "some climatic change" 2. Again "dry": Compositae maximum 1. Transition: strong reduction of Compositae, few *Cedrus* and Oleaceae
Riss	Ayyelet HaShahar (Lower Lacustrine)	122	C	4. "Dry–warm": reduction of *Cedrus*, no *Picea* or Oleaceae but 24% Compositae 3. "Dry–warm": much *Quercus* 2. "Humid–warm" (at 118 m depth): 16% *Cedrus*, some *Picea*, few Compositae or Oleaceae. "Climatic optimum" 1. "Humid–warm": increase in *Cedrus*, somewhat more Compositae than in 2

today throughout the entire sequence. The frequencies of the various constituents of the pollen spectra do, however, vary quite significantly, which in our opinion indicates considerable climatic changes, especially water available to plant life. This point will be discussed in further detail.

Emek Hula 1 Borehole

Pollen spectra for the Ayyelet HaShahar Formation, of Mindel-Riss age, through the Ashmura Formation, of Würm age, are summarized in Table 6.10. This sequence was penetrated by the Emek Hula 1 Borehole. Twelve side-wall cores from Emek Hula 1, penetrating 460 m of Quaternary lacustrine and paludal sediments, were submitted for palynological investigation by the Lapidoth Oil Company, to determine the stratigraphy of the well (Horowitz 1970b). The borehole is located at the central part of the now dry Hula Lake (Figure 6.17), at coordinates 207588 and 279178 of the Israeli grid. Most of the samples consist of gray marl, very rich in organic material, and some consist of a very limey peat. Most yielded good pollen assemblages, and about 200 grains were counted from each. Some samples were poorer in pollen grains and three contained none. The results are summed up in Table 6.10 as percentages of the total sum of counted pollen and spores. No arboreal pollen calculations are given separately and the entire spectrum is the basis for the calculations, discussion, and conclusions. This was decided because during most of the Quaternary the forest

TABLE 6.10
Pollen Spectra from Emek Hula 1 Borehole[a]

	Hulata Formation		Benot Ya'akov Formation					Ayyelet HaShahar Formation	
	Riss–Würm Stage		Riss II Stage			RI–RII Stage RI Stage		Mindel–Riss Stage	
	90 m	126 m	155 m	162 m	212 m	250 m	280 m	373 m	439 m
Arboreal pollen									
Quercus spp.	—	2	34	28	21	6	22	11	14
Olea europaea	—	—	4	2	4	2	13	6	3
Pistacia spp.	—	—	—	0.5	—	0.5	2	1	—
Pinus halepensis	—	4	—	0.5	—	—	—	—	—
Cedrus libani	—	—	—	1	—	—	—	—	—
Fagus sp.	—	—	—	2	0.5	—	1	—	—
Ceratonia	—	—	1	—	—	—	—	—	—
Celtis	—	—	—	—	0.5	—	—	—	—
Acer syriacum	—	—	—	—	—	0.5	—	—	—
Acacia albida	4	—	—	—	—	—	—	—	—
Total Arboreal pollen	4	6	39	34	26	9	38	18	17
Nonarboreal pollen									
Gramineae	46	28	29	19	35	16	35	46	44
Cyperaceae	27	16	9	11	9	6	12	14	20
Compositae	4	—	—	1	6	8	2	1	4
Umbelliferae	—	4	5	10	5	3	4	3	2
Cruciferae	—	—	—	3	4	0.5	0.5	—	—
Centaurea	—	—	—	—	1	1	—	0.5	—
Plantago	—	—	1	—	1	—	—	—	—
Chenopodiaceae	—	—	8	10	3	23	7	4	5
Artemisia	—	—	4	6	2	24	9	4	2
Ephedra	—	—	1	—	—	2	—	1	1
Other nonarboreal pollen	4	—	1	4	4	1	0.5	0.5	—
Total nonarboreal pollen	81	48	58	64	70	85	60	74	78
Bank vegetation	15	46	3	2	1	4	3	1	2
Water plants	—	—	1	0.5	4	—	1	—	2
Total counted	26	98	80	218	207	216	199	216	92

[a] From Horowitz, 1973.

or maquis did not cover the entire country, therefore the arboreal pollen spectrum alone cannot be regarded as a significant source of information.

The palynological spectrum was divided into three parts. The first represents arboreal pollen, the second nonarboreal pollen, and the third local elements, such as bank vegetation and water plants. The samples are quite widely spaced and therefore no pollen diagram is included for this well. The Ayyelet HaShahar Formation, of Mindel–Riss Interpluvial age, is represented by samples from 373 and 439 m, which display similar pollen assemblages. The lowermost is rather poor in pollen, the arboreal attaining 17–18%, of which the olive share is fairly high compared to other samples. Gramineae and Cyperaceae form about 60% of the total spectrum and the rest consists of small amounts of grains produced by open field vegetation. Pollen of bank vegetation and water plants appear in low numbers. The Benot Ya'akov Formation, of Riss Pluvial age, is represented by samples from 155, 162, 212, 250, and 280 m. All but the sample from 250 m yielded pollen assemblages that are much richer in arboreal pollen than the lower and upper ones of the Ayyelet HaShahar and the Hulata formations. They include 26–39% arboreal pollen, comprising mainly oak, of *Quercus calliprinos* and *Q. ithaburensis* types. Olive is second, although much lower in frequency. Small amounts of *Pistacia, Pinus, Cedrus, Ceratonia siliqua, Celtis,* and *Fagus* are present. The nonarboreal spectrum comprises 30–40% of Gramineae and Cyperaceae, and pollen produced by open field vegetation such as Compositae, Umbelliferae, Cruciferae, Chenopodiaceae, and *Artemisia.* Small amounts of *Centaurea, Plantago, Ephedra,* Rosaceae, Papilionaceae, Cucurbitaceae, *Iris,* Labiatae, and *Ranunculus* are included. Pollen grains of bank vegetation are rather rare, only 1–3%, and those of water plants also appear in small amounts. The pollen spectrum is totally different at 250 m, the sample here being rich in pollen grains. Only 9% of arboreal pollen are present, comprised of oak, olive, and rare *Pistacia* and *Acer.* The nonarboreal spectrum is relatively poor in grains of Gramineae and Cyperaceae, only 22%, but very rich in pollen of Chenopodiaceae and *Artemisia,* that together attain 47% of the total. The two uppermost samples that were analyzed from this borehole, from depths of 90 and 126 m, represent the Hulata Formation, of Riss–Würm Interpluvial age. They display more or less similar palynological spectra. Both are poor in pollen grains and contain very few arboreal pollen. The upper one had only 4% of *Acacia,* probably *A. albida.* The lower contained 6%, divided between oak, most probably *Quercus calliprinos,* and pine. The nonarboreal pollen of these samples comprises mainly Gramineae and Cyperaceae, which together form 73 and 44% of the spectrum, while high percentages are also displayed by bank vegetation pollen representing *Populus euphratica, Typha, Rubus sanctus,* and spores of the fern *Thelypteris palustris.* Pollen grains of water plants are totally absent.

The relations of arboreal to nonarboreal pollen and composition of the groups are the basis for our conclusions. The spectra were compared to the Recent pollen spectra of the area, discussed earlier, to pollen spectra obtained from several boreholes that penetrated the late Quaternary sediments of the Hula Valley, discussed further on, and to spectra from the outcrops of these formations, which were dated by mollusk and vertebrate fauna, by flint implements and by radiogenic methods (Horowitz 1973). The relative frequency of arboreal pollen grains seems to be a good indicator of tree cover of the area during the time of deposition. Recent values are about 15% in the center of the lake. The composition of the arboreal pollen spectrum and, particularly, the relation of oak to other trees serve as climatic indicators. Warm climate is apparently characterized by higher percentages of olive grains, humid climate by flourishing of oaks, and dry climate by general diminishing of the number of arboreal pollen and the appearance of pollen of trees like pines and acacias. The nonarboreal pollen group, which originates mainly from plants growing in the Hula Valley, in marshes and open fields, serves as a source of information as to local hydrographic conditions, especially the relations of lake, marshes, and open fields within the Hula Valley proper. Gramineae and Cyperaceae mainly grow in the marshes around the lake. Open-field vegetation surrounds the marshes and covers part of the mountains' slopes. Bank vegetation and water plants indicate proximity of the lake's shoreline or the existence of open water bodies. The relations of these vegetal elements to the climate, topography, and hydrography of the Hula Valley are discussed by Horowitz (1971). High percentages of pollen grains of Chenopodiaceae and *Artemisia* seem to indicate drier conditions and some salinity in the area.

The sector that overlies the Riss–Würm deposits of the Hulata Formation is not discussed here, as it is analyzed in much more detail in other boreholes discussed further on. It seems that pollen spectra of the Ayyelet HaShahar Formation, the formation penetrated by the lowest sector of the Emek Hula 1 Borehole, comprise almost 20% arboreal pollen, of which some are olive grains; Gramineae and Cyperaceae, which share 60% in both samples analyzed from 373 and 439 m; and a proportionate amount of open-field vegetation. These spectra are very similar to those of Recent sediments in the Hula Valley, discussed earlier. This sector was apparently deposited under Interpluvial climactic conditions.

The pollen spectra of the Benot Ya'akov Formation, penetrated by this borehole, except for the sample from 250 m, show that the extent of the forest was much greater than at present and comprised a considerable number of olives, together with *Pistacia* and other trees. The variety of species of the nonarboreal pollen assemblage of the four samples indicates humid climatic conditions. The low number of marsh vegetation pollens, and especially the low percentages of Gramineae and Cyperaceae, the low number of pollens derived from bank vegetation, and the occurrence of pollen produced by water plants, show that during the time of deposition of these four samples, the lake was greater in area than at present, on account of the area occupied by marshes. The pollen spectra indicate pluvial climatic conditions, and the sequence was deposited during the Riss Pluvial times. Especially indicative are pollen grains of *Fagus,* that are known from the Quaternary in Israel only in Riss Pluvial deposits. Similar pollen assemblages to those of the four samples, together with minor amounts of *Fagus,* were recovered from the outcrop of lacustrine deposits of Riss Pluvial age of the Benot Ya'akov Formation at the Gesher Benot Ya'akov outcrop south of Lake Hula, discussed earlier. The sample collected at 250 m within the sector represented by the four samples yielded a different pollen spectrum, which consists of about 50% Chenopodiaceae and *Artemisia,* representing a xerophytic and slightly halophytic environment. The low values of arboreal and marsh vegetation pollen also point to a dry climate, which it seems occurred in Israel during an interstadial within the Riss Pluvial, known also from some other localities in the world, which separates the Riss I from the Riss II pluvial phases (West 1968).

The uppermost two samples, from the Hulata Formation, are very poor in arboreal and open field vegetation pollen, which indicates a dry climate. The high percentages of pollen of bank vegetation together with the absence of pollen of water plants indicate that a lake did not exist during this time, and the area was covered entirely by marshes. The high percentages of Gramineae and Cyperaceae pollen also support this conclusion. Borehole K-Jam (Horowitz 1971), which is discussed further on, was drilled very close to the location of the Emek Hula 1 Borehole (Figure 6.17) and penetrated 123.50 m of sediments. Its lower part is very similar to that of these two samples. It seems that this sector was deposited under very dry and warm climatic conditions, somewhat drier and warmer than those at present, which prevailed in the area during the Riss–Würm Interpluvial. It seems therefore that the sequence penetrated by Emek Hula 1 Borehole, about 460 m, was deposited continuously in middle through late Quaternary times, during part of the Mindel–Riss Interpluvial, the Riss Pluvial, the Riss–Würm Interpluvial, the Würm Pluvial, and the Holocene. Deeper and older strata, such as the post-Mindel Yarda Basalt that is exposed not far from the borehole locality at the Gesher Benot Ya'akov outcrop, were not penetrated by this borehole and are expected to underlie the penetrated sequence. These strata would then overlie the Mindelian Mishmar HaYarden Formation at this locality (Horowitz *et al.* 1973). The assumption of Quaternary sedimentary fill of about 1600 m for the Hula Basin (Horowitz 1973; Yuval 1967) is further strengthened by palynostratigraphic conclusions from Emek Hula 1 Borehole. At this borehole the late-middle through late Quaternary is represented by almost 500 m of sediments. Since the sedimentary history of the Hula Basin probably dates back to the beginning of the Glacial Pleistocene (Horowitz 1973) a fill of about 1600 m is likely to exist in the area, conclusion also supported by gravimetric survey of the Hula Valley (Yuval 1967).

Pollen Diagrams from the Hula Basin

Horowitz (1971) has drawn up three pollen diagrams for boreholes drilled in the Hula Valley. The longest was obtained from a borehole that was drilled in the center of the Basin, K-Jam, which reached a total depth of 123.5 m, penetrating the Ashmura and the Hulata Formations. Two other boreholes were drilled in the northern part of the Hula Basin, reaching a depth of about 15 m each. Borehole UP-15 is the northernmost (Figure 6.17); it penetrated a well-developed sequence of the Mallaha Formation peat. Borehole UP-6, drilled at the southern end of the swamps not far from the lake, encountered a thin layer of peat overlying marls of the Ashmura Formation. The sequences penetrated in both boreholes are stratigraphically correlative, the difference in lithology being a result of the slow desiccation process of Lake Hula in which the lacustrine marls are deposited, and its substitution by marshes, depositing peat. The pollen diagrams obtained for the three boreholes are given in Figures 6.19, 6.20, and 6.21.

Pollen percentage curves for various significant trees are based on the sum of arboreal pollen. The main elements of the maquis are shown together on the same column to facilitate comparison. Higher values in the curve of the *Quercus* pollen seem to indicate increase of humidity and decrease of temperature. Its peaks are characteristic of pluvial climates. Pollen grains of *Quercus* were not identified to the species level because many of them are fractured or badly preserved. Peaks of *Quercus* seem to be accompanied by higher percentages of *Q. ithaburensis* grains. The curve of *Olea europaea* pollen shows quite an opposite picture. Peaks of that curve are typical, apparently, of a warm climate. Although olive is an insect-pollinated tree, its pollen grains are very abundant in the air. This was discerned from Recent sediments of Lake Kinneret, discussed earlier, and was also reported by Tas and Feinbrun (1962), from the airborne pollen spectra in the area of Jerusalem. Spectra with as much as 40% *Olea* pollen can be seen in the diagram, probably representing warm periods. *Pistacia* pollen grains, which could not be identified to the species level (see also Horowitz and Baum 1967), seem to be notably underrepresented in the pollen spectrum. This was also observed in the Recent sediments of Lake Kinneret. Similar underrepresentation of *Pistacia* pollen in sediments from Iran, where the tree is very common, is noted by Wright *et al.* (1967). The curve of *Pistacia* follows that of *Olea europaea,* its peaks indicating a warm climate. *Pinus halepensis* is apparently another indicator of a warm and dry climate. Today it grows in places that are warmer and drier than the places where oak grows, and these relationships between the two probably also existed in the past. (See also, Horowitz and Zak 1968 and van Liere 1966).

The pllen curve for bank trees represents mostly *Salix acmophylla* and *Populus euphratica*. Some grains of *Acer* and *Ulmus*, restricted in our region to river banks, are included as well. The bank vegetation was not much affected by climatic changes. These trees grow in a biotope which is not so much influenced by humidity and temperature changes as long as the river does not dry up. Changes in the curve of the bank trees reflect in a reciprocal way the percentage cover of the surrounding maquis or forest. Whenever the pollen production of the maquis increases, the curve of the bank trees drops, and vice versa. The pollen curve for Cupressaceae, which represents mainly *Cupressus sempervirens*, displays peaks under warm and dry conditions. This tree is today characteristic of the Mediterranean climate. *Picea* and *Cedrus libani* curves behave generally like the curve of the bank trees, probably for similar reasons: *Picea* and *Cedrus* grow in the high part of the Lebanese mountains, and a change in climate will only change the elevation of their vegetational belt, without changing considerably the area occupied by these trees. Thus, their pollen production is maintained at a more or less constant level, and hence spreading of the local maquis or forest will cause a drop in the curves of *Picea* and *Cedrus* due to partial or total masking. A curious phenomenon is thus apparent. A certain increase in percentage of northern elements points to a decrease of humidity and a possible rise in temperature, not the other way around, as might have been expected at first glance. In the last column of this group percentages are presented for pollen derived from various trees that are only minor elements in the spectrum. Interestingly enough, these include *Abies, Juglans, Castenea,* and *Corylus,* which do not grow in the country today. Their percentage, however, is insignificant, even in the older samples. The climax forest of the cool and humid pluvial period is believed to have been composed mainly of *Quercus ithaburensis.* During the warm and dry interpluvials a mixed maquis composed of *Quercus ithaburensis* and *calliprinos* together, *Olea europaea, Pinus halepensis,* and *Pistacia* formed the climax vegetation. The interstadials, warm and humid, were apparently characterized by a mixed forest or maquis, in which oaks and olives are the main trees, sharing almost equally the arboreal part of the pollen spectrum.

Pollen curves for open field vegetation are given under two columns in the pollen diagrams, as percentages of total grains counted and as percentages based on total nonarboreal pollen. In the diagram for K-Jam, pollen grains of batha plants are excluded, but this does not change the picture essentially because the amount of these elements is very small. Recent values for the open field vegetation curve are approximately 25% in both cases. The behavior of this curve is somewhat strange at first glance. In general it follows the arboreal pollen curve, but in some cases it takes an opposite trend. To explain this, the topography of the region and the water balance of the basin must be taken into consideration in addition to climatic factors. A slight increase in percentage of arboreal pollen is usually accompanied by a slight increase in the open field vegetation values, but a considerable increase in arboreal pollen is sometimes accompanied by a decrease in open field vegetation. This is possibly due to the fact that the vegetation cover is far less than 100% over the region. A slight increase in humidity, which may come together with a drop in temperature, causes at first spreading of both maquis and open field vegetation, together with an extension of the lake area, which consequently results in a decrease in the marsh vegetation part of the spectrum. Higher humidity causes further spreading of maquis, which becomes a true forest at the expense of the open field vegetation. An increase in open field vegetation may also be due to deforestation by humans, which enabled development of ruderal vegetation.

The pollen curve for marsh vegetation is based on the total number of counted grains and mainly includes pollen of Gramineae and Cyperaceae. This curve is characteristic of the relation between the area occupied by marshes and the area occupied by the lake in the closed Basin. The apparent contradiction in the decrease of marsh elements with an increase of humidity and higher open field and arboreal pollen values may be due to the topography of the basin. With a retreat of the lake, large areas of the former lake bottom become marsh. When the lake level rises and its shorelines advance toward the steep mountain borders of the basin, most of the marsh area becomes submerged. The possibility that reduction of marsh vegetation may result from improved drainage of the basin should be excluded since this would cause both the lake and the marsh area to diminish, as can be seen today after completion of the Hula Land Reclamation Project. A decrease in marsh vegetation pollen is then an indicator of higher humidity and water availability for maintaining the lake and possibly of a lower average temperature as well. This seems to be the only way to explain the partial contradiction between the pollen curves of arboreal and marsh vegetation.

The last group of pollen curves is of nonarboreal plants. In the first column a comparison is made between groups of ecological significance: hydrophil plants, Gramineae and Cyperaceae, *Thelypteris palustris* (which is sometimes given separately), and open field plants. The curve for batha vegetation is given usually in a separate column because of its low values. The curve for the total arboreal pollen calculated on the same basis, as a percentage of the total nonarboreal pollen, is given for comparison. The values for batha vegetation, so low as to have practically no significance, are probably due to the distance of that vegetation formation from the area of deposition. The plants are relatively low, which prevents long distance transport by winds. The pollen curve for hydrophil plants is also of little significance because of its low values. Mostly it follows peaks of the arboreal pollen curve, pointing to higher humidities. The plants whose pollen contribute to this curve grow on the outer rim of the marshes. The transport of their pollen to the Basin is partly obstructed by marsh vegetation, which is higher and stands in their way. This problem was treated in Denmark by Tauber (1965, 1967). An increase of humidity would cause some expansion of this vegetational belt. The curve for Gramineae and Cyperaceae reflects the extent of the marshes. Because of the great number of pollen produced by these plants and their proximity to the area of deposition they are highly overrepresented in comparison to other hydrophil plants. As already mentioned, the total area of marshes may have been smaller during pluvial periods, thus peaks in the Gramineae and Cyperaceae curves represent interpluvial conditions, while lows are probably indicative of pluvials. The curve for the spores of the fern *Thelypteris palustris* seems to be a good indicator of proximity to the shoreline of the lake. The spores of this fern, which grows only on the banks of the lake and rivers, are relatively heavy and are carried only by the water. Spores that come with rivers are deposited within the immediate vicinity of their outlet into the lake. The peak of this curve is considered, therefore, as indicating a nearby shore, or a river inlet.

Pollen curves for various nonarboreal plant groups are given separately at the end of each diagram, based on the total number of nonarboreal pollen. Peaks for Umbelliferae, Cruciferae, Papilionaceae, and Compositae indicate a humid, fairly cool climate. *Artemisia* and Chenopodiaceae pollen were much more frequent under dry conditions than they are today. *Rubus sanctus* and *Lythrum salicaria* curves attain peaks under humid conditions. Comparing these with the curve of *Thelypteris palustris*, which is also a plant growing on the shore, *Lythrum* and *Rubus* represent pollen grains that are relatively light and well carried by winds. While the distribution of *Thelypteris palustris* spores is confined to the near shore area, pollen of *Rubus* and *Lythrum* are dispersed all over the lake, better indicating true abundances, which are mainly controlled by humidity. The pollen curve for *Polygonum acuminatum* points to the location of a belt of these plants in the marsh area. These grains are very heavy, which limits their distribution. In samples taken in the middle of the lake they are practically absent.

The absolute ages presented in the tables and pollen diagrams (Figures 6.19–6.21; Tables 6.11–6.13) were calculated by interpolation from the rate of sedimentation, based on radiocarbon age determinations. The radiocarbon dates are given in the pollen diagrams. The rate of sedimentation in the marshes was found to be about 2.8 mm per year and in the middle of the lake about 1.6 mm per year. Compaction was probably more influential in the middle of the basin, where the sequence of sediments is considerably more extensive.

Borehole K-Jam Borehole K-Jam, which was drilled at the center of Lake Hula and penetrated down to 123.5 m, was divided according to the pollen diagram (Figure 6.19) into seven zones. The lowermost, from the total depth of 123.5 up to 95 m, was characterized by great poverty of pollen grains of arboreal and open field vegetation, low percentages of *Quercus* pollen relative to pollen of other trees, a high percentage of *Cupressus* pollen at the bottom, the presence of *Picea, Abies,* and *Cedrus,* and the occurrence of the thermophilous tree *Acacia albida.* The nonarboreal pollen group points to a vast area of marshes and decreasing area of the lake, which can be seen from the high percentages of Gramineae, Cyperaceae, and *Thelypteris palustris. Artemisia* pollen is present in low quantity, while percentages of hydrophil and open field plants are very low. This part of the section was probably deposited under warm and dry climatic conditions, somewhat drier and warmer than today, during the Riss–Würm Interpluvial. The next section of the diagram, from 95 up to about 82 m, displays a completely different picture. The arboreal pollen share exceeds 50% in places, and the proportion of *Quercus* pollen increases. Pollen of bank trees is totally absent. Pollen of *Olea europaea* shows some increase. The curve of open field vegetation increases as well, while the one representing marsh vegetation decreases. Pollen of northern trees disappear. In the nonarboreal section, a decrease of Gramineae and Cyperaceae is seen, while curves of other hydrophil plants display peaks. All these trends probably indicate that this part of the section was deposited under humid and cool, i.e., pluvial, conditions. The area of the lake was apparently much larger than at present, as was concluded from the absence of *Thelypteris palustris* spores, while a peak appears in the curve of *Rubus sanctus.* This stage is climatically comparable to the first stadial of the Würm Pluvial. The third zone, from 82 to about 50 m, is very poor in samples and only a very general picture could be drawn. Arboreal pollen comprise 20–25% of the spectrum; pollen of open field vegetation only slightly less. Pollen of marsh vegetation formed 50–60% of the total. *Quercus* is the main element among the tree pollen (60–70%), but olive pollen also appear in considerable numbers (10–20%) and *Picea* pollen occasionally appear. In the nonarboreal group, Gramineae and Cyperaceae prevail, together with water plants and *Thelypteris.* Pollen of hydrophil and open field plants are rare. It seems that this part of the section was deposited during the early-Middle Würm Interstadial, when the climatic conditions were not so extreme as during the interpluvial, but humidity was lower and temperatures somewhat higher than during the pluvial phase, indicated by Zone 2.

The fourth zone, extending from 50 to 35 m, displays

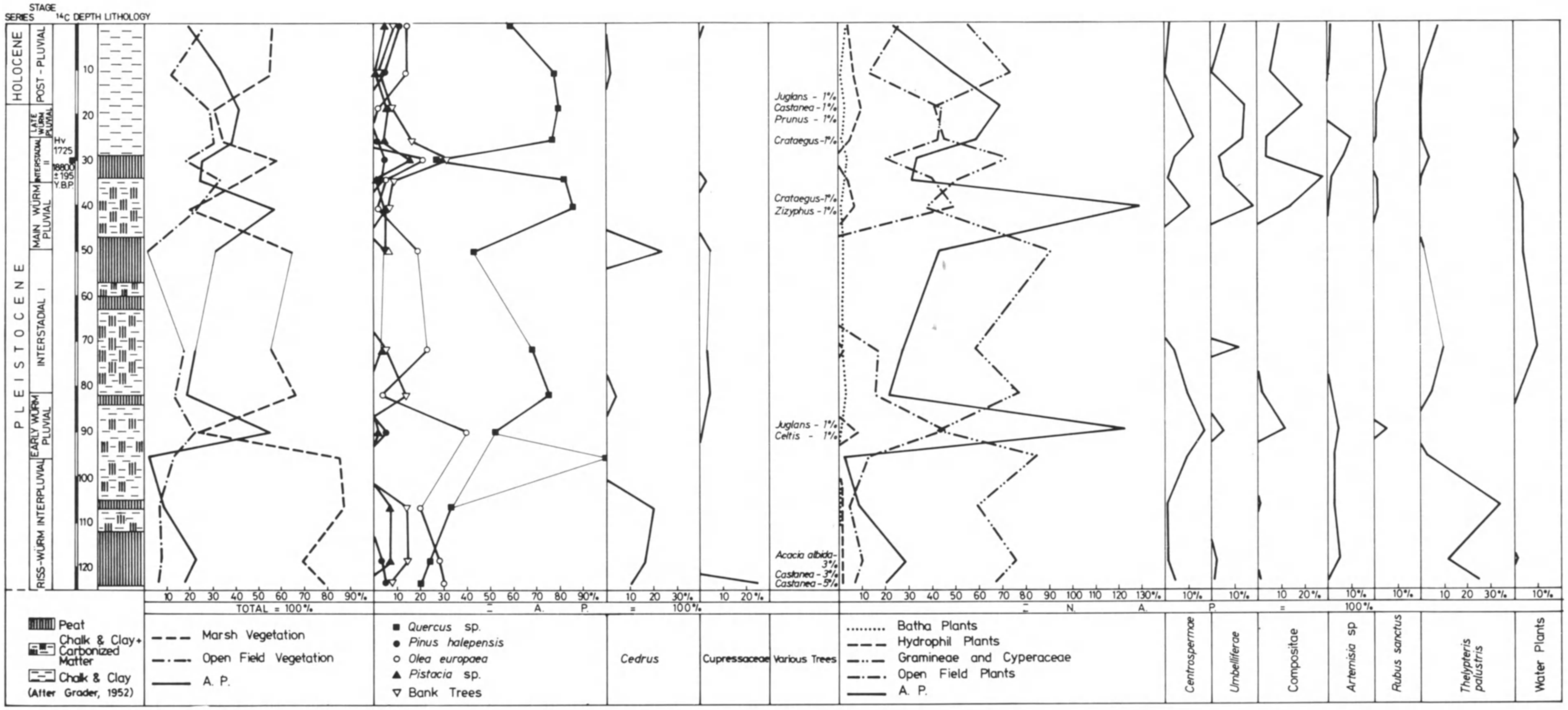


FIGURE 6.19. *Pollen diagram of the Hulata and Ashmura Formations, penetrated by K-Jam Borehole at the center of the Hula Lake. (From Horowitz 1971.)*

TABLE 6.11
The Main Paleoclimatic and Paleolimnologic Conclusions Drawn from the Pollen Diagram of Borehole K-Jam, Hula Valley[a]

Absolute age (Years B.P.)	Stage	Formation	Zone	Depth (m)	Main Palynological features	Climate	Extension of Hula Lake
	Holocene	Ashmura	7		A.P. low; O.F. medium; Gram. + Cyp. medium; mixed A.P. spectrum.	Warm and dry	Small
4500–5000				8	A.P. medium; O.F. medium; Gram. + Cyp. increasing; *Quercus* prevailing.	Warm and humid	Medium
11,000–12,000	Late Würm		6	18	A.P. high; *Quercus* prevailing; O.F. high; Gram. + Cyp. low.	Cool and humid–pluvial	Great
16,000–18,000	Middle–Late Würm Interstadial		5	25	A.P. medium, various components; O.F. medium; Gram. + Cyp. high; *Thelyp. pal.* medium.	Warm and humid–interstadial	Small
20,000–22,000	Middle Würm		4	35	A.P. high; O.F. high; Gram. + Cyp. low; *Quercus* prevailing.	Cool and humid–pluvial	Great
28,000–32,000	Early–Middle Würm Interstadial		3	50	A.P. medium; O.F. medium; Gram. + Cyp. high; *Thelyp. pal.* medium; *Quercus* and *Olea* prevailing.	Warm and humid–interstadial	Medium
45,000–50,000	Early Würm		2	82	A.P. high; O.F. high; Gram. + Cyp. low; *Quercus* prevailing.	Cool and humid–pluvial	Great
60,000–70,000	Riss–Würm	Hulata	1	95 123.5	A.P. very low, various components; O.F. very low; Gram. + Cyp. prevailing; *Thelyp. pal.* high.	Warm and dry–interpluvial	Small

[a] From Horowitz (1971).

once more evidence for pluvial climatic conditions. The main features are similar to those described above for the Early Würmian zone, but somewhat more marked. The forest vegetation comprises mainly *Quercus* with only minor contributions by other trees. The open field vegetation is rich in species and shows high percentages within the nonarboreal spectrum, and the same holds true for hydrophil vegetation. Gramineae and Cyperaceae decrease considerably. This zone was deposited during the Middle Würm, or Pleniglacial II Phase, when pluvial conditions prevailed in the region. The areal extension of the lake at that time was relatively great. The fifth zone, from 35 to about 25 m, probably indicates another interstadial. Open field plants show a decrease in values, arboreal pollen and those of hydrophil plants are prominent, while Gramineae and Cyperaceae, *Artemisia, Thelypteris,* and Cupressaceae curves display peaks. The forest changes to maquis. *Quercus* decreases, while *Olea, Pistacia,* and pines increase their proportions. The lake was very small, or perhaps nonexistent, during these times. Sediments deposited at the time in the vicinity of K-Jam consist almost entirely of peat, of the type that develops today in the marshes. Radiocarbon analysis yielded an age of about 18,800 ± 195 years B.P. for a sample collected from a depth of 30 m. This section was deposited at a time corresponding to the interstadial that separated the Main Würm from the Late Glacial in Europe. Climatic conditions in the Hula area at that time

TABLE 6.12
Paleoclimatic and Paleolimnologic Conclusions Drawn from the Pollen Diagrams of Boreholes U.P. 6 and U.P. 15, Hula Valley[a]

Depth (m)	Main Palynological features	Climate	Absolute age (based on C^{14})	Stage	Extension of Lake Bula
	A.P. low; O.F. low; Gram. + Cyp. high; Mixed A.P. spectrum.	Warm, humidity increases		Sub-Atlantic	Small
6.5			2200–2500		
	A.P. decreasing; O.F. decreasing; Gram. + Cyp. increasing; Bank trees increasing.	Warm and dry		Sub-Boreal	Small
11–12.5		Short warm and dry phase	4500–5000		
	A.P. high; O.F. high; *Quercus* and *Olea* prevailing; Gram. + Cyp. medium.	Warm and humid		Atlantic	Medium

[a] From Horowitz (1971).

were warm and humid, typical for an interstadial within a pluvial period in northern Israel. The sixth zone, from 25 up to approximately 18 m, is characterized by pollen spectra representing the last phase of the Würmian Pluvial. It was not as extreme as the two preceding pluvial phases, but the climatic conditions are colder and more humid than those at present. This is once more shown by peaks in open field vegetation and arboreal vegetation, especially of oak. The termination of Zone 6 marks the transition from the Pleistocene into the Holocene, about 11,500–12,000 years B.P.

The uppermost zone, from 18 m to the surface, could be divided into two parts, but the boundary between them could not be placed accurately because of the relatively restricted number of samples available. This part of the section was studied in more detail in the two shallow boreholes UP-15 and UP-6, which will be discussed next. The lower part reflects a climate that was more humid than at present. The oak forest still existed as such, while the areas of open field and hydrophil vegetation began to decrease. Gramineae and Cyperaceae, on the other hand, began to increase, and so did *Thelypteris palustris*, proba-

TABLE 6.13
Late Pleistocene–Holocene Paleoclimates and Vegetation of the Hula Valley Surroundings, Based on Pollen Diagrams

Absolute age (Years B.P.)	Stage			Climate	Vegetation
	Holocene	Post-Pluvial	Sub-Atlantic	Warm, somewhat humid	Mediterranean maquis
2200–2500					
			Sub-Boreal	Warm and dry	
4500–5000					
			Atlantic	Warm and humid	Oak and olive forest
7000–7500					
			Boreal	Warm and dry	Mediterranean maquis
9500–10,000					
			Pre-Boreal	Warm, somewhat humid	
11,500					
	Late Pleistocene	Würm Pluvial	Late Würm	Cool and humid–pluvial	Oak forest
16,000–18,000					
			Interstadial	Warm and humid–interstadial	Oak and olive forest
20,000–22,000					
			Middle Würm	Cool and humid–pluvial	Oak forest
28,000–32,000					
			Interstadial	Warm and humid–interstadial	Oak and olive forest
45,000–50,000					
			Early Würm	Cool and humid–pluvial	Oak forest
60,000–70,000					
		Riss–Würm Interpluvial		Warm and dry–interpluvial	Poor Mediterranean maquis

bly as a result of the shrinkage of the lake. At a depth of 7–9 m there are indications that the forest was changing to the present-day maquis, and the lake reached its present-day configuration. Horowitz (1971) concludes therefore (see also Tables 6.11 and Table 6.13) that the sequence penetrated by the K-Jam Borehole, namely the upper part of the Hulata Formation and the entire Ashmura Formation, including the latter's uppermost part, which corresponds in time to the Mallaha Formation in the north, represents a continuous section from Riss–Würm Interpluvial times to the present. The glacial and interglacial intervals, known from Europe, have been recorded in the pollen spectra as pluvial and interpluvial and the main interstadials have been recorded as warmer intervals within the cooler pluvial.

Boreholes UP-15 and UP-6. These two boreholes, drilled in the south and in the center area of the marshes north of Lake Hula (Figure 6.17) yielded similar pollen diagrams, with the same bearings, trends, and fluctuations (Figures 6.20 and 6.21). This showed that local conditions have not masked considerably the regional picture, and that pollen spectra recorded in sediments at one locality could be taken as representative. Samples from UP-15 were radiocarbon dated and an account follows of this borehole, while UP-6 will not be discussed further. Both boreholes encountered about 15 m of the topmost sediments of the Hula Valley. The results are summed up in Table 6.12. The lowermost sector of the section penetrated by UP-15, from 15 m up to about 12.5 m, is characterized by arboreal pollen that form about 35% of the total spectrum and consist of equal quantities of *Quercus* and *Olea europaea* pollen. *Pistacia* pollen are present. Pollen of open field vegetation are represented by a great number of species and point to a considerable distribution. The values of *Thelypteris* spores are low. The climate is concluded to have been warm and humid, and this part of the sequence was apparently deposited 7000–5000 or 4500 years B.P., during the Atlantic Stage of the Holocene. This is also supported by a radiocarbon age of 4565 ± 75 years B.P., obtained for a sample from 11.25 m. At a depth of about 12 m, a brief dry phase took place, after which humidity increases but not to the extent of the former, Atlantic Stage. This dry phase possibly caused shrinkage of the lake, which is indicated by a peak in the *Thelypteris* curve and the beginning of peat deposition. It indicates the beginning of the Subboreal Stage, which is characterized by pollen spectra indicating a warm and dry climate. Sediments were deposited during the Subboreal Stage down to a depth of 7.5 m in this borehole. A short, wet phase marks the beginning of the Subatlantic Stage at a depth of about 7 m. It is recorded in the curve of *Thelypteris* as a peak which shows, in this case, an increase in the area of the lake. The beginning of this phase is estimated to be around 2500 years B.P. It should be noted that the *Thelypteris* curve shows peaks that indicate only the distance from the lake shore. If the borehole was drilled in an area that was then marsh, the peak will indicate increasing size of the lake, while if it was drilled in the lake area, a peak will indicate that the size of the lake is decreasing. Therefore this curve should be interpreted with some caution. From 2500 years B.P. to the present, the climate has been somewhat more humid than it was during the Subboreal, which is indicated by a slight increase in the oak percentage of the arboreal pollen. This section, from about 6.5 m and up to the surface, was deposited during the Subatlantic, the latest stage of the Holocene. The two boreholes therefore penetrated sequences deposited during the last 7000 years, representing a part of the Atlantic, the Subboreal, and the Subatlantic stages of the Holocene.

To sum up the environmental conditions in the Hula Valley and surroundings during approximately the last 80,000 years, the following picture emerges (Table 6.13). Earlier than 60,000–70,000 years ago, during the Riss–Würm Interpluvial, the climate was warm and dry, somewhat warmer and drier than the present. The lake barely existed, and the area for the most part was covered by marshes. Arboreal vegetation was very poor and apparently comprised a border garigue, with some scattered Mediterranean maquis trees. From 70,000–60,000 up to about 50,000–45,000, during the Early Würmian Stadial, the climate was cool and humid and the lake extended far beyond its present-day limits. The arboreal vegetation comprised an oak forest, most likely with some northern elements such as *Cedrus libani.* From 50,000–45,000 up to 32,000–28,000 an interstadial is indicated, with a warm and humid climate. The lake's area shrank somewhat and the arboreal vegetation comprised a well-developed Mediterranean maquis, mainly consisting of oaks and olives. From 32,000–28,000 up to about 22,000–20,000, the Middle Würmian Stadial, of a cool and humid climate, prevailed, in which the vegetation and lake behaved in the same manner as during the preceding Early Würmian phase. From 22,000–20,000 up to 18,000–16,000 another interstadial, warm and humid, is recorded, once more with a slight shrinkage of the lake and development of a Mediterranean maquis with oaks and olives, while the Late Würtman Stadial is recroded from 18,000-16,000 up to about 12,000 years ago. The climate was once more cool and humid, the lake expanded once more, and the oak forest took its place on the surrounding hills and mountains. From about 12,000 up to about 7,000 years ago, the climate became much warmer and drier than before and the lake shrank considerably. The Mediterranean maquis took its place once more on the surrounding hills, apparently in much the same pattern as at present. The Atlantic Stage of the Holocene, which took place from 7500 up to about 5000 or 4500 years ago, was characterized by a warm and humid climate, by some increase in the lake area, and by quite an increase in the proportion of oaks in the maquis vegetation. About 4500

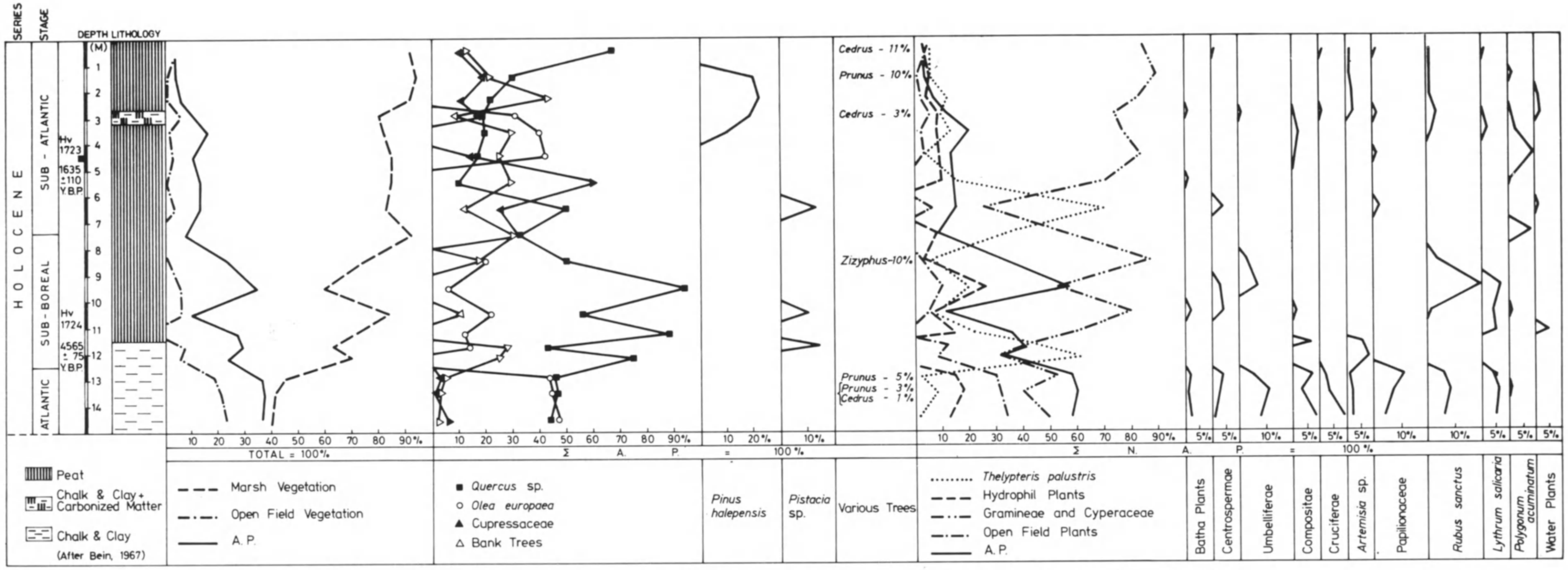


FIGURE 6.20. *Pollen diagram of the upper part of the Ashmura Formation, penetrated by U.P. 6 Borehole just north of the Hula Lake. (From Horowitz 1971.)*

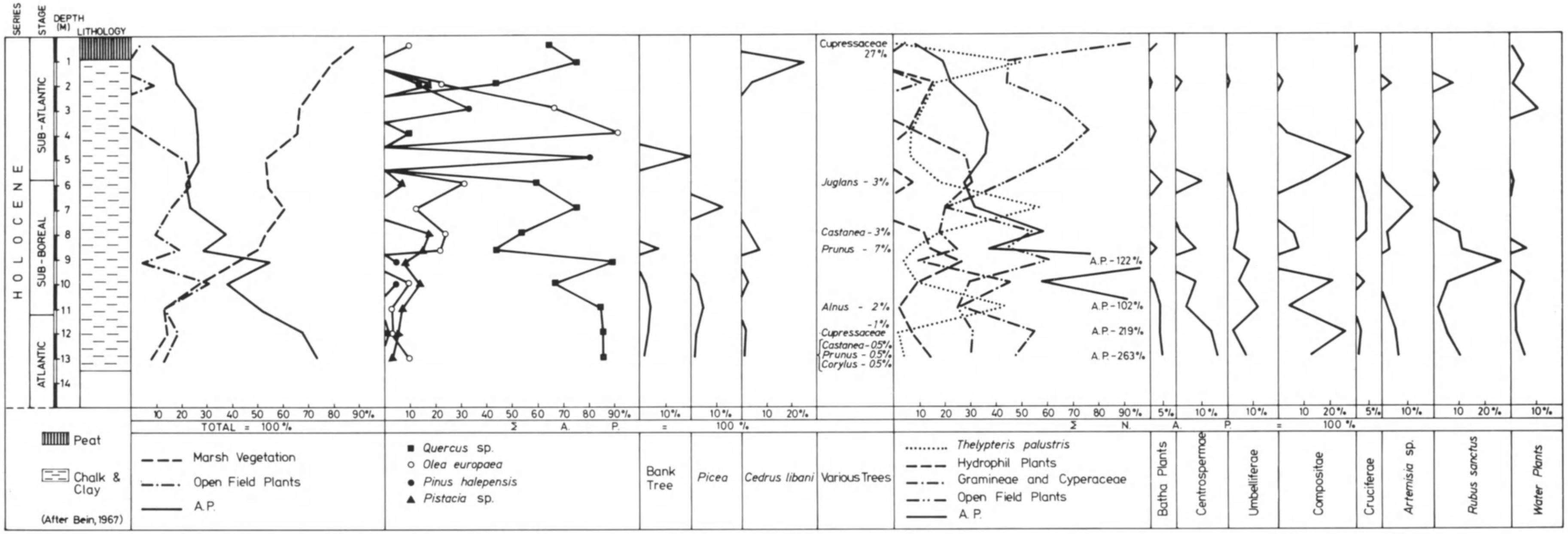


FIGURE 6.21. *Pollen diagram of the Mallaha Formation, penetrated by U.P. 15 Borehole, north of the former Hula Lake. (From Horowitz 1971.)*

years ago, the climate deteriorated again, the lake shrank to its present-day configuration, and the vegetation became once more of the typical Mediterranean type, which occupies the area today.

CENTRAL JORDAN VALLEY

The Quarternary sequence of the Central Jordan Valley comprises the Cover Basalt of Preglacial Pleistocene age, of more or less the same nature as this formation appears in the Northern Jordan Valley. The downfaulting of the rift valley at the beginning of the Glacial Pleistocene and subsidence of the valley floor resulted in accumulation of a suite of formations, grouped together under the term "Jordan Group" (Horowitz 1974). While most of these are lacustrine formations, two are fluviatile and two are volcanic. The Jordan Group comprises a sequence of several hundred meters. The subsidence of the rift valley floor in the Central Jordan Valley was less extensive than at the Hula Valley. Lowermost in the sequence is the Erk el-Ahmar Formation, mainly of lacustrine nature, interfingering with some conglomerate and paleosol horizons. It is unconformably overlain by the Ubeidiya Formation, for which four members are known, two of them lacustrine and two fluviatile or terrestrial. The Ubeidiya Formation is strategically overlain by the Yarmouk Basalt, which yielded an age of about 680,000 years (Siedner and Horowitz 1974). The Naharayim Formation (Picard 1943), of fluviatile nature, covers the Yarmouk Basalt and is in turn covered by the Raqqad Basalt, which is overlain by the lacustrine Lisan Formation. The deposition of the Lisan Formation ceased abruptly about 18,000 years ago due to a tectonic subsidence of the Dead Sea in the south and the formation of Lake Kinneret. In the southern part of the Central Jordan Valley, at the Bet She'an area and further south toward the Southern Jordan Valley, the upper Lisan Formation comprises a sheet of conglomerates and loams of fluviatile origin, the Fatza'el Member. In the Lake Kinneret Basin, the Tabgha Formation began to be deposited about 18,000 years ago, and is still deposited at present.

All the formations, except the Fatza'el and the Tabgha, which overlie the Lisan conformably, are separated by unconformities. The Erk el-Ahmar and Ubeidiya Formations are separated by an erosional unconformity and are both separated from the overlying formations by an abrupt angular unconformity. The Naharayim Formation rests on this angular unconformity and is in turn separated from the Lisan Formation by an erosional unconformity (Horowitz 1974).

Outcrops of the Jordan Group

Pollen analyses were carried out for samples collected from all the formations comprising the Jordan Group, but a pollen diagram is available only for the sequence of the Tabgha Formation. This is mainly due to the bad state of preservation of pollen grains in most of the outcrops of these formations, because of oxidation. Therefore, only the general nature of conditions at the time of deposition of these formations could be estimated. A sample collected in 1972 by E. Tchernov of the Department of Zoology, Hebrew University, Jerusalem, from the Erk el-Ahmar Formation, consisting of an organic clay, yielded the following pollen spectrum: arboreal pollen 29%, comprising only oak and questionable occurrences of *Corylus* and *Picea*, nonarboreal pollen comprising 38% Umbelliferae, 21% Gramineae and Cyperaceae, 2% Liliaceae, 3% Chenopodiaceae, 2% Compositae, 2% *Artemisia*, 2% *Ephedra*, and 2% Papilionaceae. The relatively high percentage of oak grains, being the sole constituent of the arboreal pollen spectrum in this area, seems to indicate a pluvial climate, with oak forest growing on the hills surrounding the Erk el-Ahmar Lake. The high percentages of open field vegetation, and especially Umbelliferae, point most probably to considerable areas occupied by this kind of vegetational formation, such as the present-day Yizre'el and Central Jordan valleys.

A very rich pollen spectrum was yielded by a peaty layer within the Ubeidiya Formation, No. 3-12 (Picard and Baida 1966) which was collected by O. Bar-Yosef, Department of Archaeology, Hebrew University, in 1969. Results of this analysis were published in Bar-Yosef and Tchernov (1972). Several leaf impressions of *Pistacia lentiscus*, *Rhus tripartita*, and *Myriophyllum spicatum* were also recovered from the Ubeidiya Formation by Lorch (1966), but due to the very restricted number of specimens, they seem to be of little significance. The pollen spectrum reads as follows: arboreal pollen 84%, of which oak comprises 81%, juniper 2%, and *Olea europaea* 1%; nonarboreal pollen 16%, of which Gramineae and Cyperaceae form 12%, Umbelliferae 1%, Cruciferae 1%, Compositae 1%, and *Rubus*, Papilionaceae, Chenopodiaceae, and Malvaceae together 0.5%. This spectrum undoubtedly represents pluvial conditions. The striking prevalence of oak pollen over all other constituents, even through the sample analyzed was peat, in which quite a number of locally derived pollen grains should have been found, seems to justify this conclusion. A pollen spectrum recovered from a sample collected from the Naharayim Formation, not far from the old Ruthenberg Power Plant (Horowitz, unpublished data), contained 45% arboreal pollen, of which *Quercus* comprised 40%, *Populus* 2%, *Salix* 2%, and *Fagus* 1%. Nonarboreal pollen comprised 55%, of which Gramineae and Cyperaceae formed 24%, Umbelliferae 6%, *Artemisia* 7%, Chenopodiaceae 9%, Papilionaceae 3%, *Centaurea* 3%, *Rubus* 0.5%, *Typha* 2%, and Labiatae 0.5%. This pollen spectrum once more probably represents pluvial conditions, with oak forest prevailing over the surrounding hills. The occurrence of *Fagus* pollen grains, although in minor quantity, seem to point to a Rissian age for this Formation, which is also justified by other stratigraphic data (Horowitz 1974). A pollen spectrum from the upper part of the Ami'az Member of the Lisan Formation in the Central Jordan Valley, collected near the Jordan River, not far from Newe Etan (Horowitz, unpublished data) contained 34% arboreal pollen of which *Quercus* is 30%, *Olea europaea* 1%, *Populus* 2%, *Pistacia* 0.5%, and *Salix* 0.5%. The nonarboreal pollen spectrum for this sample comprises 66%, of which Chenopodiaceae is 15%, Umbelliferae 7%, *Ephedra* 3%, *Artemisia* 15%, Compositae 10%, Crucifereae 3%, Gramineae and Cyperaceae 12%, and *Rubus* 1%. This pollen spectrum again indicates pluvial climatic conditions with a prevailing oak forest, but it is most likely influenced by the surrounding, somewhat salty marshes of the Lisan Lake, with a halophyte vegetation comprising mainly Chenopodiaceae and *Artemisia.* The salinity of the Lisan Lake apparently has nothing to do with climatic conditions, but rather with the uplifting of the salt plug of Mt. Sedom, which has partly dissolved in the water of the Lake (Zak 1967).

Pollen spectra of the Fatza'el Member (Alon 1976) will be discussed in more detail in the chapter dealing with pollen analyses of prehistoric sites, since most of its horizons contained numerous flint implements. A generalized pollen spectrum reads as follows: arboreal pollen 30%, of which *Quercus* is 11%, *Pinus halepensis* 9%, *Olea europaea* 8%, and *Acacia* 2%. Nonarboreal pollen forms 70%, of which Compositae is 22%, Gramineae 25%, Chenopodiaceae 9%, Liliaceae 4%, *Plantago* 2%, *Poterium spinosum* 2%, and others 6%. The samples of the Fatza'el Member that yielded the above pollen spectrum were collected in the northern part of the Southern Jordan Valley, near the settlement of Fatza'el. The Recent arboreal figure for this area is only 5%, of which *Pinus halepensis* and *Olea europaea* are the main constituents. It is therefore quite clear that a value of 30% for the fossil arboreal pollen indicates a pluvial climate. The pluvial climate, which in the north was characterized by a prevalence of oak over all the other arboreal constituents, is characterized southward by a mixture of oak, pine, and olive in the forest. The nonarboreal vegetation in this area during pluvial times resembled more or less that of the present, but was much better developed and covered a much greater area.

Tabgha Formation

A pollen diagram for the Tabgha Formation sediments, drilled in Lake Kinneret, is given by Horowitz (1971). Depths are given from below the water surface, and the water depth was 14 m at the place of boring. A sequence of 16 m of the Tabgha Formation was penetrated by Borehole D-1016-2 and was divided by Horowitz into four zones (Figure 6.22). The lowermost, from 30 to 27 m, is characterized by low arboreal pollen percentages, by medium open field vegetation values, by medium Gramineae and Cyperaceae values, and by high values of Compositae; this profile represents a warm and dry climate. The second zone, from 27 to 23 m, is characterized by high arboreal pollen percentages, by low open field vegetation, by high Gramineae and Cyperaceae, and by low Compositae. This probably represents a cool and humid climate, when the forest was quite well developed, and savannahs of grasses and *Zyziphus* were growing around Lake Kinneret. The third zone, from 23 to 19 m, shows a marked decrease in the arboreal pollen curve, an increase in the open field vegetation curve, and medium values for Gramineae and Cyperaceae. The Compositae rate is rather high. This zone represents once more a warm and dry climate. The fourth zone, from 19 to 14 m, is marked by an increase in the arboreal pollen value, and some decrease in open field vegetation, Gramineae, Cyperaceae, and Compositae values. A marked increase of the arboreal pollen curve is seen at about a depth of 18 m, then a decrease toward 17 m, and another increase, mainly by higher percentages of pine, *Pistacia,* and some Cupressaceae. The first peak in this zone, at a depth of about 18 m, comprises high percentages of *Olea europaea* accompanied by almost similar percentages of oak. This resembles an interstadial spectrum from the Hula Valley, while it seems that the second peak, which goes up to the surface, represents some influence of human forestation activities, especially the high percentages of *Pinus halepensis.* As a net result, it seems that the arboreal pollen values for this uppermost part of the diagram should be somewhat reduced.

Based on radiocarbon dating of shells from a depth of 18–18.5 m in D-1016-2 Borehole, which gave 2370 ± 90 years B.P., Horowitz concluded in 1971 that it represents approximately the last 10,000 years, or roughly almost the entire Holocene. It now seems that this conclusion is not valid, and the sequence penetrated by this borehole should be taken as representing the last 18,000 years. The reason for the rather young date for shells collected from 18 to 18.5 m must be sought in the warm, saline springs that are known from the vicinity of this borehole. These springs (Mazor 1962) are known to be radioactive, which probably resulted in a much younger age for the shells analyzed. The influence of the saline springs can also be seen in the pollen diagram by some percentages of redeposited spores of Pliocene age, presented in the first column of the diagram and appearing almost continuously along the entire borehole. It is suggested therefore that the lowermost zone of the borehole represents the Middle-Late Würm Interstadial. The second zone, with the high arboreal pollen values, represents the Late Würmian Stadial in this area, while the upper two zones represent the Holocene. The first, rather warm and dry period represents the Preboreal and Boreal stages, which are also known to be quite warm and dry from the Hula Valley data, while the uppermost zone represents in its lower part the peak for the Atlantic Stage, in which oak

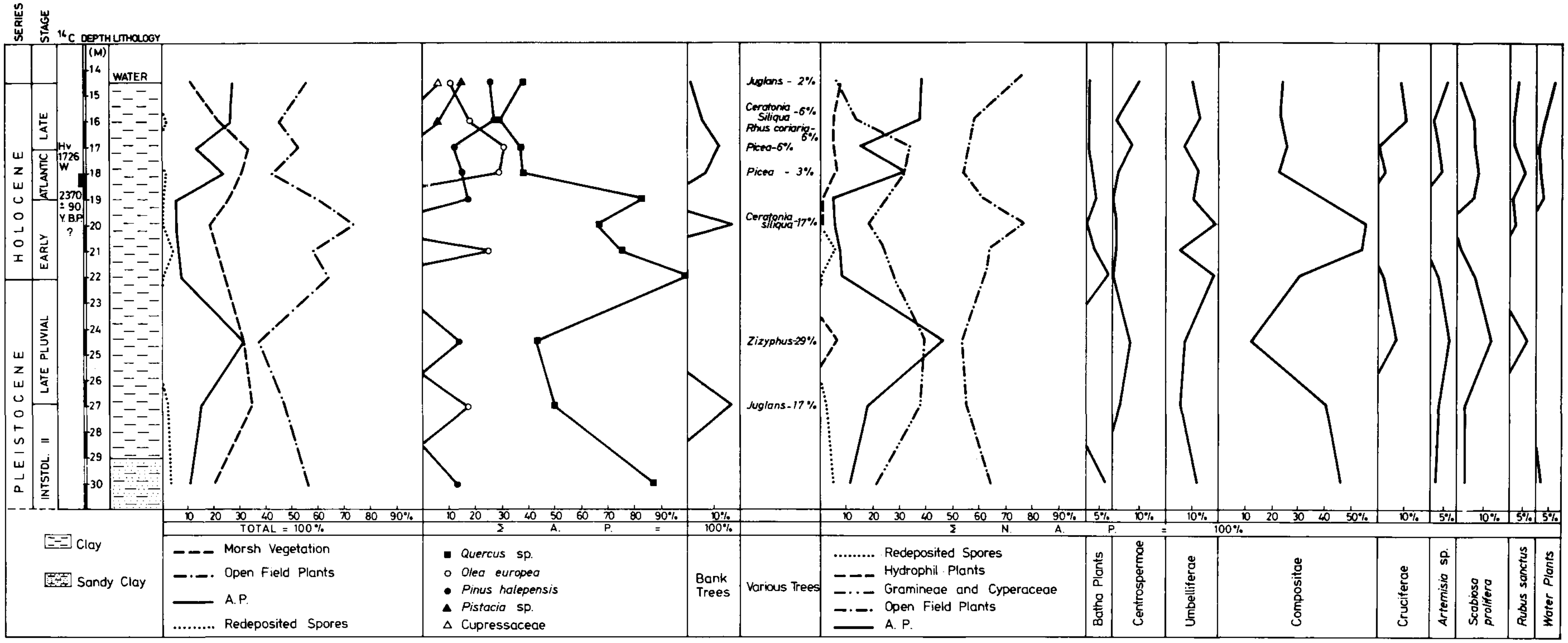


FIGURE 6.22. *Pollen diagram of the Tabgha Formation sediments, penetrated by D-1016/2 Borehole, Lake Kinneret. (From Horowitz 1971.)*

and olive prevailed in the surrounding maquis, while the upper part represents some desiccation which took place subsequently.

Another sequence of the Tabgha Formation was penetrated by D-1021-1 Borehole, which was also drilled under 14 m of water and reached the base of the Formation at 36 m. Unfortunately, this borehole was not adequately sampled and only four samples have been analyzed, representing quite wide intervals in the borehole. The depths and results of the analyses are given in Table 6.14. The sequence was divided into two parts, the upper one from the top down to about 30 m, which yielded pollen spectra typical for the Holocene. The lower part is considerably richer in arboreal pollen among which *Quercus* prevails. Compositae show much lower values than in the upper section. This part of the section was probably deposited during the Late Würmian Pluvial phase, which commenced some 18,000–16,000 years ago and came to an end some 12,000 or 11,500 years ago, with the beginning of the Holocene.

TABLE 6.14
Pollen Spectra of Samples from Borehole D-1021-1, Lake Kinneret[a]

	Depth (m) (Water depth—14 m)			
	21.5–25.5	25.5–29.5	29.5–31.5	31.5–36.5
Arboreal pollen				
Quercus sp.	22	14	28	26
Olea europaea	1	4	0.5	1
Pinus halepensis	—	1	—	—
Pistacia sp.	0.5	1	2	1
Cupressaceae	—	—	—	1
Cedrus libani	—	1	—	0.5
Picea sp.	—	—	—	0.5
Ceratonia siliqua	—	—	0.5	—
Abies sp.	—	—	—	0.5
Salix acmophylla	—	—	1	2
Populus euphratica	1	—	1	2
Tamarix sp.	—	1	—	—
Total arboreal pollen	24	21	33	32
Nonarboreal pollen				
Asphodelus sp.	—	—	1	—
Ephedra sp.	1	—	2	1
Liliaceae	0.5	1	—	—
Phlomis type	0.5	—	—	—
Centrospermae	7	10	5	8
Umbelliferae	11	5	5	8
Compositae	5	32	3	4
Cruciferae	1	—	1	1
Artemisia sp.	8	1	6	8
Scabiosa prolifera	—	1	—	—
Papilionaceae	—	2	1	0.5
Convolvulaceae	—	1	—	—
Centaurea sp.	1	—	—	1
Gramineae	29	21	41	33
Cyperaceae	8	4	1	3
Rubus sanctus	2	1	—	1
Typha angustata	0.5	—	—	0.5
Plantago sp.	1	—	—	—
Ranunculaceae	0.5	—	—	—
Mentha type	0.5	—	—	0.5
Potamogeton sp.	1	—	—	—
Ranunculus aquatilis	—	—	1	—
Total nonarboreal pollen	75	78	67	68
Redeposited grains	—	—	—	1
Total number of counted grains	248	140	283	335

[a] From Horowitz (1971).

DEAD SEA BASIN

The Quaternary sequence of the Dead Sea Basin is little known. Since it is the terminal depositional basin in the Jordan Rift Valley system, an extensive amount of sediments was accumulated there during the Quaternary. These are totally buried, and only the youngest Quaternary formations crop out in the Dead Sea area. The rest of the sequence is only known from several deep boreholes that were drilled in the 1950s and 1960s, in search for oil. Of these, only three boreholes (Figure 6.17) penetrated the entire Quaternary sequence. The first, Arava No. 1, was drilled about 22 km south of the Dead Sea, in the sebkha area, and penetrated 1700 m of marginal facies conglomerates, coarse sandstones, and grits, sediments which are practically of no use for palynological analysis. The second borehole, En Gedi 2, was drilled near the settlement of En Gedi, on the western margins of the Dead Sea. This borehole penetrated down to about 1500 m, of which the deepest 200 m are probably of Pliocene age, containing some rare foraminifera. The Quaternary sequence comprises mostly lacustrine marls, interfingering with conglomerates. A series of boreholes drilled near Mezada down to 800 m also encountered alternations of marls and conglomerates, with some salt tongues in the sequence. These boreholes did not reach the Pliocene. The most complete sequence was penetrated by Melekh-Sedom 1 borehole, drilled in 1968 in the center of the southern basin of the Dead Sea. This borehole penetrated about 3.5 km of mostly lacustrine sediments, clays, shales, and silts, of which the lowest kilometer probably represents the late Pliocene Amora Formation. Both the En Gedi 2 and Melekh-Sedom 1 boreholes, together with several samples from the Mezada boreholes, have been analyzed palynologically; unfortunately the samples are quite widely spaced so that no detailed pollen diagram could be drawn.

The late Quaternary is much better represented in the Dead Sea area, where a series of Würmian sediments crops out. These are defined as part of the Lisan Formation, comprising three members: the lower, clastic, Hamarmar Member, the middle, Ami'az Member, composed of finely laminated marls and aragonite, and the upper, fluviatile Fatza'el Member. Only the Hamarmar Member, analyzed by Rossignol (1969b), yielded pollen spectra that were sufficient for drawing a profile. The "Graben Fill," of Pliocene through Recent age, was designated as the Dead Sea Group (Neev and Emery 1967). The Quaternary part of this sequence was designated by Horowitz (1974) as the Upper Dead Sea Group. Sediments that have accumulated in the Dead Sea itself, since the termination of the Lisan Lake, have been temporarily called the "Unnamed post-Lisan Sediments," and represent a chronostratigraphic equivalent of the Tabgha Formation of Lake Kinneret. Pollen analyses of En Gedi 2 Borehole (Horowitz 1966a) have shown two pollen and spore associations, alternating along the section. The first is characterized by abundance of pollen grains of *Quercus* and Chenopodiaceae, and the appearance of other arboreal pollen grains, such as *Moringa aptera, Pistacia, Tamarix*, and others; pollen grains of open field plants are also quite abundant and comprise Compositae, Euphorbiaceae, Crucifereae, *Ephedra*, Labiatae, Papilionaceae, Umbellifereae, and others. In the lower part of the sequence, this association is also accompanied by fern spores, which have probably been redeposited from the dissolved Pliocene salts of the Sedom Formation, which is known to contain these spores (Horowitz and Zak 1968). This association most presumably indicates a pluvial period, with higher humidity and a slightly cooler climate than that dominating the Dead Sea region today. The other association is dominated by pollen grains of Chenopodiaceae, but sometimes *Artemisia* is also abundant. Other pollen grains are present but rare, and only a few arboreal pollen could be detected. This palynological association seems to represent the interpluvials.

Pollen analyses of the Melekh-Sedom 1 Borehole, although quite widely spaced, give a more systematic picture. The results are summarized in Table 6.15 and Figure 6.23 (Horowitz 1968b). The upper part of the sequence penetrated by this borehole, from the surface down to about 2000 m, is quite rich in pollen grains of *Quercus*, probably *Quercus calliprinos* and *Quercus ithaburensis*. These two oak species are the main components of the present Mediterranean maquis. *Tamarix*, which grows along rivers, is also common in this part of the sequence. Nonarboreal plants are represented mainly by the families Chenopodiaceae, Compositae, and Gramineae, and the genera *Artemisia, Ephedra*, and *Centaurea*. The sequence between 2000 and 2600 m is devoid of any identifiable pollen grains, while the sequence below 2600 m yielded typical pollen assemblages of the Pliocene Amora Formation. It is suggested that the sequence from 2600 m and up to the surface represents the Upper Dead Sea Group of Quaternary age. There are several indications of climatic changes along the sequence of Melekh-Sedom 1 Borehole (Figure 6.23), including variations in oak pollen percentages, appearances and disappearances of pollen grains derived from trees like *Olea, Picea, Pistacia, Fagus, Juglans*, and others. These variations, indicating mostly changes of humidity, are typical of the pluvials of the Quaternary in Israel. Pollen assemblages from Melekh-Sedom 1 present almost the same picture as that recorded from the En Gedi 2 Borehole, for its upper 1400 m. Apparently, the upper 1400 m of Melekh-Sedom 1 correspond to the upper 1300 m of En Gedi 2. This correlation was based mainly on a horizon in which fern spores are quite common, from 830 m down to 1280 m in Melekh-Sedom 1, which occurs in En Gedi 2 at 800–1000 m, in core 2 of Borehole JEC-9, and in the Mezada group of boreholes, at depths of 400–600 m. Pollen grains of *Picea* appear in Melekh-Sedom 1 at

TABLE 6.15
Pollen Spectra from Melekh Sedom 1 Borehole, Drilled in the Southern Basin of the Dead Sea

	Depth of sample (m)																								
	95	186	274	366	469	552	643	823	917	1000	1100	1189	1283	1372	1466	1554	1643	1737	1829	1945	2603	2899	3002	3374	3468
Arboreal pollen																									
Pinus	2	—	—	—	—	—	—	—	0.5	—	—	—	—	—	—	—	—	—	—	—	1	29	38	—	—
Picea	—	—	—	—	—	—	—	—	0.5	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cupressus	—	—	0.5	1	—	5	—	—	3	—	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Quercus	3	20	23	6	38	13	13	34	13	20	18	13	26	17	16	19	20	21	6	10	14	6	1	—	—
Olea	—	1	1	1	—	3	—	2	5	—	—	—	—	—	—	—	—	—	—	—	1	3	—	—	5
Pistacia	—	—	—	1	—	—	—	—	0.5	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—
Prunus	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	12	—
Fagus	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—
Populus	—	—	—	1	—	1	2	—	3	—	4	4	—	—	—	—	—	—	—	—	—	—	—	—	—
Tamarix	—	1	6	3	2	5	6	—	2	—	4	2	5	—	1	3	—	—	—	0.5	—	—	—	—	—
Other arboreal pollen	—	1	—	—	—	—	—	—	—	—	4	—	—	—	—	—	—	—	—	—	—	—	3	—	—
Total arboreal pollen	5	23	30.5	13	40	23	23	36	27.5	24	34	19	31	17	17	25	20	21	6	10.5	16	41	43	12	5
Nonarboreal pollen																									
Chenopodiaceae	73	48	48	59	9	40	39	5	47	20	21	49	30	42	47	29	42	19	65	49	58	9	31	—	42
Gramineae	9	4	1	1	2	0.5	2	—	3	4	11	7	—	2	1	6	2	10	3	5	2	6	7	63	16
Compositae	6	13	12	8	24	8	13	—	3	12	18	7	7	6	7	10	15	19	6	12	8	3	2	—	26
Cyperaceae	1	—	—	5	—	3	—	—	—	—	—	—	—	—	—	—	—	2	3	1	5	—	—	—	—
Cruciferae	—	1	1	1	—	1	—	—	1	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—
Papilionaceae	—	1	0.5	—	2	0.5	—	2	1	8	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—
Umbelliferae	—	2	1	1	—	1	—	—	1	—	4	—	—	2	—	—	—	—	3	—	—	1	—	—	—
Ephedra	5	1	1	4	4	4	—	3	5	4	—	2	—	2	11	3	12	6	10	8	11	29	13	25	5
Artemisia	—	3	5	2	16	1	22	42	6	20	7	11	25	29	15	26	5	21	—	12	—	12	1	—	5
Centaurea	—	1	1	1	2	3	—	2	2	8	4	2	3	—	1	—	2	—	—	—	1	—	1	—	—
Other nonarboreal pollen	2	3	1	4	—	7	2	7	4	—	4	2	3	—	—	—	2	—	3	1	—	—	—	—	—
Total nonarboreal pollen	96	77	71.5	85	59	70	78	64	75	76	69	80	70	83	82	—	80	79	93	90	85	59	56	88	94
Fern spores	—	—	—	—	—	—	—	3	2	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—
Total counted	102	216	282	222	45	203	54	59	198	25	28	45	61	48	74	31	41	48	31	206	114	34	90	8	19

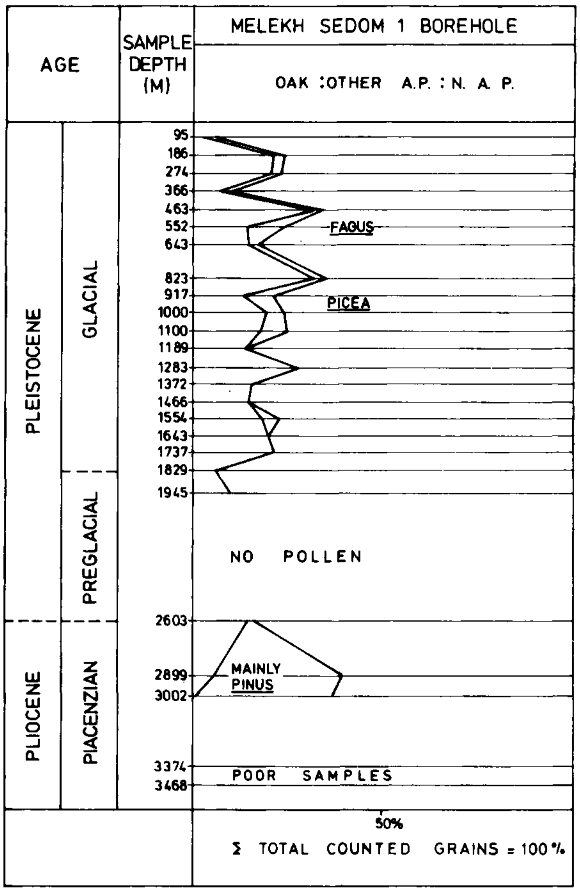


FIGURE 6.23. *Relations of oak pollen, other arboreal pollen, and nonarboreal pollen in Melekh-Sedom 1 Borehole.*

about 900 m, and in En Gedi 2 at about 850 m. It seems therefore that the Quaternary sequence penetrated by the Melekh-Sedom 1 Borehole is more complete than the one penetrated by the boreholes drilled in the margins, where the lower part of the sequence is apparently missing.

Conclusions drawn from pollen analyses of the boreholes in the Dead Sea area are of course only preliminary. It is tempting to correlate the climatic phases, especially those recorded in Melekh-Sedom 1 Borehole (Figure 6.23), with those climatic changes known much better for formations outcropping in the Central and Northern Jordan Valley. However, I will refrain from such an attempt and leave the data in this state until further information can be gathered. It seems likely that the sequence penetrated by Melekh-Sedom 1 Borehole, at a depth of 2000–2600 m, which is devoid of any pollen grains, should be correlatable with the Preglacial Pleistocene deposits known as the Ghor el-Qatar Series, or the Bethlehem Conglomerate. This conjecture is based on negative evidence, namely the lack of pollen grains, but the fact is that after a few thousand Quaternary samples have been analyzed from all over the country, almost evey sample of lacustrine sediment contains some pollen, while most fluviatile sediments contain none. Therefore, it seems that this part of the sequence corresponds with the fluviatile sediments of the Bethlehem Conglomerate, rather than with the lacustrine sediments of the Dead Sea Basin. If this conjecture is accepted, then the sequence from 2000 m up to the surface, penetrated by Melekh-Sedom 1 Borehole, represents the Glacial Pleistocene in the Dead Sea Basin. Climatic changes known from the north are represented by differences in the proportions of constituents of the successive pollen spectra.

Pollen analyses of the Hamarmar and Ami'az members, cropping out in the southern Dead Sea area (Rossignol 1969b), have shown that pollen were not preserved in sufficient numbers in the Ami'az, but a few samples from the underlying Hamarmar yielded quite good pollen and spore spectra (Table 6.16). Rossignol distinguished between three palynological zones. Zone 1 at the base is represented by two samples in which *Pinus halepensis* pollen are dominant; other arboreal pollen are rare, but some oak and olive pollen appear. The steppe elements, the halophytes, Compositae, Chenopodiaceae, and *Ephedra*, are much less represented, while Gramineae are quite common. Other nonarboreal pollen include *Asphodelus*, Dipsaceae, *Plantago* and some spores. The second zone, of which five samples have been analyzed, is characterized by a considerable diminution in the percentage of *Pinus halepensis*, higher values of Chenopodiaceae, some increase in the Compositae, *Artemisia*, and *Ephedra*, and lower values of Gramineae. Other arboreal pollen are quite rare, such as *Quercus*, *Pistacia*, *Olea*, *Tamarix*, and *Acer syriacus*. The third zone, of which only one sample was analyzed, is marked by partial return of the conditions of the first zone, namely an increase of *Pinus halepensis*, and diminution in Chenopodiaceae, Gramineae, and *Artemisia*. Compositae do not vary much, but *Ephedra* rises. Arboreal pollen are somewhat more abundant, among which oak shows some increase. According to Rossignol, the median zone represents a climate that was more arid than today, but was preceded and followed by more humid phases. It seems that the Hamarmar could be correlated with the lower part of the Würmian sequence of the Hula Valley, including the Early Würmian humid phase, quite a long interstadial, and apparently the beginning of the Main Würmian phase in Zone 3.

BIRKET RAM

Birket Ram, although not situated in the Jordan Rift Valley itself, yielded valuable information on the late Quaternary climatic sequence of the northern part of the country from pollen spectra recovered from its sediments. Birket Ram is an explosion crater occupied by a

3LE 6.16
len Spectra of the Hamarmar Formation, Southern Dead Sea[a]

		Pollen										
nple nber	Zone	*Quercus* spp.	*Pinus halepensis*	Other arboreal pollen	Gramineae	Cyperaceae	Compositae	Cheno-podiaceae	*Artemisia*	*Ephedra*	Other nonarboreal pollen	Total counted
2	I	0.5	60	2	19	0.2	4	1	0.5	1	11	488
5		2	36	0.2	29	3	6	13	1	4	6	517
7	II	2	7	0.5	11	2	5	55	4	8	6	932
28		1	9	0.2	6	1	10	36	7	14	16	653
29		1	9	1	8	1	13	38	6	11	13	1273
30		1	13	—	7	1	17	34	6	6	15	278
31		1	9	3	11	0.5	15	31	2	4	23	220
35	III	3	32	1	3	3	11	8	1	28	9	464

Generalized after Rossignol (1969b).

TABLE 6.17
Late Pleistocene–Holocene Paleoclimates and Vegetation of the Northern Golan, Drawn from the Pollen Diagram of Borehole P-8, Birket Ram[a]

Absolute age (Years B.P.)	Stage		Climate	Main palynological features	Vegetation
7000–7500	Holocene		Warm, humid	A.P. medium, Irano-Turanian rather high	Well developed Mediterranean maquis
11,500			Warm, dry	A.P. low, Irano-Turanian and batha high	Mediterranean maquis
16,000–18,000	Würm Pluvial	Late Würm	Cold, dry	A.P. high (coniferous trees)	Cedars forest, some oaks
20,000–22,000		Interstadial	Warm, humid	A.P. low, Batha high	Mediterranean maquis
28,000–32,000		Middle Würm	Cool, humid	A.P. high (*Quercus* + conifers), Irano-Turanian rather high	Oak forest, cedars forest not far
45,000–50,000		Interstadial	Warm, humid	A.P. low, Irano-Turanian high	Mediterranean maquis
		Early Würm	Cool, very humid	A.P. high (*Quercus*), Irano-Turanian low, Batha low	Well developed oak forest

[a] After Weinstein (1976).

lake formed about 70,000 years ago (Mor 1973), and in which sediments have accumulated since. A borehole, No. P-8, drilled by Tahal (Water Planning for Israel) in 1969 at the center of Birket Ram, to a depth of 185 m, penetrated about 80 m of sediments under 11.5 m of water, which consisted mostly of clays and diatomites overlying a sequence of basalts, tuffs, and scorias (Kidron 1971). The sedimentary part of this sequence was analyzed palynologically (Weinstein 1976) and a pollen diagram is given in Figure 6.24. The conclusions of this study are summarized in Table 6.17. The pollen diagram is divided into three parts. The first includes distribution curves for pollen grains of two ecological groups, arboreal pollen and open field vegetation. These are based on the total number of pollen grains counted in each sample. The second part is based on the total number of arboreal pollen grains and represents distribution curves for oak, conifers, and Cupressaceae. Other trees, which generally

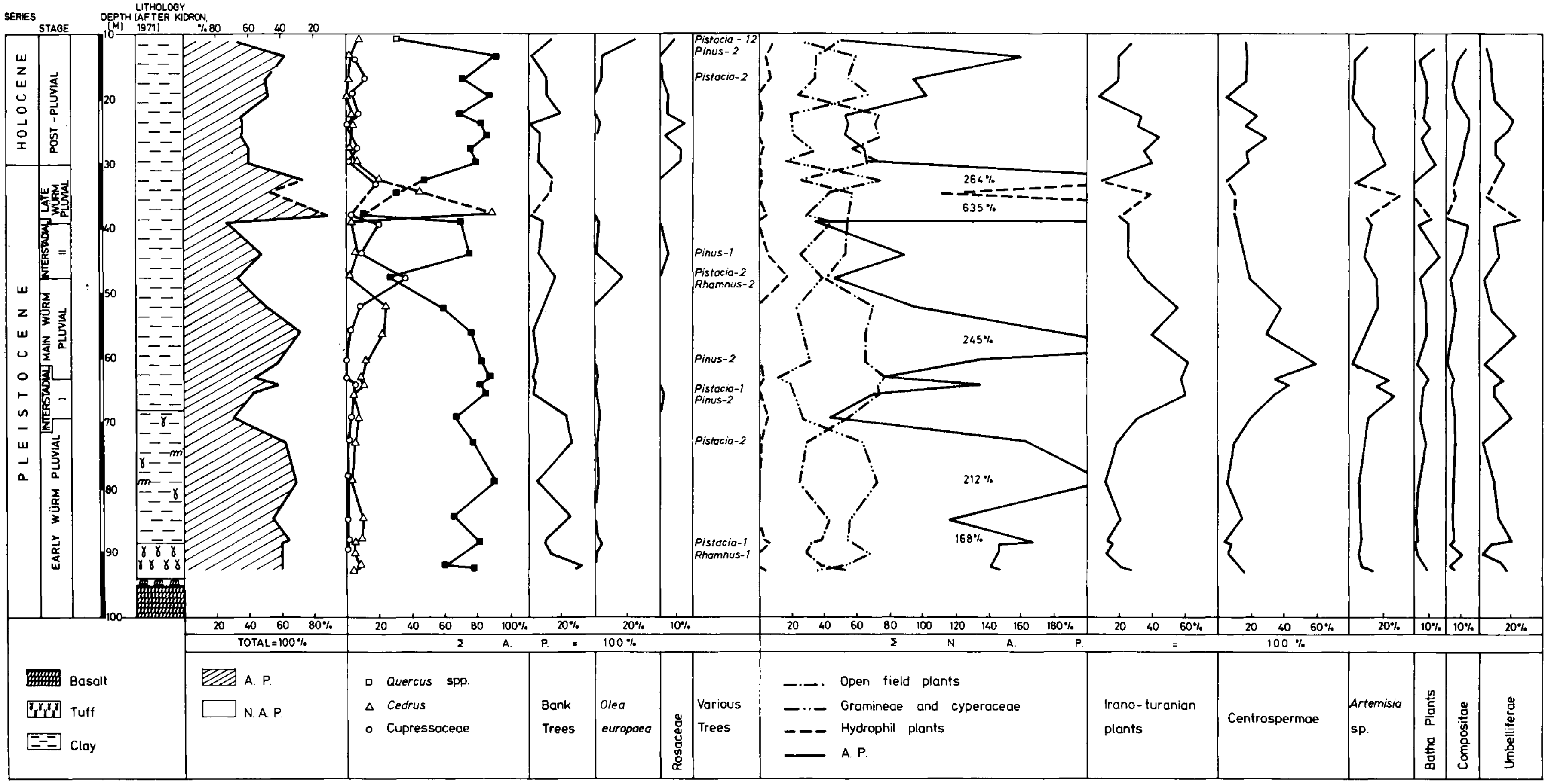


FIGURE 6.24. *Pollen diagram of the Birket Ram crater lake sediments, penetrated by P-8 Borehole, drilled at the center of the lake. (From Weinstein 1976.)*

show quite low values, are represented by separate curves. The third part is based on the total number of nonarboreal pollen grains. In the first column the relations of Gramineae, open field vegetation, hydrophil vegetation, and arboreal pollen are compared. Separate columns display distribution curves for the main groups of nonarboreal pollen. The curve for the Irano-Turanian plants includes Centrospermae and *Artemesia,* which are also displayed separately. The discussion and conclusions are based on the Recent pollen spectrum, discussed earlier, and on the following assumptions.

Essential changes in the arboreal pollen curve should indicate general climatic changes, which affected the entire region, and mainly those that are connected with changes in humidity, temperature, and rainfall. When the arboreal pollen curve is calculated against the total sum of nonarboreal pollen grains equalling 100%, the changes are graphically much more accentuated, and could be compared to specific changes in the composition of the nonarboreal vegetation. The Recent values are 33% for arboreal pollen as calculated from the total sum of counted pollen, and 50% as calculated against the nonarboreal pollen sum. A decrease of the arboreal pollen values should indicate a drier and possibly warmer climate. An increase in these values probably indicates higher water availability for plant life and sometimes lower temperatures as well. The spectra of the various arboreal pollen constituents are calculated according to the total sum of arboreal pollen in each sample. It is suggested that an increase of the oak percentage indicates an increase of humidity and some decrease of temperature, while an increase of conifer pollen, and especially *Cedrus,* indicates a drop in temperature, but not necessarily an increase of humidity. Moreover, a slight increase in conifer pollen apparently points to some desiccation, while during humid periods these grains are masked to some extent by the thick oak forest that grows around the crater lake. Similar conditions were pointed out by Horowitz (1971) for the Hula Basin. Oaks and conifers comprise together most of the arboreal pollen spectrum and increases in arboreal pollen values are mostly caused by an increase of one or both of these constituents. Other trees, like *Pistacia* and olive, which apparently indicate a warmer climate, generally have lower values, and their increase probably indicates dry and warm periods. The Cupressaceae, most likely representing *Cupressus sempervirens,* also seem to point to a drier and warmer climate when they increase. The curve for pollen of bank trees is only of local significance and inversely reflects the cover percentage of the forest trees over the area. At any rate, in this small basin they do not seem to be of great significance, since no running water is poured into the lake.

The Recent nonarboreal pollen spectrum mainly comprises two groups: Gramineae and ruderal plants. It seems that Gramineae show some tendency to increase when the climate is more humid, whereas a decrease in humidity and an increase in temperature would probably result in an increase of ruderal plants. It should be noted that ruderal plants have no significance as an ecologic group in the borehole samples, and instead represent the Irano-Turanian vegetation. This is the basis for the assumption that an increase in temperature and decrease in humidity would be indicated in an increase in these plants. Pollen of nonarboreal hydrophil plants are quite rare and appear in the same manner as bank trees, apparently increasing in drier periods. Once more, this only indicates diminishing of the vegetation cover of the area, because hydrophil plants and bank trees have more or less constant coverage, being dependent only on the existence of water and not so much on the general climatic conditions.

Weinstein divided the pollen diagram recovered from Birket Ram into seven zones (Table 6.17). The lowermost zone, from a depth of about 92 m up to about 69 m, is characterized by a very high arboreal pollen percentage, more than 60%, which mainly comprises oak (75–80% on the average). Conifers form up to 10% of the arboreal pollen spectrum. Pollen of Irano-Turanian vegetation shows quite low values (15–20%), while Gramineae is very high, up to 70% and more, and open field vegetation is only 35%, on the average. A slight decrease of the arboreal pollen value within this zone, at a depth of 85 m, results from a decrease in the oak percentage, accompanied by some slight rise of the conifers and the Centrospermae. *Pistacia* and *Rhamnus* appear in small values. Above this drop the arboreal pollen increases again and oak percentages reach up to 90%. Within the arboreal pollen, some grains of *Fraxinus* were also recovered from this uppermost part of the lowermost zone. It seems that pollen spectra of the lowermost zone represent an oak forest that was very well developed in the area of Birket Ram, most probably under more humid and somewhat cooler climatic conditions as compared with the present, namely, during a pluvial period. Some slight decrease of the humidity at a depth of 85 m is indicated by a slight increase of the Irano-Turanian pollen and the conifer forest, most probably due to some thinning of the oak forest around the lake. The relative thinning of oak forest around the lake is also accompanied by higher percentages of *Pistacia* and *Rhamnus.* The humidity rises again at the upper part of this zone and reaches even higher values than have been recorded in the lower part, especially indicated by the very high percentages of oak pollen. This increase of humidity is also indicated by the decrease of pollen grains produced by Irano-Turanian vegetation and also by batha vegetation. The batha apparently existed only as an undergrowth of the oak forest in the vicinity of Birket Ram, and when the oak forest is well developed, the batha is masked by the higher arboreal pollen values, although probably present in the same amounts as before.

The second zone, from a depth of 69 m to about 63 m, is characterized by a drop in the arboreal pollen curve, down to 30–40%, including a drop of the oak down to 65% of the total arboreal pollen. Very slight increases of Cupressaceae, up to 4%, olive, up to 3%, some *Cedrus*, to 9%, together with *Pistacia*, pine, and Rosaceous trees appear in this zone. Gramineae shows quite a decrease, dropping to 20%, while Irano-Turanian vegetation rises to 55–60% with a considerable increase of Umbelliferae (53%). These trends probably point toward thinning of the oak forest around Birket Ram, which might be a result of a drier and perhaps even warmer climate, characterizing this second zone of the section. It seems that this zone represents an interstadial within a pluvial stage. The third zone, from 63 to 47.5 m, is characterized by an increase of the arboreal pollen up to 71%, in which oak forms 57–86% and the cedars 8–23%. Some pine pollen grains were also encountered. The Irano-Turanian vegetation values are quite high, up to 61%, while the Gramineae (25–30%) are relatively low. This zone seems to represent another pluvial phase. This pluvial phase, however, is somewhat less humid than the former one, Zone 1, which is indicated by the higher percentages of Irano-Turanian vegetation and the appearance of pine pollen grains. It seems that the higher percentages of *Cedrus libani* point to some decrease in temperature, lower than that represented by the pluvial phase of Zone 1. It seems that indications of the peak of humidity precede those of the peak of low temperature, which is quite clear when regarding the mode of distribution of the plants. An increase of humidity will very quickly result in an increase of vegetation cover and of oak forest around the lake. It will take only some tens of years for an oak forest to flourish once more if the climatic conditions are suitable, while it would take much longer for an entire vegetation belt to lower its elevation on account of the area occupied by oaks. This, apparently, is a process that would take a couple of hundred years. It seems therefore that the drop of temperature and the increase in humidity climatically come together, while vegetationally, they show some phase shift.

The fourth zone, from a depth of 47.5 m up to approximately 39 m, is typified by a decrease, down to 30%, in the arboreal pollen curve. Within the arboreal pollen spectrum, Cupressaceae form some 35% and olive about 17%, which is a considerable increase for both. The appearance of *Pistacia*, pine, and Rosaceous trees is evident. Some slight increase, up to 47%, of arboreal pollen is recorded within this zone at a depth of about 44 m, together with increases of batha, up to 15%, Compositae, up to 8%, and Umbelliferae, up to 12%. The values for Irano-Turanian pollen are almost constant along the entire zone, maintaining a median of 20–25%. It seems that this zone represents quite a dry climate, which is indicated by the increase of Cupressaceae, while the increase of olive, especially at the beginning of the zone, together with the appearances of *Pistacia*, pine, and Rosaceous trees, probably indicates higher temperatures for this interstadial. It seems that the oak forest was poorly developed around Birket Ram at this time, and the slight increase of humidity at a depth of 44 m mainly caused some increase of Mediterranean maquis and undergrowth of batha, and not so much of the entire forest formation. The fifth zone, from approximately 39 to 30 m, is typified by very high arboreal pollen percentages, up to 86%, in which *Cedrus libani* comprises the main constituent, up to 88% of the total, together with only 9% of oak and 2% of Cupressaceae. Unfortunately, the samples are too widely spaced in this zone to enable an accurate evaluation of the palynological spectra. The spectra probably represent pluvial conditions, colder than the previous period, the lower temperatures having a more pronounced influence on the vegetation than the higher humidity. It should be noted though that this cool and dry pluvial phase might be only of a local significance, because somewhat higher humidity during the pluvial, as indicated for the same phase in the Hula Valley, might result in higher amounts of snows on the Hermon range, which, causing a barometric high, will cause a relative drop in the humidity, or rather in the availability of water to plant life on the Golan Plateau. This would result in the representation of a dry and cold stadial.

The sixth zone, from 30 to 22.5 m, is once more characterized by a drop in the arboreal pollen down to 35%, which mostly comprises oak grains (75–80%), with slight contributions by Cupressaceae (up to 5%) and olives (up to 2%). The values of the conifer forest pollen drop considerably, down to less than 5%, while an increase can be seen for Rosaceous trees, up to 15%, Irano-Turanian vegetation, up to 40% and more, and batha pollen, up to 9%. Gramineae are relatively low, about 30%, but open field vegetation is high, about 60%, which comprises mainly Umbelliferae, 10–15%, and Compositae, up to 29%. It seems that the arboreal spectrum of this zone indicates poor oak maquis in the vicinity of Birket Ram, which, accompanied by some Cupressaceae and olives, seems to indicate a trend of drying up and warming at this phase. The increases of Irano-Turanian and batha elements also point toward some drying up of the climate, together with the introduction of Rosaceous trees, which probably indicate the beginning of development of the typical postpluvial, Holocene nature of the vegetation of this area. In the seventh zone, from 22.5 to 13.5 m, the arboreal pollen rises again, up to 60%. This rise is somewhat lower than previous increases. Oaks are almost the only constituent, up to 89% of this spectrum, with some Rosaceous and olive grains. At a depth of about 17 m there is a decrease in oak, down to 48% of the arboreal pollen percentage, with some increases of Cupressaceae, up to 12%, olive, 4%, and batha, up to 7%. The Irano-Turanian vegetation pollen are represented by about 20% of the pollen spectrum. Gramineae increase up to 60%, while Umbelliferae and Compositae, included with open field vegetation, show some decrease. Toward the present period, which is represented by Recent samples collected at a depth of 11.5 m, the water depth of the crater lake, some decrease can be seen in the arboreal pollen, down to 33%, and also in the share of oak within this spectrum. A considerable increase of olive grains, up to 25%, as well as increases of Rosaceous, up to 10%, of *Pistacia* and batha vegetation, each up to 12%, and quite high percentages of Irano-Turanian vegetation, up to 27%, is typical for these samples. The increase of arboreal pollen in the seventh zone, which is mainly in the oak proportion, points to some development of oak forest around the lake. It is, however, less pronounced than the increases during pluvial phases, and probably represents the somewhat more humid Atlantic phase of the Holocene. Toward the present, represented by the Recent samples, the humidity drops somewhat, causing a decline of the oak forest, while present conditions are most likely a result of both a drop of temperature known also in other areas of the country and the intervention of man by deforestation and planting of Rosaceous trees, olives, and other plants.

To sum up, the similarity of climatic trends indicated by the Birket Ram borehole to those indicated by the K-Jam borehole drilled in the Hula Valley is quite striking. It seems that the Birket Ram borehole penetrated the Holocene and the Würmian sequence. Zones 1, 3, and 5 represent the Early, Middle, and Late Würmian pluvial stadials, same as recorded in the Hula Valley. It should be noted that a slight decrease of pluvial conditions in the middle of the Early Würmian Stadial at the Birket Ram sequence was not recorded in the Hula Valley, probably due to the spacing of the samples. The same decrease in pluvial conditions was also seen in the Early Würmian sediments of the Tabun Cave, to be discussed later (Horowitz, in Jelinek *et al.* 1973). This is probably the reason for subdivision of the Early Würm into Würm I and Würm II in France, while in other areas, such as Holland, where this drop is not so well indicated, the Early Würm is taken only as a single phase. This is also the reason why the Würmian is divided into four phases in the French stratigraphy, while in the central and western European there are only 3 stadials.

The pluvial phases are recorded by considerably higher percentages of arboreal pollen. The constitution of the arboreal pollen spectra changes with the pluvial phases, being dominated by oaks at the first stage, oaks and cedars at the second stage, and cedars largely in the third stage. This seems to indicate a trend of successively cooler and drier pluvial phases in the northern Golan, in contrast to successively more humid phases recorded in the Hula Valley. As discussed earlier, this might well be a local phenomenon in the vicinity of the Hermon Range, caused by higher amounts of snow at each succeeding pluvial phase. It might well be that the pluvial phases are mainly characterized in Israel by higher humidities, but as with the European glacials, for which the last Würmian phase is known to be the coldest, the possibility that the pluvial phases in Israel became cooler towards the end of the Würmian cannot be excluded. The Holocene, represented by the sixth and seventh zones, is not well documented in the Birket Ram sequence because of the scarcity of samples along this part of the section. It seems that the drier and warmer Preboreal and Boreal stages, which predate 7500B.P., are recorded within the sixth zone, while the beginning of the seventh zone recorded the increase of humidity of the Atlantic period. As this zone approaches the present, the decrease of humidity is evident. The influence of man on the natural vegetation can be seen quite considerably in the Recent surface samples collected from the lake bottom at a depth of 11.5 m by the increase of the proportion of pollen derived from cultivated and ruderal plants.

CONCLUSIONS

The Quaternary pollen spectra of correlative sediments were divided by Horowitz (1971) into three main groups. The first group comprises pollen spectra which bear more or less similar characteristics to the present-day spectra, except naturally for some local influences or in some cases a slight diminishing of the proportion of arboreal pollen. These spectra are thought to represent interpluvial climates. The second group encompasses spectra in which the proportion of arboreal pollen is considerably higher than present-day rates. To the north, the proportion of arboreal pollen may attain up to 70–80% of the total pollen spectrum and is totally dominated by oak grains. To the south, the proportion of arboreal pollen decreases, but oak is still the prevailing element, while olive pollen, accompanied by some other trees, begins to appear. The nonarboreal pollen spectrum to the north is very rich in number of species and much more varied than at present. To the south, and especially in the Negev, Compositae overtake Gramineae in comparison to the Recent spectra. This group of spectra is thought to represent pluvial climates, when the climatic belts shifted 200–300 km southward of their present-day situation. The northern parts of the country were covered by a well-developed oak forest, sometimes accompanied by occurrences of trees such as *Picea, Corylus, Castanea, Fagus,* and *Cedrus.* This kind of forest resembles the present-day mountainous forest of northern Lebanon and extends north to Turkey. Most of the oak pollen represented by these spectra from the north of the country seem to have derived from *Quercus ithaburensis* rather than *Quercus calliprinos,* which is prevalent in Israel at present. This seems to suggest some amount of summer rain during the pluvial periods in Israel. *Quercus ithaburensis* is a deciduous tree, while *Quercus calliprinos* is evergreen and maintains some of its growth during the rainy winter season.

Quercus ithaburensis needs some summer rain to maintain its growth, which is chiefly restricted to the spring and summer. To the south the oak forest became mixed with thermophil trees, of which the most abundant was the olive. Even the present-day desert areas of the Central Negev were covered by stands of trees and by quite well-developed Mediterranean maquis in pluvial times, of the same type that prevails today on the Carmel and Galilee mountains. The third group of pollen spectra comprise average percentages of arboreal pollen, higher than at present, but lower than during the pluvial periods, comprising mainly equal palynological shares of oak and olive grains. To the south this assemblage is replaced by a Mediterranean maquis, while in the Negev area Compositae prevail, with some occurrences of trees, mainly olive with some oak. These pollen spectra seem to represent interstadial climates within the pluvial periods, in which water availability was considerably higher than at present, probably including some amounts of summer rain, while the temperatures were similar to those of the present or even somewhat higher. These conditions were ideal for the development of olive groves, which is a typical thermophilous and humid loving plant.

The Quaternary sequence is typified by four repetitions of the pluvial pollen assemblages during the Glacial Pleistocene. These are separated by typical interpluvial assemblages. The earliest two pluvial phases could only be analyzed in general, while the upper two were analyzed in much more detail, due to the abundance of outcrop and borehole material. The second pluvial period, attributed to the Riss, shows two pluvial phases separated by an interstadial. The last, Würm Pluvial, is divided into three pluvial phases separated by two interstadials. The four major pluvials were correlated with the European glacials through cross-correlation with the Mediterranean marine ingressions. Most of the Holocene is typified by pollen assemblages that are more or less similar to the present-day spectra, but the Atlantic period, which lasted from about 7000 up to 4500 years ago, yielded typical interstadial spectra, representing a warm and humid climate with some amount of summer rains.

The Quaternary flora of Israel seems to be of the Mediterranean type throughout the entire period and the major contributions to its composition were probably introduced to the country before the Quaternary. The major vegetational changes caused by the pluvial and interpluvial climates were caused by migration from the north to the south during pluvial periods and vice versa during the interpluvials, but the nature of the vegetation remained more or less of the same type. The flora of Israel comprises elements which penetrated the country from various environments. Tropical elements are relics from the Miocene period, in which the country enjoyed a more or less tropical climate and was connected with the tropical environments of Africa. Plant fossils discovered within the Miocene Hazeva Formation and pollen analyses of corresponding sediments have clearly indicated the tropical nature of the flora during these times (Horowitz 1974b). Paleoarctic elements penetrated the country in Pliocene times (Horowitz 1974, 1974b), when the Jordan Valley was open to the north and the present-day Litani River flowed to the Hula Valley. Mediterranean elements began to develop in Late Miocene times and by the beginning of the Quaternary the Mediterranean type of vegetation was already well established. A minor group of endemic plants exists in Israel, but these are for the most part not represented in the pollen spectra.

POLLEN ANALYSES OF ARCHAEOLOGIC AND PREHISTORIC SITES

The first pollen analysis of a prehistoric site in Israel was carried out by van Zeist (in Echegaray 1966), on sediments from the terrace of El-Khiam in the Judean Desert. The yield was rather poor and of no significance; therefore no further discussion is given. Some attempts by Rossignol (personal communication) to analyze sediments from archaeological sites in Israel proved unpromising, since the pollen spectra recovered were rather poor. It was not until the beginning of the 1970s, when J. Schoenwetter of the Arizona State University at Tempe, Arizona (personal communication, 1971) developed a technique for separating pollen grains from rather large samples of sediments, about 250–500 gm, that a systematic survey of sites began in Israel. This survey was mostly carried out by the Palynological Laboratory of the Institute of Archaeology, Tel-Aviv University, by the present author and his students. Lately, some palynological analyses of sites were carried out by students of the present author at the Institute of Archaeology, Hebrew University of Jerusalem. Results of these pollen analyses are given here, representing the Jordan Valley, the Negev, and the coastal plain sites. An attempt is also made to arrange the sites more or less chronologically, but wherever a multilayered site was studied, results are summed up together for this area, which might include several interconnected sites. Locations of the analyzed sites are given in Figure 6.17.

JORDAN VALLEY

Ubeidiya

One of the most interesting and ancient sites in Israel, the site of Ubeidiya, of Mindel age, situated in the Central Jordan Valley (Figure 6.17), has unfortunately yielded only a very limited number of pollen spectra that could be studied. These were recovered from the Ubeidiya Formation in which the site is embedded and were discussed earlier. The correlative beds, of the Mishmar HaYarden Formation at the Gesher Benot Ya'akov area, in which some artifacts were found, have yielded rich pollen spectra, also discussed earlier. In general, the spectra are characterized by very high percentages, up to 80%, of arboreal pollen, comprised almost solely of oak pollen grains. No further discussion is given here, since these spectra were discussed in more detail earlier.

Gesher Benot Ya'akov

This site, which has yielded an enormous number of Late Acheulian flint and basalt handaxes is situated just north of the bridge at Gesher Benot Ya'akov (Figure 6.17). The implements are embedded in the Benot Ya'akov Formation sediments, which were discussed in the previous chapter. In general, these sediments are characterized by very high percentages of arboreal pollen, of which oak forms the major constituent. Minor amounts of *Fagus* pollen grains were found in this formation, characteristic of the Rissian sediments of the Jordan Valley. No further discussion of these spectra is given here, since they were discussed earlier.

Fatza'el

This site is situated in the northern part of the Southern Jordan Valley, in Wadi Fatza'el, near the settlement of the same name (Figure 6.17). It encompasses artifacts from the Kebaran through the Chalcolithic and its lower part is embedded in the Late Würmian Fatza'el Member sediments. Pollen analyses of the site were carried out by Alon (1976) and the results are summed up in Table 6.18, which gives the pollen spectra of the various beds, and Figure 6.25, which is the pollen diagram for the site. Sediments bearing Kebaran artifacts (Bed FZ-7) of an estimated age of 13,500 B.P. are characterized by a rather high percentage of arboreal pollen (28%), of which oak shares 10%, pine 8%, olives 5%, *Acacia* 2%, *Tamarix* 2%, and Rosaceous trees 1%. The nonarboreal pollen, comprising 64%, is composed of Compositae 24%, Gramineae 35%, Leguminosae 1%, Chenopodiaceae 3%, *Poterium spinosum* 1%, and pollen grains of cereals 2%. Compared with the Recent pollen spectrum for this area, in which the arboreal pollen comprise only 5%, this spectrum undoubtedly represents pluvial conditions that prevailed in the country during the Late Würmian Stadial. The occurrence of cereal pollen grains is somewhat strange. The samples were collected with great care to prevent any possible contamination, and *Eucalyptus* pollen, the common contaminants is not present in the spectra. If the cereal pollen grains really belong to the spectrum, which is still somewhat doubtful until much more information is gathered, then this is the first indication of cereals from paleoenvironments in Israel and apparently in the entire world.

A pollen spectrum recovered from the Geometric Kebaran A artifact bearing stratum, designated FZ-3b, yielded even more than the preceding samples, 30%

TABLE 6.18
Pollen Spectra from the Farza'el Sites, as Percentages of the Total Number of Counted Grains in Each Suite of Samples[a]

	Kebaran FZ VII	Kebaran FZIII East	Kebaran FZ IIIA	Geom. Kebaran A.	Early Natufian	Late Natufian	Chalcolithic	Recent
Arboreal pollen								
Quercus sp.	10	14	1	11	—	1	2	1
Pinus halepensis	8	8	3	10	—	1	—	1.5
Olea europaea	4	1	—	8	8	1	2	1.5
Poterium spinosum	1	—	—	2	—	—	1	1.2
Rosaceae	1	—	—	—	—	2	—	—
Tamarix sp.	2	—	—	—	—	—	—	—
Acacia sp.	—	—	—	—	—	—	—	—
Total arboreal pollen	28	27	7	32	12	5	5	5.1
Nonarboreal pollen								
Compositae	26	33	33	22	27	64	41	37
Gramineae	37	39	52	25	46	29	27	43
Chenopodiaceae	3	—	—	10	15	1	16	8
Cruciferae	2	—	—	—	—	—	8	3
Umbelliferae	—	—	—	—	—	1	1	0.5
Liliaceae	1	—	—	4	—	2	2	0.4
Papilionaceae	—	—	—	3	—	—	—	—
Cereals	—	—	—	—	—	—	—	3
Total nonarboreal pollen	71	72	93	63	88	95	95	94.9

[a] After Alon (1976).

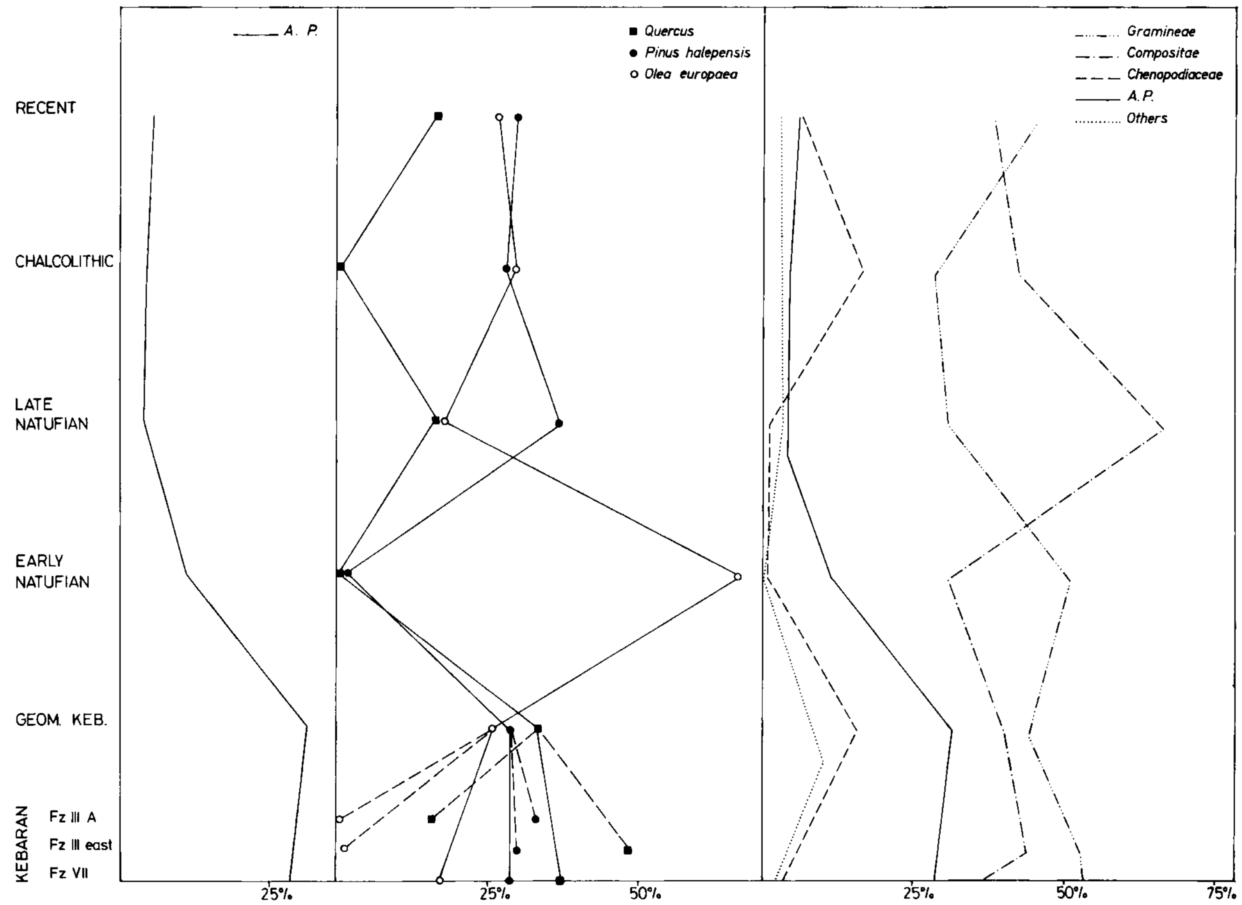


FIGURE 6.25. *Pollen diagram from Fatza'el. (From Alon 1976.)*

arboreal pollen grains, of which oak forms 11%, pine 9%, olive 8%, and *Acacia* 2%. The nonarboreal pollen, which forms the remaining 70%, consists of Gramineae 25%, Compositae 22%, Chenopodiaceae 9%, Liliaceae 4%, *Plantago* 2%, *Poterium spinosum* 2%, and other plants 6%. The age of this bed is estimated at 12,500 B.P., and the pollen spectrum once more indicates pluvial conditions, which still existed during the latest Würmian in the country. Bed FZ-4, bearing an Early Natufian implement assemblage, contains much less arboreal pollen, only 5%, shared between oak, pine, olive and *Tamarix*. The nonarboreal pollen spectrum is dominated by Compositae, 63%, with Gramineae, 28%, and minor percentages of Chenopodiaceae, Liliaceae, Umbelliferae, and *Scabiosa prolifera*. This pollen assemblage is totally different from the previous ones and points to the onset of climatic conditions typical for the early part of the Holocene, a rather dry and warm climate, more or less like that of the present-day climate of the area. The Late Natufian artifact bearing bed, FZ-6, yielded only a very poor pollen spectrum with an estimated age of 8300 years B.P. Only 44 pollen grains were recovered, of which 14% are arboreal pollen, shared between olive, 9%, and *Acacia*, 5%, while the nonarboreal is represented by 54% Gramineae and 32% Compositae. Tentatively it might be concluded that this pollen spectrum represents rather warm conditions, but this should be taken only as a very preliminary indication until further evidence is gathered.

A sample collected from a Chalcolithic site, which is situated on top of the Fatza'el Formation, of an estimated age of 4300 years B.P., yielded a very rich pollen spectrum, of which only 4% is of arboreal origin, shared equally between pines and olives. The nonarboreal pollen spectrum is dominated by Compositae, 41%, Gramineae, 27%, Chenopodiaceae, 16%, and Cruciferae, 8%, while Liliaceae, Umbelliferae, and *Poterium spinosum* appear in low numbers. This pollen spectrum very much resembles the present-day spectra discussed above, and it seems that climatic conditions during the Chalcolithic inhabitation of this area were more or less similar to those at present. A Mousterian site in the close vicinity of the Fatza'el site, embedded in travertines, did not yield any pollen that could be identified, probably due to oxidation of the grains during deposition of the travertines.

CENTRAL NEGEV

A great number of late Quaternary prehistoric sites, of Mousterian through Chalcolithic cultures, were studied by Marks and others (Marks 1976). Pollen spectra of some of these are given by Horowitz (1976a) and the rest, included here, have not been previously published. Although the sites encompass quite a span of time, in no place were they found in one sequence, and it seems that stratigraphically the sediments containing artifacts are separated by periods of nondeposition or erosion. Therefore, no pollen diagram is included for these sites, although it is quite tempting to do so. The results and pollen spectra are summarized in Table 6.19. Discussion of the results follows in stratigraphic order of the prehistoric cultures. Present-day conditions in the area, to which the pollen spectra are compared, were discussed earlier.

Mousterian Sites

Most of the samples collected from Mousterian sites yielded almost no pollen, probably due to oxidation of the grains during deposition, or later. Four samples yielded positive results, of which a sample collected from a depth of 1.50 m at site D-35 was especially rich. More than 200 pollen grains were determined and counted in this sample and the average pollen spectrum for the Mousterian of the Central Negev sites follows: arboreal pollen account for 25%, excluding *Tamarix,* which is only a local bank tree, and does not comprise part of the regional vegetation. These include *Quercus calliprinos*, 9%, *Olea europaea,* 10%, *Amygdalus,* 1%, *Pinus halepensis*, 2%, *Pistacia,* 2%, *Zyziphus,* 1% and *Tamarix,* 12%. Nonarboreal pollen comprised Gramineae and Cyperaceae, 17%, Chenopodiaceae, 17%, Compositae, 13%, Crucifereae, 6%, *Artemisia*, 4%, and others, 8%. This is a rather surprising pollen spectrum, when compared with the Recent one. Arboreal pollen, which makes up 25% of the spectrum, is shared between *Quercus* and *Olea* as the major elements, also including pollen of trees that are nowadays relics of a Mediterranean vegetation in the area (Danin 1970). This spectrum resembles the ones obtained for Recent samples from the northern part of Israel, which represent a quite well-developed Mediterranean maquis of mixed oak, olive, pistachio, pine, and some other trees. The *Amygdalus, Pistacia,* and *Zyziphus* should be considered as comprising a considerable part of the maquis vegetation, since they are always underrepresented in pollen spectra because of poor pollen production in comparison with the oaks and olives.

The paleoclimate and vegetation of the Central Negev during the period of Mousterian occupation were totally different from those of the present day. It seems that climatic belts were approximately 200–250 km south of their present position, and the desert border was well to the south of the Avedat area. The same shift is seen in the analysis of sediments containing Mousterian artifacts from the north of the country, from the Tabun Cave in Mt. Carmel, discussed later (Jelinek *et al.* 1973), which indicate a vegetation that is comparable to that known from the present day in northern Lebanon. The same picture was obtained also from the Hula Valley and Birket Ram boreholes for the first Würmian Stadial and it seems that during this time Mousterian people occupied Israel. Chronologically, this period may be placed between 70,000–40,000 years ago (Horowitz 1974, 1975; Siedner and Horowitz 1974). It seems that the Negev sites may be dated to more than 50,000 years ago (Crew 1976). The Mediterranean climate and rich vegetation of the Central Negev during the Mousterian occupation also resulted in the trapping and deposition of loess sediments. Presently loess is accumulated only in areas where the annual precipitation is higher than 200 mm (Yaalon and Ganor 1966), which is probably due to vegetation cover that helps to trap the windblown dust. Without such a vegetation cover, as is presently the situation in the Central Negev, the loess is deflated by the strong winds and floods. The higher humidity and availability of water also raised the groundwater table of the Central Negev, resulting in stronger spring activity. Indeed, some fossil spring deposits containing Mousterian artifacts are present in the area (Goldberg 1976). Paleoenvironmental conditions undoubtedly favored human occupation and settlement of the Central Negev. The combination of rich flora and probably rich fauna, the somewhat cooler climate and less acute diurnal differences of temperature and humidity, all created a most suitable environment.

Mid-Upper Paleolithic Transition

Five samples yielded pollen spectra from the site D-101, which is characterized by a transitional culture, between Middle and Upper Paleolithic, and radiocarbon ages of around 40,000 years B.P. and more. Since most of them are rather poor in pollen grains they are combined together here to give an average pollen spectrum comprising the following: arboreal pollen 17% (excluding *Tamarix,* which is 2%). The arboreal pollen constituents are *Quercus calliprinos,* 2%, *Olea europaea,* 2%, *Pinus halepensis,* 8%, *Acacia,* 3%, and *Cupressus sempervirens,* 2%. The nonarboreal spectrum is totally dominated by Gramineae, 59%, with some Chenopodiaceae, 14%, very low values of Compositae, 3%, and other nonarboreal pollen, 3%. The conclusions drawn from this pollen spectrum should be regarded as very preliminary in nature, since the total number of counted grains of all the samples does not exceed 90.

The nonarboreal spectrum, however, is typical for the present-day pollen of the area, and therefore it seems to

TABLE 6.19
Pollen Spectra from Prehistoric Sites of the Avedat Area, Central Negev

			Arboreal pollen							Nonarboreal pollen														
Site	Sample	Culture and radiocarbon dates	*Quercus*	*Olea*	*Amygdalus*	*Pinus*	*Pistacia*	*Tamarix*	Others	Gramineae and Cyperaceae	Chenopodiaceae	Compositae	Umbelliferae	*Artemisia*	*Plantago*	Liliaceae	Cruciferae	Papilionaceae	*Ephedra*	*Typha*	Labiatae	*Capparis*	*Scabiosa*	Cereals	Total counted
Recent	Surface			2					*Retama* 1	20	81		1												105
D1	20–25 cm	PPN"B" 8,500 B.P.		4	1	1	1			19	18	25	1										2	7	78
	10–15 cm	Natufian	6	6	2	1	1		*Acacia* 1	23	127	44	1	10	1										224
D16	15–20 cm	ca. 11,000 B.P.	4	4		1	4	1		26	82	20		16	3							4	4		169
	30–40 cm						1		*Juniperus* 1	9	16	2		1											29
	n.d.				1				*Acacia* 1	15	19	7				2									45
D31	10–16 cm	Late Upper		1						17		1					16								35
	60–65 cm	Paleolithic								6	8	2													16
D34	15–20 cm	ca. 17,500 B.P.	4				1	25		23	5	6				1									65
D22	ca. 10 cm		14	5	1	1	3	1		18	33	9	3	3			2	4				6			103
D27A	ca. 10 cm	Upper	15	1	1	1			*Juniperus* 1	25	61	18		1				4	2	1		3			134
D27B	ca. 10 cm	Paleolithic	7	3	1					32	32	19				1									95
D101	Combined	Mid–Upper Paleolithic transition 40,000–45,000 B.P.	2	2		8		2	*Acacia* 3 *Cupressus* 2	59	14	3	1	1	1										90
D15	70–75 cm			2						11	6								1						20
	E1, 70–77 cm	Mousterian	4					2		10	16	1	1	2											36
D35	W1, 1.50 cm–1.60 m	>50,000 B.P.	22	25	3	5	5	30	*Zyziphus* 2	43	43	33	1	9			15		6		1	10			253
	n.d.		1	1		3				7	9	26													47

represent rather dry climatic conditions for the site under study. The arboreal pollen rate is rather high compared with the present-day spectrum but its composition should be taken into consideration. *Acacia* and *Tamarix* are local trees that grow in the wadi bed and could have been easily incorporated in the sediment. It should be noted also that the sediments of this site were deposited in water, as can be seen by the inclusion of unicellular algae in these sediments. This is probably the reason for the relatively higher percentage of arboreal pollen grains, derived either from trees growing in the wadi bed as relics such as the oaks and olives, which are probably relics of a former Mediterranean flora that occupied the area in Mousterian times, and *Acacia* and *Tamarix,* which have been typical wadi bed trees in this area up to the present. Pine and cypress pollen grains are easily carried by winds over rather long distances and might have grown in quite distant areas, perhaps some 40–50 km north of the site. It seems therefore that in fact the actual share of aboreal grains should be regarded as much lower than the one displayed by the pollen spectrum. It seems that in the case of site D-101, the composition of the nonarboreal pollen spectrum should be taken into consideration as much more representative of conditions in the area, which seem to be rather dry in comparison to the previous and successive sites.

Upper Paleolithic Sites

Samples were collected and palynologically analyzed from three sites that yielded artifacts characteristic of the Upper Paleolithic (D-22, D-27a, and D-27b). The relative yield was much better than that of the Mousterian samples, but the spectra were not so rich; approximately 100 pollen grains could be determined and counted for each. The average pollen spectrum is as follows. Arboreal pollen total 16%, consisting of *Quercus calliprinos,* 10%, *Olea europaea,* 3%, *Amygdalus,* 1%, *Pinus halepensis,* 1%, and occasional occurrences of pistachio, *Tamarix,* and *Juniperus.* The nonarboreal pollen spectrum is shared by Gramineae and Cyperaceae, 25%, Chenopodiaceae, 35%, Compositae, 15%, and 3–5% of pollen derived from other plants. Compared to the average Mousterian spectrum the share of the arboreal pollen in the Upper Paleolithic is lower, displayed by a drop of *Olea europaea.* The remainder of the arboreal pollens, and especially the oaks, still maintain about the same values as for the Mousterian. Once again, the pollen spectrum for the Upper Paleolithic is markedly different from the Recent spectrum. It seems that the Upper Paleolithic spectrum indicates a cool Mediterranean climate, somewhat cooler than that of the Mousterian occupation. This is indicated by a decrease in the proportional occurrence of olives, which tend to grow in warmer and somewhat more humid conditions than those of the present-day Mediterranean climate of central and northern Israel. The oaks, on the other hand, can better resist the cool and dry climate, and they presently naturally grow as far south as Judea. It should be noted that similar trends could be seen for deposits of the same age, the Middle Würmian Stadial, from the Hula Valley and Birket Ram boreholes. The nonarboreal pollen spectrum does not differ essentially from that of the Mousterian. The high Compositae values indicate a higher humidity when compared to the Recent spectrum, in which almost no pollen of this group is recorded, although some Compositae do grow in the area. The Compositae also react in the same way in response to higher humidity in the north of the country (Horowitz 1971, 1973). The same seems true for the higher percentages of the grasses and sedges, Gramineae and Cyperaceae, whose share within the nonarboreal spectrum is higher than at present on account of the Chenopodiaceae.

The paleoclimate and vegetation of the Central Negev during Upper Paleolithic times can be referred to as Mediterranean in nature, most likely resembling present-day northern Judea or Samaria. The climatic belts, it seems, were about 100 or 150 km south of their present position. Approximately the same shift was also observed in the Hula and Birket Ram, for the second Würmian Stadial, dated at about 32,000–22,000 years ago. It seems that these Upper Paleolithic pollen spectra should be stratigraphically and chronologically placed within this interval. Unfortunately, no radiocarbon dates are available for these sites as yet, since most of them have only surficial deposits with no material suitable for absolute dating.

Late Upper Paleolithic Sites

Two sites of Late Upper Paleolithic culture are known in the Avedat–Aqev area, D-34 and D-31. Although the pollen spectra for each are quite poor, they will be treated separately, as it seems that D-34 is somewhat older than D-31, which is well-dated radiometrically by four samples, yielding an age of 17,000–18,000 years B.P. (Marks 1976). The pollen spectrum from D-34, although relatively poor, shows approximately the same pattern represented in the earlier, Upper Paleolithic spectra. It comprises 7% arboreal pollen (excluding *Tamarix*) of which *Quercus calliprinos* forms 6% and pistachio 1%. *Tamarix* forms 39% of the spectrum. The nonarboreal pollen spectrum comprises 35% of Gramineae and Cyperaceae, 8% Chenopodiaceae, 9% Compositae, and 1% pollen grains derived from other plants. The average pollen spectrum of site D-31 comprises only 3% arboreal pollen, shared between olive, *Amygdalus,* and *Acacia,* while the nonarboreal pollen show 40% Gramineae and Cyperaceae, 28% Chenopodiaceae, 10% Compositae, 16% Crucifereae, and 3% pollen derived from other plants.

As compared with the Recent spectrum, both Late Upper Paleolithic spectra are richer in Compositae and somewhat richer in arboreal pollens, although only a few of the latter occur. This indicates that the vegetation was somewhat richer than today, while the climate was more humid. During this period there appears to be a slight drying of the climate between occupations of sites D-34 and D-31, seen in the drop of arboreal pollen, and particularly in the drop of *Quercus,* although this may have been only a minor change, as the level of Compositae remains constant. The spectra, compared with the preceding Upper Paleolithic and Mousterian, are much poorer, produced by vegetation that might be compared with that presently growing in the northwestern Negev. Therefore, the Avedat area at this time was mostly covered by herbs with some scattered stands of trees. By comparing the spectra of the Avedat area with those of the Hula Valley and the Birket Ram sequences, and by relying on radiocarbon dates, it may be determined that the Late Upper Paleolithic occupation of the Negev occurred at the termination of the Middle-Late Würm Interstadial phase. The somewhat more favorable climatic conditions and richer vegetation enabled settlement of the Central Negev, but such occupation had to be much closer to permanent water sources, which remained only as springs. The "paradise" of Mousterian and Upper Paleolithic occupations had ceased to exist in Late Upper Paleolithic times.

Epipaleolithic and Natufian Sites

Prior to the Natufian occupation there is a significant temporal break of several millennia in the palynological record. Although a Geometric Kebaran A site, D-5, occurs in the area, it produced no pollen, while Early Kebaran sites are totally absent. Thus, from approximately 17,000 years B.P. to the Natufian occupation at approximately 11,000 years B.P., there are no palynological data. The Natufian site of Rosh Zin, D-16, produced excellent pollen spectra from two of three samples analyzed. The average pollen spectrum of these samples shows 7% arboreal pollen, excluding *Tamarix,* of which *Quercus calliprinos* forms 2.5%, *Olea europaea,* 2.5%, with rare occurrences of pistachio, *Amygdalus, Pinus halepensis, Acacia albida,* and *Juniperus.* The nonarboreal pollen spectrum comprises 14% Gramineae and Cyperaceae, 53% Chenopodiaceae, 16% Compositae, 6% *Artemisia,* and 4% pollen derived from other plants. This spectrum indicates a rather humid climate, necessary for maintaining the high Compositae percentage as well as for maintaining some oaks and olives. It is once more a Mediterranean type, although somewhat drier than during both the Mousterian and Upper Paleolithic occupation periods. It is clear, however, that it signifies a considerable climatic amelioration over the Late Upper Paleolithic at D-31 and is comparable to the environment around the southwestern Judean hills of the present day.

Pre-Pottery Neolithic B Sites

Samples have been collected and analyzed from the Pre-Pottery Neolithic B site, D-1, which has radiocarbon dates averaging 8600 years B.P. (Servello 1976). Stratigraphically this site falls within the termination of the Preboreal Stage of the Holocene (Horowitz 1971). Only one sample from the site yielded pollen and was not rich. The results, therefore, should be considered as preliminary. The pollen spectrum comprises arboreal pollen, totalling 8%, of which *Olea europaea* forms 5%, the rest shared between *Amygdalus, Pinus halepensis,* and *Pistacia.* The nonarboreal spectrum comprises Gramineae and Cyperaceae, 24%, cereals, 9%, Chenopodiaceae, 23%, Compositae, 32%, and 3% of *Scabiosa prolifera.* This is the first appearance of cereal pollen grains in the sediments of the Central Negev; these were not observed in any of the older sites. The pollen spectrum for the time of the Pre-Pottery Neolithic B settlement indicates vegetation and climate that can be compared with those of the Northern Negev, around the present Be'er Sheva area. This is based mainly on the relatively high Compositae percentage. The trees of the Avedat area were most probably relics, although certainly more abundant than at present. The location of the site, adjacent to the streambed of Nahal Zin, may well account for the level of arboreal pollen, since even today relic trees occur in the larger wadi bottoms, such as Nahal Loz and Nahal Horesha. *Amygdalus* and *Pistacia* are typical trees, which can still be found in the Central Negev (Danin 1970). Pines, however, are not presently known in the area, and it is possible that olive pollen was produced by trees that were cultivated by the Neolithic people. It must be pointed out, however, that there is no difference between wild and domestic olive pollen grains. On the other hand, it is highly probable that the Neolithic people cultivated cereals of some kind. Whether this cultivation took place within Nahal Zin is problematic, since even cereals could be carried to the site from another area. At any rate, cereals were probably cultivated in the area during some period of the Pre-Pottery Neolithic occupation, because their pollen do not travel long distances, as was discussed above for the Recent Kinneret samples.

Chalcolithic Sites

Pollen spectra from four Chalcolithic sites in the Central Negev were analyzed (Horowitz, unpublished data) and the spectra are given in Table 6.19. The results are divided into two groups. Spectra from site D-60 (F7-3B) and D-62 (second stratum, Level B) form the first group, which yielded rather high arboreal pollen rates, about 8% each, mainly divided between oak, olive, and pine, with some occurrences of juniper, *Tamarix,* and *Retama roetam,* while the nonarboreal pollen spectrum showed about 20% Compositae, 30% Chenopodiaceae, and 24% Gramineae and Cyperaceae, with some occurrences of other pollen grains. The second group, represented by D-61 (stratum 1), and 168-86 5A-1, is much poorer in arboreal pollen grains, with an average of 3%, divided between oak, olive, and some others, while the nonarboreal pollen spectrum is characterized by very high percentages, around 80%, of Chenopodiaceae. It seems quite clear that the first two samples were deposited under climatic conditions that were more humid than those at present in the area, while the last two samples were deposited under conditions more or less comparable to those prevailing in the area today. Unfortunately, no dates are given for these sites and it is very difficult to tie them to any of the stratigraphical sequences known from the north. It seems, however, just as a preliminary conjecture, that the first two sites should be assigned to the Atlantic period, while the last are most probably post-Atlantic (or pre-Atlantic) and their inhabitants already suffered from the drying up of the Negev during these times.

Conclusions

To sum up, it appears that prehistoric occupation of the Central Negev in Late Quaternary times was highly dependent upon suitable climatic conditions, which permitted the development of vegetation, and probably the presence of a rich wildlife. Such conditions are known for the Late Quaternary of Israel during the humid Würmian pluvial stadials, and somewhat also during the Preboreal and Atlantic stages. Given both the radiocarbon dates and pollen evidence it seems clear that Mousterian occupation of the Central Negev took place during the Early Würmian Stadial, when the Central Negev maintained a fertile Mediterranean environment. The Mousterian settlement of the Central Negev was terminated by the succeeding desiccation, which began some 40,000 years ago, at the period represented by Site D-101, corresponding to the commencement of the Early-Middle Würm Interstadial. Archaeologically, there is a break in the prehistoric record after Site D-101 occupation, which most probably encompasses the major part of the Early–Middle Würm Interstadial. The Avedat area was again occupied during the Upper Paleolithic, when the available pollen spectra indicate a reintroduction of the Mediterranean environment, but somewhat less developed than during the Mousterian. This may be correlated with the second stadial of the Würmian Pluvial. By Late Upper Paleolithic times, however, the environment had deteriorated to steppic conditions, and sites are found only in very close proximity to perennial springs. This period would seem to encompass part of the Middle–Late Würm Interstadial and maybe also the early Late Würm. Data are lacking from that point until the Natufian period, at approximately 11,000 B.P., when the pollen again suggest a rather poor Mediterranean environment.

Climatic conditions during Pre-Pottery Neolithic B times were somewhat better than at present, but less favorable than during the Würm Pluvial, when the area was amenable to some habitation. There still remains a question as to the nature of these conditions, considering the presence of the cereal pollen. In Chalcolithic times, during the Atlantic period, to which the first two Chalcolithic sites are temporarily assigned here, climatic conditions were once more somewhat better than at present, enabling habitation. It seems therefore that habitation of the Central Negev took place for the most part when the climate was somewhat better, or during certain periods, when it was a great deal better than the present-day desert conditions. Only two or three sites are known from the area, which indicate climatic conditions similar to the present for most of the Late Quaternary. These are D-101 and the two non-Atlantic Chalcolithic sites. It seems though that even then local conditions during the late Quaternary were somewhat better than at present, since trees are represented in the pollen spectra, as opposed to the present-day spectrum, in which trees are practically absent.

CENTRAL-WESTERN NEGEV

Samples have been palynologically analyzed (Horowitz, in press) from two early Holocene sites in the Central–Western Negev Highlands, northwest of the Ramon erosion cirque, the Natufian site, E-22G-7, of Rosh Horesha and the post-Natufian pre-Neolithic site, E-22G-12, of Abu Salem (Figure 6.17).

Rosh Horesha

Rosh Horesha is a site that yielded Natufian artifacts and an average radiocarbon age of approximately 10,700 years B.P. (Marks, in press). This site is located in one of the small wadis that drains the Har Harif plateau to Nahal Horesha. Four samples were collected from Rosh Horesha, and the average pollen spectrum is as follows: arboreal pollen makes up 9%, divided between *Juniperus*, 3%, *Pinus halepensis*, 2%, *Pistacia*, 2%, *Olea europaea*, 1%, and *Acacia*, 1%. The nonarboreal pollen spectrum comprises 56% Gramineae and Cyperaceae, 19% Chenopodiaceae, and 5% Compositae, together with rare occurrences of Cruciferae, Malvaceae, *Ephedra*, and *Artemisia*. The surprising find, however, was some 9% of pollen grains derived from cereals. Comparing this pollen spectrum to the Recent one, it seems that the variety of pollen species is much greater in the Natufian spectrum, which has, for instance, 9% arboreal pollen, as compared with no arboreal pollen at all for the Recent. The nonarboreal Natufian pollen spectrum comprises much more Compositae and Chenopodiaceae and the occurrence of cereal pollen in the fossil deposits is striking. It seems that this pollen spectrum indicates a much richer natural vegetation, probably maintained by a more humid climate, that seems to resemble the present-day northwestern Negev or southern Shefela. The higher percentage of Gramineae and Cyperaceae pollen, typical of the drier environment in the Negev, was probably derived from the vegetation of nearby wadis. This becomes obvious when comparing the Rosh Horesha spectrum with that at the site of Abu Salem, discussed later. The latter is only somewhat younger, but is situated on the plateau of Har Harif rather than in the wadi. The two spectra are very similar if the high Gramineae and Cyperaceae of Rosh Horesha is considered to be from the restricted local influence of the wadi, while the local environment of Abu Salem comprised more Compositae and Chenopodiaceae, growing on the plateau during the early Holocene. The occurrence of cereal pollen in the Natufian spectra must indicate that these plants were cultivated at the time, approximately 10,700 years B.P. in the Central-Western Negev, by the Natufian people.

Abu Salem

Abu Salem is a site that yielded artifacts of a post-Natufian, pre-Neolithic affinity, and an average radiocarbon age of 10,250 B.P. (Marks, in press). Six samples were analyzed from this site and the pollen yield was fairly good. The pollen spectrum comprises 4–5% arboreal pollen, of which *Olea europaea* comprises 2%, *Amygdalus* and *Juniperus* 1% each, with rare occurrences of *Acacia*. The nonarboreal pollen spectrum is dominated by Chenopodiaceae, 47%, Compositae, 26%, and Gramineae and Cyperaceae, 17%, together with occurrences of Umbellifereae, Liliaceae, Crucifereae, *Artemisia, Ephedra,* and *Zygophyllum*. Besides, about 1% of cereal pollen was encountered. It seems that the only difference between this spectrum and that of Rosh Horesha lies in the ratio of the Gramineae and Cyperaceae pollen, discussed previously. The rest of the pollen spectra from Abu Salem seem to indicate that the environmental conditions, rich vegetation, and higher humidity as compared with the present did not change much from Natufian times in the interval of approximately 500–600 years. The cultivation of cereals probably continued also in post-Natufian pre-Neolithic times in the Har Harif area. To sum up, at the earlier stage of the Holocene, the Preboreal, the area of the Central-Western Negev was more humid than at present and maintained a richer vegetation, including some stands of trees. Cereals were cultivated in this area at least from Natufian times onward.

COASTAL PLAIN

Tabun Cave

The Tabun Cave is located on the western escarpment of Mt. Carmel (Figure 6.17). The cave opens northwestward, facing the Mediterranean coastal plain, which was, until quite recently, covered with open field vegetation and some marshes. Mt. Carmel is covered with a Mediterranean mixed maquis, comprising chiefly oaks and pistachio, with some pines and other minor elements (Zohary 1959). Only cultivated olive trees grow here now, but these are known to have grown wild in Israel throughout the Pleistocene. The prevailing winds in the region are northwesterly or westerly. The cave was formed by the dissolution of a Cenomanian reef core, which probably occurred in early or middle Pleistocene times. It is filled with a sequence of about 25 m of sediments, of which the lower part is a calcareous sandstone, the middle part a loess type sediment, and the upper part a breccia, very rich in red loam (Jelinek *et al.* 1973). Most of the layers contain artifacts and bones. The present account is based on pollen spectra recovered from about 30 samples collected along the entire sequence. Preliminary findings, based on only 12 samples, were reported by Horowitz (in Jelinek *et al.* 1973). Conclusions from the present account, supported by many more samples distributed along the entire sequence, seem to be quite reliable. The location of the samples are shown in Figure 6.26, the pollen spectra in Table 6.20, and a pollen diagram for the Tabun beds is given in Figure 6.27.

Of the thirty analyzed samples, 23 contained quite rich pollen spectra, and from many of them at least 150 pollen

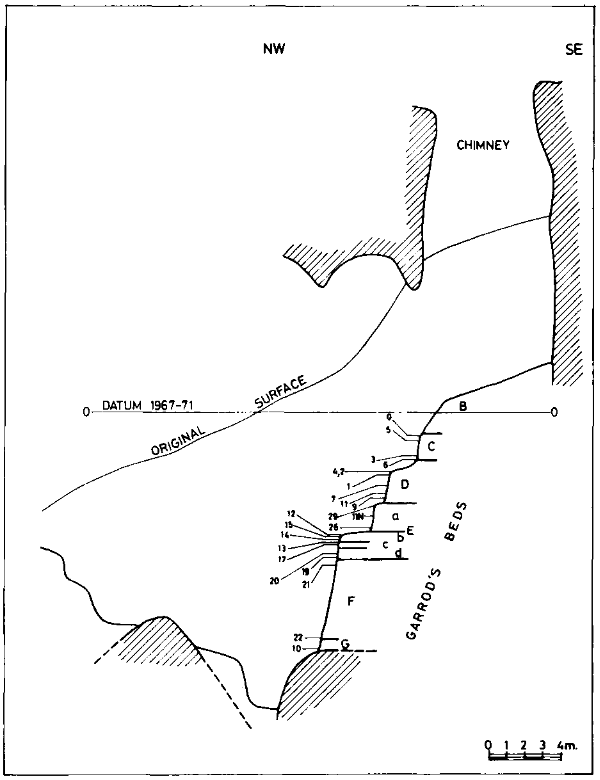


FIGURE 6.26. *Schematic cross section and pollen sample locations from the Tabun Cave, Mount Carmel.*

TABLE 6.20
Pollen Spectra from Tabun Cave

Sample number	—	0	5	3	6	2	4	1	7	11	9	29	11N	26	12	15	14	13	17	20	19	21	22	10
Garrod's Layer	—	C Top	C	C Lower	C Lower	D	D	D	D	D	D	Ea	Ea	Ea	Eb	Eb	Eb	Ec	Ec	Ed	Ed	F Upper	F/G	G
Bed number	—	5	9	21 and 22	22	35B	35B	36	36A	37	39	42	48	47	51	52	54	54	55	57	Base 58	80	—	—
Square number	—	2	4	8	8	8	8	8	8	8	8	15	36	24	38	38	38	39	39	45	45	45	—	—
Depth: cm below Datum 1967–1971	—	Ca. 120	Ca. 160	Ca. 290	300	303–315	335–345	375–380	390–395	435	442	505–507	575	630	675	680	690	712	725	763–770	804–810	830–838	1450	1480
Quercus spp.	1	—	16	24	14	4	15	16	58	21	35	—	9	—	12	2	—	4	—	1	—	9	3	6
Pinus halepensis	9	—	5	8	2	7	2	9	6	2	3	—	4	7	1	—	2	6	—	—	—	—	1	3
Olea europaea	4	—	1	1	1	—	—	2	—	1	—	1	2	—	1	—	—	—	1	5	14	3	1	1
Pistacia spp.	2	—	1	1	1	—	1	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cupressus sempervirens	3	—	—	—	1	4	1	3	—	1	—	—	1	—	1	—	—	—	—	—	—	—	—	—
Picea sp.	—	—	—	—	—	—	—	—	—	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Corylus avellana	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Other arboreal pollen	—	—	—	—	—	—	1	1	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total arboreal pollen	19	0	23	33	20	15	19	33	64	36	38	1	17	7	14	2	2	11	1	6	14	12.	5	10
Gramineae and Cyperaceae	27	1	66	65	71	76	74	61	32	45	47	76	12	57	17	19	62	38	46	23	22	33	31	32
Compositae	23	89	—	1	7	6	6	3	2	12	1	7	44	24	44	47	6	30	32	50	27	23	50	5
Chenopodiaceae	8	—	—	2	1	—	—	2	1	—	13	14	—	13	24	30	29	17	17	21	37	31	12	1
Umbelliferae	—	—	—	—	—	—	1	1	1	4	—	—	18	—	—	—	—	—	—	1	—	—	1	—
Cruciferae	14	—	—	—	—	—	—	1	—	1	—	1	1	—	—	—	—	—	—	—	—	—	—	—
Scabiosa prolifera	—	4	—	—	—	2	—	—	—	—	—	—	1	—	—	—	—	—	1	—	—	—	—	50
Artemisia sp.	—	—	—	—	1	—	—	—	—	—	1	—	3	—	—	—	—	4	1	—	—	—	—	—
Other nonarboreal pollen	9	6	1	—	1	1	1	—	1	2	—	—	3	—	—	2	—	—	—	—	—	—	1	3
Total nonarboreal pollen	81	100	67	67	80	85	81	67	36	64	62	99	83	93	86	98	98	89	99	94	86	88	95	90
Total counted	265	168	171	135	153	151	138	152	158	85	151	83	93	46	127	53	48	47	59	102	52	90	103	149

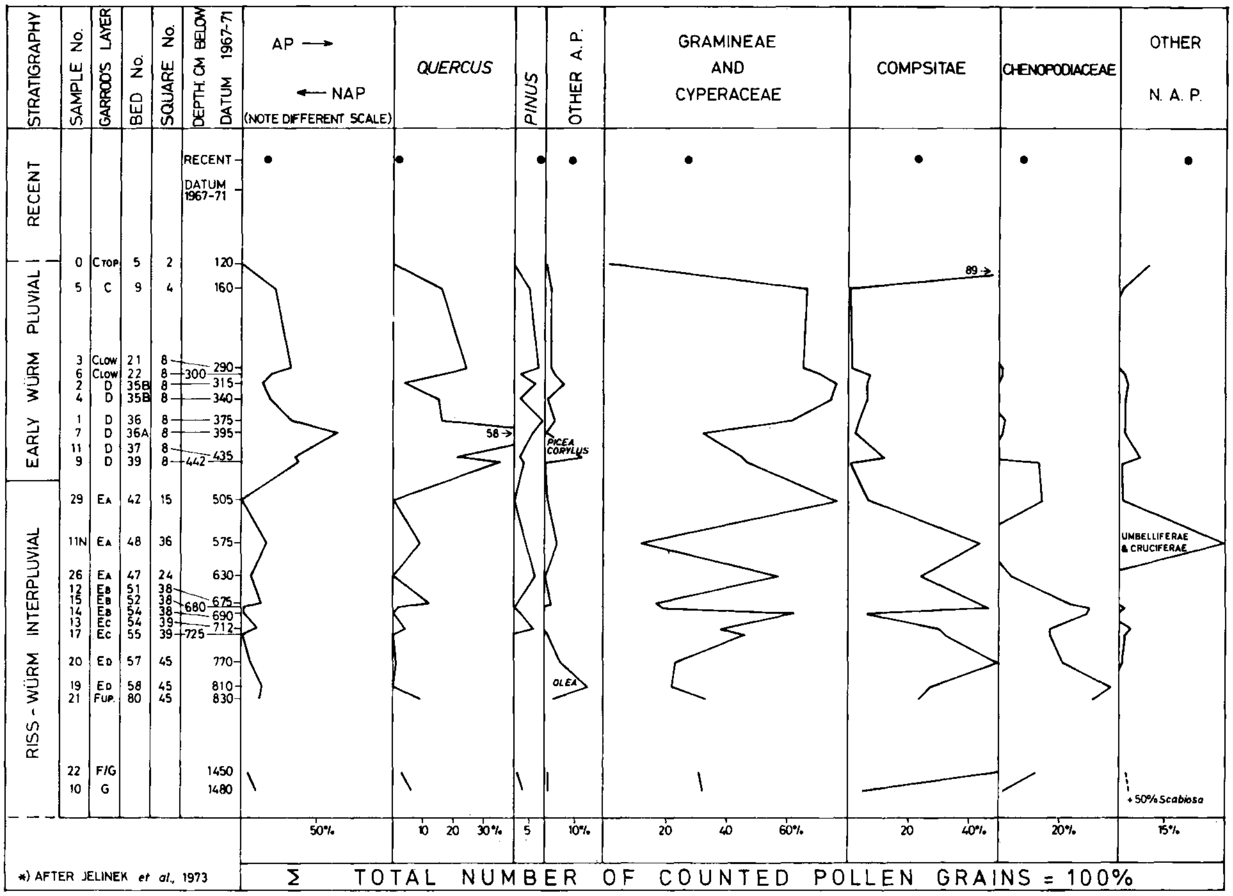


FIGURE 6.27. *Pollen diagram of the Tabun Cave sediments. Location of samples is given in Figure 6.26.*

grains were counted. Seven samples contained only very few pollen grains, apparently due to postdepositional oxidation of the organic material. The Tabun Cave was excavated by Garrod and Bate (1937) who designated by letters (G to A) to the various beds exposed and excavated at the cave. In the late 1960s and early 1970s a joint expedition from the University of Arizona and the University of Michigan, headed by A. J. Jelinek and W. R. Farrand, reexcavated some parts of the cave, assigning different designations to the various beds (Jelinek *et al.* 1973). Both Garrod's and Jelinek's designations are given in Table 6.20, to facilitate comparison. The samples analyzed from the Tabun Cave sequence represent Bed G at the bottom of the sequence, two samples from the lower part and the upper part of Bed F, and Beds E, D, and C, which are the best developed in the sequence. Several samples that were processed from Bed B, which is the loamy breccia on top of the sequence, yielded no pollen at all. Bed A, which is the Recent soil, was totally removed by Garrod during her excavation, and no samples could be collected.

At first glance, one could divide the pollen spectra into two definite sections. The lower one, representing Beds G, F, and E, is characterized by very low percentages of arboreal pollen, even lower than present-day percentages, and very high percentages of Chenopodiaceae in relation to Gramineae and Cyperaceae. Compositae also show quite high percentages. This lower part is also characterized by the poor number of species represented within the arboreal and the nonarboreal pollen spectra. Some of the samples were rather poor in pollen grains, but it seems that the spectra taken together are quite sufficient to draw conclusions. The second sector is represented by Beds D and C, which is characterized by rather high percentages of arboreal pollen, much higher than the present rate, almost no Chenopodiaceae at all, rather low Compositae rates, and high Gramineae and Cyperaceae, together with some occurrences of other open field elements. The arboreal pollen spectrum represents mainly high percentages of oak and pine, which are considerably more represented than in the Recent spectra. Although the Recent spectrum contains 19% arboreal pollen, most are derived from cypress, olives, and pines, which are cultivated in the area, so that the figure for arboreal pollen in the Recent sediments should really be diminished at least by half.

Bed F, which lacked pollen grains for the most part, really displays a hiatus within the pollen sequence, a hiatus that is represented by at least 6 m of sediment. I should not like, therefore, to connect the profiles for Bed G and the transition from F to G (samples 10, 22, and 24) with the upper part of Bed F (samples 21), and the rest of the samples that represent Bed E, although all of them are more or less of the same nature. The samples collected from the base of the sequence are all poor in arboreal pollen grains, but the nonarboreal pollen spectrum differs considerably, comparing the three samples. In sample 10 the prevailing element of the nonarboreal spectrum is *Scabiosa prolifera,* which forms up to 50% of the total. Compositae form the main elements in sample 24, while Compositae and Gramineae form the main elements in sample 22. It seems, though, that these are only local influences, probably due to the abundance of one or two species in the immediate vicinity of the cave. It should be remembered that this is a cave that forms a trap for pollen grains, but these are filtered through the vegetation that grows in the area close to the cave opening, which naturally is much better represented than all the rest.

The upper part of Bed F and the entire sequence of Bed E, between the depths of about 8.40 and 5.5 m below the area sampled in the years 1967–1971 by Jelinek *et al.* (Figure 6.26), represent very dry, interpluvial climatic conditions, which probably prevailed in the area during the Riss–Würm Interpluvial. It should be noted that during this interpluvial the Monastirian sediments of the transgressive Mediterranean were laid down quite close to the cave (Michelson 1970). The sea that flooded the coastal plain at this time surpressed any possibilities for development of open field vegetation in these areas, and apparently only the halophil vegetation of the sand dunes and the coastal plain, namely, the Chenopodiaceae, could have been developed at this time. This is most likely the reason for the high percentages of Chenopodiaceae grains in the samples represented by Beds E, F, and G. It can be seen, therefore, that the influences on the pollen spectra, represented within the lower part of the sequence of the Tabun Cave, are twofold: the dry climate and the scarcity of trees on the one hand, and the transgressive sea and its halophil vegetation on the other.

The samples collected from Beds D and C, on the other hand, represent totally different climatic conditions than the ones below. This is true for almost all of the samples, except for sample 0, which was collected at the top of Bed C, and it is not certain that this sample really represents a part of Bed C. The rest of the samples are typified by rather high shares of arboreal pollen grains and a very high percentage of oak within the arboreal pollen, together with pine, olive, pistachio, cypress, and sometimes occurrences of northern trees like *Picea* and *Corylus,* as in sample 11. This suite of samples most likely represents pluvial climatic conditions, in which the forest on the Carmel was much better developed than at present; it is definitely much better developed than during the preceding interpluvial. The sea had regressed and apparnetly some kind of forest was also developed on the coastal plain. The transition between Bed E and Bed D is marked by the diminishing number of Chenopodiaceae and the increasing number of Gramineae and Cyperaceae. Apparently the Gramineae and Cyperaceae occupied the marshes that developed due to the regressing sea, while the Chenopodiaceae and Compositae, most probably *Inula viscosa,* which grew close to the sea, propagated westward with the retreating sea. This process occurred with the onset of pluvial climate, which is marked by increase in the arboreal pollen spectra. A slight decrease of the arboreal pollen curve, together with some increase of the pine and cypress share within the arboreal pollen curve, can be seen in sample 2, at the transition between Bed D and Bed C. It seems that Beds D and C represent together the first phase of the Würmian Pluvial in Israel, while the transition between them marks the subdivision of this pluvial phase into two subpluvial phases, as can be seen also in the Birket Ram Borehole pollen diagram.

To conclude, sediments began to be accumulated in the Tabun Cave sometime during Riss–Würm Interpluvial times, when the climate was dry and the sea was rather high, most probably reaching not far from the cave. During this time, Beds G, F, and E were deposited. Following the onset of pluvial climatic conditions, with a well-developed forest and a retreat of the sea, Beds D and C were deposited in the cave. The granulometric differences between these two suites of sediments are also quite obvious (Jelinek *et al.* 1973). The lower part of the sequence is characterized by sandy sediments, while the upper part is characterized by loess-like sediments. It seems that when the sea was closest to the cave, part of the sand dunes were blown into the cave. When the sea was farther from the cave, during pluvial times, only small, silt-sized particles could have been blown this distance and no sand grains could have reached the cave. Bed C is covered by Bed B, which most likely represents the collapse of the cave's ceiling, together with downsifting or washing of red terra rossa, which forms the loam within the gravels of Bed B. This event probably prevented any further possibility of life within the cave, which was in fact almost sealed. Some soil formation in the top of Bed B, designated by Garrod as Bed A, was probably a result of subaerial processes.

Ganei Hata'Arukha Site

The Ganei Hata'arukha site is situated a few hundred meters north of the Yarkon River near Tel Aviv, about 4 km east of the present shoreline. A succession of strata was uncovered by (Mrs.) H. Kaplan of the Museum of Antiquities of Tel Aviv/Jaffa (personal communication 1971). A Chalcolithic settlement was found overlying several barren strata that will be considered here as "pre-Chalcolithic." Pottery of Proto-Urban, Early Bronze, and Middle Bronze IIA was found in layers overlying the Chalcolithic strata; these are overlain in turn by sterile, "post-MB IIA" sediments. The sediments in which the Chalcolithic site is buried are generally sandy loams, varying somewhat in color and texture from one horizon to another. A mudstone horizon covers the Chalcolithic settlement and is overlain by a Middle Bronze IIA sandy horizon. The lateral time stratigraphic equivalents of the mudstone horizon, of Proto-Urban and Early Bronze Age, are found several hundred meters north of the Chalcolithic site on a hill slope that apparently was not covered by the marsh which has deposited the mudstone and buried the Chalcolithic settlement.

Results of the palynologic analyses are summed up in Table 6.21 as percentages of the total number of counted pollen. This number was not high, but it is presumed that the general conclusions drawn from the spectra are reliable. The pre-Chalcolithic strata yielded a spectrum that is rather poor in arboreal pollen, not taking into account the bank trees *Populus, Salix,* and *Tamarix,* which grew on the Yarkon River banks. The nonarboreal pollen comprises mainly Compositae. The suite of samples from Early Chalcolithic through approximately 2800 B.C., Nos. 14, 8, 7-A, 4, and 9, show relatively higher percentages of arboreal pollen as compared with Sample No. 13, the pre-Chalcolithic, below. Gramineae and Cyperaceae prevail among the nonarboreal pollens and the spectrum is rich in numbers of species. Among the arboreal pollens, those of *Quercus* are the main components. The samples above, Nos. 3-A, 7, 3, and 1, are much poorer in *Quercus* pollen. The two samples collected from the MB IIA strata are very rich in *Cupressus sempervirens* pollen. Samples collected from the pre-Chalcolithic and "post-Early Bronze" strata show approximately the same palynological characteristics, except for the high cypress percentages of the Middle Bronze IIA sample. It seems that cypress was cultivated by the Middle Bronze IIA people, possibly for the use of its timber, since it is a straight, fast-growing tree in comparison to other Mediterranean trees. The rest of the pollen spectra of these samples is quite similar to the Recent pollen spectra of the area, indicating climatic conditions not far different from the present day for both pre-Chalcolithic and post-Early Bronze times. It seems therefore that the pre-Chalcolithic strata can be assigned to the Boreal Stage of the Holocene, which was similar to the present-day climate, while the "post-Early Bronze" strata are assigned to the Subboreal and the Subatlantic stages, for the same reason.

The Chalcolithic through Early Bronze strata were apparently deposited under a more humid climate, which is concluded on the basis of the much more abundant *Quercus* pollen and the relative abundance of Gramineae and Cyperaceae over Compositae. The higher humidity probably corresponds to the climatic optimum of the Atlantic Stage. This higher humidity apparently caused slow rising of the groundwater table, which resulted in a gradual spreading of marshes on the Yarkon River floodplain. These marshes determined the location of the sites. The Chalcolithic people lived not far from the Yarkon and its marshes and dug their pits into the soil. It seems that the pits reached the groundwater table and then were paved with stones. During Atlantic times, with the increase of humidity and rising of the groundwater table, the bottoms of the pits were submerged and the people had to build second and third floors; these were excavated by Kaplan. The process of rising groundwater continued at least until Early Bronze times, in the middle of the third millenium B.C., and pushed the Proto-Urban and then the Early Bronze people northward up the hill. A decrease of humidity at the end of the Atlantic, followed by lowering of the groundwater table, caused southward migration of the site, downhill in the direction of the retreating water.

CONCLUSIONS

Pollen analyses of prehistoric sites indicate that Israel was considerably populated during the humid periods. In these periods people migrated as far south as the Negev and Sinai. During the drier interpluvials and some of the interstadials, the population was restricted to the northern part of the country. Therefore, the settlement record in the south is intermittent, representing only the pluvial, humid phases, while only in some localities in the north of the country, especially in caves and rock shelters, could complete settlement succession be found. Artifacts of Late Acheulian, Mousterian, Late Paleolithic, Epipaleolithic, Neolithic, Chalcolithic and Early Bronze I cultures are found in the Negev, while the rest of the stages, covering drier periods in the country, are found only to the north. Sites of interpluvial age are found only in caves in the north of the country, such as Tabun and Amud, while artifacts that are embedded in sediments which yielded pluvial pollen spectra, are known from all over the country. Open-air interpluvial sites are known from the Orontes River terraces about 200–250 km north of Israel, where even during the drier interpluvials the climate was comfortable enough to support settlement. Another reason for the rarity of interpluvial sites in Israel lies in the distribution of sediments. During the interpluvials the coastal plain was covered by dunes, which did not support a suitable environment for human life, while in the Jordan Valley, the interpluvial sediments are mostly covered by succeeding pluvial lacustrine sediments, so that even if people dwelled in these places the chance of finding their artifacts is in fact rather limited. The mountainous areas, on the other hand, were subject to erosion in the interpluvials.

TABLE 6.21
Percentages of Constituents of the Pollen Spectra from Ganei Hata'arukha Site, near Tel Aviv

Layer	Sample number	*Quercus* spp.	*Pinus halepensis*	*Olea europaea*	*Cupressus sempervirens*	*Populus euphratica*	*Tamarix* spp.	*Salix acmophylla*	Total arboreal pollen	Gramineae	Cyperaceae	Compositae	Chenopodiaceae	Malvaceae	Umbelliferae	*Scabiosa prolifera*	*Rubus sanctus*	Other nonarboreal pollen	Total nonarboreal pollen	Total number of counted pollen	Musci spores (not counted)
Post MB IIa	1	3	—	1	—	2	—	3	9	2	3	86	—	—	2	—	—	—	93	117	—
MB IIa, app. 2000 years B.C.	3	1	1	—	31	1	—	1	35	45	1	16	—	—	—	—	1	2	65	157	v
	7	—	—	—	66	6	—	—	72	20	6	3	—	—	—	—	—	—	29	35	—
Post EB, Pre MB IIa	3a	3	2	—	3	—	—	—	8	64	5	19	—	—	—	—	—	2	90	62	—
Between Proto-Urban and EB, app. 2800 years B.C.	9	15	—	—	3	23	—	—	41	38	15	3	3	—	—	—	—	—	59	40	—
	4	22	1	1	—	4	—	—	28	4	20	33	3	—	1	—	2	7	70	69	v
Proto-Urban, app. 3000 years B.C.	7a	10	—	—	40	—	—	—	50	20	10	10	—	—	—	—	—	10	50	10	—
Early Chalcolithic, app. 3500 years B.C	8	11	—	—	—	—	—	—	11	56	—	—	11	—	—	—	—	22	89	9	—
	14	13	2	4	—	—	—	13	32	2	13	27	—	13	2	10	2	—	69	52	v
Pre-Chalcolithic	13	—	2	2	—	—	2	7	13	9	—	68	2	2	4	4	—	—	88	57	—

The pollen spectra of the sites show some predominance of various pollen grains over others, and especially of two groups: pollen of ruderal plants, of which the most abundant are Chenopodiaceae, accompanied by pollen grains of cultivated plants in the more recent sites. Among the pollen of cultivated plants, those derived from cereals are of great importance. They are first recorded in the Pre-Pottery Neolithic B sites of the Central Negev. Several cereal pollen grains were also recorded from the Kebaran site at Fatza'el, but this occurrence is somewhat doubtful. Pollens of other cultivated plants occur in several other sites, of which the more common are almonds and olives, while in the later sites, such as those of the Early Bronze and Middle Bronze cultures, cypress was cultivated as well. Also interesting is the relatively high percentage of pollen grains derived from Malvaceae, which are found in many of the later sites, from the Kebaran onwards. These are probably derived from one of the plants of this family, *Malva sylvestris,* locally known as Khubeiza, which is still consumed as food by present-day Arab and Bedouin inhabitants of the region.

7

Quaternary Fauna

E. TCHERNOV

Pleistocene deposits in Israel have furnished a wealth of fossil material, in particular from the late, but also from the middle Pleistocene, giving a sound basis for studies other than prime descriptions of species and "alpha" taxonomy. Studies concerning paleoecological, evolutionary, and biogeographical aspects of some of these fossils have already been published, but much more material awaits consideration, in particular that from the quite recently discovered sites of Ubeidiya and Erk-el-Ahmar (Jordan Valley). Much the same is true for several groups of veretebrates from other sites, for example, the teleost fishes, amphibians, reptiles, insectivores, and some ungulate families, which as yet have not been widely found in Israel, and are still poorly understood. The most important biological roles of such studies is their ability to provide building stones for the understanding of evolutionary trends of species on the one hand, and the dynamic changes of total biotic communities on the other. Because it covers a relatively short geological time span, the Quaternary has the advantage of providing finely accumulated strata with large communities and rich diversity of species, which are uninterruptedly connected with contemporary faunas, furnishing temporal sequences of evolutionary lines. This creates a confident basis for detailed analyses of changing distributions, of describing minute anatomical diversions and providing a sensitive measure of variability of populations in space and time.

Israel stands at a biogeographical crossroads during the Neogene and Pleistocene periods. Hence the timing of geological and paleontological events in the Levantine corridor during the Neogene is crucial to the interpretations of immigrations of organisms between Eurasia and Africa, and the evolution of the extremely complicated biomes in the south Palearctic province. As yet, very little is known about Neogene animal life in the Levant (Savage and Tchernov 1968), but Pleistocene faunas reflect those paleontological events that took place during the Neogene in the region, and may clarify the vexing problem of interconnection between the two realms.

In earlier Miocene times (Middle Burdigalian), about 17–18 MY ago, Eurasia was invaded by a swarm of endemic mammal groups from Africa, dominated by probosideans, tragulids, anthracotheres, and African rhinoceroses (Savage and Tchernov 1968). This assemblage of large mammals, described from the Negev Miocene, appears to consist entirely of endemic African early Miocene taxa, and thus dates from the time before the mid-Burdigalian land bridge to Eurasia was created (Van Couvering 1972). Plate tectonic theory (Dewey *et al.* 1973) suggests that this invasion came about as a result of the drawing up of the northeast edge of the Afro-Arabian continent against the margin of the Eurasian continental body by subduction (plate consumption) along the present Anatolian–Iranian tectonic suture line. The first wave of immigrants contained known elements of the North African early Miocene fauna only (Savage and Hamilton 1973). East African early Miocene representatives such as ambelodont proboscideans and hominoids did not enter Eurasia until the middle Miocene (Middle Vindobonian). On the other hand, middle Miocene mammals of Eurasia found it difficult to spread into Africa at a time when proboscideans and other African forms found it easy to emigrate into Eurasia. The post-Burdigalian invaders, which now reside in Africa, are relatively few, and include advanced fissipeds (felines, canids, hyaenids, viverids), equids, advanced rodents, and lagomorphs. None are known as yet from beds in eastern Africa older than 12 MY. Hence it is clear that Israel played a crucial link in the Miocene land bridge between the two provinces. It is also obvious that the Levant played an integral part in the faunal evolution of Africa. Even today there is a strong "African stamp" upon the fauna of Israel, which gradually dimishes northward. African elements hardly existed north of the Ponto-Aralo-Caspian (or the Paratethys) line (Tchernov 1968, 1975a).

It is now generally believed that progressive desiccation was the principal climatic trend during the late Pleistocene of Israel. This shift in the climate toward a drier regime has presumably been the principal cause of local extinction of the tropical component of the eastern Mediterranean fauna. The impact of both the northern glacial sequence and the close proximity of a large desert belt upon the terrestrial and freshwater faunas of Israel throughout the Pleistocene is yet to be fully understood in depth. An attempt has been made in the following pages to collate all the available information on faunal assemblages and their changes during the Quaternary of Israel in the light of the biogeographical evolution and environmental transformations that took place in the area.

VERTEBRATE AND MOLLUSK BEARING DEPOSITS

Most of the vertebrate and mollusk bearing beds from the early and middle Pleistocene were deposited in a variety of freshwater bodies. Hence there is frequent and close association between vertebrate and freshwater mollusk communities (often intermingled with disseminated plant material). As a rule the aquatic organisms represent autochtonous communities, while the terrestrial elements are allochtonous, although usually displaced only short distances into the fossiliferous sites. The type of sediments and the relatively good preservation of mammalian teeth and fine bones of birds suggest that skeletal parts were sorted to a certain degree by currents. In this way the vertebrate and the mollusk remains in these deposits may faithfully reflect the original diversity of species, and the natural distribution of species in the surroundings of the sites. Only the exposures at Giveat Shaul were deposited under a montane terrestrial environment.

Most of the late Pleistocene bone bearing deposits came from prehistoric sites in which the deposition of microvertebrates was due to diurnal and nocturnal raptors (in particular *Tyto alba,* the barn owl). Excluding a few cave dwellers and anthropophile organisms, the great majority of animal remains in prehistoric sites constitute a true thanatocoenosis. Having been sampled at random by owls, the thanatocoenotic communities of microvertebrates may reflect their original distribution in the vicinity of a particular site, enabling quantitative analyses of natural habitats, paleoecology, and paleoclimate. Larger vertebrates were mostly collected by man, and may largely reflect the hunter's choice at any given time.

No attempt is made to discuss the systematic position of fossil remains, nor to deal with their taxonomic problems. The aim of this chapter is to present ad hoc information that has accumulated during the last 50 years of paleontological research in Israel, commencing with the work of Bate (1927). The taxonomic position of many fossil species is still in dispute and needs thorough study and a taxonomic reevaluation (for example, insectivores, chirophera, and a few groups of ungulates). Some groups have never been studied at all in Israel (in particular, land snails, fish, amphibians, and reptiles, for which only preliminary lists exist in the literature). The avifaunal remains from late Pleistocene sites are sometimes redundant, and only small numbers of these can be examined at present. The location of all fossil bearing sites in Israel is given in Figure 7.1.

MAMMALIAN FAUNA OF THE BETHLEHEM CONGLOMERATE

The fortuitous discovery of the bone bearing bed of Bethlehem was made by Bate in 1934, and the results of the preliminary excavation by Gardner and Bate in 1935–1936 were published in further detail in 1937. Stekelis completed the excavations in 1940 and Hooijer reviewed the faunal record in 1958. Clark (1961) examined the lithic finds, and Shaw (in Clark 1961) described the geology. An assemblage of large mammal bones was unearthed from a water pit dug in the town. The section revealed coarse layers of conglomerate and gravel with a clayey matrix and red loam, probably deposited in water. The gravel consisted mainly of subangular flint pebbles and large blocks of limestones (minor constituent). Hence the material may be assumed to be very little sorted. Fish and crocodilian teeth, which were found in the Bethlehem Conglomerate near Jerusalem (Horowitz 1970a), further indicate that sediments in this area were deposited in water.

The mammalian fauna of Bethlehem is older than all other Quaternary faunas known from the Near East, and its age is suggested as latest Tertiary or Preglacial Pleistocene. Its composition is as follows: 1, *Nyctereutes megamastoides* (Canidae); 2, *Homotherium* sp. (Felidade); 3, *Archidiskodon* cf. *planifrons* (Elephantidae); 4, *Hipparion* sp. (Equidae); 5, *Dicerorhinus etruscus* (Rhinocerotidae); 6,

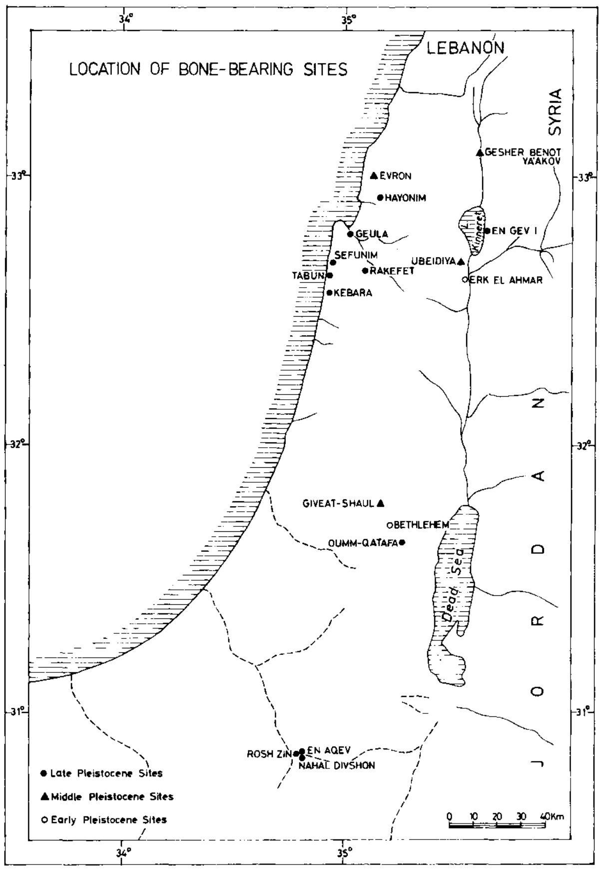


FIGURE 7.1. *Location map of faunal bearing sites in Israel.*

Sus cf. *strozzi* (Suidae); 7, *Giraffa* cf. *camelopardalis* (Giraffidae); 8, *Leptobos* sp. nov.? (Bovidae); 9, *Gazellospira torticornis* (Bovidae). Worth noting is the lack of Cervidae, which probably had not yet entered the eastern Mediterranean region from the north (Bar-Yosef and Tchernov 1972). *Nyctereutes, Dicerorhinus,* and *Gazellospira* are characteristic of the Villafranchian of Europe, while *Giraffa* gives an African stamp to the Eurasiatic assemblage of Bethlehem.

ERK EL-AHMAR FORMATION

The site of Erk el-Ahmar is located some 10 km south of Lake Kinneret (Figure 7.1). The limnic deposits of the site dip 25° E and are overlain by horizontal beds of the Late Pleistocene Lisan Formation (Picard and Baida 1966, 1966a) with a sharp unconformity. The western rim of the Jordan River along the stretch of the Erk el-Ahmar exposures is predominantly built of downstepping faulted and tilted blocks (Picard 1965; Schulman 1959). Its outcrops, with sporadic caps of horizontally bedded Lisan, form a deeply faulted block through which the Jordan River forced its way southward in post-Würmian times (Bar-Yosef and Tchernov 1972; Tchernov 1973). Out of 18 species of mollusks found at Erk el-Ahmar (Tchernov 1975), only seven were also found in the overlying Ubeidiya Formation (Table 7.1). From Ubeidiya, 15 species have been described (Tchernov 1973), six of which still live in the Jordan Valley, while only one is extinct (*Melanoides dadianus*). The rest of the Ubeidiya malacofauna is still found in Israel, with the exception of *Leguminaia chantrei,* which retreated from the Central Jordan Valley and at present inhabits the tributaries of the Orontes in Syria. The malacofauna of Ubeidiya is therefore quite modern in comparison to Erk el-Ahmar. Among the species found in Erk el-Ahmar, five are extinct (Table 7.1): *Viviparus apameae, Bythinia multicostata, Melanoides dadianus, Melanoides jordanicus, Unio subrectangularis,* and five species must have subsequently receded from Israel, as they are not found in younger deposits. Two, *Hydrobia acuta* (= *H. fraasi*) and *Dreissena chantrei,* are characteristic of late Pliocene freshwater beds in Israel, and have never been found in younger Pleistocene deposits, while *Viviparus unicolor* and *Pisidium pirothi,* which at present inhabit the Nile system, are unique to this site in Asia. *Melanopsis doriae* is restricted to Mesopotamia. Three endemic species (now extinct) characterize the site of Erk el-Ahmar: *Unio subrectangularis, Melanoides jordanicus,* and *Bithynia multicostata.*

Remains of fishes (Cichlidae and Siluridae in particular) are known to occur in abundance in most of the layers. Remains of other groups of vertebrates occur, but are extremely rare; however, several exposures have not as yet been sampled. Schulman's (1959) statement that the "similarity of these beds to those described from Ubeidiya in its faunistic assemblage . . . is self evident" cannot be considered valid now in the light of the comparison here, amplified in Table 7.1. The Erk el-Ahmar assemblage consists of many fossil species, some of which are characteristic of the local late Pliocene, while a few others are strictly endemic. In Ubeidiya the assemblage is dominated by newcomers, none of which is endemic. The newcomers of Ubeidiya are pulmonates and bivalves, while only two species of pulmonates were found in Erk el-Ahmar, *Lymnaea lagotis* and *Gyraulus piscinarum.* The mixture of only a few modern species with Pliocene forms and the predominance of fossil types in Erk el-Ahmar indicate much older assemblages than at Ubeidiya. On the other hand, this assemblage is too young to be of Miocene or early Pliocene age, as it contains a typical Sarmatic element (*Melanoides dadianus*), and endemic species of the Orontes (*Bythinia syriaca, Viviparus apameae*), which evolved later and could only subsequently have invaded the developing Jordan Valley. The extinction of five species of mollusks, the retreat of five further species from the region, and subsequent extensive invasion of many modern newcomers, such as those found in the beds of Ubeidiya, must have taken place over a long time. As all the typical local Neogene elements still take part in the Erk el-Ahmar assemblage, the time span between the two formations is long enough to exclude the older one from the middle Pleistocene. Hence an appropriate date for Erk el-Ahmar would be early Glacial Pleistocene.

FAUNAL ASSEMBLAGES OF THE UBEIDIYA FORMATION

The area of Ubeidiya, 3 km southwest of Lake Kinneret (Figure 7.1), is renowned for its important geological exposures. As early as the turn of the century it was often used as a key to understanding the geology of the Jordan Valley as a whole. The site of Ubeidiya, where the majority of excavations have been made, is situated at the foot of the graben's western escarpment. Other exposures are scattered in the vicinity of the settlement of Kinneret, and on the graben's eastern bank near Tel Qazir. The prehistoric site and the bone bearing beds are situated in one of the western exposures. Attempts to locate additional implementiferous beds in the other known exposures have generally revealed sterile, deep lake sediments, with few remains of fishes and freshwater mollusks. The Ubeidiya site is therefore situated at the ingression–regression boundary of the ancient Ubeidiya Lake. Trenches cut through the formation by heavy machinery enabled Bar-Yosef and Tchernov (1972) and Picard and Baida (1966, 1966a) to study the nature of the sediments, as well as the lateral changes of the lake's shorelines. Following a detailed study of Picard and Baida (1966), four well-defined alternating cycles could be distinguished from the geological sections of Ubeidiya:

TABLE 7.1
Comparison of Fossil and Living Mollusk Assemblages in the Central and Northern Jordan Valley

Erk el-Ahmar (Early Pleistocene) Central Jordan Valley	Ubeidiya Formation (Early Middle Pleistocene) Central Jordan Valley	Mishmar HaYarden Formation (Early Middle Pleistocene) Northern Jordan Valley	Benot Ya'akov Formation (Late Middle Pleistocene) North Jordan Valley	Lisan Formation (Late Pleistocene) Central Jordan Valley	Recent	
					Hula Basin (lake and marshes)	**Lake Kinneret (lake proper)**
Theodoxus jordani	*Theodoxus jordani*	*Theodoxus jordani*	*Theodoxus jordani*	*Theodoxus jordani*	***Theodoxus jordani***	***Theodoxus jordani***
Viviparus unicolor						
Viviparus apameae			*Viviparus apameae*			
Valvata saulcyi	*Valvata saulcyi*	*Valvata saulcyi*	*Valvata saulcyi*		***Valvata saulcyi***	
Hydrobia acuta						
			Hydrobia longiscata	*Hydrobia longiscata*	***Hydrobia longiscata***	
Falsipyrgula barroisi						***Falsipyrgula barroisi***
Bithynia syriaca						
	Bithynia hawaderiana	*Bithynia hawaderiana*	*Bithynia hawaderiana*	*Bithynia hawaderiana*	***Bithynia hawaderiana***	***Bithynia hawaderiana***
Bithynia multicostata						
Melanopsis praemorsa	*Melanopsis praemorsa*	*Melanopsis praemorsa*	*Melanopsis praemorsa*	*Melanopsis praemorsa*	***Melanopsis praemorsa***	***Melanopsis praemorsa***
Melanopsis doriae						
Melanoides tuberculatus	*Melanoides tuberculatus*				***Melanoides tuberculatus***	***Melanoides tuberculatus***
Melanoides dadianus	*Melanoides dadianus*					
Melanoides jordanicus						
Lymnaea lagotis	*Lymnaea lagotis*	*Lymnaea lagotis*	*Lymnaea lagotis*		***Lymnaea lagotis***	
		Lymnaea palustris				
Planorbarius planorbis	*Planorbarius planorbis*	*Planorbarius planorbis*				
Gyraulus piscinarum	*Gyraulus piscinarum*	*Gyraulus piscinarum*	*Gyraulus piscinarum*		***Gyraulus piscinarum***	
		Anisus spirobis				
		Segmentina nitida				
	Acroloxis lacustris	*Acroloxis lacustris*			***Acroloxis lacustris***	
					***Ferrissia* sp.**	
				Ancylus fluviatilis		
		Succinea elegans			***Succinea elegans***	
Dreissena chantrei						
	Unio terminalis	*Unio terminalis*	*Unio terminalis*		***Unio terminalis***	***Unio terminalis***
	Unio semirugatus					***Unio semirugatus***
	Leguminaia chantrei					
"*Unio*" *subrectangularis*						
	Corbicula fluminalis				***Corbicula fluminalis***	***Corbicula fluminalis***
		Pisidium moitessierianum	*Pisidium moitessierianum*			
		Pisidium obtusale				
		Pisidium milium				
		Pisidium personatum				
		Pisidium amnicum				
	Pisidium casertanum				***Pisidium casertanum***	
Pisidium pirothi						
					Pisidium annandeli	

1. The Li Member. A silt, limestone, and clay complex of the old limnic cycle, from which a wealth of molluskan fossils were collected (Table 7.1), and studied by Tchernov (1973). Only a few layers contained rich vertebrate remains.
2. The Fi Member. This member overlies the Li, and consists of a swampy, terrestrial, and fluviatile complex of gravels and conglomerates, which forms the older fluviatile cycle. It is in this sedimentary cycle that the major archaeological excavations have been carried out and most of the vertebrate assemblages unearthed.
3. The Lu Member. This member is the upper limnic cycle, composed mainly of silts and clays. Few bones, but several scattered mollusk bearing layers are known from this cycle.
4. The Fu Member. This member is the upper fluviatile cycle, composed of gravels and fossil soils.

The sediments exposed farther north at the Ubeidiya site were deposited in a deeper part of the lake. Toward the south deposition of sediments occurred in much shallower water, usually close to the shore, or immediately offshore. Deposition of the lower and upper limnic cycles (Li and Lu) always occurred under water, although it took place in very shallow water at the southern part of the site. The fluviatile Fi and Fu cycles are limnic to the north, but shift rapidly to terrestrial deposits further south. Most of the layers contain mollusk remains, a few of which, especially in the Li cycle, yielded enormous quantities of perfectly preserved freshwater mollusks (Tchernov 1973). The great majority of bones were found in the Fu, but other cycles contained scattered ossiferous layers. The ratio between terrestrial and freshwater vertebrates differs according to habitats; in limnic deposits freshwater dwellers predominate, while in fluviatile and marshy sediments terrestrial animals are the majority. For some time a Villafranchian age was suggested for the Ubeidiya Formation according to its faunal composition (Stekelis *et al.* 1960). Yet the "old" fauna coexisted with more "modern" forms. Haas (1966) expressed doubts concerning "the legitimacy of the claims for any use of European faunistical results in view of the faunal discrepancies . . . and the considerable distance in space". In addition, Tchernov (1968) stated that "faunistically it is true that Villafranchian elements are represented in the Ubeidiya Formation, but one should date an assemblage rather according to its newer elements than the old ones which most probably are survivors. . . ." There are a few habitats in Israel, especially along the Jordan Valley, and formerly also in the coastal plain riverines, where "stragglers" that invaded the area long ago survived to later times. (Tchernov 1975a). Ubeidiya's lithic assemblages show strong typological affinities with those of Olduvai Gorge, Upper Bed II (Leakey 1967; Stekelis *et al.* 1969). On this basis, it seems appropriate to date the Ubeidiya to the early Middle Pleistocene.

Among the mollusks 15 freshwater and 3 terrestrial species were found (Tchernov 1973) (Table 7.1). Definite identifications of fishes, amphibians, and reptiles are not yet available and still await thorough study. Haas (1966) could distinguish among the fishes remains of Siluridae (*Clarias* cf. *lazera*), Cyprinidae (*Barbus*), Cichlidae, and Cyprinodontidae. The presence of cichlid fishes in Ubeidiya and in Erk el-Ahmar is of great importance, indicating the existence of Ethiopian elements in the Levant as early as the early Glacial Pleistocene period (Tchernov 1975a). Remains of amphibians included *Discoglossus* (Discoglossidae), *Pelobates* (Pelobatidae), and *Hyla* (Hylidae). A rich assemblage of reptiles is known from Ubeidiya, but only a small part of it has been analyzed. Remains of *Crocodylus* sp. are known from a few of the layers, mainly in the Fi cycle. The rich fauna of Testudinata included, according to Haas (1966), *Clemmys, Emys, Tryonix* spp. and a *Pelomedusa*-like pleurodire. The list of lizards include *Varanus* cf. *bolkai* (known from the Oriental region), *Agama*, and numerous partly identified Lacertidae, Scincidae, Geckonidae, and Ophidia. Sixty-six species of birds were found (Tchernov, in preparation), and about 50 species of mammals. Altogether the fauna of Ubeidiya includes more than 150 species, and may be much larger when all the groups are thoroughly studied. Further details on the fauna of Ubeidiya in comparison to other assemblages will be discussed later.

MISHMAR HAYARDEN FORMATION

A complex of freshwater series, tilted at an angle of 70° to 80° is known from the northern part of the Jordan Valley (Horowitz 1973; Tchernov 1973). Picard (1963) considered this complex to be of Villafranchian age, calling it the "tilted freshwater series"; however, its molluskan assemblage (Table 7.1) suggests its correlation with the Ubeidiya Formation. In a section exposed near the new bridge at Gesher Benot Ya'akov (Figure 7.1), two facies were distinguished (Tchernov 1973). One comprised littoral deposits of an open, turbulent lake, characterized by the predominance of costated *Melanopsis* and *Theodoxus*. The second, younger facies is composed of sediments deposited under a marshy, or rather shallow still lake, where *Planorbis, Gyraulus, Physa,* and *Lymnaea* were in majority. No *Viviparus* was found in this series. Fourteen freshwater and a single terrestrial species of mollusk were identified from this complex. Remains of vertebrates and artifacts were very rarely found and have not yet been identified. A quarry in Sharia, near Hama, Syria (van Liere 1966), which has produced spheroids, chopping tools, and flakes comparable to the finds in Ubeidiya, may be broadly contemporaneous. Unfortunately the only faunal evidence at Hama was the remains of an *Archidiskodon* sp. (van Liere and Hooijer 1961).

MAMMALIAN FAUNULE FROM LATAMNE, ORONTES, SYRIA

The Orontes hydrographic system, its geology, floral, and faunal evolution was integrally connected with the Jordan Rift Valley (Tchernov 1973, 1975), particularly during the Neogene and early Pleistocene periods, and hence is included in this discussion. The site at Latamne, in the Orontes Valley, Syria, which is a continuation of the Rift Valley, appears to be younger than Ubeidiya. According to Hooijer (1961), the fauna extracted from the gravel under the site deposit represents an end-Mindel or Great Interglacial age. "Because of the presence of *Hippopotamus* and camel it seems most likely that the Latamne fauna should be related to an interglacial rather than to a pluvial and therefore should be considered approximately Great Interglacial (Mindel–Riss) in age (Hooijer 1961)."

The lithic assemblage of Latamne is typologically more evolved than that of Ubeidiya (Clark 1967, 1968), and geologists have observed that a tectonic movement also occurred here following the prehistoric occupation (de Heinzelin 1968; van Liere 1966). If the tectonic movements of the Rift Valley were synchronous, although a distance of 350 km separates the two areas, we may assume that the tectonic movements that postdate the Ubeidiya Formation postdate the Latamne Formation as well. Since the site of Latamne occurs in the uppermost part of the formation, which is considered to be of middle Pleistocene age, and the main living floors of Ubeidiya are deep within its formation, it seems both on stratigraphic and archaeological grounds that the site of Ubeidiya antedates Latamne. Faunistically, the *Hipparion, Leptobos, Pannonictis,* Machairodontidae, and *Archidiskodon* of Ubeidiya are all older forms than those represented in Latamne. Only *Stegodon* occurs in both sites. The *Elephas trogontherii* found at Latamne replaced the *Archidiskodon* of Ubeidiya (Hooijer 1959), and *Dicerorhinus hemitoechus* replaced *Dicerorhinus etruscus* of Ubeidiya. Hooijer's age definition, which seems reasonable to us, further supports the idea of assigning Ubeidiya to the Mindel. The mammalian fauna of Latamne includes: 1, *Stegodon* cf. *triogonocephalus;* 2, *Elephas trogontheri;* 3, *Equus* sp.; 4, *Dicerorhinus* cf. *hemitoechus;* 5, *Hippopotamus amphibius;* 6, *Orthogonoceras* (= *Megaceras*) *verticornis;* 7, *Camelus* sp.; 8, Antilopidarum (gen. et sp. indet.); 9, *Bison* cf. *priscus;* 10, *Canis* cf. *aureus;* 11, *Crocuta crocuta.*

MAMMALIAN REMAINS FROM THE EVRON QUARRY

The site of Evron is located (Figure 7.1) in the northern coastal plain of Israel. A preliminary survey of artifact and faunal assemblages was carried out (but never published) by R. Neuville and G. Haas in 1945. Stekelis (1950) considered the industry associated with the fauna to be of Upper Acheulian affinity. On the basis of typological criteria, following a reinvestigation of the Evron quarry, Prausnitz (1969) evaluated the assemblage as Lower to Middle Paleolithic. According to Issar and Kafri (1969, 1972) the fauna and artifacts were exposed in red loams, which underlie black clays, deposited just behind a Tyrrhenian dune ridge. Bone bearing beds of middle Pleistocene age are rare in the eastern Mediterranean region. The site of Evron, when further excavated, may fill in yet another important gap in the faunal succession of Israel, in particular between those of the Ubeidiya and Gesher Benot Ya'akov Formations (= the *Viviparus* beds). The faunal material unearthed to date at Evron is not sufficient to better determine its stratigraphic position more precisely. The list of fauna is as follows: 1, *Elephas trogontherii;* 2, *Hippopotamus amphibius;* 3, *Metridiochoerus evronensis* (see Haas 1970); 4, *Dama* sp.; 5, *Crocuta* sp.

MAMMALS AND FRESHWATER MOLLUSKS FROM THE BENOT YA'AKOV FORMATION

The site at Benot Ya'akov, in the Hula Basin (Figure 7.1) was first discovered in 1933 by Garrod and Gardner. The results of their preliminary survey were published by Stekelis *et al.* (1937, 1938), and a detailed description of its implementiferous beds by Stekelis (1956). The fauna was listed and later on described in detail by Hooijer (1959, 1960, 1962), and freshwater mollusks by Tchernov (1973). Stekelis (1956, 1960) described Middle Acheulian artifacts from these layers, which showed a strong African stamp (Gilead 1970). Quite a few species of mollusks that were found in the older, Mishmar HaYarden Formation, no longer appear in this one (Table 7.1). The implementiferous beds are associated with vertebrate remains, which were described by Hooijer (1959). The Benot Ya'akov Formation yielded the following mammals (Hooijer 1959, 1960, 1962): 1, *Elephas trogontherii;* 2, *Stegodon mediterraneus;* 3, *Equus caballus;* 4, *Dicerorhinus merckii;* 5, *Sus* cf. *scrofa;* 6, *Hippopotamus amphibius;* 7, *Dama* cf. *mesopotamica;* 8, *Cervus* cf. *elaphus;* 9, cf. *Bison priscus.* The list of freshwater mollusks from these layers is given in Table 7.1.

FAUNULE FROM A KARST FISSURE NEAR JERUSALEM

In the western suburbs of Jerusalem (Giveat Shaul) in the Judean hills, 800 m above sea level, a karst breccia was found (Tchernov 1968b), located in a Cenomanian limestone setting. The breccia is composed of fossil red soil, fragments of stalagmites and stalactites, some irregularly shaped limestone pebbles with an average diameter of 10 cm, and two small pieces of flint (about 5 cm each), neither showing any trace of having been humanly worked. The animal remains consisted of broken bones and numerous isolated teeth of small mammals, mainly rodents. While Late Pleistocene caves, formed during the Würm period, are still well preserved in the mountainous, mainly Mediterranean parts of the country (above the 200-mm isohyet), this type of cave could conceivably have been formed and could have persisted during the earlier erosive cycle of the middle Pleistocene, from which period most caves have now been almost or completely eroded away.

The occurrence of a mammalian faunule, mainly of rodents, in a karst fissure filling of middle Pleistocene age, is significant not only because of its rarity in the Near East, but especially as it sheds light on the vexing question of whether karst caves did in fact exist in Israel during this period. Evidence of contemporary human activity is rarely found during the Riss period within caves. One explanation for this finding has been simply to deny the existence of karst caves during this period. This karst filling does, however, appear to be the remains of a cave, and the fauna extracted from it comprises 11 species of rodents, some of which show affinities with the rodents of the Ubeidiya Formation, such as *Meriones obeidinesis*, *Cricetus cricetus*, and *Allocricetus bursae*. A few others relate closely to general Pleistocene assemblages from Israel, namely *Apodemus mystacinus*, *Apodemus sylvaticus*, *Apodemus flavicallis*, and *Spalax* aff. *ehrenbergi*. All the rest are new forms, namely *Jordanomys haasi*, *Cryptomys asiaticus*, *Myomimus judaicus*, *Mesocricetus* sp. n. and *Gerbillus* sp. n. The only middle Pleistocene fauna previously described from Israel was limited to large mammals (Hooijer 1959). The remains of insectivores were also found in abundance in this filling. It is evident, both from the paucity of remains of larger mammals (Cervidae or Bovidae), and from the large numbers of teeth of the smaller, mainly nocturnal, mammals, which were found in isolated accretions, that most of the material was brought from nearby by owls, whose pellets accumulated on the cave floor. Unfortunately, the material is rather badly preserved; only isolated teeth are in good condition. Bovid or cervid remains could point to the habitation of this cave by man, but the evidence is slight, and more direct proof is needed. The list of rodents found in this site, in comparison with other assemblages is given in Table 7.2.

OUMM-QATAFA CAVE

The cave of Oumm-Qatafa is situated in the Judean Desert (Figure 7.1), not far south of Jerusalem, and was excavated by Neuville (1951), who described a long sequence of prehistoric cultures from this site. Faunal remains were found in layers F (Tayacian), E (Tayacian and Acheulian), and D (Acheulian and Micoquian) to which Neuville generally attributed dry and/or warm conditions. The fauna well agree with this conclusion, but contradict it for such a long period (Haas 1951; Tchernov 1968). Analysis of the faunal remains in view both of population variability of each species, as well as the faunal assemblage of each layer, revealed no changes whatever. Assuming the fauna to have been distributed over the entire length of time proposed by Neuville (1951) (200,000–300,000 years!), changes of fauna and ranges of variabilities should have been evident. The micromammalian fauna does not show any interstage changes; the relationship between species hardly changes in each separately examined layer, and the range of variability of populations of all levels is only slightly larger than in a zero-time population. The faunistic picture is extremely uniform throughout the sequence, regardless of the wide cultural changes. The time span of the cave sediments, at least the bone bearing layers, should therefore be much shorter than proposed by Neuville.

Rust (1950) points out that the Oumm-Qatafa cultural stages are at least partially older than the Yabrudian industry and, hence presumably pre-Würm in age. The composition of the Oumm-Qatafa rodents is reminiscent of the faunal assemblage described by Bate (1937, 1942, 1943) from level G of Tabun (= Tayacian), claimed by Farrand (1969) to be warm and dry. Howell (1959) regarded this stage as of "an early upper Pleistocene (= Last Interglacial) age." Following Woldstaedt (1962) the more or less maximal absolute age possible for Oumm-Qatafa, assuming that it does not antedate the Eem Interglaciation (excluding layers C and B, which are sterile), has been interpolated for our purpose at 120,000 years B.P. The list of rodents is given in Table 7.2, while the avifaunal material will be discussed later (see also, Tchernov 1962). The record of fossil carnivores and ungulates as determined by Haas (1951) and Vaufrey (1951) is as follows: 1, *Rhinoceros merckii*; 2, *Equus "mauritanicus"*; 3, *Alcelaphus buselaphus*; 4, *Bos* sp.; 5, *Gazella* sp.; 6, *Capra ibex*; 7, *Cervus elaphus*; 8, *Dama mesopotamica*; 9, *Procavia syriaca*; 10, *Lagomys* sp.; 11, *Canis lupaster*; 12, *Vulpes vulpes*; 13, *Crocuta crocuta*; 14, *Felis pardus*; 15, *Felis sylvestris*; 16, *Ursus syriacus*.

TABUN CAVE, LEVELS F–E

A faunal record from the Eem Interglacial, somewhat younger than the fossiliferous layers of Oumm-Qatafa, is known from Levels F–E of Tabun Cave, Mt. Carmel (Figure 7.1), (Garrod and Bate 1937; Jelinek *et al.* 1973). The existence of interpluvial conditions during the E–F depositional intervals at the site of Tabun was also proved through extensive pollen analysis by Horowitz (in Jelinek *et al.* 1973), and sedimentological studies (Goldberg and Farrand, in Jelinek *et al.* 1973). The faunal assemblages from Oumm-Qatafa, Levels F–E of Tabun, and the vari-

TABLE 7.2
Comparison of Three Rodent Assemblages from the Middle Pleistocene of Israel

Ubeidiya Formation (Mindel)	Giveat Shaul Fissure Filling (Riss)	Oumm-Qatafa Cave (Riss–Würm)
Hystrix sp.		*Hystrix* sp.
	Cryptomys asiaticus	
		Sciurus anomalus
Peridyromys sp.		
Myomimus sp.		
	Myomimus judaicus	
		Myomimus roachi
Spalax minutes		
	Spalax aff. *ehrenbergi*	*Spalax ehrenbergi*
		Spalax neuvillei
Parallactaga sp.		
Parapodemus jordanicus		
Progonomys sp.		
Apodemus mystacinus	*Apodemus mystacinus*	*Apodemus mystaccinus*
Apodemus flavicollis	*Apodemus flavicollis*	*Apodemus flavicollis*
Apodemus sylvaticus	*Apodemus sylvaticus*	*Apodemus sylvaticus*
		Arricanthis actos
		Rattus haasi
		Mastomys batei
		Mus musculus
Mus sp.		
Allocricetus bursae	*Allocricetus burase*	
		Allocricetus jesreelicus
		Allocricetus magnus
Nannocricetus sp.		
	Mesocricetus sp.	
		Mesocricetus aramaeus
Cricetus cricetus	*Cricetus cricetus*	
Cricetus kormosi		
Cricetus angustirostris		
Gerbillus sp.	*Gerbillus* sp.	
		Gerbillus dasyurus
Meriones obeidiensis	*Meriones obediensis*	
		Meriones tristrami
		Psammomys obesus
Jordanomys pusillus		
	Jordanomys haasi	
Lagurodon cf. *aranke*		
Arricola jordanica		
		Ellobius fuscocapillus
		Microtus guentheri

ous fossiliferous beds from late Pleistocene prehistoric sites constitute in Israel a complete succession, right up to the Holocene period, in Israel, and affords detailed view of changes that took place throughout this period. The fauna from Levels F–E of Tabun was first described by Bate (1937, 1942, 1943); the carnivores were reevaluated by Kurtén (1965), and the rodents by Tchernov (1968). The fauna as a whole still shows some affinities with that of Oumm-Qatafa and Giveat-Shaul, but some new elements are represented in Tabun F–E, never recorded in earlier levels. The list of rodents represented in Tabun F–E is as follows: 1, *Hystrix* sp.; 2, *Allocricetus magnus;* 3, *Sciurus anomalus;* 4, *Meriones tristrami;* 5, *Myomimus roachi;* 6, *Apodemus flavicollis;* 7, *Spalax ehrenbergi;* 8, *Apodemus sylvaticus;* 9, *Spalax neuvillei;* 10, *Apodemus mystacinus;* 11, *Microtus guentheri;* 12, *Arricanthis ectos;* 13, *Ellobius fuscocapillus;* 14, *Rattus haasi;* 15, *Mesocricetus aramaeus;* 16, *Mastomys batei;* 17, *Allocricetus jesreelicus;* 18, *Mus musculus.*

Pleistocene Insectivora and Chiroptera from the Near East have never been thoroughly studied, and are in need of taxonomic reevaluation. Following Bate (in Garrod and Bate 1937) the following species have been recorded. Insectivora: *Crocidura xantippe* and *Talpa chtonia;* Chiroptera: *Megaderma watwat, Myotis* cf. *baranensis,* and *Rhinolophus* sp. According to Kurtén (1965) the following carnivores were represented in Tabun F–E: *Hyaena hyaena, Vulpes vulpes, Felis silvestris, Ursus arctos,* and *Canis lupaster.* Representation of ungulates in the Tabun F–E, according to Bate (in Garrod and Bate 1937) is as follows: *Hippopotamus amphibius, Alcelaphus* sp., *Phacochoerus garrodae, Gazella* spp., *Sus gadarensis* (= *S.*

scrofa), *Bos* sp., *Capreolus capreolus, Equus caballus, Dama mesopotamica, Equus hemionis, Capra* sp., and *Rhinoceros* cf. *hemitoechus*. Other mammals recorded from these layers are *Procavia syriaca, Lepus* sp., and *Elephas* sp.

THE LATE PLEISTOCENE FAUNAL RECORD

Numerous late Pleistocene prehistoric sites have been found and studied in Israel, but only several have yielded sufficient vertebrate remains really to reflect the faunal picture of the area surrounding the sites; and of these only a few have been thoroughly studied. The sites that will be considered important for our discussion are the following: Jebel Qafza, Tabun Cave, Geula Cave, Hayonim Cave, Sefunim Cave, Kebara Cave, En-Gev, En Aqev, Rakefet Cave, Jericho, and Nahal Divshon.

The cave at Jebel Qafza, Galilee, near Nazareth (Figure 7.1) contains a long sequence of sediments containing Middle and Upper Paleolithic cultures. Vandermeersch (1966, 1969) reexcavated the site after Neuville's work. The micromammalian remains were analyzed by Haas (1971), and the ungulates by Bouchud (1974). Layers XVII to XXII overlap Layer D of Tabun to which Farrand (1969) attributed a "Lower Levalloisian age." Indeed, the fauna as a whole shows a close similarity to that of Tabun D (Table 7.3). The younger Mousterian levels of Qafza (Layers IX to XVI) might be correlated broadly with Tabun C and B (Table 7.3). Tabun Layer C, but also, and in particular, Layer B, represent a different fauna (Bate 1937, 1942, 1943; Haas 1972; Tchernov 1968). The "old" components of Tabun D no longer appear in Tabun B; some of them became extinct, and others retreated northward and eastward (like *Ellobius* and *Talpa*; see Table 7.3). The genus *Allocricetus* and two species of Murinae (*Mastomys batei* and *Rattus haasi*) are not represented in the post-Eem horizons. Geula Cave (Mt. Carmel), near Haifa (Figure 7.1) contains a Levalloiso-Mousterian industry (Wreschner *et al.* 1967), for which ^{14}C dating gave for layer B_1 an age of 42,000 (±1700) years B.P. The fossiliferous layers are especially rich in small mammals. The fauna is described by Haas (1967), Heller (1970), and Frenkel (1970), the list of which is included in Table 7.3. Hayonim Cave, Layer E (Western Galilee; Figure 7.1) is thought to be well-correlated with Tabun B, for which several radiocarbon analyses have given dates of approximately 40,000 years ago. Some overlap with Tabun C is possible; as in the lower levels of Tabun's Layer E, older elements like *Talpa* begin to be represented (Table 7.3). Sefunim Cave (Mt. Carmel; Figure 7.1) was explored by A. Ronen (University of Haifa). The fossiliferous beds have yielded a distinctive variety of vertebrate and mollusk remains from Levalloiso-Mousterian, Upper Paleolithic, Epipaleolithic, and Neolithic occupations. The fauna of the Levalloiso-Mousterian occupation is included in Table 7.3. The fauna from later periods is similar in great measure to assemblages found in Hayonim and Rakefet, and will not be dealt with separately. Older phases of the Upper Paleolithic are represented in Kebara Cave (Figure 7.1), which was excavated by M. Stekelis; his results were never published. Fauna from this site is meager, but it is the main assemblage existing from this important cultural phase. "Since the Middle Paleolithic–Upper Paleolithic transition in the eastern Mediterranean area took place some 34,000–35,000 years ago [Farrand 1969]," and "since the Upper Paleolithic of Kebara is not the oldest one [O. Bar-Yosef, personal communication]" an age of 30,000 years is hereby proposed for this stage.

Older phases of the Upper Paleolithic were exposed as well in the Sefunim Cave (Layer 12). No changes in the fauna throughout the Upper Paleolithic occupations could be detected; only higher proportions of arboreal elements to open land dwellers is significant in this period. Hayonim Cave, Layer D, is the only well-documented Aurignacian occupation in Israel. A date of 20,000 years is generally accepted for this stage. Aurignacian faunal remains were unearthed also from layers 9, 10, and 11 of Sefunim Cave. The bulk of species is similar in both sites, save for *Dryomys nitedula* (Gliridae, Rodentia) which appears for the first time in the Levant at Sefunim Cave. Upper Paleolithic sites occur in both the Avedat–Aqev and Har Harif areas (Figure 7.1) (Marks 1975). Some fauna has been found at a Late Levantine Upper Paleolithic site of the Avedat–Aqev area (Tchernov 1976): Artiodactyla (Bovidae), *Capra ibex* and *Gazella* cf. *dorcas*; Perissodactyla (Equidae), *Equus hemionis*; and Lagomorpha (Leporidae), *Lepus* cf. *europaeus*. Most of the reptilian remains are *Agama stellio* (Agamida). A few egg shell fragments of ostrich (*Struthio camelus*) were also recovered from this site.

Hayonin Cave, Layer C, contains extensive sediments of Kebaran microlithic industry (Bar-Yosef and Tchernov 1966) to which an age of 15,000 years is generally attributed. Compared with other Epipaleolithic sites, the fossil record of Hayonim C is very rich and includes a wealth of microfaunal remains, which will be dealt with later. Excavations at En Gev I (Central Jordan Valley; Figure 7.1) afforded an extensive Kebaran industry (Davis 1974; Stekelis *et al.* 1966). The fossil record is as follows: *Gazella gazella, Dama dama mesopotamica, Capra aegagrus, Bos primigenius, Capreolus capreolus, Cervus elaphus, Sus scrofa, Equus (Asinus) hydrantinus, Lepus europaeus, Felis silvestris, Vulpes vulpes*, and several species of birds. A very rich Natufian fauna was excavated from Hayonim Cave, Layer B (Bar-Yosef and Goren 1973; Bar-Yosef and Tchernov 1966). The Natufian is dated at about 10,000 B.C. The list of fauna will be dealt with in the general discussion later. Natufian deposits from the Negev were excavated at Rosh-Zin, site D16 (Figure 7.1). The following species were identified (Tchernov 1976) from this site: *Capra ibex, Gazella* cf. *dorcas, Dama dama mesopotamiea, Equus (Asinus)*

TABLE 7.3
Representation of the Mammalian Faunas of Tabun Levels D–C–B in Several Levalloiso-Mousterian Sites in Israel

	Tabun D (Qafza XVIII–XXII)	Tabun C (Geula) (Qafza IX–XVI) (Hayonim E)	Tabun B (Sefunim 13)
Erinaceus europaeus	+	+	+
Crocidura raaveolens	+	+	+
Crocidura russula	+	+	+
Crocidura leucodon	?	+	+
Talpa chtonia	+	+	−
Rhinolophus ferrum-equinum	+	+	+
Rhinolophus hipposideros	+	+	+
Myotis spp.	+	+	+
Procavia syriaca	+	+	+
Lepus europaeus	+	+	+
Hystrix angressi	−	+	−
Hystrix indica	−	−	+
Sciurus anomalus	+	+	+
Spalax ehrenbergi	+	+	+
Spalax neuvillei	+	+	+
Myomimus roachi	+	+	+
Mitrotus guentheri	+	+	+
Ellobius fuscocapillus	+	+	−
Mesocricetus aramaeus	+	+	−
Mesocricetus auratus	−	+	+
Arricanthis ectos	+	+	−
Rattus (?Mastomys) nazarensis	+	+	+
Rattus rattus	−	−	+
Mus musculus	+	+	+
Apodemus sylvaticus	+	+	+
Apodemus flavicollis	+	+	+
Apodemus mystacinus	+	+	+
Meriones tristrami	+	+	+
Gerbillus sp.			
Hippopotamus amphibius	+	+	+
Sus gadarensis (= *Sus scrofa*)	+	+	+
Phacochoerus garrodae	+	+	−
Capra sp.	+	+	+
Bos primigenius	+	+	+
Alcelaphus buselaphus	+	+	+
Gazella gazella	+	+	+
Camelus sp.	−	+	+
Dama mesopotamica	+	+	+
Cervus elaphus	+	+	+
Capreolus capreolus	+	+	+
Equus caballus	+	+	+
Equus hemionus	+	+	+
Dicerorhinus hemituechus	+	+	+
Crocuta crocuta	+	+	+
Hyaena hyaena	+	−	−
Felis pardus	+	+	+
Canis lupus	−	+	+
Canis lupaster	+	+	+
Vulpes vulpes	+	+	+
Ursus arctus	+	+	+
Nyctereutes vinetorum	+	?	−

hemionis, Spalax ehrenbergi, Meriones, and numerous egg shell fragments of *Struthio camelus.* Of the Lacertilia *Agama stellio* was in abundance. A rich Neolithic assemblage of micromammals was recorded from Rakefet Cave (eastern Mt. Carmel; Figure 7.1). A good sample of Neolithic fauna was unearthed in Sefunim Cave, discussed later. Excavations of a pre-Pottery Neolithic site (Marks 1975) at Nahal Divshon, Negev (Figure 7.1) yielded only four species of mammals: *Bos primigenious, Capra ibex, Gazella* cf. *dorcas,* and *Dama dama mesopotamica.*

ORIGINS OF THE FAUNA OF ISRAEL

FRESHWATER MOLLUSKS

A comparison of Plio-Pleistocene mollusk assemblages from the Jordan Valley is given in Table 7.1. Most impressive is the faunal disruption which took place during the early and middle Pleistocene and the distinct faunal differences between the Northern and Central Jordan Valley assemblages. The Ubeidiya Formation in the Central Jordan Valley, and the Mishmar HaYarden Formation of the Hula Basin, dated as middle Pleistocene, were correlated with the Mindel (Elster) Glaciation. Tchernov (1973) suggested that the two closely situated localities may have been at least in part hydrologically isolated, and that each had some connections with the Orontes system to the north, through different drainages. The assemblages known from the "*Viviparus* beds" (Benot Ya'akov Formation), dated to the middle Pleistocene and correlated with the Riss (Salae) Glaciation, show a few endemic elements during this period (Bar-Yosef and Tchernov 1972; Horowitz 1973; Picard 1963).

The Miocene mollusk faunas of Israel have never been thoroughly studied, but several scholars (Picard 1943; Schulman 1959) who investigated the Neogene contributed some information concerning its malacofauna. The predominant elements of the freshwater Pliocene deposits are *Theodoxus* sp., *Hydrobia* cf. *acuta* (= *H. fraasi*), *Melanoides tuberculatus, Melanopsis* sp., and *Dreissena* sp. This ancient aggregation of species dominates the changing water bodies of Israel until more consistent connections with a range much further north (the Euro-Siberian realm) were established, mainly by the Orontes system (Tchernov 1973) during the Pliocene. Numerous freshwater elements then invaded the Jordan Valley area from Syrian inland waters, many of which were of Sarmatian origin. The subgenus *Neritaea* is known in Israel from the Miocene, but has not been identified specifically. *Theodoxus jordani* is the only recent representative of this genus in Israel (Dagan 1971), and, as far as we know, goes back to the beginning of the Pleistocene. *Theodoxus* is unknown at present from the Golan Heights, an area that separates the Orontes system from the Jordan system. Fossil *Theodoxus* is known from Pliocene outcrops on the Golan Heights, but the species disappeared there during the middle Pleistocene. The absence of *Theodoxus* was noted in late Pleistocene deposits of the Damascus district (Schütt 1973). Its disappearance from the Golan Heights is probably a consequence of middle Pleistocene tectonics in the Jordan Rift Valley (Picard 1965; Picard and Baida 1966, 1966a). Hence, the Jordan Valley populations of *Theodoxus jordani* have been isolated from the Orontes since the middle Pleistocene.

Viviparus apameae invaded the Central Jordan Valley toward the end of the Pliocene, but it survived there for only a short time during the early Pleistocene, as it has never been found in later deposits in this area. Nor was it found in the early middle Pleistocene of the Hula Basin (Picard 1965). It is only later, during the middle Pleistocene, that *V. apameae* suddenly reappears as a predominant species in the Northern Jordan Valley (in the "*Viviparus* beds"), but again for a very short period. *V. apameae* is known from the Pliocene of the Orontes, but not from the Pliocene of the Lebanon–Anti-Lebanon district (Blanckenhorn 1897). It is possible that *Viviparus* managed to reinvade the Northern Jordan Valley by slow, steeplechase waterways long after it became extinct elsewhere. *Viviparus unicolor* is a Nilotic species, and its unique occurrence in Asia in the Jordan Valley early Pleistocene deposits proves that hydrological connections existed between the Jordan and Orontes systems during this period. However, *V. unicolor* together with *Pisidium pirothi* (Table 7.1) are the only known Ethiopian prosobranchs to penetrate the Jordan Valley. *Tilapia galilea, Clarias lazera* (Teleostei), *Crocodylus niloticus, Trionyx triunguis* (Chelonia), and *Hippopotamus amphibius* are other examples demonstrating a faunal transition from the Ethiopian realm to the Levant during the late Neogene and early Pleistocene. Such faunal exchanges were later on gradually interrupted subsequently. On the other hand, none of the typical Sarmatic elements (*Hydrobia longiscata, Falsipyrgula, Melanopsis, Melanoides dadianus*) or species endemic to the Orontes and Jordan systems (*Bythinia syriaca, Bythinia hawaderiana, Viviparus apameae* and others), ever reached the Nile system; some of them were found somewhere on the way (Tchernov 1971, 1971a), while a few others never left the Jordan Valley.

Valvata saulcyi is widespread over the region from the Pliocene on, and still occupies most of the water bodies from Syria down to the edge of the Levant desert. *Melanopsis,* much like *Theodoxus,* is an early inhabitant of the Levant, and is known from several Miocene and Pliocene deposits in Israel. Though an ancient element, it never succeeded in penetrating deeply into the Sinai Peninsula (Tchernov 1971a), or the Nile. *Melanoides dadianus* is a Sarmatic species that reached the system of the Jordan during the early Pleistocene and survived there until the middle Pleistocene, long after it became extinct in the north. *Melanoides tuberculatus* is probably the oldest element of all, as evidenced by its wide distribution in Africa and Asia. It is found at the most isolated springs of the southern Sinai (Tchernov 1971a). *Melanoides jordanicus* is an endemic species with strong affinities to the Sarmatic group of *Melanoides;* it did not survive the early Pleistocene. Only two pulmonates were found at Erk el-Ahmar: *Lymnaea lagotis* and *Gyraulus piscinarum*. Both are typical Palearctic species that first appeared in Israel at the onset of the Pleistocene. Both species still inhabit most of the freshwaters of the Levant. The Central Jordan Valley has never been rich in freshwater pulmonates. Four species are known from the Ubeidiya Formation (Table 7.1), while in the Northern Jordan Valley eight species existed during the same period, most of which disappeared later. To our knowledge, the genus *Dreissena* did not survive the middle Pleistocene of Israel. Much like *Leguminaia chantrei, Hydrobia acuta, Anisus spirorbis,* and *Segmentina nitida* it retreated to northern Asiatic water bodies during the early and middle Pleistocene. *Unio subrectangularis* has been found only in Erk el-Ahmar. On the other hand, the genus *Pisidium* is an ancient element that is still widespread over the Levant.

The mollusk assemblages from the Lebanon–Anti-Lebanon area are basically different from the Orontes (Ghab district) malacofauna. The Lebanon–Anti-Lebanon Pliocene outcrops yielded four freshwater pulmonates out of a total of eight species, three prosobranchs and one bivalve. From the Pliocene of the Ghab district six species of prosobranchs are listed, three of them bivalves, but there were no pulmonates among these. When compared with the Jordan Valley assemblages, the Lebanon–Anti-Lebanon fauna shows closer affinities with the Northern Jordan Valley Mishmar HaYarden Formation fauna; five species are common to both, but especially noteworthy is the unique existence of *Anisus spirorbis* in both sites. This species was found neither in the Orontes nor in the Central Jordan Valley. On the other hand, the Pliocene sites of the Ghab show closer affinities with the fauna of the Central Jordan Valley, in particular with the assemblage of Erk el-Ahmar. Of the ten species listed from Ghab, eight were found in Erk el-Ahmar. *Corbicula fluminalis,* which is absent from Erk el-Ahmar, must have arrived in the Central Jordan Valley somewhat later, as it is quite widespread in all the Ubeidiya sedimentary cycles. The Pleistocene outcrops of northern Syria yielded 14 species (Blanckenhorn 1897), 12 of which existed during the early to middle Pleistocene of the Central Jordan Valley. The late Pleistocene assemblage from the Damascus district (Schütt 1973) is very similar to the present fauna of the Hula Basin (Tchernov 1973). Eleven species from Iran (Starmühlner and Edlauer 1957) were listed from the Plio-Pleistocene of Syria and the Jordan Valley, some of which still survive in Syria and Israel. They are as follows: *Hydrobia acuta* (early Pleistocene of Erk el-Ahmar), *Bithynia badiella* (Recent), *Melanopsis doriae* (early Pleistocene of Erk el-Ahmar), *Melanoides tuberculatus* (Neogene, Pleistocene, and Recent), *Lymnaea palustris* (early middle Pleistocene, Hula Basin), *Planorbarius planorbis* (Pleistocene and Recent), *Gyraulus piscinarum* (Plio-Pleistocene and Recent), *Anisus spirorbis* (early middle Pleistocene, Hula Basin), *Succinea elegans* (= *S. pfeifferi*) (Pleistocene and Recent), *Pisidium casertanum* (Pleistocene and Recent), and *Corbicula fluminalis* (Pleistocene and Recent). Two additional species absent from Israel but common to Syria and Iran are *Lymnaea stagnalis* and *Succinea putris* (= *S. elegans*).

The above list indicates that an extensive faunal exchange took place during the early Pleistocene through the Jordan–Orontes–Mesopotamian water systems and that the Jordan system was almost completely disrupted in the middle Pleistocene. Wide-scale faunal transitions occurred during certain periods, whereby some northern Asiatic elements were introduced into Israel when the Ethiopian fauna was still dominant. In the post-Pliocene a new wave of fauna invaded the Jordan Valley, consisting of *Unio semirugatus, Unio terminalis, Leguminaia chantrei, Corbicula fluminalis, Acroloxus lacustris,* and *Planorbarius planorbis.* Hence, Erk el-Ahmar represents a stage when faunal transition from the north was still extensive. This process gradually ceased toward the middle Pleistocene. How far it extended back into the Neogene is not yet known. The Pliocene and Miocene freshwater mollusks require further study. It is hard to explain the route by which mollusks reached the Hula Basin. The hydrological connections between the northern and central sectors of the Jordan system were evidently poor during the early and early middle Pleistocene, as shown by the surprisingly different malacofaunas (Table 7.1) in as closely situated basins as these (Tchernov 1973). It was only during the later middle Pleistocene that the hydrological connections between the Jordan and the Orontes were blocked, and tighter links were established between both Jordan basins following the second tectonic movements along the Rift Valley.

FRESHWATER FISH

Only two sites have yielded abundant remains of freshwater fish, namely Erk el-Ahmar and Ubeidiya. Fish remains from late Pleistocene sites are rare and scattered, and have never been thoroughly examined. A preliminary examination of the freshwater fish record from

Ubeidiya was published by Haas (1966). A general determination of the fish fauna from Erk el-Ahmar was attempted by Tchernov, which should be regarded as provisional. The most frequent elements in Erk el-Ahmar is *Clarias* (Clariidae), which is represented by at least two different species. Remains of *Clarias* are also known from Miocene outcrops in the Negev (Savage and Tchernov 1968), proving the Ethiopian groups to be very old in the Near East. Another group of African origin, which is well documented in Erk el-Ahmar and Ubeidiya, is the Cichlidae. The existence of hydrographic connections with the Nile enabled freshwater faunal exchange with Africa during the earliest Pleistocene. Of great interest are the remains of Cyprinodontidae in Erk el-Ahmar and Ubeidiya. This group originated in the Red Sea, but is known to occur in the eastern Mediterranean region as well. Invasion of several genera into freshwaters could have taken place during the late Miocene (mainly in the Ponto-Aralo-Caspian region; Kosswig 1967), and during the Pliocene into Israel, when the sea invaded the Jordan Valley (Horowitz and Zak 1968). When most of the Pliocene water bodies refreshened in the valley toward the end of the Pliocene, some of the marine elements found a refuge there while successfully adapting themselves to the new environmental conditions (Por 1963). In addition to the above mentioned groups recovered from Ubeidiya and Erk el-Ahmar, the representation of Cyprinidae (like *Barbus*) in both sites is worth noting.

AMPHIBIA

No amphibians were recorded from Erk el-Ahmar, but in a few layers from Ubeidiya they were recovered in a great abundance. The most important find from Ubeidiya is unquestionably the genus *Discoglossus*, which existed in the Hula Basin until recent times, proving this Palearctic element to be represented in Israel at least throughout the Pleistocene. Like many other Palearctic freshwater elements, it probably found its way to the Jordan Valley via the watercourses of the Orontes. *Hyla* (Hylidae) is another dominant form in the Ubeidiya Formation, originating in the Palearctic region. Most of the late Pleistocene sites include moderate quantities of anuran remains of the species *Rana ridibunda, Bufo viridis, Hyla arborea,* and *Pelobates syriacus. Discoglossus* has never been found outside the Rift Valley. No remnants of urodeles have been identified as yet from the Pleistocene of Israel.

FRESHWATER REPTILES

As was previously noted, a thorough study of the Pleistocene reptiles of the Near East has never been carried out, and our knowledge is restricted to scattered fragments of information. Remains of *Trionyx* (and *Hippopotamus*) from the Mishmar HaYarden and the Ubeidiya formations are known from the Northern and Central Jordan Vallely (Figure 7.2). Both species found their way to Turkey, probably through the Orontes system. Worth noting is the fact that early Pleistocene pygmy *Hippopotamus* is known from Cyprus. This endemic fossil population was cut off from northern Syria during the late Pliocene, when Cyprus became isolated from the mainland, proving that *Hippopotamus* should have been represented in Syria during the Pliocene. It did not take a long time to undergo an explicit process of nannism. Much the same is true for the pygmy elephants of Cyprus. Three typical Ethiopian elements were found in the Ubeidiya; a pleurodire turtle (*Pelusios* or *Pelomedusa*), which is known from the Pliocene of Egypt, *Emys,* and another representative of the Tryonichidae. Drastic changes in the hydrographic system of the Jordan Valley were probably the main cause of extinction of many tropical elements (Figure 7.2). A typical Oriental element, *Varanus bolkai,* is known from the Ubeidiya Formation, but became extinct shortly thereafter. A similar element, *Ketupa zeylonensis* (Aves) was recovered as well from Ubeidiya, but succeeded in surviving up to the present. Representatives of the Agamidae (the most frequent species is *A. stellio*), Chameleonidae (of African origin), Lacertidae, Scincidae, Geckonidae, the genus *Ophisaurus* (in abundance), and Ophidia are known from the middle and late Pleistocene, most of which were unearthed from prehistoric sites.

BIRDS

General Remarks on the Fossil Avifauna of Ubeidiya

The avifauna of the Central Jordan Valley consists at present of about 240 sedentary and migratory species. Sixty-six species of birds, represented by 674 specimens, are recorded from the Ubeidiya Formation, which comprises more than 25% of the recent avifauna, making this avifossil community one of the richest known in species diversity. The census of species and specimens from five avian bearing beds is given in Table 7.4. The list may faithfully reflect the actual distribution of birds in the surroundings of the site during the Ubeidiya period. This is evidenced (*a*) by the fact that the assemblage represents an extremely heterogenous spectrum of habitats where almost all the possible adaptive zones are covered by the differenct species; (*b*) the number of species in each family is in proportion to the status of those species at present, hence the number of nonpasseriformes, 35 species (about 50%), fits the normal ratio; and (*c*) the relation of large birds to small birds agrees well with the present condition. In this way the fossil avifauna may reflect the nature of habitats which actually existed around the site of Ubeidiya. Yet, two common, wide-

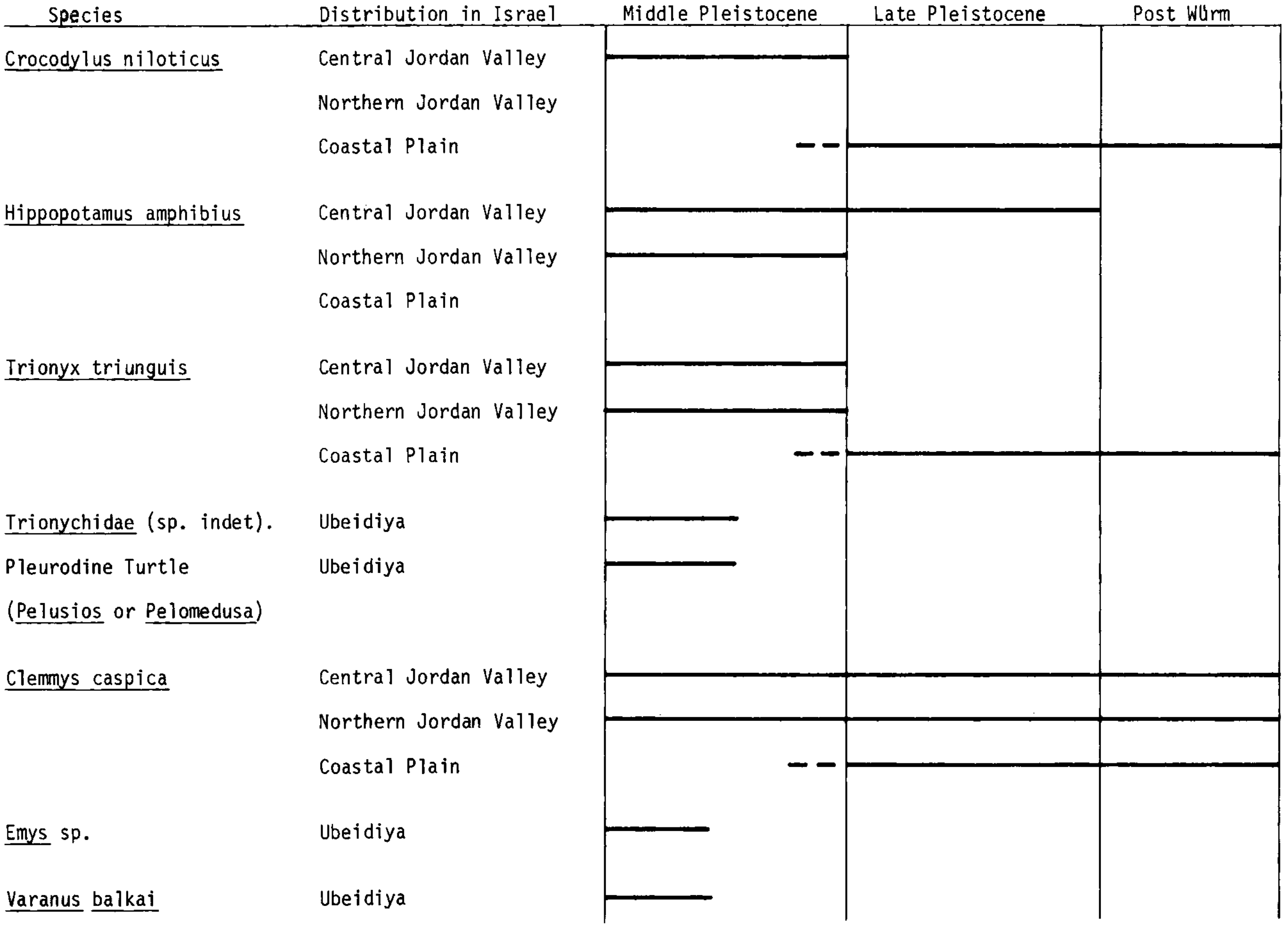


FIGURE 7.2. *Distribution of freshwater reptiles and* Hippopotamus *in the Pleistocene of Israel.*

spread and diversified groups of birds (Table 7.4) that should be represented in such an heterogeneous landscape are missing from the fossil record: the Charadriidae and the Coraciiformes. Also, typical aerial birds, the Apodiformes and the Hirundinidae, have never been recorded.

The great majority of species were found in layers II-23 and II-24, while only a few representatives were found in other beds. Layer III-12 includes mainly passeriform species, while layers II-26 and II-36 yielded exclusively nonpasseriform groups. Layer II-23 includes 21 exclusive species, while layer II-24 only 15. Twenty-five species are common to both layers (and none to all layers). Layer II-23 is not only the richest in diversity, but also the most prolific in number of specimens. It is obvious that the passeriformes predominate in number of specimens, but this is as a rule true for any Recent assemblage. Among the song birds the most common species are *Petronia brevirostris* and *Melanocorypha gracilis,* both of which are fossil species. Next to them come *Alauda jordanica* and *Sturnus vulgaris.* Among 66 species, six are fossils and new to science; four more might in the future be designated as new species; they are currently included with *Butorides* sp., *Francolinus* sp., *Oriolus* sp., and *Sturnus* sp. Poorly recorded, the material for these four was insufficient for definite conclusions. Anyway, they are not known among the Middle Eastern and European avifaunas. *Pica pica, P. porphyrio,* and *Phalacrocorax africanum* do not exist at present in the area, but were recorded either from the near past (Tchernov 1968a) or from prehistoric periods (Tchernov 1968a, 1962). Four other species are extremely rare at present in the Middle East; they are hardly ever seen on an annual basis (*Phalacrocorax carbo, Anhinga rufa, Strix butleri,* and *Ketupa zeylonensis*).

Ecological Considerations Many species of birds share their daily activities between two or more habitats, sometimes extremely different. Habitats may differ for breeding, roosting, or feeding. Starlings, for instance, nest in holes but feed mainly in meadows by probing their bills deep into the topsoil. On winter grounds they roost, sometimes in large flocks, on trees. Thus a given ecotype can influence the way an avian community functions. Exploitation of the ecosystem obviously changes from species to species. In order to reconstruct the old land-

TABLE 7.4
Quantitative Comparison of the Avifauna in Five Avifossil-Bearing Layers of Ubeidiya

	Number of specimens				
Species	III-12	II-23	II-24	II-26 (= I-15)	II-36
Podiceps cristatus	—	1	1	—	—
Podiceps auritus	—	—	—	—	—
Phalacrocorax afircanum	—	1	—	—	—
Phalacrocorax carbo	—	2	—	—	—
Anhinga rufa	—	2	1?	—	—
Butorides sp. (aff. *striattus*)	—	—	1	—	1
Ardea purpurea	—	—	—	—	1
Anser Albifrons	—	—	1	—	—
Tadorna tadorna	—	4	1	—	—
Nettion crecca	—	3	5	—	2
Anas acuta	—	3	3	1	—
Anas penelope	—	3	1	—	—
Aythya sp.	—	1	7	—	—
Milvus pygmaeus	2	1	—	—	—
Accipiter cf. *gentilis*	—	—	1	—	—
Falco subbuteo	—	1	—	—	—
Falco cf. *peregrinus*	—	—	1	—	—
Falco sp.	—	1	—	—	—
Aquila chrysaetus	—	—	—	3	2
Aquila sp.	—	2	—	1	—
Alectoris baryosefus	—	2	5	—	—
Francolinus sp.	—	1	—	—	—
Rallus aquaticus	—	4	5	—	—
Porzana spp.	—	3	—	—	—
Crex crex	—	1	1	—	—
Gallinula gigantea	—	—	—	*1*	—
Fulica stekelesi	1	2	1	—	—
Porphyrio porphyrio	—	1	2	—	—
Sterna hirundo	—	—	1	—	—
Columba livia	—	7	2	—	—
Streptopelia sp.	—	—	1	—	—
Strix cf. *butleri*	—	2	1	—	—
Asio cf. *capensis*	—	2	—	—	—
Athene noctua	—	—	1	—	—
Ketupa zeylonensis	—	1	—	—	—
Melanocorypha calandra	3	21	18	—	—
Melanocorypha gracilis	—	84	91	—	—
Alauda jordanica	1	34	24	—	—
cf. *Calandrella* sp.	—	4	4	—	—
Anthus cf. *campestris*	—	—	9	—	—
Anthus cf. *pratensis*	—	—	5	—	—
Motacilla alba	—	18	10	—	—
Motacilla cf. *cinerea*	—	1	—	—	—
Lanius excubitor	—	1	—	—	—
Lanius sp.	—	1	—	—	—
Oriolus sp.	—	—	1	—	—
Sturnus vulgaris	6	34	33	—	—
Sturnus sp.	—	1	1	—	—
Pica pica	—	1	—	—	—
Corvus corax	—	1	1	—	—
Corvus cornix	—	2	—	—	—
Corvus monedula	—	8	1	—	—
Pycnonotus barbatus	—	—	2	—	—
Sylvia sp.	—	—	1	—	—
Acrocephalus sp.	—	1	—	—	—
Saxicola cf. *torquata*					
Oenanthe sp.	—	1	—	—	—
Cercomela cf. *melanura*	—	1	—	—	—
Turdus sp.	5	7	—	—	—
Parus sp.	—	1	—	—	—
Petronia brevirostris	2	98	43	—	—
Fringilla coelebs	2	8	2	—	—
Carduelis cf. *chloris*	—	10	—	—	—
Acanthis sp.	—	—	3	—	—
Coccothraustes coccothraustes	—	—	1	—	—
Emberiza sp.	—	—	2	—	—
Total number of specimens	22	391	299	6	6
Total number of species	8	49	41(42)	4	4

scape and interpret past habitats, two main functional habitats of two assemblages have been taken separately into consideration. The assemblages of layers II-23 and II-24 were divided into groups of species, occupying different adaptive zones. Table 7.5 displays the main nestling zone, and Table 7.6 the main feeding grounds. The assemblages fall naturally into five groups of general habitats, where each species carries on a cardinal part of its daily activities.

1. Aquatic. Many species feed in aquatic surroundings, but only a few nest here.
2. Swamps and Marshes. Many speceis that nest in moorlands and inside the luxurious vegetation of the marshes feed on aquatic organisms.
3. Grassland. This habitat is probably the main feeding and nestling ground for many species. It might be extremely varied, from very wet meadows to very dry seasonal grassland; or from herbage to low grass landscapes.
4. Wood of trees. Fossil leaves and pollen identified from the Ubeidiya proved the occurrence of at least six species of trees whose woods were important as habitats: *Quercus, Cupressus, Juniperus, Olea, Pistacia,* and *Rhus* (Bar-Yosef and Tchernov 1972; identified by Horowitz; Lorch 1966). The wood was used as a major nestling ground for many species in the Ubeidiya period, but was only partially exploited as a feeding quarter.
5. Rocks. The rocky landscape was at the rift escarpment, and most probably terminated toward the east and the west the ecological belts around Ubeidiya Lake (Bar-Yosef and Tchernov 1972).

Analyses of habitat requirements based on the general feeding and nestling habits of the different species display the following picture (Figure 7.3):

1. Birds feeding on aquatic organisms (Table 7.6) include 13 species, 12 of which were found in layer II-23 and eight in II-24. The freshwater community (Tables 7.5 and 7.6) suggests a varied lake with an heterogeneity of ecotopes. Thus an extensive sheet of still open water existed for the grebes, with extensive reed beds for the cormorants and snake birds; and there was shallow water with rich bottom vegetation, surrounded by a broad belt of marshy vegetation for the ducks, pochards, and coots. The fish owl (*Ketupa zeylonensis*) could have preyed upon fish only in the open. Eight species occupied the lake as a nestling ground, further evidence for an open water area.

2. The marshy, swampy habitat was rather varied as seen from the list of birds. It included moorland areas covered with luxurious beds of vegetation, bogs, and reed marshes mainly for the herons, pygmy cormorants, and reed warblers. Beds of reeds and rushes and aster lilies were present as the main quarters for Ralliformes and geese. Slow streams and river banks served the wagtails. Many species of birds that feed in water or grassland prefer the marshy, swampy biotopes as their main nestling ground.

3. The grassland belt, which most probably encircled the marshy region, sustained a great variety of birds. It was a complex of biotopes where geese could graze, wagtails could pick up insects, birds of prey could depredate, and ducks could roost and nest. Tall grasses and herbage were available for quails; scrub, thorny maquis, and dry grass growth were exploited by partridges and shrikes. Many of the species presumably preferred the transition areas between the grassland and the woods.

4. Within the woodland biotopes the largest class of the Ubeidiya birds found their nestling grounds, as they do today. Thorn bushes (like *Zyziphus* trees) are preferred by the great grey shrike. Directly below the top of coniferous and broadleaved trees, the nests of goshawks were found. Wooded mountainous landscape is typical for *Falco subbuteo.* Kites and magpies prefer at present riverine forests and parklands for their nestling grounds.

5. Typical rock dwellers that nest as well as feed in rocky habitats are few in the Ubeidiya (Tables 7.5 and 7.6).

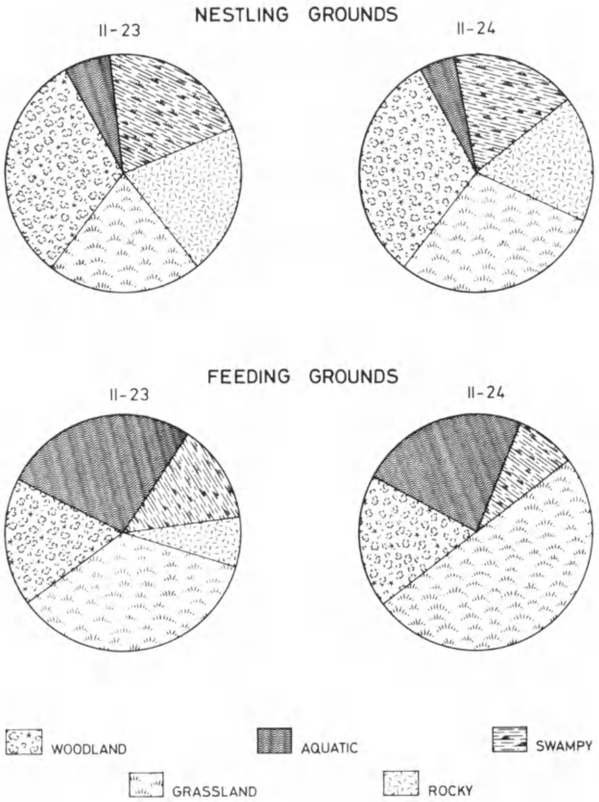


FIGURE 7.3. *Nestling and feeding grounds of the Ubeidiya avifauna.*

TABLE 7.5
Classification of Ubeidiya Habitats, Based on Nesting Preference of Birds

<table>
<tr><th>Aquatic</th><th>Swamps and marshes</th><th>Grassland</th><th>Woodland</th><th>Rocks</th></tr>
<tr><td><i>Podiceps cristatus</i></td><td><i>Phalacrocoras africanus</i></td><td><i>Nettion crecca</i></td><td><i>Milvus pygmaeus</i></td><td><i>Phalacrocorax carbo</i></td></tr>
<tr><td><i>Podiceps auratus</i></td><td><i>Anhinga rufa</i></td><td><i>Anas penelope</i></td><td><i>Accipiter</i> cf. <i>gentilis</i></td><td><i>Falco peregrinus</i></td></tr>
<tr><td><i>Fulica stekelesi</i></td><td><i>Butorides</i> sp. (cf. <i>striattus</i>)</td><td><i>Tadorna tadorna</i></td><td><i>Falco subbuteo</i></td><td><i>Aquila chrysaetos</i></td></tr>
<tr><td></td><td><i>Ardea purpurea</i></td><td><i>Alectoris baryosefus</i></td><td><i>Streptopelia</i> sp.</td><td><i>Columba livia</i></td></tr>
<tr><td></td><td><i>Aythya</i> sp.</td><td><i>Francolinus</i> sp.</td><td colspan="2"><i>Athene noctua</i></td></tr>
<tr><td></td><td><i>Anser albifrons</i></td><td></td><td colspan="2"><i>Lanius excubitor</i></td></tr>
<tr><td></td><td><i>Rallus aquaticus</i></td><td><i>Porzana</i> spp.</td><td></td><td></td></tr>
<tr><td></td><td><i>Porphyrio porphyrio</i></td><td><i>Crex crex</i></td><td><i>Lanius</i> sp.</td><td><i>Strix</i> cf. <i>butleri</i></td></tr>
<tr><td></td><td><i>Gallinula gigantea</i></td><td><i>Melanocorphya calandra</i></td><td><i>Oriolus</i> sp.</td><td><i>Ketupa zeylonensis</i></td></tr>
<tr><td></td><td><i>Sterna hirundo</i></td><td><i>Melanocorypha gracilis</i></td><td><i>Sturnus vulgaris</i></td><td><i>Oenanthe</i> sp.</td></tr>
<tr><td></td><td><i>Asio</i> cf. <i>capensis</i></td><td><i>Alauda jordanica</i></td><td><i>Sturnus</i> sp.</td><td><i>Cercomela</i> cf. <i>melanura</i></td></tr>
<tr><td></td><td colspan="2"><i>Motacilla alba</i></td><td><i>Pica pica</i></td><td><i>Petronia brevirostris</i></td></tr>
<tr><td></td><td><i>Motacilla</i> cf. <i>cinerea</i></td><td>cf. <i>Calandrella</i> sp.</td><td><i>Corvus cornix</i></td><td></td></tr>
<tr><td></td><td><i>Acrocephalus</i> sp.</td><td><i>Anthus</i> cf. <i>campestris</i></td><td colspan="2"><i>Corvus corax</i></td></tr>
<tr><td></td><td></td><td><i>Anthus</i> cf. <i>pratensis</i></td><td colspan="2"><i>Corvus monedula</i></td></tr>
<tr><td></td><td></td><td><i>Saxicola</i> cf. <i>torquata</i></td><td><i>Pycnonotus barbarus</i></td><td></td></tr>
<tr><td></td><td></td><td><i>Emberiza</i> sp.</td><td><i>Sylvia</i> sp.</td><td></td></tr>
<tr><td></td><td></td><td></td><td><i>Turdus</i> sp.</td><td></td></tr>
<tr><td></td><td></td><td></td><td><i>Parus</i> sp.</td><td></td></tr>
<tr><td></td><td></td><td></td><td><i>Fringilla coelebs</i></td><td></td></tr>
<tr><td></td><td></td><td></td><td><i>Carduelis chloris</i></td><td></td></tr>
<tr><td></td><td></td><td></td><td><i>Acanthis</i> sp.</td><td></td></tr>
<tr><td></td><td></td><td></td><td><i>Coccothraustes coccothraustes</i></td><td></td></tr>
<tr><td>II-23 = 3</td><td>II-23 = 9</td><td>II-23 = 13</td><td>II-23 = 13</td><td>II-23 = 10</td></tr>
<tr><td>II-24 = 2</td><td>II-24 = 7</td><td>II-24 = 13</td><td>II-24 = 13</td><td>II-24 = 8</td></tr>
<tr><td>3</td><td>14</td><td>16</td><td>22</td><td>13</td></tr>
</table>

TABLE 7.6
Classification of Ubeidiya Habitats, Based on Feeding Habits of Birds

Aquatic	Swamps and marshes	Grassland	Woodland	Rocks
Podiceps cristatus	*Butorides* sp (aff. *striattus*)	*Anser albifrons*	*Accipiter* cf. *gentilis*	*Corvus corax*
Podiceps auratus		*Milvus pygmaeus*	*Falco subbuteo*	*Oenanthe* sp.
Phalacrocorax africanus	*Ardea purpurea*	*Falco peregrinus*	*Lanius excubitor*	*Cercomela melanura*
Phalacrocorax carbo	*Rallus aquaticus*	*Alectoris baryosefus*	*Lanius* sp.	*Aquila chrysaetus*
Anhinga rufa	*Porzana* spp.	*Francolinus* sp.	*Oriolus* sp.	(Layer I-15)
Tadorna	*Gallinula gigantea*	*Crex crex*	*Pica pica*	
Nettion crecca	*Asio* cf. *capensis*	*Columba livia*	*Corvus cornix*	
Anas acuta	*Motacilla* cf. *cinerea*	*Streptopelia* sp.	*Pycnonotus barbatus*	
Anas penelope	*Acrocephalus* sp.	*Strix* cf. *butleri*	*Sylvia* sp.	
Aythya sp.		*Athene noctua*	*Turdus* sp.	
Fulica stekelesi		*Melanocorypha calandra*	*Parus* sp.	
Sterna hirundo		*Melanocorypha gracilis*	*Carduelis chloris*	
Ketupa zeylonensis		*Alauda jordanica*	*Acanthis* sp.	
		cf. *Calandrella* sp.	*Coccothraustes coccothraustes*	
		Anthus cf. *campestris*		
		Anthus cf. *pratensis*		
		Motacilla alba		
		Sturnus vulgaris		
		Sturnus sp.		
		Corvus cornix		
		Corvus monedula		
		Saxicola cf. *torquata*		
		Fringilla coelebs		
II-23 = 12	II-23 = 6	II-23 = 16	II-23 = 8	II-23 = 3
II-24 = 8	II-24 = 3	II-24 = 20	II-24 = 7	II-24 = 0
13	9	23	13	4

These five main ecological divisions predominated as long as a freshwater body existed in the area. During later periods of the middle Pleistocene no freshwater bodies are known to occur in the Central Jordan Valley (Bar-Yosef and Tchernov 1972; Tchernov 1973). Not until the late Pleistocene was the valley refilled with water, but this time it was a saline water body, the Lisan Lake. Only in late Würmian times did a new freshwater lake come into existence, Lake Kinneret. In the Northern Jordan Valley, at the Hula Basin, a freshwater lake existed more or less uninterruptedly throughout the Glacial Pleistocene (Horowitz 1973). This lake was encircled by swamps and marshy belts, wet meadows, and patches of wood, bordered to the west and east by the rocky escarpments. This kind of landscape persisted until very recently, and probably was reminiscent of conditions during Ubeidiya times southward, in the Central Jordan Valley. When the two successive layers, II-23 and II-24, are compared, certain faunal changes are noticed, in spite of the fact that both are lithologically very similar. These changes must have taken place during a comparatively short span of time. When the habitat requirements of the nesting communities are compared (Table 7.5; Figure 7.3) only small, almost negligible changes are found. Grassland and woodland areas were slightly more abundant during the period of layer II-24, while the aquatic and marshy zones were reduced. When the feeding grounds of the communities of the two layers are compared, differences are notable. A significant augmentation of the grassland zone took place, while the aquatic areas, in particular the marshes, were reduced. It is thus obvious that layer II-24 represents drier conditions, which resulted in a slight receding of the lake.

Zoogeographical Considerations Faunal exchanges between Africa, southern Asia, and the Levant were still effective during the Miocene (Crowford 1971; Tchernov 1975a), but no exchange of terrestrial forms with the regions north of the Sarmatic province (Laurasia) was possible until the Pontian. Following regression of the Tethys, as a result of later Miocene orogenic movements (Savage 1967), passages to the north and to the east were widely opened toward the Levant. In this way all the region between the Ponto–Aralo–Caspian province and the southern Palearctic desert belt was invaded by elements from northern realms. Consequently many of the original Oriental and Ethiopian elements were reduced drastically in number of species, the majority of which became extinct, while others underwent endemism in favorable biotopes. During the Pliocene the developing desert belt steadily erected barriers between Africa, southern Asia, and the Levant. This barrier became more effective with time. The large scale invasion of elements from the north after the Messinian introduced into the eastern Mediterranean region species from various biogeographical provinces, and of various faunal types. The faunal relationships that were established with the Sarmatic, Turkestanian, and circum-Mediterranean provinces were preponderant before the common historical events. However, the Levantinian fauna also has a strong European stamp upon it. Very few elements from the Arctic and Siberia are known to occur in the Levantinian fauna (Tchernov 1975a).

Analysis of faunal types recovered from Ubeidiya is given in Table 7.7. A faunal type is considered here as a species which is historically characteristic of one or several biogeographical provinces. A province is defined by the particular history of its fauna, and the degree of endemism within the regional biomes. As only few tropical (Oriental and Ethiopic) species are represented in the avifossil record, we ignored their provincial regions (Figure 7.4). Save for *Cercomela melanura* and *Strix butleri,* no desert or arid elements are found in the assemblage of Ubeidiya. There is only one cosmopolitan representative in the record from Ubeidiya, and only one Arctic type (Table 7.7). Two species are distributed all over the Old World, while six are Holoarctic. The Palearctic group predominates, with 16 species. More restricted in distribution are the European, Turkestanian, and Sarmatic groups. (There is only one pure Sarmatic faunal type, *T. tadorna*). Species that are restricted to its eastern side are considered as Mediterranean. Most of the species described as new originated within the eastern Mediterranean region, and may be considered as endemic. Two typical Mediterranean species (*Strix butleri* and *Melanocorypha calandra*) are known to occur at present in the same regions, and probably did not change very much their distributional pattern. The Ethiopian and Oriental groups include relatively many more species that are known at present in the Jordan Valley (Figure 7.4; Table 7.7). When the fossil assemblage is compared with the Recent Central Jordan Valley avian community (excluding rare visitors and accidental species) it is obvious that a considerable reduction in Paleotropical elements took place during the Pleistocene, coinciding with the invasion of general Palearctic elements, but particularly with the salient augmentation of the Turkestanian–Mediterranean faunal type. It has already been stressed several times by Tchernov (1968, 1973, 1975a) and earlier hinted by Hooijer (1958) that in fact the first appearance of typical Palearctic faunal types occurred in the eastern Mediterranean in post-Villanfranchian times (see also, Bar-Yosef and Tchernov 1972). Mediterranean elements that were developed shortly after the Messinian crisis from Asiatic stocks, mainly during Pliocene and early Pleistocene times (Tchernov 1975a), have done so around the more humid Mediterranean basin. A lot of endemic species were developed especially in the eastern part of the Mediterranean, which today still constitute a major fraction of the Levantinian fauna. This fact is well documented by the avifossil record of Ubeidiya, where 17% are purely

Mediterranean types, reduced to 6.5% in the present fauna (Figure 7.4).

The insect fauna of Israel consists of 80% Ethiopians, 10% Orientals, and 10% Paleotropic (Bytinski-Saltz 1961). The opinion of Bate (1934), Garrod and Bate (1937), and Fairbridge (1962) that African animals invaded the Middle East only during the Aurignacian (later Paleolithic) does not coincide with the facts that tropical elements (*Ketupa zeylonensis, Cercomela melanura, Pycnonotus barbatus,* etc.) are already found in the region in the period of Ubeidiya. Nor does it fit with the existence of African elements in the ancient Pleistocene of Europe. Tropical elements in the Levant underwent a constant decline, since the end of the Neogene. Isolation of the tropical faunas was at first only partially effective, but toward the later Pleistocene it became almost complete, even with regard to the few xerotropic species. There is no reason to believe that Ethiopian animals reinvaded Asia (save for a few Arabian or Saharian desert species). While the number of European species remained more or less constant (Figure 7.4), Turkestanian elements gradually became more dominant. It is hard to decide the exact time when general Palearctic elements were forced southward, deep into regions which are extremely arid at present. Such movements could have taken place either through gullies and streams (which are locally more humid), or along the cooler backbones of mountainous chains. In this way *P. pica asivensis* and *Dendrocopus doriae* reached Mecca, where they survive as relics today (Meinertzhagen, 1954), along with *Rana ridibunda* (Haas, 1957). Parker (1956) mentioned a glacial Palearctic invasion into North Africa with regard to *Hyla arborea* (Anura). A few scattered populations of *Eliomys melanurus* (Rodentia) and *Carpodacus synoicus* (Fringillidae) occupy a typical rocky desert landscape and wadi escarpments

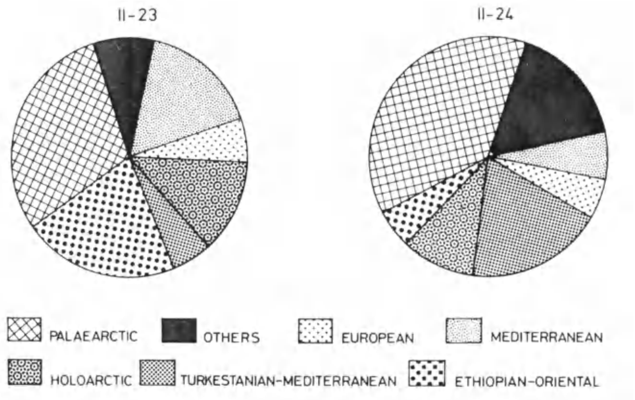


FIGURE 7.4. *Biogeographical origin of the Ubeidiya avifauna.*

.E 7.7

ification of Ubeidiya Assemblages into Zoogeographical Units, Based upon Recent Distribution and Historical Origin

mopolitan	Old World	General Holoarctic	General Palearctic	Arctic	European
peregrinus	*Podiceps cristatus* *Ardea purpurea*	*Podiceps auritus* *Nettion crecca* *Aquila chrysaetus* *Accipiter gentilis* *Sterna hirundo* *Lanius excubitor* *Corvus corax*	*Phalacrocorax carbo* *Anas acuta* *Anas penelope* *Falco subbuteo* *Rallus aquaticus* *Porzana* spp. *Crex crex* *Anthus* cf. *campestris* *Anthus* cf. *pratensis* *Motacilla alba* *Motacilla* cf. *cinerea* *Pica pica* *Corvus cornix* *Corvus monedula* *Saxicola* cf. *torquata* *Coccothraustes coccothraustes*	*Anser albifrons*	*Sturnus vulgaris* *Fringilla coelebs* *Carduelis* cf. *chloris*

kestanian– diterranean	Sarmatic	Mediterranean	Ethiopian	Oriental
nba livia *ne noctua* *alandrella* sp.	*Tadorna tadorna*	*Milvus pygmaeus* *Alectoris baryosefus* *Gallinula gigantea* *Fulica stekelesi* *Strix* cf. *butleri* *Melanocorypha calancra* *Melanocorypha gracilis* *Alauda jordanica* *Petronia brevirostris*	*Phalacrocorax africanus* *Butorides* sp. (aff. *striattus*) *Asio capensis* *Anhinga rufa* *Porphyrio porphyrio* *Francolinus* sp. *Pycnonotus barbatus* *Cercomela melanura*	*Ketupa zeylonensis* *Oriolus* sp. *Sturnus* sp.

amid the arid zone of southern Sinai and the Negev. These isolated populations were presumably cut off during the Pleistocene from the main stocks in the north.

Animals that adapted themselves (during Neogene and Pleistocene) to extremely arid habitats in the Arabo-Nubian deserts, never invaded more humid areas. None of these is known to occur even in the most degraded Mediterranean areas of the Near East, and they are rarely found in semiarid regions. Such desert animals originated either from ancient Paleotropic faunas or from southern Palearctic stock, from species that were trapped during the Neogene and Pleistocene in the slowly developing desert belt; they underwent speciation through extreme specialization to arid climates. A swift retreat of the woodland and forest dwellers (Tchernov 1962, 1968) occurred during the postglacial period, on the brink of historical time. Much of their range curtailment has been due to man. Saharan types which are found at present in Israel amidst a Mediterranean landscape demonstrate the youngest faunal community, though very restricted in area, found in the Near East, and probably the only invasion from the African continent since the early Pleistocene; but never from the Ethiopian region.

Late Pleistocene Avifauna

Table 7.8 indicates no drastic changes in the avifauna throughout the late Pleistocene period. The list of birds furnishes no evidence of a faunal break before, during, or after the Würm. *Otis* sp., *Phasianus hermonis* and cf. *Megaceryle* sp. are the only species that became extinct in the postglacial. *Phasianus colchicus, Oriolus* sp., *Pyrrhocorax graculus, Pyrrhocorax pyrrhocorax, Pica pica*, and *Sturnus* sp. retreated from Israel during the postglacial. The disappearance of these species from the eastern Mediterranean might be a result of the ever increasing aridity, followed by massive invasion of Saharan elements into formerly typical Mediterranean landscapes along the coast (Tchernov 1975a).

EVOLUTIONARY HISTORY OF THE MAMMALS OF ISRAEL

Information on the eastern Mediterranean Pleistocene mammals is still far from complete. Many new species might be revealed when more sites are uncovered, most likely from the middle and early Pleistocene. Actually, the record of many other species is spotty, and might have a longer history in this region. Some groups of mammals have not as yet been thoroughly studied, like the Insectivora, but there is still much work to do even with the much better known Rodentia. Very little is known at present regarding the ungulates from Ubeidiya, and together with the Carnivores, both await a thorough overall investigation. The wealth of material, especially of micromammals, but of other groups as well, unearthed from successive layers, presents a golden opportunity for valuable quantitative paleontological research. Figures 7.5–7.8 represent the ad hoc stratigraphic range of mammalian species in Israel.

Lagomorphs, Hyracoidea, Proboscideans and Primates

The history of lagomorphs in the Middle East is only very little understood, especially during the early and middle Pleistocene. The genus *Hypolagus* (which arose in North America in the Miocene) survived in Israel until Mindel (Ubeidiya) times, a little later than in Europe (Figure 7.5). No records of Lagomorpha are known as yet from the Riss, but, unexpectedly, a typical Asiatic genus appeared in Oumm-Qatafa (Eem Interglacial). This form was identified as *Ochotona* (= *Lagomys*) by Vaufrey (1951) and Haas (1951). The pikas are known in general as mountain animals that live among rocks and in talus screes, a biotope which very much fits the surroundings of the Oumm-Qatafa Cave. Some forms, however, might invade forested regions and plains. Bate (1937) questioned the validity of Vaufrey's and Haas' identification. Recent reinvestigations of the whole group verify the existence of *Ochotona* in the deposits of the Oumm-Qatafa Cave. The first occurrence of *Lepus* (*L. europeus* is the only species recorded) took place, much as in Europe, at the beginning of the late Pleistocene. Thus, only one species of lagomorpha at a time appeared in Israel.

While the origin of *Hypolagus* is Holoarctic, and *Ochotona* is characteristically Asiatic (but might have evolved in North America), the origin of *Lepus* is not clear. New evidence now shows that the African *L. capensis* and the Palearctic *L. europeus* (both occur in the Middle East) belong to a single species with no break or overlap in distribution down to the Cape of Good Hope. Of the Hyracoidea *Procavia capensis* (an African species) is the only representative, the earliest record of which is known from the Eem Interglacial. It is likely that remains of this group will be uncovered from earlier periods, like most of the more ancient Ethiopian elements in the Middle East. At present the Asiatic populations are completely isolated from those of Africa. The Proboscideans were mainly discussed by Hooijer (1958, 1959, 1960, 1962). Their stratigraphic range is given in Figure 7.5. The only recorded Pleistocene primates from the Middle East come from Ubeidiya, where a cf. *Macaca* sp. was identified by Haas (1966). As new material has come to light during the last ten years, the primate remains should be further explored. It is likely that new primate species will be found in the fauna, and their relationships with the European and North African faunas will be better understood.

TABLE 7.8
Comparison of the Late Pleistocene Avifauna

Riss–Würm (Oumm Qatafa)	Würm (Kebara and Qafza)	Post-Würm (Hayonim)
	Pelecanus onocrotalus	
	Ardea cinerea	
	Anas platyrhynchos	*Anas platyrhynchos*
	Anser sp.	*Anser* sp.
		Aquila pomarina
Aquila sp.	*Aquila* sp.	
	Pernis apivorus	
		Milvus migrans
	Buteo buteo	*Buteo buteo*
	Falco finnunculus	*Falco finnunculus*
		Falco peregrinus
Falco sp.		
	Accipiter nisus	*Accipiter nisus*
		Accipiter cf. *gentilis*
	Gyps fulvus	*Gyps fulvus*
	Aegypius monachus	
Ammoperdix heyi		
Alectoris chukar	*Alectoris chukar*	*Alectoris chukar*
Coturnix coturnix	*Coturnix coturnix*	*Coturnix coturnix*
	Phasianus hermonis[a]	
	Phasianus colchicus[b]	*Phasianus colchicus*[b]
Crex crex	*Crex crex*	*Crex Crex*
Chloropus gallinula		*Chloropus gallinula*
	Rallus aquaticus	
	Otis sp.[a]	
	Larus minutus	
Columba livia	*Columba livia*	*Columba livia*
	Columba palumbus	*Columba palumbus*
	Columba oenas	
Streptopelia turtur	*Streptopelia turtur*	
		Streptopelia sp.
Clamator glandarius		
Athene noctua		*Athene noctua*
Otus scops		*Otus scops*
Tyto alba	*Tyto alba*	*Tyto alba*
		Asio sp.
Apus apus		
		Apus affinis
Upupa epops		*Upupa epops*
	Coracias garrulus	
	Halcyon smyrnensis	
		Alcedo atthis
	cf. *Megacergle* sp.[a]	
Dendrocopus syriacus		
Alauda arvensis	*Alauda arvensis*	*Alauda arvensis*
Melanocorypha calandra	*Melanocorypha calandra*	*Melanocorypha calandra*
Galerida cristata	*Galerida cristata*	*Galerida cristata*
	Anthus pratensis	
Motacilla alba	*Motacilla alba*	
Motacilla cinerea		*Motacilla cinerea*
Motacilla flava		
Hirundo daurica		*Hirundo daurica*
	Hirundo sp.	*Hirundo* sp.
		Hirundo rustica
	Oriolus oriolus	
	Oriolus sp.[b]	

Continued

TABLE 7.8 (*Continued*)

Riss–Würm (Oumm Qatafa)	Würm (Kebara and Qafza)	Post-Würm (Hayonim)
Garrulus glandarius	*Garrulus glandarius*	*Garrulus glandarius*
	Pyrrhocorax graculus[b]	
		Pyrrhocorax pyrrhocorax[b]
	Pica pica[b]	*Pica pica*[b]
Corvus frugilegus		
Corrus monedula	*Corrus monedula*	*Corrus monedula*
Corvus cornix	*Corvus cornix*	
	Corrus corax	
Sturnus vulgaris	*Sturnus vulgaris*	*Sturnus vulgaris*
Sturnus sp.[b]	*Sturnus* sp.[b]	*Sturnus* sp.[b]
Onychognathus tristrami	*Onychognathus tristrami*	
		Regulus sp.
Turdus merula	*Turdus merula*	*Turdus merula*
	Turdus philomelos	*Turdus philomelos*
		Turdus sp.
		Monticola sp.
Oenanthe spp.		*Oenanthe* spp.
	Oenanthe finschii	
Phoenicurus sp.		*Phoenicurus* sp.
	Phoenicurus phoenicurus	
	Phoenicurus ochrurus	
		Saxicola torquata
Erithacus rubecula		*Erithacus rubecula*
		Luscinia megarhynchos
	Luscinia svecica	*Luscinia svecica*
		Luscinia sp.
Cercotrichas galactotes	*Cercotrichas galactotes*	
Turdoides squamiceps		
Sylvia spp.		*Sylvia* sp.
		Sylvia hortensis
		Sylvia melanocephala
		Phylloscopus sp.
Phylloscopus sp.		
Muscicapa striata		
		Cinnyris osaea
Lanius excubitor	*Lanius excubitor*	
Lanius nubicus		
Lanius senator		*Lanius senator*
Pycnonotus barbatus	*Pycnonotus barbatus*	
		Passer domesticus
Passer predomesticus[c]		
Passer moabiticus		
Passer hispaniolensis		
Petronia petronia	*Petronia petronia*	*Petronia petronia*
Carduelis carduelis	*Carduelis carduelis*	*Carduelis carduelis*
Carduelis spinus		*Carduelis spinus*
Carduelis chloris	*Carduelis chloris*	*Carduelis chloris*
Fringilla coelebs	*Fringilla coelebs*	
Coccothraustes coccothraustes	*Coccothraustes coccothraustes*	*Coccothraustes coccothrauste*
		Loxia currirostra
		Serinus canarius
Emberiza calandra	*Emberiza calandra*	*Emberiza calandra*
		Emberiza caesia

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[a] A fossil species.

[b] Does not exist at present in Israel.

[c] Markus (1964) pointed out that this form is closest to the living race of *P. domesticus* and the African *P. iogonensis*.

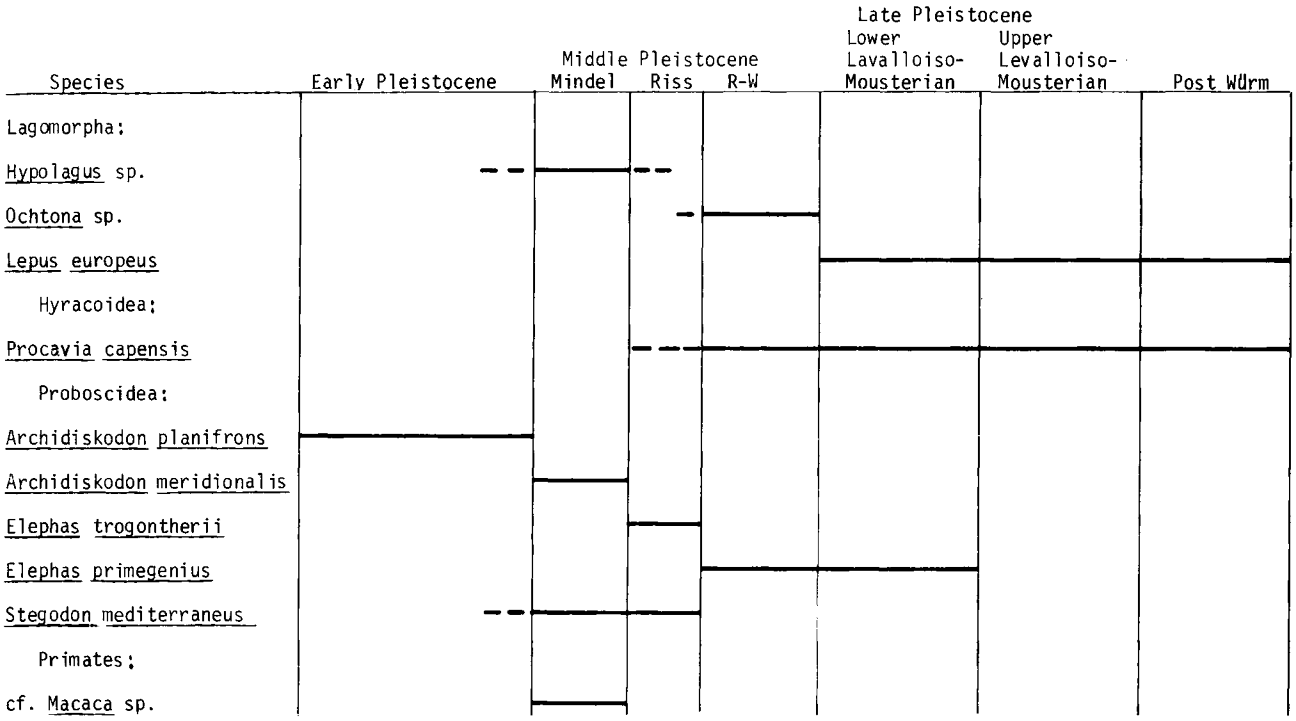

FIGURE 7.5. *Stratigraphic ranges of some Pleistocene mammals in Israel.*

Artiodactyla and Perissodactyla

The fact that the Cervidae did not appear in Israel until sometime between the Bethlehem and Ubeidiya periods is of great significance (Figure 7.6). This phenomenon was already stressed by Hooijer (1958, 1960, 1962), and by Bar-Yosef and Tchernov (1972). During the early Pleistocene the Paleotropic Antilopini were most probably dominant in the Middle East, occupying a large spectrum of biotopes, from savannahs to forests and woods. It was only during later periods that the Palearctic cervids invaded the eastern Mediterranean region, replacing many of the Antilopine species. None of the Cervidae, however, succeeded in invading the African realm south of the Sahara belt. In early middle Pleistocene times this group was already abundant. When the Bovidae and the Cervidae from the Ubeidiya Formation are thoroughly studied, this point will be better clarified.

The mammalian fauna of Bethlehem comprises only two species of Bovidae (*Gazellospira* and *Leptobos*). In the middle Pleistocene only *Leptobos* survived from the earlier periods. The single record of *Hemibos* (Pilgrim 1941), which was recovered from middle Pleistocene deposits and showed some more progressive skull characteristics than the Pinjor (Upper Simalik of India), indicates that biogeographical connections with the Oriental region were still effective during this period. *Bison* and a few undetermined antilopines were found in Ubeidiya and Benot Ya'akov. Thus, the Mindel and Riss megafauna contains almost exclusively extinct forms. It is only in Oumm-Qatafa Cave that modern African antelopes, like *Gazella* and *Alcelaphus*, are known for the first time in the Levant. It is expected that with more extensive surveys of middle and lower Pleistocene deposits in the Middle East more remains of African bovids will be recovered, much as the freshwater African elements (*Hippopotamus, Crocodylus, Trionyx, Tilapia,* etc.) were found in abundance throughout the Quaternary. *Capra aegagrus* and *Capra ibex*, being contemporaneous throughout the Eem and late Pleistocene deposits of Israel, never overlapped in distribution and shared the land in such a way that *C. aegagrus* occupied the Mediterranean rocky landscapes, while *C. ibex* exploited the arid zone. The latter species still survives along the rocky arid areas of Israel and Sinai. The three modern species of Cervidae, *Dama dama mesopotamica, Cervus elaphus,* and *Capreolus capreolus* replace in Israel the older Cervid forms (*Megaloceros, Euctenoceros,* and *Cervus* cf. *ramosus*) during the middle Pleistocene.

It is still uncertain whether *Hipparion* survived during the time represented by the Ubeidiya formations (Figure 7.6). However, *Equus* was not yet present in the Bethlehem formation. While the late Pleistocene equids are by now well known, the earlier fauna awaits a thorough revision. The earliest record of zebra-like horses, *Equus stenonis* and *Equus süssenborensis*, were first described from the Ubeidiya Formation. It is thus believed that their invasion into the Middle East took place much later than in Europe, which is in accordance with the general theory of their origin and way of distribution.

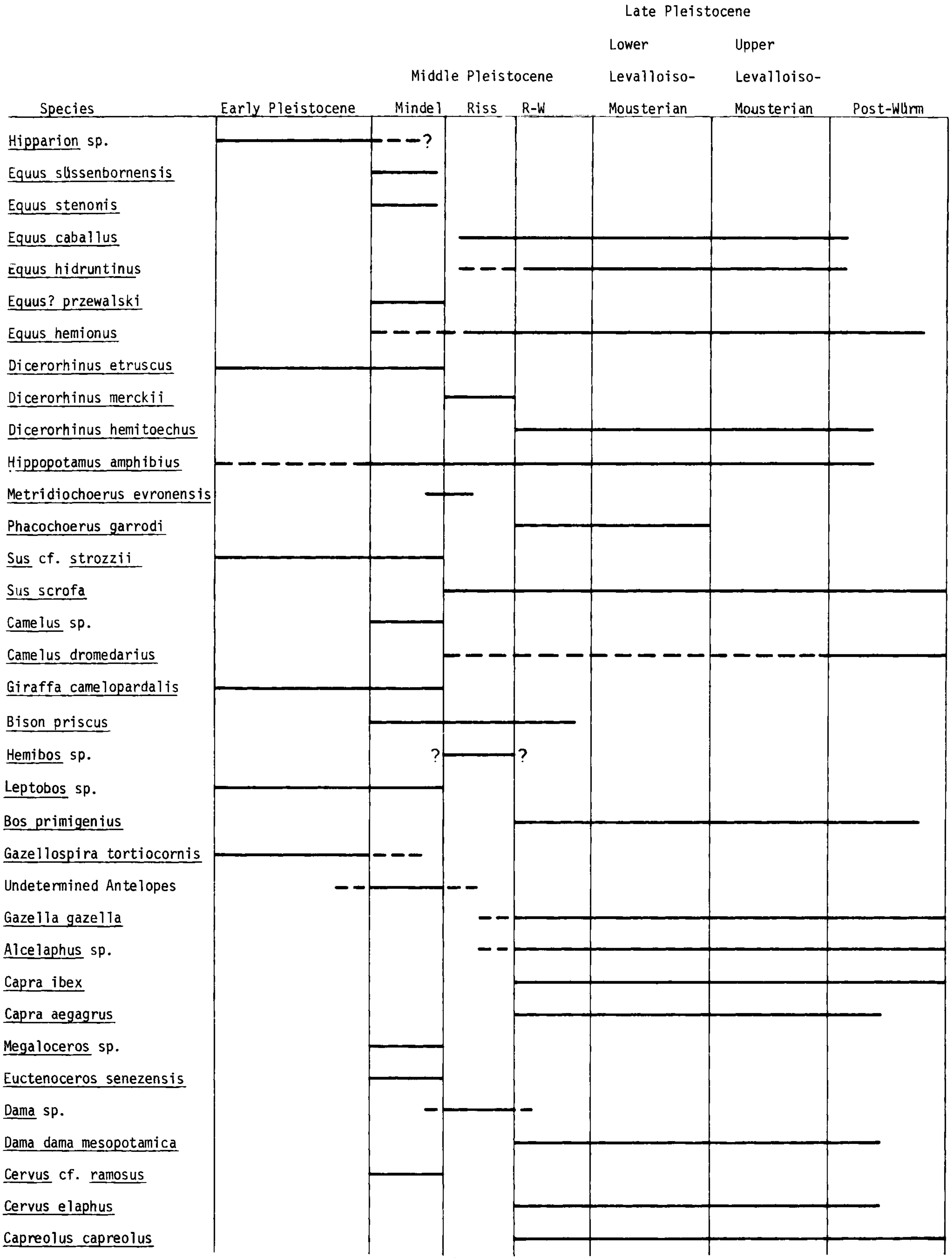

FIGURE 7.6. *Stratigraphic ranges of Pleistocene ungulates in Israel.*

The more evolved Caballine horses, like *Equus przewalski,* existed during the Ubeidiya period side by side with the earlier zebrine forms. The donkey-like Equids like *Equus hidruntinus, Equus hemionus,* and/or *Equus assinus* are fairly abundant throughout the late Pleistocene of Israel. The Villafranchian etruscan rhinoceros, *Dicerorhinus etruscus,* straggled into the middle Pleistocene of Israel, when it was replaced during the Riss period by *Dicerorhinus merckii. Dicerorhinus hemitoechus* first appeared during Eemian times in Oumm-Qatafa and survived into Epipaleolithic times! It is only logical to expect that a steppe rhinoceros, which is known to prefer a temperate climate, will better withstand the glacial periods of the eastern Mediterranean region than those of Europe. Yet, rhinocerotid remains are rarely found in the fossil record of Israel. The existence of typical Ethiopian elements like *Hippopotamus* (until the Bronze age!), *Giraffa* in Bethlehem, and *Metridiochoerus* and *Phacochoerus* during the middle Pleistocene and early Würm stresses once again the intimate biogeographical connection with Africa, a connection which was slowly cut off during the Quaternary, resulting from the intensification of the Sahara arid belt. The surviving Ethiopian elements at present are geographical relics rather than newcomers.

Carnivores

Only two species of carnivores have been described from the early Pleistocene of Bethlehem (Figure 7.7). The first is the racoon dog (*Nyctereutes*), which is typical for the Villafranchian of Europe, but persisted in China up to the middle Pleistocene. The modern racoon dog, *Nyctereutes vinetorum,* is known from the early Würm of Mt. Carmel. The second carnivore is *Homotherium* (the scimitar cat), a form known from the North African Mindel (Ternifine), but missing from Ubeidiya (or not yet found?). In Ubeidiya five species of Carnivores were determined. Of the Mustelidae *Enhydrictis ardea* is the only representative. This species persisted in the Middle East a little later (Mindel) than it is known in Europe (Waalian). Of the Hyaenidae the history of the spotted hyena is of interest. This species is known from the Ubeidiya period to the dawn of the Natufian (10,000 B.C.), when it became at last extinct in Asia, but it has continued to flourish up to the present on the African continent south of the Sahara. The Middle East seems to be its last refuge area in the Palearctic region. Once it retreated from the eastern corner of the Mediterranean, it was immediately replaced by the striped hyena (*Hyaena hyaena*). Yet the problem is that *H. hyaena* was also recovered from Oumm-Qatafa Cave, where *C. crocuta* was missing. It is suggested that the two forms displayed to some extent competitive interaction. *H. hyaena,* probably of African origin, should not be viewed as a newcomer in Asia, but rather as an old element, as Kurtén suggested in 1965 and 1968.

An undetermined *Canis* was found in the Ubeidiya deposits that is smaller than *C. lupus,* but larger than *C. aureus.* It does, however, agree in size with *C. lupaster* (Haas 1966). At any rate, a competitive relationship was also found to occur among *C. aureus* (Asiatic) and *C. lupaster* (African). When the latter form evacuated the eastern Mediterranean region, *C. aureus* replaced it, and has turned out to be one of the commonest carnivores in Israel (at present intensive agricultural activities have brought this species to the brink of extinction). Another species known from Ubeidiya is *Ursus etruscus,* which probably gave rise in Asia to *Ursus arctos.* The Ubeidiya specimens still show primitive construction of the premolars. When later remains of bears are found in Israel (Oumm-Qatafa), they take the form of *U. arctos* (Figure 7.7). The last species to be mentioned from Ubeidiya is *Megantereon* (Felidae, Smilodontini), which is probably contemporaneous with the remains of *M. inexpectatus* in the Mindel deposits of Choukoutien, the last remnants of the tribe in the Old World. The lion was still known during Biblical times, and became extinct in later historical ages. The leopard still survives in small enclaves in a few places in Israel. The rest of the late Pleistocene Carnivores still persist in Israel. Several Recent species were never recovered in prehistoric sites, namely, *Mellivora ratel, Lynx caracal,* and *Lutra lutra.*

Rodents

Remains of *Sciurus anomalus* were not found in the Ubeidiya and Giveat Shaul middle Pleistocene exposures. They first appear in the cave deposits of Oumm-Qatafa. It has shown no significant morphological changes since this period. In the layers of Oumm-Qatafa, it did not constitute an appreciable proportion of the fauna, and was much more widespread during the Mousterian, and especially in Upper Paleolithic through Natufian times. Squrrels apparently existed in Israel until the Neolithic, when they retreated northward, followed by extensive propagation of the rock dwellers *Acomys cahirinus* and *Gerbillus dasyurus* in Mediterranean regions. The genus *Hystrix* is generally very scarce in the Pleistocene deposits of Israel, either in caves, or in open sites, except for the cave of Geula (Wreschner *et al.* 1967) in Mt. Carmel, where a Mousterian industry was uncovered. This cave yielded numerous fragments of *Hystrix angressi* (Frenkel 1970) among other faunal remains. *Hystrix indica,* which is at present common in Israel, did not coexist with *H. angressi* in Mousterian times, but first appeared in the Upper Paleolithic. The existence of *Cryptomys asiasticus* (Bathyergidae) was a short episode in the Near East. It was found only in the karst fissure filling near Jerusalem. Today the family is restricted to Africa, south of the Sahara, but *Gysorhychus* in Mongolia (Mathew and Granger 1923) existed in Asia (Mongolia) in Oligocene times. It is similar in certain respects to the recent African

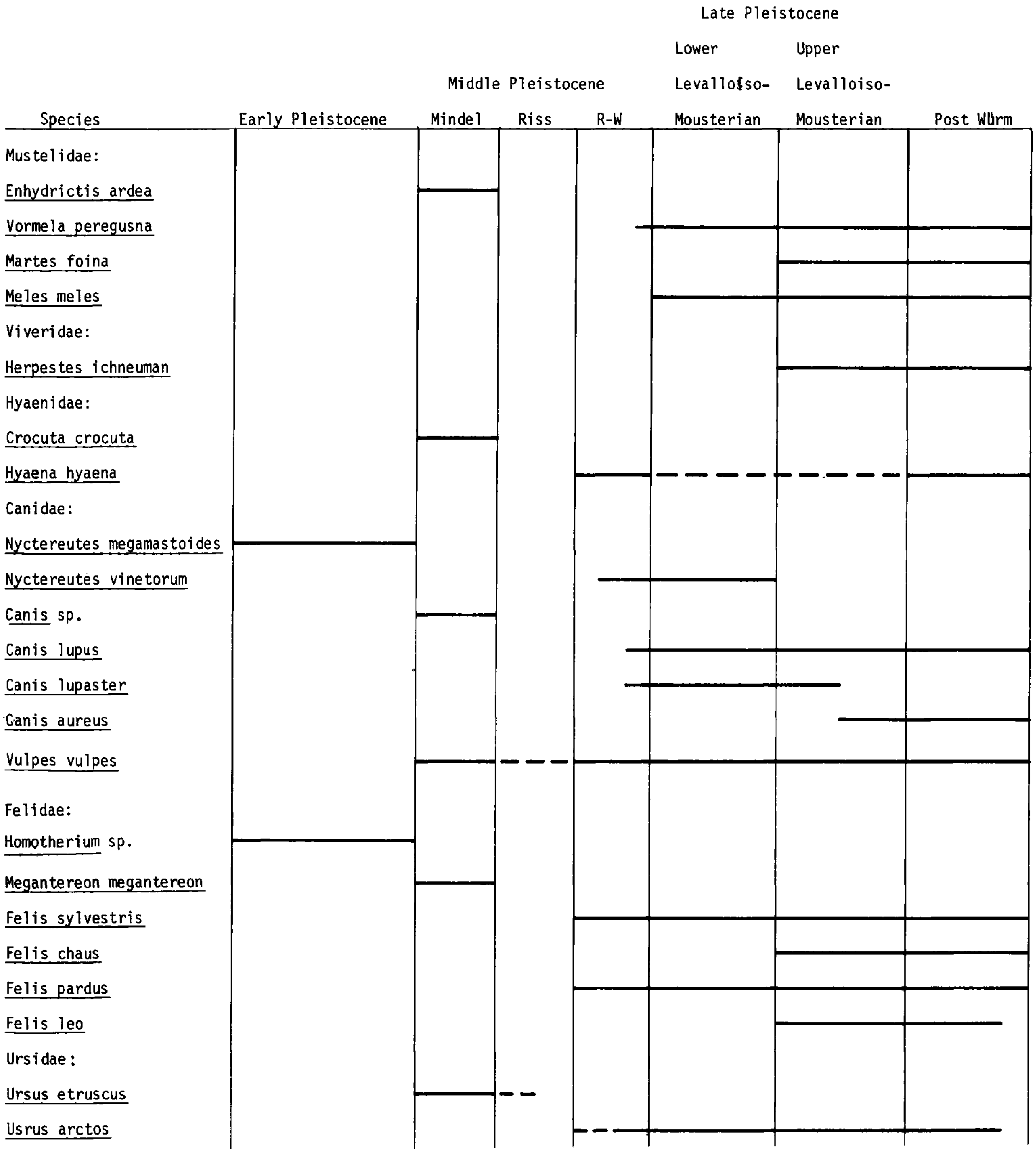

FIGURE 7.7. *Stratigraphic ranges of Pleistocene carnivores in Israel.*

genus *Georhychus*, mainly a southern African form. After the Oligocene this group was never again found in Asia; only from Miocene times onward did it begin to appear in Africa. At least one representative of an African genus reinvaded the Near East, probably during the Neogene, and survived there as late as the later Pleistocene. The habitat of *Cryptomys* as known today from tropical Africa is not well defined. As a burrowing animal, it is more commonly found in soft soils or sands, but may also be found in more rocky areas. As to vegetation cover, *Cryptomys* prefers low bushland, large clearings, or widely open forest.

The time of arrival and disappearance of several glirids in the Near East is still an unsolved problem. The most common representative of the family is *Myomimus*, which is found through the middle and late Pleistocene (Figure

7.8). *M. judaicus* was found in Giveat Shaul karst filling, while *M. roachi* and *M. quafzensis* are known from the late Pleistocene of Israel. Bearing in mind that the glirids are a fairly constant group (Herold 1958), and that the molar pattern of *M. judaicus* is quite different from that of *M. roachi* (Tchernov 1968b), the two species do not form a chronocline. Although it has not been proved that they overlapped in time, it remains a possibility. The only living representative of this genus is *M. personatus* in eastern Europe, where large relics of Pliocene habitats still exist (Kowalski 1963). This genus probably did not undergo adaptation toward arboreal life, as did most of the modern glirids, but presumably remained terrestrial. It is worth noting that *M. roachi* was the predominant glirid until as late as the Late Bronze age, and then vanished. Strangely enough, *Eliomys melanurus* is scattered today in a few isolated patches in the semiarid and arid zones of Israel and Sinai, occupying rocky desert habitats. In the northern part of the country it appears as a typical arboreal animal. The genus did not appear earlier than the Natufian (10,000 B.C.). *Dryomys*, which is found today only in the northern mountainous region of Israel, has never been recorded, and might have invaded Israel only recently. Being a terrestrial animal, the disappearance of *Myomimus* (Figure 7.8) could not be the cause for the delayed invasions of *Dryomus* and *Eliomys*, which are primarily arboreal.

Many forms of *Spalax* are known from the Pleistocene of Israel. According to the level of complexity of Pm_1, all of them belong to the *ehrenberg* group (= *Microspalax*, Méhély 1909; see also, Tchernov 1968). *Spalax minutus* (Haas 1966) from the Ubeidiya Formation is closely related to *Spalax ehrenbergi* from the Jerusalem karst filling, a species that constituted an interesting chronocline through the entire middle and late Pleistocene. It showed many gradient morphological characters that enabled us to study the evolutionary changes of the species. Two additional species were found. *S. neuvillei* appears in the Acheulian of Oumm-Qatafa (120,000 years ago); it retreated from the area toward the end of the Mousterian, about 35,000 B.C. *S. kebarensis*, which is known in Mt. Carmel from upper Mousterian through Natufian–Neolithic, was relatively large and showed a completely different and unusual construction of the coronoid process. The center of distribution of both *S. neuvillei* and *S. kebarensis* was probably far from Israel (central Asia?) which might explain their brief appearances in this area. These blind fossorial animals occupy mainly a rather open grassland to semiarid steppe landscape, but avoid wooded or forest habitats. Of the Dipodidae the only genus found was *Parallactaga* sp. This rather steppic form was found in the Ubeidiya Formation.

Among the Murinae, two Neogene "stragglers" (Haas 1968) still existed in the Central Jordan Valley during early middle Pleistocene times; the genus *Progonomys*, from which at least two different species were identified by Haas (1966), and the genus *Parapodemus*. Israel was probably the last refuge for these two genera, which were never found in any later period. Three species of *Apodemus* coexisted during the entire middle Pleistocene and most of the late Pleistocene (later Acheulian and lower Mousterian). One of the species, *A. mystacinus*, still exists in Israel today. The other two, *A. levantinus* and *A. caesareanus*, disappeared in the upper Mousterian, when *A. sylvaticus* replaced them. Today this species is limited to the northern areas of the country. Owing to the large size differences in the three coexisting species, competition between them might well have been impossible. *A. levantinus* and *A. caesareanus* showed a more highly developed tuberculation of cheek teeth than recent members of "*sylvaemus*." More ancient populations of *A. mystacinus* showed massive proportioned mandibles, and a highly developed tuberculation of cheek teeth. In younger levels this species appeared in increasing numbers, more closely resembling the "delicate" proportions of the recent form.

Two Ethiopian elements, *Arvicanthis ectos* and *Rattus (Mastomys) batei* (Murinae), appeared at the beginning of the late Pleistocene for a short period, disappearing toward later Mousterian times. *Mastomys*, which was found from the Neogene of the Asian Siwalik series, rapidly retreated from Asia after this period. The last remnant, which probably occupied the Near East in the late Pleistocene, vanished shortly thereafter, and then existed exclusively in tropical Africa. The Near East was probably populated by *Rattus rattus* shortly after the abandonment of the area by *Arvicanthis*, which is now restricted to Africa. Another rat species, *Rattus haasi*, was uncovered only from the Oumm-Qatafa beds. According to its cheek teeth pattern, *R. haasi* is in an intermediate position between the *rattus* and *norvegicus* groups, and represents the most ancient species of *Rattus* found to date in the eastern Mediterranean region. It is difficult to relate a certain biotope to this fossil species, as *Rattus* is quite euryoekous, though generally inhabiting wet areas, with high humidity and dense vegetation. An undetermined *Mus* is mentioned by Haas (1966) from the Ubeidiya Formation. This Ubeidiya *Mus* is different from *Mus musculus*, which first appears in the Oumm-Qatafa layers and existed in the region throughout the entire late Pleistocene. During this period it showed only a slight change in tuberculation of the molars and in the proportions of the skull.

Acomys cahirinus occupies bare rocky landscapes, devoid of trees. It made its appearance in the Mediterranean region of the country during the Upper Paleolithic and Postglacial times. At the same time a few wood dwelling species retreated northward and disappeared from Israel (*Sciurus anomalus*, *Cervus elaphus*, and *Pica pica*: Tchernov 1962). The wooded areas in the Near East degenerated slowly, a phenomenon which was sharply accentuated after the Natufian, when many more wood dwellers

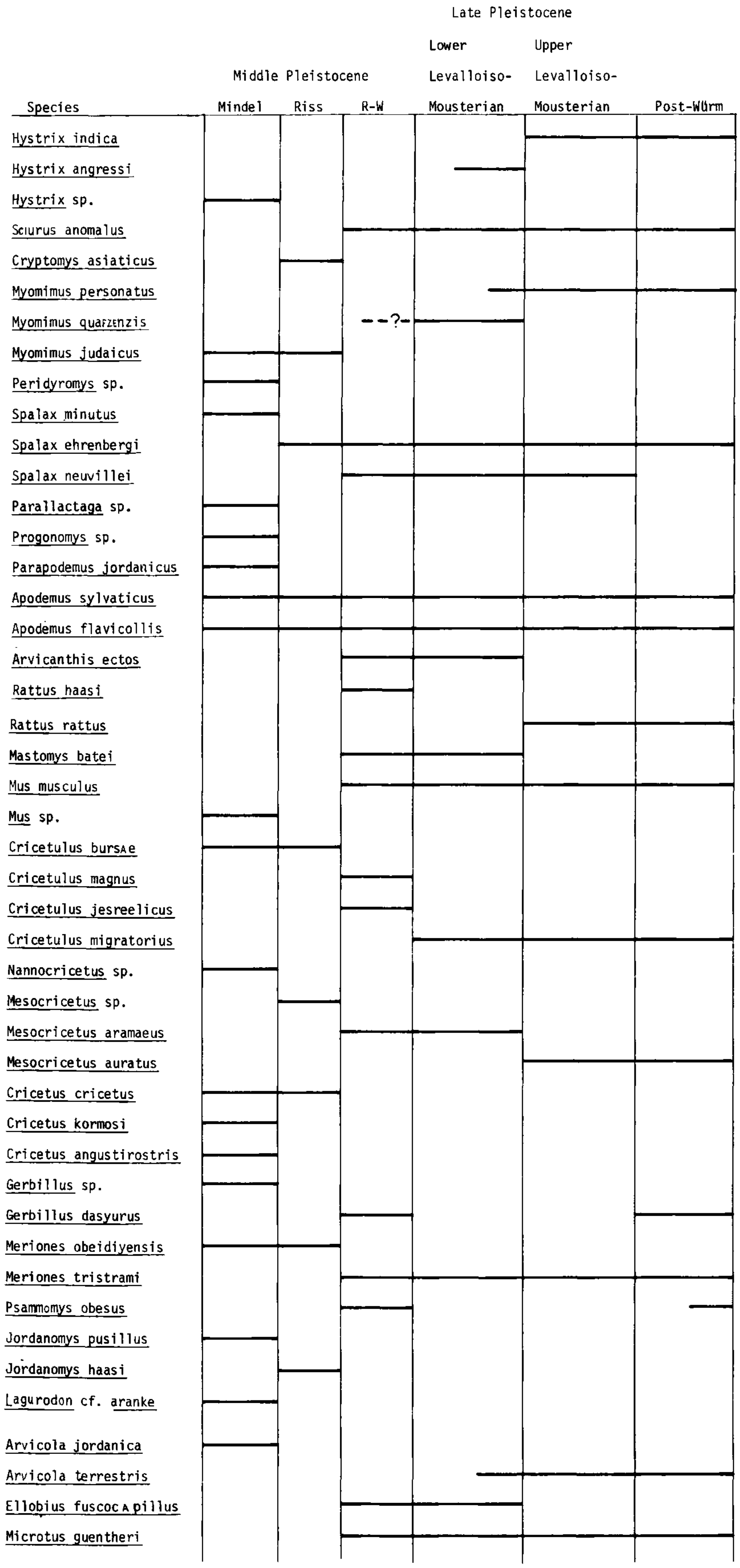

FIGURE 7.8. *Stratigraphic ranges of Pleistocene rodents in Israel.*

disappeared from the area, or retreated into isolated "islands" in northern Israel. *Acomys cahirinus,* which probably lived in the arid zones of the Near East throughout the Pleistocene, invaded northern areas in the wake of the declining Mediterranean woods and the first large scale appearance of the bare rocky biotope in a formerly typical Mediterranean region. It now occurs in Crete and Cyprus, which were cut off from the mainland in late Pliocene times. Populations of *Acomys,* having originated in Africa, should have occurred during late Pliocene times in the Near East. Typical Mediterranean flora and fauna penetrated Israel only later, probably during the early and early middle Pleistocene, a period when *Acomys* was halted until as late as the Upper Paleolithic, when large areas began to be cleared of forest. This was an appropriate moment for *Acomys* to invade this area.

In the early and middle Pleistocene, *Cricetulus bursae* inhabited Europe and the Near East. Then two new forms appeared during the late Pleistocene in the eastern Mediterranean area, long after the genus had vanished from Europe. These two species (*C. magnus* and *C. jesreelicus*) survived until the lower Mousterian. The genus *Nannocricetus* has appeared only in the Ubeidiya Formation. Three forms of the genus *Cricetus* are known from the Ubeidiya beds (*C. cricetus, C. kormosi,* and *C. angusticostris*); one of them (*C. cricetus*) continued until later periods of the middle Pleistocene (known from the Jerusalem karst filling). The genus *Cricetus* is not known from the late Pleistocene of the Near East; it had probably retreated northward. *Mesocricetus* probably first appeared in the area only during the later middle Pleistocene, having presumably been in competition with *Cricetus*. As soon as *Cricetus* had retreated, *Mesocricetus* became quite common. The dwarf-type fossil *Mesocricetus aranaeus* is quite different from *Mesocricetus auratus,* and apparently lived in a moist biotope [but not in the closely afforested region, as Bate propounded (1943)], from the Acheulian until the end of the upper Mousterian. *Mesocricetus auratus* occupied more arid grassland, appeared in the upper Mousterian, and disappeared during the Natufian–Neolithic. Another grassland species, *Cricetulus migratorius,* appeared in the Near East along with *M. auratus,* and is now not very common in Mediterranean areas.

An undetermined species of *Gerbillus* was found in the Ubeidiya Formation (Haas 1966, 1968). A much larger, and different species is known from a later stratum, the Jerusalem karst filling, both forms indicate the existence of fairly open, steppic to rocky landscapes. *Gerbillus dasyurus* lived in a biotype of bare rocks in the more arid zones of the Near East throughout the entire late Pleistocene, and manifested only a few morphological changes. It reached Mt. Carmel's Mediterranean area only as late as the Upper Paleolithic, shortly after *Acomys cahirinus* arrived, following the declining and retreating woods and forests. Much like *Acomys cahirinus, Gerbillus dasyurus* is known at present from the most arid zones of Israel and Sinai to typical Mediterranean regions of northern Israel, always occupying bare rocky slopes. *Meriones obeidiensis* is known only from middle Pleistocene sites. Later on, during the late Pleistocene, *Meriones tristrami* occupied the Mediterranean regions of Israel. It has been possible to show that during the Acheulian *M. tristrami qatafensis* was not only much larger in size than the Recent *M. tristrami,* but had a far closer resemblance to *M. persicus* (Haas 1951; Tchernov 1968). Furthermore, it is feasible that *M. persicus* and *M. tristrami* may have had a common ancestry, since they show some affinities to *M. odeidiensis*. Oumm-Qatafa Cave is situated at the fringe of a desert area, so that animals like *Gerbillus dasyurus* and *Psammomys obesus* are expected. *G. dasyurus* appears in the Mediterranean areas of Israel only in the Upper Paleolithic (Figure 7.8).

The extinct genus *Jordanomys* is known at present only from the middle Pleistocene of Israel, by two different species, *Jordanomys pusillus* from Ubeidiya and *J. haasi* from the Jerusalem karst filling. The genus is characterized by a very simple molar pattern. The representatives of this genus are probably mere stragglers from older times, which managed to survive in Israel as late as the middle Pleistocene. The genus *Jordanomys* coexisted with another extinct genus, *Lagurodon,* which had rootless molars and no cement in the re-entrant angles (Haas 1966). In Europe, this genus had disappeared by the middle Pleistocene. Both extinct genera probably occupied a cooler steppic habitat, much like the closely related genus *Lagurodon* today (Haas 1968). *Arvicola jordanica* is an extinct species that was found only in the Ubeidiya Formation, while *A. terrestris* is known only from the Mousterian of Mt. Carmel (Heller 1970), and from the Hula Basin today. *Ellobius fuscocapillus* first appeared in the Acheulian of Oumm-Qatafa, probably in a moist steppe habitat, and disappeared toward the later Mousterian. It is known as well from the Pleistocene of North Africa, but is restricted today to central Asia. The genus *Microtus* is not known prior to the late Pleistocene of the Near East. In Israel it is known by a single species, *M. güntherii,* which forms a continuous chronocline in abundant numbers during the entire late Pleistocene. This is the only vole known at present south of the borders of Syria and Lebanon.

When their biotopes are considered, these Pleistocene rodents fall into four main groupings: Mediterranean wood dwellers; moist steppe dwellers (Butzer 1971); Mediterranean open grassland to semiarid (= dry steppe) dwellers (Moreau 1955); rock dwellers. Determinations of the various ecological requirements are not, and could not, be sharply defined when fossil animals are under consideration. In order to reconstruct the main changes of biotopes and landscapes in the whole region, it is sufficient to know the general ecological requirements, and the principal kind of habitat occupied by the considered species. In cases when a whole group of species that inhabited a certain biotope vanished or retreated from the studied region, it certainly means that this kind of habitat was largely restricted, or altogether absent. Although we shall never be able to understand fully the exact habitats of extinct species, any such reconstructions will always remain highly speculative, there is general agreement as to the kind of biotopes occupied by many Pleistocene rodents. As Pleistocene landscapes in the Holoarctic regions have already been reconstructed to some extent, it is therefore feasible to allocate the fossil species to their appropriate landscapes.

Most of the moist steppe dwelling rodents did not persist for long in the Levant, and became extinct after the Ubeidiya period (early middle Pleistocene). Prominent among these are *Parallactaga* sp., *Nannocricetus* sp., *Cricetus angustirostris, Cricetus kormasi, Jordanomys pusillus,* and *Lagurodon* cf. *arankae* (Haas 1966, 1968). Other species survived even beyond the Ubeidiya times. In the karst fissure filling near Jerusalem (Figure 7.9), five such species occur, two of which (*Cricetus cricetus* and *Cricetulus bursae*) existed beyond Ubeidiya times, two others belong to genera that existed during the Ubeidiya times; but appear here as different species (*Myomimus judaicus* and *Jordanomys haasi*). The fifth is the genus *Cryptomys,* which probably occupied evergreen grassland areas, much like some of the blesmois that live in the plains of South Africa. The genus *Cricetulus* is still found during the lower part of the late Pleistocene in Oumm-Qatafa cave, comprising two new species, *A. jesreelicus* and *A. magnus.* By this time a few new genera appear for the first time, probably replacing extinct forms in similar biotopes. The new species are *Arvicanthis ectos, Rattus haasi, Mastomys batei,* and *Ellobius fuscocapillus,* all of which required dense vegetation and considerable water. Dry grassland was too arid a habitat to support the species *A. ectos* and *Mastomys batei* (Ethiopian elements), *Rattus haasi* (probably Oriental), and *Ellobius fuscocapillus* (probably originating in the Asian steppes). Only *Mastomys batei* continued to live in the lower Mousterian, while all the rest disappeared. The entire genus *Cricetulus* became extinct. From later upper Mousterian onward only *Myomimus roachi* survived, to vanish by Historical times.

There are still only a few Mediterranean grassland dwellers in middle Pleistocene times, but these increase in number of species (Figure 7.9) during the late Pleistocene. In Ubeidiya (Haas 1966) three species were listed: *Hystrix* sp., *Spalax minutus* (which Haas believes to be closely related to *Spalax ehrenbergi*) and *Meriones obeidiensis.* Porcupines are missing from the karst filling of Jerusalem, but *Spalax ehrenbergi* and *Meriones obeidiensis* are extant. The genus *Mesocricetus* (probably representing a new species) appears for the first time in the Levant. At the beginning of the late Pleistocene (Oumm-Qatafa Cave) we already find six species living in a sort of grassland landscape, two of which, *Meriones tristrami* and *Microtus güntherii,* appearing for the first time in the country, have continued up to the present. Along with *Spalax ehrenbergi,* a smaller species of mole rat (*Spalax neuvillei*) coexisted with the others. *Mesocricetus aramaeus* also appears at this time. The two last species survived

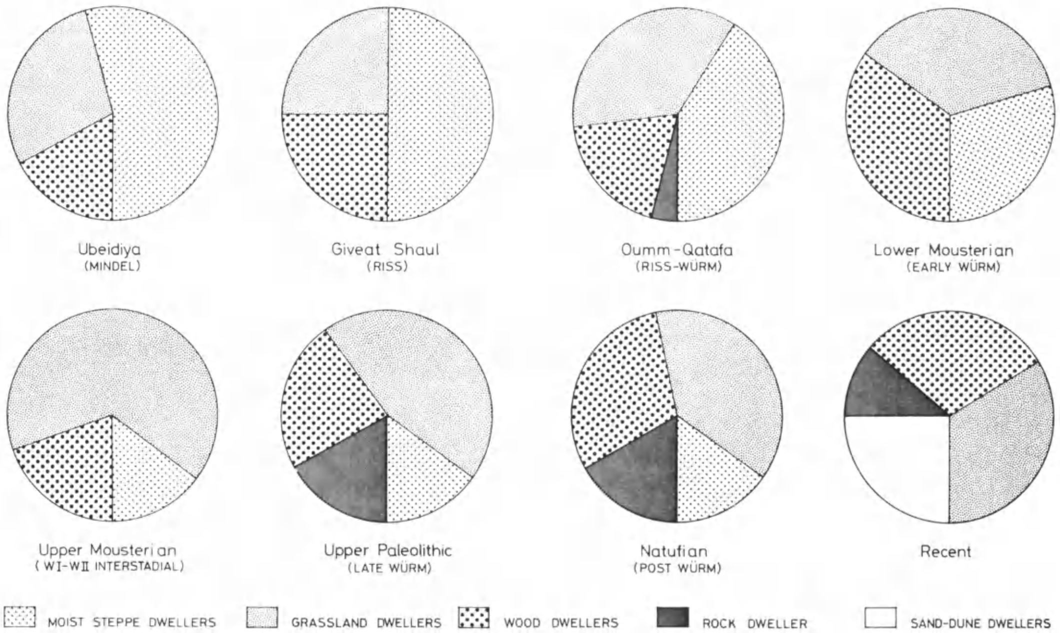

FIGURE 7.9. *Changes of habitats of rodents during the Pleistocene in Israel.*

until the upper Mousterian, when *Cricetulus migratorius* appears for the first time, a species still present today. A giant mole rat (*Spalax kebarensis*) and *Mesocricetus auratus* appear in the upper Mousterian; the first existed for a short period and is no longer found in post-Paleolithic layers, while the other is quite abundant in the country at least as late as the Mesolithic (= Natufian), but retreats northward to the Syrian plateau probably during the Neolithic.

Wood dwellers fluctuate more or less around the same relative number of species (Figure 7.9) during the Pleistocene. No squirrels were found in middle Pleistocene strata. *Sciurus anomalus* first appears in Oumm-Qatafa (early late Pleistocene) and disappears from the area during the post-Natufian. Several species of *Apodemus* are common in the Israeli Quaternary, of which *A. mystacinus* alone is known to have survived throughout the Pleistocene epoch. *A. levantinus* and *A. caesareanus* became extinct toward the upper Mousterian, when *A. sylvaticus* first appeared, and since then has been only rarely recorded. It is restricted at present to the northern part of the country. *Progonomys* sp. and *Parapodemus jordanicus* (Ubeidiya Formation) were considered wood dwellers, but since this is not proved it remains merely a speculative possibility. Strangely enough, arboreal dormice were not found until the Natufian. The genus *Dryomys* is known only from the Recent fauna of Israel. Rock dwellers (Figure 7.9) (*Acomys russatus* and *Gerbillus dasyurus*) in the Mediterranean region of Israel appeared only in the Upper Paleolithic, when desiccation and deforestation processes started in the Levant. Only in the post-Natufian (= uppermost Paleolithic) did the sand dune dwellers move into the coastal plain of Israel, which is designated as the youngest faunal invasion in the Levant.

The most striking phenomenon that resulted from the ecological changes during the Pleistocene of Israel is the fast and drastic elimination of steppe animals. Except for *Myomimus roachi*, no steppic species are found in the upper Mousterian, when grassland dwellers entirely replace them. The wood dwellers remain more or less constant in relative number of species. The severe desiccation process at this time was critical for the moist steppe dwellers, and mainly animals living in more arid open land biozones are found from the upper Mousterian onward. The fact that during the Upper Paleolithic (Figure 7.9) there is a shrinkage of grassland elements is not a result of a more rainy period (contemporaneous with the Würm), but rather because part of the area became too arid; bare rocks were exposed, and rock dwellers first appeared. Shortly after the Natufian, sand dune dwellers appear. The desiccation that has taken place in the Levant since the middle Pleistocene has no correlation with glacial or global climatic fluctuations, a fact that has been stressed by the author (Tchernov 1968). The fauna as a whole fails to show small climatic fluctuations (which certainly occurred), but is highly affected by major changing trends in the regional climate.

ORIGINS OF FAUNA: A GENERAL CONSIDERATION

As we have already stressed, for terrestrial faunas the desert belt was effective as a barrier to entry into the Levant only in Late Neogene and Pleistocene times. As a result, an impressive number of endemic species like *Microlaps mülleri* and *Atractaspis engaddensis* (snake) (Haas 1952), *Cinnyris osaea* and *Onychognathus tristrami* (birds) (Tchernov 1962), and *Procavia syriaca* were established in the Near East. Xerotropic forms, such as those which follow, could have better withstood desiccation, and have as a rule conspecific relatives in Africa south of the Sahara, as faunal exchanges were prolonged until a much later period. Examples of these are *Turdoides squamiceps*, *Falco concolor*, and *Corvus rhipidurus* (birds), and *Caracal caracal* and *Mellivora ratel* (carnivores). The rapid desiccation process, which intensified with time, caused the fauna left within the developing desert zone to undergo rapid adaptation to arid habitats. Once the developing desert belt served as an effective barrier faunal exchanges no longer significantly occurred between the Near East, Africa (south of the developing Sahara) and southern Asia. On the other hand, faunas that had originated in the northern realm freely invaded the Levant and North Africa (following the regression of the Paratethys Sea); thus the main zoogeographical units were established. By comparison with the Ethiopian region, the Orient shared much fewer species in common with the Levant. Examples of these are *Rhynchocalamus melanocephalum* (snake), *Ketupa zeylonensis* (fish owl), and *Nesokia bacheri*, known as well from the late Paleolithic of the Sudan (Robinson 1966).

The opinions of Bate (1934), Garrod and Bate (1937), Woldstaedt (1962), and Fairbridge (1962) that African animals invaded the Middle East only during the Aurignacian (Late Paleolithic) do not coincide with the facts that typical Paleotropic (particularly Ethiopic) elements are found in the region beginning with the Miocene (Savage and Tchernov 1968), in the early Pleistocene of Bethlehem (Bate 1934, 1942, 1943; Gardner and Bate 1937; Hooijer 1958), or in the early middle Pleistocene of Ubeidiya, Gesher Benot Ya'akov (Hooijer 1959), and Jerusalem (Tchernov 1968b). Nor does it fit with the existence of African elements in the ancient Pleistocene of Europe. The presence of tropical animals in the Levant had undergone a constant decline since the end of the

Neogene. Isolation of tropical faunas was at first only partially effective, but toward the late Pleistocene it became almost total (even with regard to a few xerotropic species). There is no reason to believe that Ethiopian animals reinvaded Asia.

Cooler steppe conditions, which prevailed during the Pliocene, humid at the beginning and becoming more arid toward the end, established Asiatic steppe biomes as far as northern African Atlantic shores. Semiarid to desert conditions were no doubt accentuated along the southern stretches of Palearctic Asia, and resulted mainly from the increasing heights of the mountainous ranges of central Asia during the Neogene (Ovchinnikov 1946). The imprint of Irano-Turanian vegetation is still impressive in the semidesert regions of the Near East. In more arid areas—southern Sinai, southern Israel, and Arabia—Irano-Turanian relics occur mainly at higher altitudes, amid regions that are floristically Saharo-Sindic. It must be conceded that the expansion of Eurasiatic forms in the Pliocene appeared to be a large scale phenomenon that affected major parts of the already well-determined Palearctic region, and reached the Atlantic shores of Africa, where trees like *Pistacia atlantica* still grow, but never succeeded in crossing the developing Saharan belt. For instance, in the late Pleistocene of Sudan, the central Asiatic borrowing vole *Ellobius* still existed. Though very scattered, none of the Bethlehem remains (see earlier discussion) is of European origin, but exclusively Afro-Asian. Central and western European genera and species first appear in the Levant not earlier than early middle Pleistocene, as found in the Ubeidiya Formation (Haas 1968). While the number of Mediterranean species remained more or less constant until the end of the Würm, Eurasian steppe animals were slowly reduced in number of species throughout the Pleistocene of the Near East. However, species such as *Lagurodon, Allocricetus, Cricetus* spp., *Jordanomys,* and *Ellobius* were already adapted to more arid habitats, and are still dominant in some regions.

It is hard to determine the exact time when Mediterranean elements forced southward deep into regions that are now extremely arid. Such movements could have taken place either through gullies and streams or along the cooler spines of mountainous chains. Parker (1956) mentioned a glacial Palearctic invasion into North Africa with regard to *Hyla arborea.* A few scattered populations of *Eliomys melanurus* occupy a typical rocky desert landscape and wadi escarpments amid the arid zone of southern Sinai and the Negev. These isolated populations were probably cut off during the Pleistocene from the main normal arboreal dormice, found to the north. Animals that underwent (during the Neogene and Pleistocene) extreme adaptation to arid habitats in the Arabo-Nubian deserts (of which southern Israel and the Sinai peninsula share an integral part) never invaded more humid areas. None of these is known to occur even in the most degraded Mediterranean areas of the Near East, and rarely are they found in semiarid regions. These elements are as a rule limited to an isohyete of 70–100 mm or less. A few species known from the Israeli-Sinai fauna are *Uromastix aegyptius, Uromastix ornatus,* and *Agama sinaita* (Agamidae, Lacertilia); *Oennthe leucopyga* and *Cercomella melanura* (birds); *Gerbillus nannus, Sekeetamys calurus,* and *Acomys russatus.* Such desert animals originated either from ancient Paleotropic faunas, or from the southern Palearctic stock of species that were trapped during the Neogene and Pleistocene in the slowly developing desert belt, undergoing speciation through extreme specialization to arid climates.

A swift retreat of wood and forest dwelling species (found to be at their maximum in the Late Pleistocene of the Near East) took place during postglacial times, partly on the brink of historical time (apparently due to the influence of man). The dual effect of climate and man forced a few forest dwellers (for instance, three species of deer, or *Sciurus anomalus*) far northward. This phenomenon coincided with rapid penetration by a few typical Saharan species, which invaded the stretches of dunes (Tchernov 1968) along the Mediterranean coastal plain of Israel as far as Acre to the north. A few gerbillids (Zahavi and Wahrman 1957) underwent swift speciation during the short postglacial period (i.e., *Gerbillus allenbyi* and *Meriones sacramenti*). Most of the Saharan newcomers (being well adapted to dunes) could not nevertheless move eastward and join the less well adapted dune dwellers of the Arava or the dunes of central and southern Sinai, as the Recent to sub-Recent dunes of the Mediterranean coastal plain were never geographically connected with the much older dunes of the Arava and southern Sinai. This new Saharan group of animals is found in Israel amid a typical Mediterranean area, still raising a kind of a paradox for local naturalists. This faunal assemblage, though very restricted in area, is the youngest found in the Near East, and is probably the only invasion from the African continent since the early Pleistocene. It should be noted that fauna from the Ethiopian region did not take part in this invasion. The Neogene faunas of the Near East are essentially Afro-South Asian in composition. The earlier Pleistocene Bethlehem Conglomerate contains close to 60% of Paleotropic elements (as a rough estimate). At the beginning of the middle Pleistocene (Ubeidiya Formation), the percentage of Paleotropic species decreased to 30% of the total fauna, and today it is close to 20%. The steady decrease of tropical elements began in the Neogene, but was accentuated throughout the Pleistocene, parallel with and as a result of the establishing of a south Palearctic desert zone, and the desiccation trend of the entire area.

8

Anthropology

Hominids, which apparently arrived in Israel from Africa through the developing Syrian-African Rift Valley, settled in the country long ago. Already in Mindel times, and perhaps earlier, occupation of the Jordan Valley and the coastal plain took place, and relics of man's activity are known over all subsequent periods. The settlement pattern was highly dependent on the availability of suitable environments until the end of the Pleistocene. During the Holocene, the picture changed, however, and man, by the development of agriculture, gained some independence from environmental conditions. He learned to adapt his economic activities to the changing climatic, hydrologic, and edaphic phenomena. The present chapter aims at describing the cultural development of hominids and, later, of *Homo sapiens*, in the area of Israel. Respective accounts were contributed by several colleagues of the author, each in his own field.

THE SEARCH FOR EARLY MAN IN ISRAEL

B. Arensburg and Y. Rak

REVIEW OF THE MAJOR EXCAVATIONS

This chapter reviews the major descriptive reports relating to both early and comparatively recent anthropological material uncovered in Israel and will attempt to ascertain the significance of these discoveries. The past 75 years have witnessed the discovery of numerous human skeletal remains in Israel. The motivation for excavation in this region has been twofold: first, the search for evidence related to the Bible; second, the geographical position of Israel as a junction of the three continents of the Old World, with the hope that here fossil hominids might be discovered, thus contributing to the human evolutionary record.

On June 19, 1925, readers of the *Times* of London could find a short note in the news section announcing the discovery of a fossilized hominid in the Galilee, near Lake Tiberias. A few weeks later, on August 14, 1925, a two-page chronicle appeared in the same newspaper, with large photographs of the fragment and preliminary reports by Turville-Petre, the field archaeologist who unearthed the remains, and Sir A. Keith, the British anthropologist who described them. The sensationalist nature of these news reports on the Galilee Man stemmed from the fact that no human remains related to a Mousterian industry had yet been found outside of Europe. Seventy-seven years of anthropological research had elapsed since the discovery at Gibraltar of the first adult Neanderthal. During this time, the existence of a Mousterian population in Africa or Asia had been viewed with skepticism; the origins of the Neanderthals, their distribution and affiliations, the chronology of the remains, and their relationship to the so-called Mousterian implements had been discussed only with reference to their European presence. Turville-Petre's discovery, therefore, provided evidence of a wider distribution of Neanderthal peoples and thus opened up new perspectives in the study of fossil man.

Thus, the interest in human bones from Israel is relatively recent. The discovery of the Galilee Man gave an unexpected impetus to anthropological research in the country. In the following decade, 1925–1935, outstanding finds of fossil hominids were made, and their full significance for the study and understanding of human evolution in the upper Pleistocene was already recognized at that time. In 1928, D. A. E. Garrod of the British School of Archaeology in Jerusalem excavated the cave of Shukbah in Wadien-Natuf, not far from Jerusalem. She discovered a new cultural assemblage that she called Natufian (Garrod 1932), a Near Eastern representative of the Epipaleolithic (Mesolithic) age. Some 45 Natufian skeletons unearthed from this site furnished the first glimpse of the post-Paleolithic population of Israel (Keith 1931, pp. 203–224). In the same cave, Garrod discovered fragmentary skeletal remains of several individuals deriving from Mousterian levels. Keith remarks that only part of these remains had Neanderthal affinities. In early 1929, Garrod began excavation in Wadi el-Mughara, in the Carmel. After 21 months of fieldwork, her efforts led to the discovery of a Mousterian cemetery in the Mugharet es-Skhul, some human remains (probably pre-Mousterian) in Mugharet el-Tabun, and an Epipaleolithic burial in Mugharet el-Wad (Garrod and Bate 1937; McCown and Keith 1939). The skeletal material from Skhul comprises two children, 4 and 5 years old, probably male, one 8–10-year-old male, two females between 30 and 40 years old, and five males between 30 and 50 years old. Isolated bones and teeth indicate the presence of a few other individuals at this site. In Tabun Cave the complete skeleton of a 30-year-old female and the mandible of a male were unearthed, as well as other isolated human bones and teeth. It should be noted that, years after the McCown and Keith report was published, a revised reconstruction was made by Snow (1953) of the often-quoted specimen Skhul V, and, consequently, he arrived at a different set of measurements.

Typological thinking still dominated the field of anthropology in the 1930s. It was only the fact that the Skhul specimens were found in one cave at the same level that saved each from being considered a separate taxon (McCown and Keith 1939). The intensive search for the "missing link" in human evolution and the way in which the fossil record was viewed left its imprint on the anthropological literature of that time and, undoubtedly, led to the assigning of generic status to the specimens of Mt. Carmel. Mugharet el-Wad was relatively poor in Middle Paleolithic artifacts but was rich in Upper Paleolithic, and especially Natufian, industries. In the lower layers, mandibles and isolated teeth, vertebrae, limb bones, and other remains were found in the Aurignacian levels. In the top layer, a large Natufian burial ground containing some 80 skeletons was situated on the front terrace and extended partially into the cave (Garrod and Bate 1937; McCown 1939). While Garrod was working at Wadi el-Mughara, two other sites were being excavated. The cave of Kebara, a few kilometers south of Tabun, was dug by Turville-Petre in 1931, and, in the same year, Rene Neuville, the French consul in Jerusalem, excavated Erk el-Ahmar in the Judean Desert. The Kebara cave yielded a very rich Natufian industry; a burial pit containing skeletons of some 50 individuals was found, but they were fragmentary, and very little information could be obtained from this material (McCown 1939). Some mandibles and axial bones from the Upper Paleolithic were also unearthed by Turville-Petre at this site (McCown and Keith 1939). In the Erk el-Ahmar terrace, seven Natufian skeletons that had been discovered by Neuville in 1931 were described by Vallois (1936). Several years later, from 1933 to 1935, Neuville and Stekelis excavated the cave of Qafza, near Nazareth (Neuville 1951). The site was rich in Upper and Middle Paleolithic industries. Fragments of skull and limb bones of two individuals lay in the Upper Paleolithic level, and four other specimens were discovered in the Mousterian levels (Vallois and Vandermeersch 1972).

Interest in biblical history led to a series of extensive archaeological expeditions in the Holy Land. The first anthropological report on human remains recovered from a large archaeological excavation was that of Tell Gezer, discovered by Macalister in 1901–1902 (Macalister 1912). These remains, however, were not well-dated and may belong either to the Bronze or to the Iron Age. Human skeletal material from two mounds, Megiddo (Guy 1938) and Lachish, was unearthed and studied by Hrdlička (1938), Risdon (1939), and Parry (1936). Some 68 human skeletons from Megiddo, ranging from the Chalcolithic to the Iron Age, were studied; from Lachish, more than 600 skeletons from the Iron Age were described. Anthropology has benefited greatly from this large body of research on the morphology of these former inhabitants of the region.

The study of ancient man was interrupted by the political unrest beginning in 1939, and not until 1960 were there new discoveries of human fossils. Possibly the most important of this new series of finds is the middle Pleistocene deposit of Ubeidiya in the Jordan Valley (Stekelis 1966), where a few skull fragments and three teeth associated with an early tool industry were unearthed. These fragments, however, are too few to permit a more specific taxonomic decision than *Homo* sp. (Tobias 1966). Yet, these are not the only pre-Würmian fossil remains found in Israel. Anati and Haas (1967) described some fossilized cranial fragments, possibly belonging to *Homo erectus*, from the site of HaZore'a in the Yizre'el Valley. Indeed, the abundance of Acheulian industries in Israel (Gilead 1970), as found in caves and open-air sites throughout the country, would seem to confirm the occurrence of flourishing pre-Neanderthal populations in the region. A new period of discoveries from the Middle Paleolithic started with the excavations in 1961 of the Amud Cave, not far from the Zutiye Cave. The Amud Man, first in a series of four individuals (Suzuki and Takai 1970), is a complete skeleton of a 25-year-old male. The other specimens from this site are represented by skull fragments only (Amud II, an adult male, and Amud III and IV, 4- and 3-year-old infants, respectively). A few years later, in 1964, the renewal of the excavations in the cave of Kebara under the direction of M. Stekelis led to the finding of a Mousterian 9-month-old Neanderthal child (Smith and Arensburg 1977). The most recent discoveries occurred around the end of the 1960s: the very important finds of Bernard Vandermeersch (1969) in the Qafza Cave. Vandermeersch again exposed the old Mousterian cemetery, which had first been excavated by Neuville and Stekelis. Qafza has yielded more than 10 Mousterian skeletons. Their position in the most ancient Mousterian layers, as well as their neanthropic morphological affinities, gives these remains a fundamental place in the study of human evolution. Renewal of excavations in the Tabun and Zutiye Caves, regrettably, did not produce new fossil evidence (Gisis and Bar-Josef 1974; Jelinek *et al.* 1973). However, a reassessment of the stratigraphy of those sites demonstrated that the Tabun female skeleton and the Zutiye frontal bone were older than originally believed. The Mousterian sites of Me'arat Shovakh (Binford 1966) and Hayonim Cave yielded scanty human remains.

The Mousterian population of Israel was, evidently, large when judged by the great number of prehistoric sites of that period, the considerable time-span covered by each site, and the many fossils recovered. Such an abundant anthropological assemblage is unusual for a geographical area as limited in size as Israel. A peculiar fact in the paleoanthropology of Israel is the almost complete absence of Upper Paleolithic human remains. It is rather surprising that in a country so rich in early human remains there is a gap for the period traditionally related to the emergence of modern man. More than 50 years of archaeological excavations appear to confirm this fact. Indeed, the Upper Paleolithic layers of Qafza, el-Wad, Kebara, Emireh, el-Khiam Terrace, and many other sites have yielded only isolated human skeletal fragments. However, in recent years Upper and Epipaleolithic remains have been found at two sites in Israel. Stekelis and Bar-Yosef (1965) found a skeleton of a Kebaran female on the eastern shore of Lake Tiberias. A few years later, Bar-Yosef (1973), in the same area of En Gev, discovered a second female skeleton, this time in the context of a Late Aurignacian industry (Arensburg 1977). The only Upper Paleolithic bones of male specimens come from the Qafza Cave, where two frontal bones were discovered some years ago by Neuville and Stekelis (Vallois and Movius 1952). The latter bones are morphologically strong and rugged, in sharp contrast to the remains of the females from En Gev, yet not so robust as the European Cro-Magnon or Combe Capelle remains. The mandibles from el-Wad and Kebara found in Upper Paleolithic layers (McCown and Keith 1939), as well as the skeletons from En Gev, have the same Natufian affinities.

The Natufian period in Israel is rich in human remains. They are present in sites in almost all latitudes, from the rainy Galilee to the dry Judean Desert. Since the first discovery of the Natufian culture by Garrod in the Shukbah Cave in 1928 (Garrod 1932; Keith 1931), hundreds of skeletons have been found in the caves of el-Wad (Garrod and Bate 1937; McCown 1939), Kebara (McCown, 1939; Turville-Petre 1932), Erk el-Ahmar (Neuville 1951; Vallois 1936), Nahal Oren (Crognier and Dupouy 1974; Noy *et al.* 1973; Stekelis and Yizraeli 1963), Eynan (Perrot 1966), and Hayonim (Bar-Yosef and Goren 1973; Bar-Yosef *et al.* 1973). Major reports on the anthropology of the Natufians are those of McCown (1939), Ferembach (1961), Bar-Yosef *et al.* (1973), and Arensburg (1973). The large amount of Natufian skeletal remains unearthed, as well as the possibility of studying archaeologically the cultural and economic transformation that occurred during and after the Epipaleolithic, allow reconstruction of the relationships between biological and cultural development of such populations. The more recent historical periods are outside the scope of the present work. In any event, the Neolithic, Chalcolithic, and the later populations have to date received little attention.

THE PLACE OF EARLY MAN IN ISRAEL

If we refer to the Neandertals as the human population living in Europe during the first part of the Würmian Glaciation, the Neanderthaloid affinities of Galilee man cannot be sustained. The chronology of the Zutiye Cave, the associated industry, and morphology of the human bones leave no doubt about the earlier Paleolithic affiliation of this fossil. Now, McCown and Keith (1939) described the men from Mount Carmel as "the remains of a single people, the Skhul and the Tabun types being but extremes of the same series," and stated that "the Tabun type possesses many features that link it to the Neanderthal type of Europe while the extreme Skhul type passes toward a Neanthropic form such as that found at Cro-Magnon. Between these extremes are intermediate forms [p. 12]." These authors assume that all the Mount Carmel people belong to a "Paleanthropic genus," according to the so-called characters of "greater taxonomic value." According to them, the "Galilee man and the Mount Carmel specimens should be regarded as members of the same group. His place is apparently towards the Tabun extreme of this group [p. 16]." Yet, a reevaluation (e.g., Vandermeersch 1977) of the morphological and chronological facts involving all these remains suggests a certain confusion in the aforementioned views. Thus, the more recent excavations at Tabun (Jelinek *et al.* 1973) indicate that a large gap of time separates the Tabun and Skhul groups. The fact that remains are found in the same general locality surely is not enough to consider them members of the same population. Stratigraphical, faunal, morphological, and other chronological considerations must be taken into account. An even older age was assigned to the remains of the Galilee man (Gisis and Bar-Yosef 1974), increasing the distance between this fossil and the Skhul population. We can agree with Howells (1958) that "In the Skhul series, as in those from Tabun, there was no trace of the characteristic classic Neanderthal morphology [p. 405]," and that "the people from Skhul and Djebel Qafza were well advanced toward anatomically modern man, more so than populations of southeastern Europe at the time (or the Levant at a slightly earlier time) [p. 405]." Stewart (1960) pointed in the same direction when he affirmed that "there is no reason now to regard the Skhul specimens as anything other than representatives of an early variety of modern man [p. 1438]" and multivariate analysis of Howells (1975) arrived at similar conclusions.

The remains of the Amud Man, discovered by Suzuki (Suzuki and Takai 1970), are somewhat ambiguous in their chronological, as well as morphological, position. According to Suzuki, Amud I could be in an intermediate position between the Galilee–Tabun specimens and the Skhul–Qafza. This view seems hazardous to us, especially if the chronology accepted by Suzuki (35,00 B.P.) is relevant. This date seems inconsistent with the pre-Würmian remains from Zutiye and the early Würm of Tabun, and even with the more recent Skhul and Qafza specimens. The Amud man is, indeed, new evidence of the great variability of human types within the Paleolithic population of Israel. Some authors (Ashley-Montagu

1940, 1951; Dobzhansky 1944; Hooton 1946; Weckler 1954; and Thoma 1957, 1958, 1965) believe that the noted variability is the result of hybridization. We are inclined to agree with Stewart (1960), who felt that "it is simpler and more reasonable to strip the Mount Carmel remains of the role of a population and especially a hybrid population, and to recognize their two components as fundamentally distinct [p. 1438]." The final report on the remains from Qafza is still in preparation, and, regrettably, we lack the full story concerning this site. Most likely, however, this report will confirm the facts already stated by Vandermeersch (1972), in the sense that "nous disposon (à Qafza) d'*Homo sapiens,* vrais artisans d'une industrie Mousterienne" and "L'Homme de Qafza est un point sur la route qui a conduit aux hommes du Paléolithique Superieur. . . ."

We may summarize as follows: There is a great antiquity to the genus *Homo* in the Land of Israel, exemplified by the remains from Ubeidiya (Bar-Yosef and Tchernov 1972; Tobias 1966) and HaZore'a (Anati and Haas 1967). The remains from Zutiye and Tabun, traditionally regarded as Neanderthals, should belong to a pre-Neanderthal group. Representatives of the classical European Neanderthals so far have not been found in Israel. Skhul and Qafza remains certainly belong to a *Homo sapiens* population related to a Levalloiso-Mousterian industry. A major chapter in the anthropology of Israel should include Upper Paleolithic men. Yet, there is a lack of data from this period. The close resemblance of the "Atlithian" and Kebaran skeletons from Nahal En Gev I and En Gev II, respectively, with the Natufians, indicates a close relationship between these two groups and points to an autochthonous origin of the Epipaleolithic people. This population, with its multiple activities in food gathering, hunting and fishing, possibly incipient agriculture, animal domestication, trade, village organization, burial rituals, artistic expressions, rich stone and bone industries, etc., may well be considered as standing at the beginning of our modern civilization (Arensburg 1973; Bar-Yosef *et al.* 1973).

PALEOLITHIC INDUSTRIES

We shall describe the Paleolithic industries in Israel in a tentative chronological order, based on the stratigraphical relations when these are known, otherwise on techno-typological grounds.

Stratigraphically, the earliest human artifacts known from Israel are some tools found in the Erkel Ahmar Formation and a small chopping tool found at Nahal Shiqma (Lamdan *et al.* 1977) together with several bones, one of which is a long bone of a huge size, apparently that of a giraffe or a camel (E. Tchernov, Department of Zoology, Hebrew University of Jerusalem, personal communication, 1976). The chopping tool and the bone were found in a sandy fluviatile terrace of Nahal Shiqma (Figure 8.1), assigned by Horowitz to the Hasi Member of the Gaza Formation, of Günzian Age. Two occurrences of late Günzian sites were described from the Lebanon (Hours 1975). The first of these early sites is Sharia, in the neighborhood south of Hama (Figure 8.2; van Liere and Hooijer 1961) on the banks of the Orontes, where a high terrace occurs, consisting of pebbles and gravel with thin beds of sand and silt. The assemblage consists of very few artifacts, two spheroids, some irregular globular cores, and small flakes with plain high-angle butts. Some are cortex flakes from river pebbles. There are no bifaces. Some of the faunal remains associated with these finds were defined by Hooijer as of *Archidiskodon meridionalis* and dated to the late Günz. Another occurrence of similar flakes is reported by van Liere (1966) from a terrace of the Orontes, about 70 m above the present level of the river at Rastan, between Homs and Hama. This assemblage also includes pebble cortex flakes, with no cores and no bifaces. The Rastan Formation, like the Sharia, is referred to the end of the Günz. These cultures are assigned by Hours to the Para-Acheulian industry. Stratigraphically, the next industry was found only in Lebanon, near Borj Qinnarit, southeast of Sidon, in a fossil beach at 95 m above present sea level (Hours and Sanlaville 1972). This sea level is assigned by Hours and Sanlaville to the Günz-Mindel Interglacial. The industry consists of two pebble tools, two cores, one large anvil, two heavy flakes and ten small *eclats de taille,* or preparation flakes. This industry is also assigned by Hours (1975) to the Para-Acheulian, which is thought to be younger than the African Olduvan and may be correlative with the Clactonian of Europe. No sites of Günz-Mindel Interglacial age are known from Israel.

EARLY ACHEULIAN IN ISRAEL

A. Ronen

Industries occur in some localities in Israel, both in the Jordan Valley and in the coastal plain. By far, the best known is the site of Ubeidiya, embedded within the Ubeidiya Formation of the Central Jordan Valley (Bar-Yosef and Tchernov 1972). Here, in various deposits that were formed on a lake shore, 14 lithic assemblages have been unearthed. Chopping tools form the most common and characteristic tool, accompanied in some of the assemblages by spheroids, trihedral picks, and primitive handaxes. The entire Ubeidiya series (Figure 8.3) has a crude appearance; that is, the tools are made by rather coarse flakes, which indicates the sole use of a

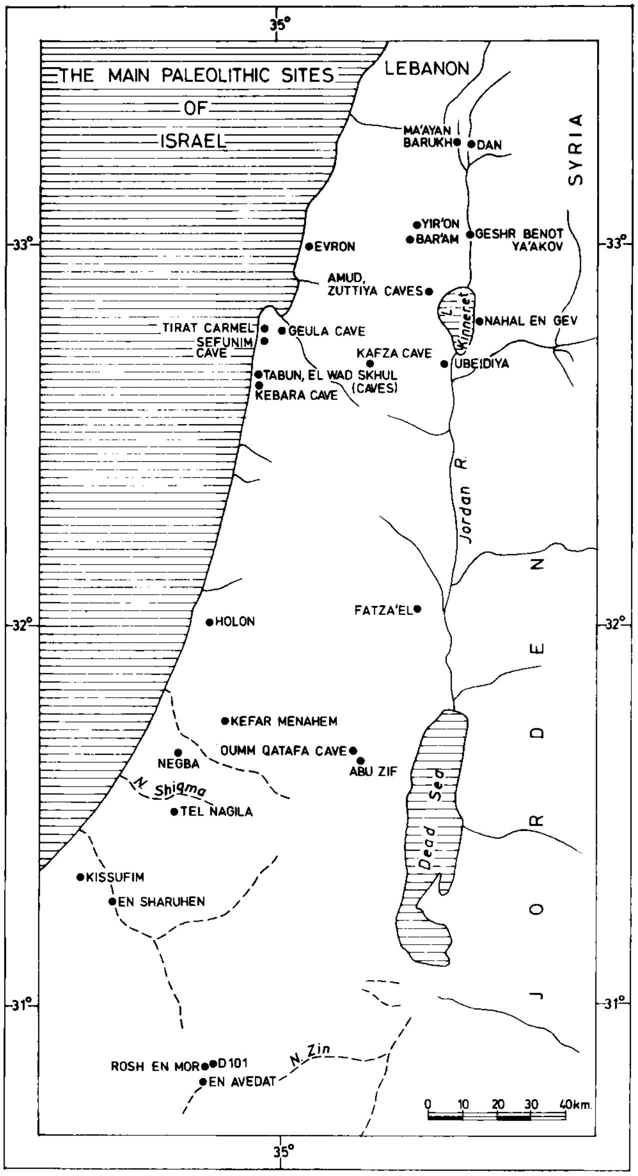

FIGURE 8.1. *Location map of the main Paleolithic sites in Israel.*

hard hammer, and with flake tools with utilization retouch, rather than deliberate shaping. Spheroids are, on the whole, the most carefully made shaped tools. Their near-perfect symmetrical shape required the removal of numerous, rather small flakes. The Ubeidiya industry is made of flint, basalt, and limestone. Although basalt is the most common raw material in the vicinity, flint and limestone tools outnumber those of basalt. Furthermore, each of the rocks serve mainly for the fabrication of a certain class of tools. Hence, a choice of a suitable raw material is clearly attested at Ubeidiya. The frequency of the major tool classes changes with time. From the oldest layer, spheroids and light-duty tools are numerous, and handaxes are absent. The middle layers are characterized by handaxes and trihedrals, accompanied by only a few light-duty tools. The latest phase resembles the earliest. Handaxes disappear, but rare trihedrals are present and light duty tools become abundant again (Figure 8.4). A few sites in the coastal plain, Kefar Menahem and Negba, have Ubeidiya-like assemblages, although spheroids have never been found in any significant numbers outside Ubeidiya. At Kefar Menahem, a test excavation uncovered a lithic industry that consisted of chopping tools, flake tools, and crude handaxes (Gilead and Israel 1975). At Negba, a small series came to light during earth work (I. Eshel, Institute of Archaeology, Tel-Aviv University, personal communication, 1977). The series includes chopping tools, trihedral picks, and crude handaxes, all of large size. Sites bearing similar characteristics, assigned by hours (1975) to the early Middle Acheulian, are quite numerous in Lebanon. The best-known are the sites at Nahr el-Kebir, at Joubb Janine II, and at the Beqa'a, all assigned a Mindel age by Hours.

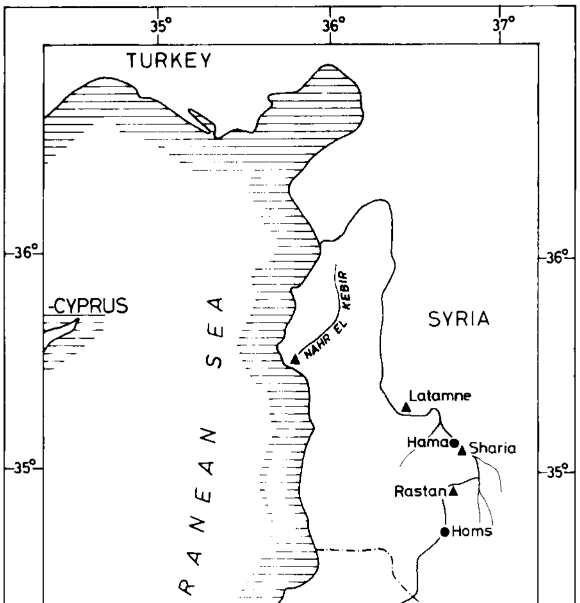

FIGURE 8.2. *Location map of the main Early Paleolithic sites in Lebanon and Syria.*

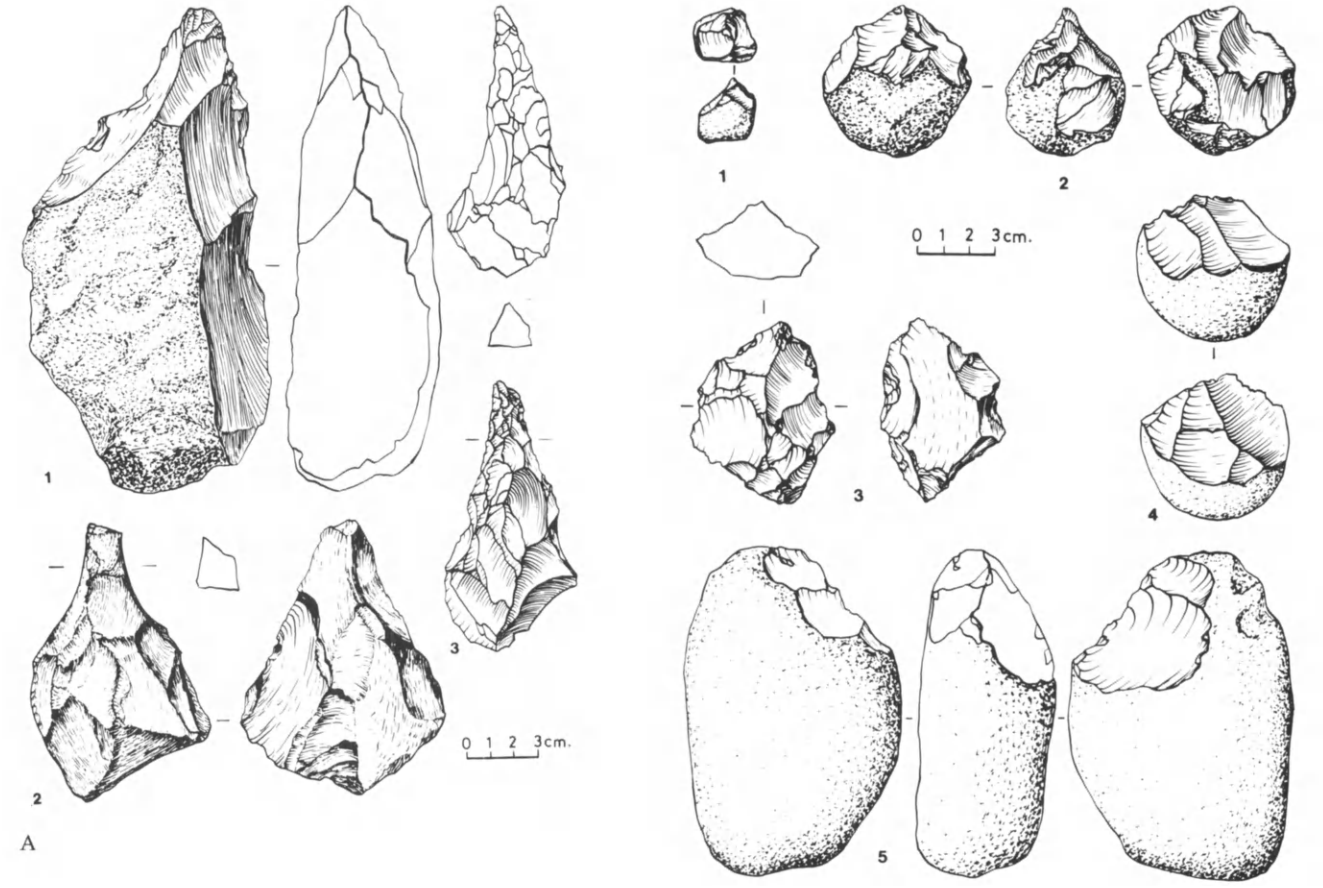

FIGURE 8.3. *Artifacts from Ubeidiya. (A) 1, Flint handaxe. 2, Limestone trihedral pick. 3, Flint trihedral pick. (B) 1, 2, 4, 5, Flint chopping tools. 3, Alternately retouched thick flake.*

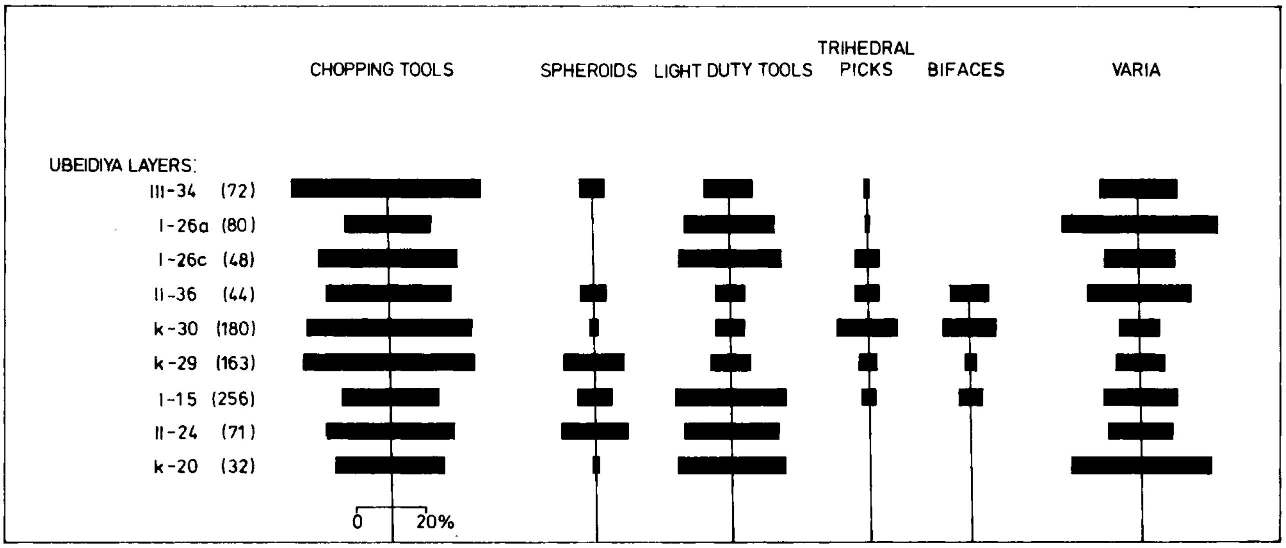

FIGURE 8.4. *The main industrial components of the Ubeidiya assemblages. (After Bar-Yosef and Tchernov 1972.)*

The following phase of lithic industries seems to be present at the Evron Quarry in the Western Galilee coastal plain, now in the course of excavation (Brunnacker, in preparation; Gilead and Ronen 1977; Issar and Kafri 1972; Prausnitz 1969; Ronen and Amiel 1974; Ronen and Prausnitz, in preparation). There are at least two, and possibly four, horizons in a "pseudo-gley" and in the underlying red loam. The site yielded lithic assemblages and faunal remains. The principal tools are handaxes of great size, with as few as 12–15 flakes per tool. A characteristic subgroup are some bifacial cleavers with narrow edges (Figure 8.5). The chopping tools and flake tools are accompanied by a few racloirs and awls. The flake tools are small and thin, with a quite fine workmanship. Globular calcareous concretions of a particular size served as hammer stones. There is no Levallois technique. The Evron Quarry was probably a hunting–butchering site in a marshy area near a river. The fauna hunted comprises elephant, warthog, hippopotamus, and deer. Other sites of this age are not known from Israel but are quite abundant in Syria and Lebanon. The best known of these is the site of Latamne, which was studied in great detail (Clark 1967, 1968). The fauna, according to Hooijer (1961), points to the end of the Mindel or, more probably, the beginning of the Great Interglacial as the age of the occupation. Pollen analyses by Horowitz (unpublished data) indicate a flora at the time of occupation that is typically interpluvial for this area. Sites of the South Beqa'a (Besançon and Hours 1970) also belong to this culture.

MIDDLE ACHEULIAN

The following, Middle Acheulian phase consists of assemblages that seem to be later than the Evron Quarry and earlier than the Upper Acheulian. The most important problem concerned with these sites is that most have no definite or exact stratigraphic assignment. They are found either on the surface or associated with paleosols. It is quite difficult, however, to assess the exact phase of the Riss during which these sediments were laid down. Middle Acheulian assemblages are known from Bar'am and Yir'on in the Upper Galilee mountains, Holon in the coastal plain, Gesher Benot Ya'akov in the Jordan Valley (Figure 8.6), and the lowest hand-

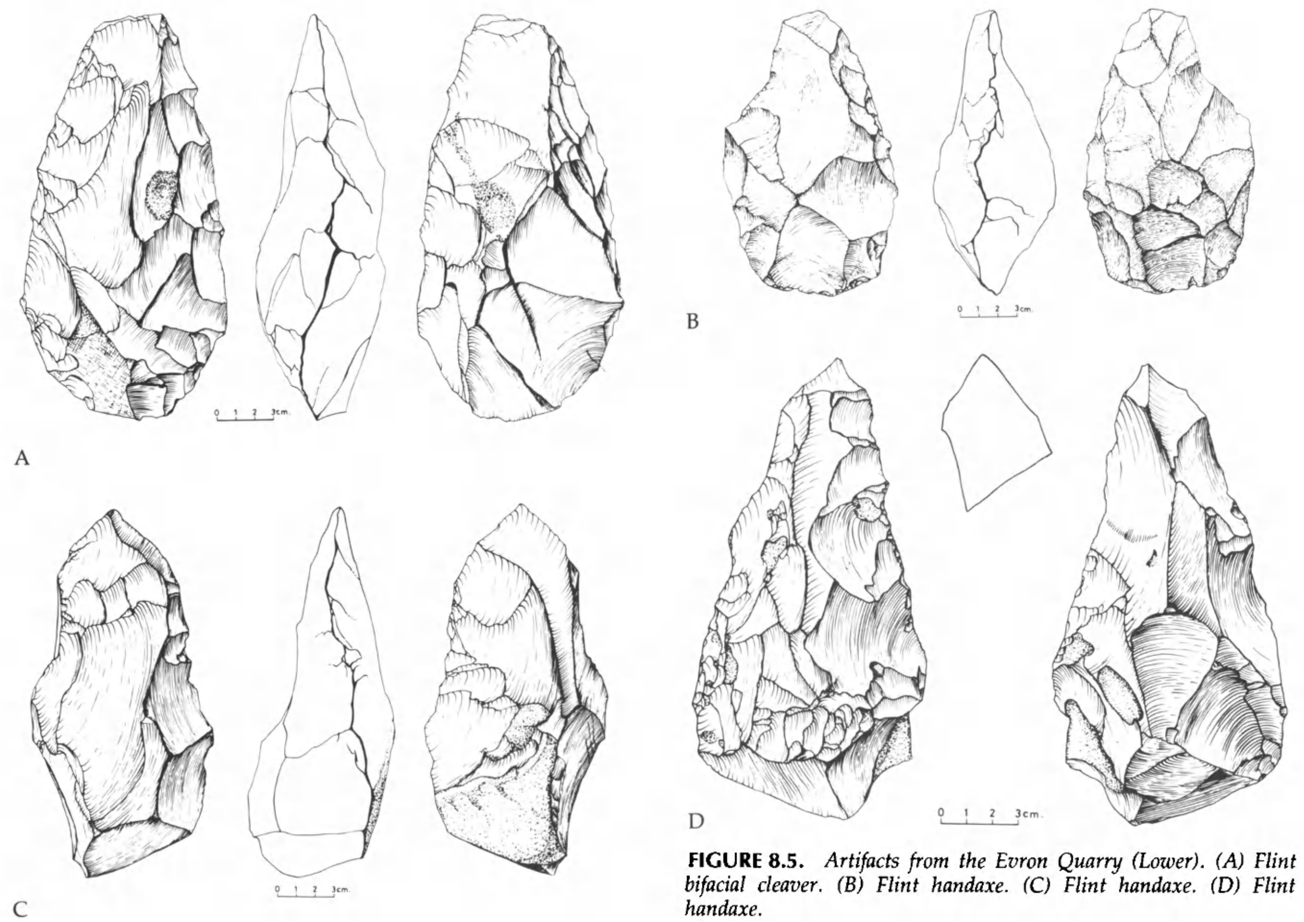

FIGURE 8.5. *Artifacts from the Evron Quarry (Lower). (A) Flint bifacial cleaver. (B) Flint handaxe. (C) Flint handaxe. (D) Flint handaxe.*

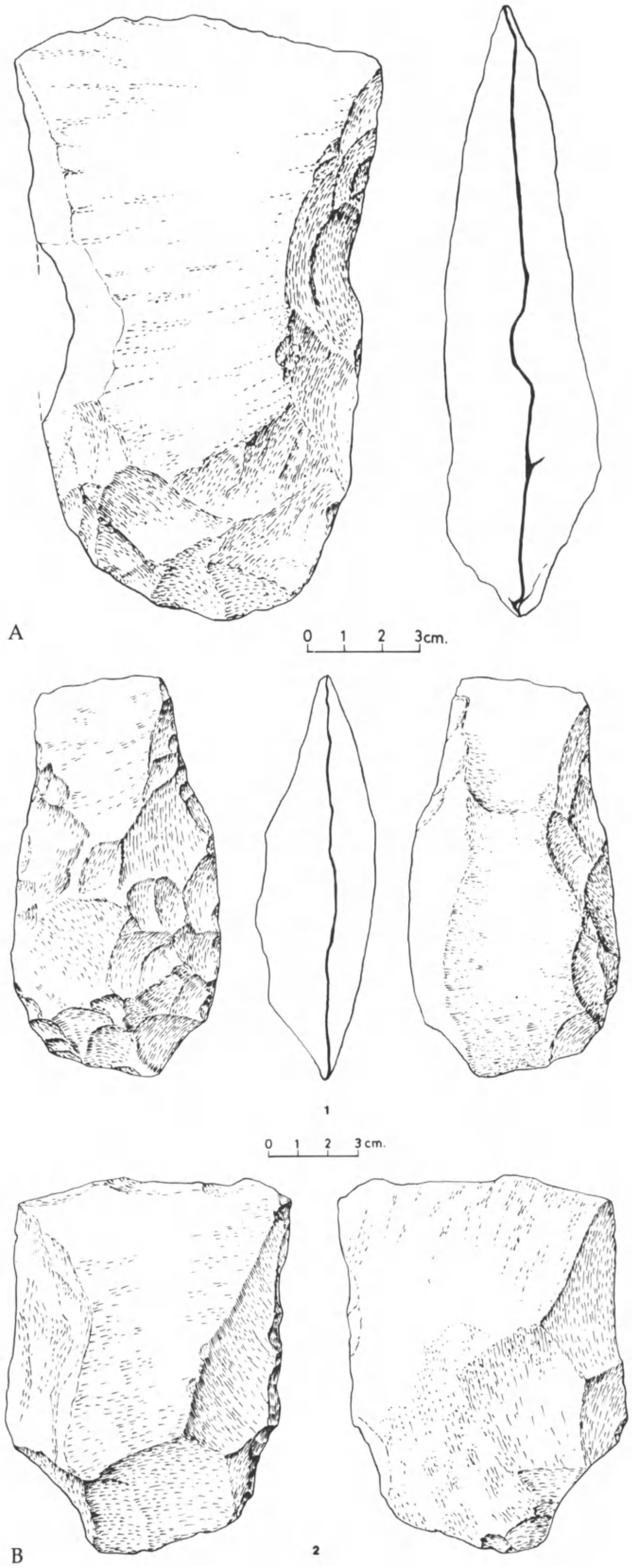

FIGURE 8.6. *Artifacts from Gesher Benot Ya'akov. (A) Basalt flake cleaver. (B) Basalt flake cleaver.*

axe occurrences in the caves of Oumm Qatafa in the Judean Desert and at Tabun in the Carmel. This group has in common the presence of bifaces, the use of a soft hammer, and the absence of Levallois technique. Otherwise, each of these assemblages has its own distinctive features. Bar'am (Ronen *et al.* 1975) and Yir'on have both crude and fine handaxes, the first numerically dominant. The flakes here are the largest and thickest in Israel, non-Levallois and unfaceted. These sites are found at the surface, at the edge of basalt flows of Preglacial Pleistocene age, associated with paleosols formed on these basalts during more humid periods. Their stratigraphical relations to other Acheulian industries cannot be established, but on typological and technological grounds the richest of these industries, Bar'am, appears to be the oldest among the "Middle Acheulian" series (Brustin 1976).

The oldest assemblage at Gesher Benot Ya'akov, Layer V (Stekelis 1960), is outstanding in two aspects. First, it is made almost exclusively of basalt, whereas elsewhere basalt is but rarely utilized, except for Ubeidiya, which has a considerable basalt tool component, although far less than at Gesher Benot Ya'akov. Second, cleavers represent here 50% of all bifaces, whereas, in Israel, cleavers normally do not exceed 3% and rarely reach 10% of the bifaces. The unique occurrence of Gesher Benot Ya'akov V is an intrusion of African affinity within the Israeli Acheulian (Gilead 1970). The industry is well-made on the whole. Tabun G, the lowest occupation level at this cave (Garrod and Bate 1937), was originally termed "Tayacian," that is, a nonhandaxe industry. In fact, it is an Acheulian with a low number of handaxes (Jelinek 1975; Jelinek *et al.* 1973), mainly ovates. It is unknown as yet whether the Tayacian layers of Oumm Qatafa also belong to this peculiar Acheulian, with a few bifaces. The two other series of the "Middle Acheulian" phase, Oumm Qatafa E (Neuville 1951) and Holon (Noy 1967), somewhat resemble but do not share any of the particularities of the former assemblages. Handaxes are well-made, with a fine soft-hammer workmanship. Pointed handaxes increase, and ovates decrease in number. The Levallois technique is present, but its precise frequency is as yet unknown. Sites of Middle or Middle–Late Acheulian affinity are quite common in Lebanon (Hours 1975), and about 130 of them are known, although only a few have been studied in detail. It seems, however, that what is defined in Israel as "Middle Acheulian" and "Upper (or Late) Acheulian" fall under a single name in Hours' (1975) classification, the "Middle–Late Acheulian."

UPPER ACHEULIAN

The Upper Acheulian (Figures 8.7 and 8.8) is known from many sites and find spots all over Israel. Many of

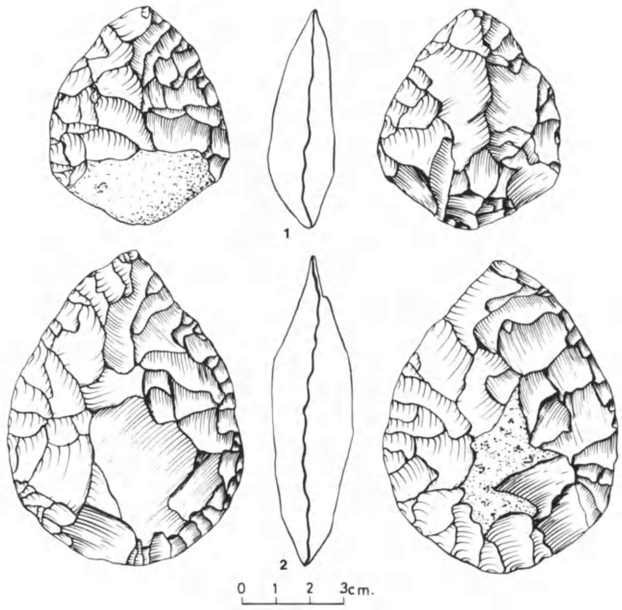

FIGURE 8.7. *Upper Acheulian cardiiform handaxe, Ma'ayan Barukh.*

these are found just on the surface. The assemblage is characterized by the finest workmanship of handaxes, as indicated by their thinness, symmetry, and small size. These were achieved with the greatest number of flakes per surface area in the entire Acheulian. The flake tool component of most Upper Acheulian series is very much like that of the Middle Paleolithic. The Upper Acheulian is divided into several groups, which may have temporal or cultural significance, or both. Originally proposed by Gilead (1970), the groups are modified here according to recent data.

1. Ma'ayan Barukh and Oumm Qatafa D2. In this group, large and rather thick handaxes are dominant, mostly of the rounded type (Stekelis and Gilead 1966). Levallois technique seems to be poorly represented but the flake industry is not well known. This group actually occupies, stratigraphically and typologically, a midpoint between the "Middle" and the Upper Acheulian, between Oumm Qatafa E and D1.
2. Kissufim-Evron (Upper). This group seems to be the most common among the Upper Acheulian of Israel. Pointed handaxes increase and rounded ones decrease as compared to earlier series. The flake industry is of Levallois technique and at present cannot be distinguished from the Mousterian (Gilead and Ronen 1977); Ronen *et al.* 1972).
3. Shiqma Group. Studied only recently (Lamdan *et al.* 1977), the handaxes of this group are like the former, but the flake industry here is of a denticulate aspect, the first such occurrence in both the Lower and the Middle Paleolithic of Israel. This group is found in several find spots along Nahal Shiqma in the southern coastal plain. The industry is of Levallois technique.
4. Yabrudian. This group is present only in the cave of Tabun, as well as the site of Yabrud (Syria), and seems to be stratigraphically younger than the rest of the described Upper Acheulian industries. It seems that the sediments containing the Yabrudian culture are of Riss-Würm Interpluvial age (Horowitz, in Jelinek *et al.* 1973). The handaxes are thin and fine. The major character is, however, the flake industry, which is non-Levallois and has numerous side scrapers of special types, canted, pointed, or canted and pointed. The Israeli Acheulian exhibits several evolutionary trends. First, the mean length of handaxes decreases from the oldest to the latest phases. Second, the reduction in size is accompanied by a growing amount of labor invested in the manufacture of handaxes. Third, pointed forms increase and rounded ones decrease in time. The Levallois technique appears during the Middle Acheulian, but does not seem to be in constant use. Table 8.1 shows the principal indices of some Paleolithic assemblages in Israel.

EARLY PALEOLITHIC FLAKE INDUSTRIES

Formerly, the flake assemblages without handaxes included the Tayacian, Amudian, and pre-Aurignacian (Bar-Yosef 1975a; Ronen 1975). Since the publication of these studies, however, the Tayacian has been eliminated as a distinct entity, and a new industry has been added. The pre-Aurignacian of Tabun is present in a single horizon near the top of the Yabrudian layer E at Tabun (A. J. Jelinek, University of Arizona, personal communication, 1973). This assemblage, non-Levallois in technique, is very rich in blades (blade index 50) and in Upper Paleolithic types of tools (39%!). This high index is composed mainly of backed knives (32%). Burins and end-

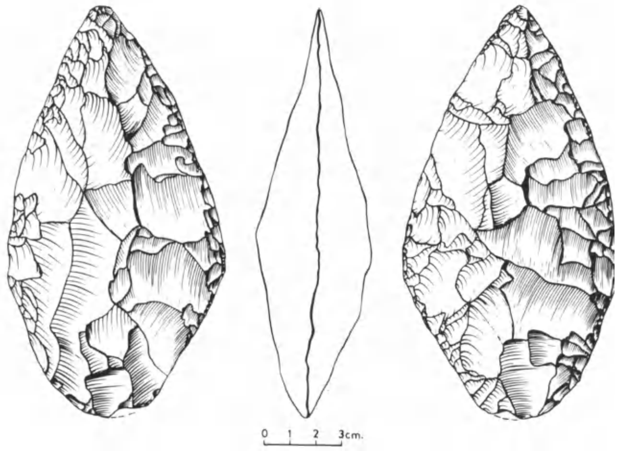

FIGURE 8.8. *Upper Acheulian amygdaloidal handaxe, Kissufim.*

TABLE 8.1
Principal Indices of Some Early Paleolithic Assemblages (Essential)

	Evron Quarry[a]	Bar'am[b]	Kissufim[c]	Evron (Upper)[d]	Pre-Aurignacian[e]
Levallois index	7	2	54	33	5
Facetting index	18	15	73	47	25
Blade index	7	3	16	23	50
Typological Levallois real index	9	14	49	27	2
Racloir index	11	20	35	45	17
Mousterian group	11	26	45	49	17
Upper Paleolithic group	13	25	8	13	39
Denticulate group	17	6	5	5	2

[a] Ronen and Prausnitz (in preparation).
[b] Ronen *et al.* (1974).
[c] Ronen *et al.* (1972).
[d] Gilead and Ronen (1977).
[e] Jelinek (1975).

scrapers are not numerous (Jelinek 1975). The precise nature of the Amudian at Zutiye is less well known, except that blades, knives, and other Upper Paleolithic forms existed there as well (Garrod 1970; Turville-Petre 1927). A new nonhandaxe industry was recently discovered near Tel Nagila, in the southern coastal plain (Lamdan *et al.* 1977). At present, the series contains only a few hundred items. Even though there exists a slight possibility that handaxes may yet turn up there, we consider it as a nonhandaxe industry, and refer to it as the Nagilan industry.

The Lower Paleolithic age of the Nagilan is deduced from its stratigraphical position and its faunal assemblage. The industry is on top of the hamra in this area, in which handaxe industries of the Shiqma group were also found; it is sealed by thick clay layers, believed to date from the Last Glacial period. The fauna includes mainly equids and elephant; the latter has never previously been found in Israel with post-Acheulian industries. The Nagilan assemblage (Figure 8.9) is of extremely small dimensions, non-Levallois in technique, and dominated by denticulates and notches (38%). The flakes are thick, often with cortex. The items differ physically and typologically from any Acheulian flake industry in the area. On the other hand, this microindustry somewhat resembles the flake tool component of the industry from the Evron Quarry. It is summarized as follows.

Item	Average size
64 flakes	28 × 24 × 8 mm
10 small cores	20 × 12 × 12 mm
25 medium cores	65 × 18 × 18 mm

MIDDLE PALEOLITHIC

The Mousterian industries of the Middle Paleolithic in Israel always employed the Levallois technique, and are all practically devoid of handaxes. Two facies may be clearly discernible at present. (*a*) Abu-Sif type (Figure 8.10). This facies is characterized by a high proportion of blades and elongated points and a high frequency of Upper Paleolithic elements. The Mousterian tools are relatively few. This type of Mousterian is dominant in the south of Israel, in the Negev and Judean Desert (Marks 1976; Neuville 1951). In the north, only Tabun D, the

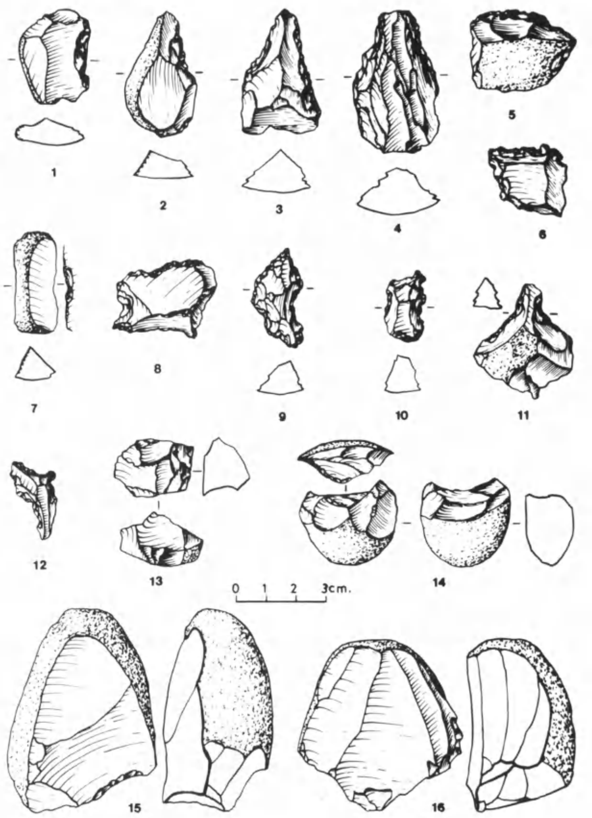

FIGURE 8.9. *Artifacts of the Nagilan Culture, Nahal Shiqma. 1-7, Side scrapers. 8-12, Becs and awls. 13, Small core. 14, Chopper. 15, 16, Cores.*

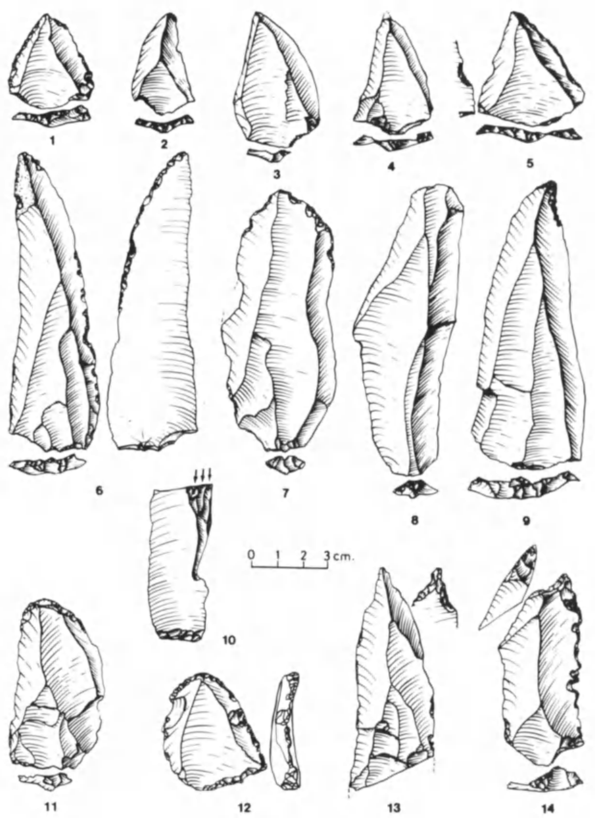

FIGURE 8.10. *Mousterian artifacts of the Abu Sif type, from Rosh En Mor, near Avedat. 1–6, Levallois and retouched Levallois points. 7, 8, Levallois blades. 9, Awl on a Levallois point. 10, Burin. 11, 12, End scrapers. 13, 14, Awls.*

oldest Mousterian layer in that site, belongs here. This facies may represent the earliest Mousterian, and indeed all the dated occurrences of this type indicate an early Last Glacial period. (*b*) Tabun C–B type (Figure 8.11). We include in this facies all the Mousterian assemblages other than the Abu-Sif type. Blades are less numerous and the Mousterian component, especially side-scrapers, are more numerous than in the Abu-Sif type. Elongated points are replaced by broad and short points. Later assemblages of this facies have a smaller mean size (e.g., Tabun B; Skhul), but this trend does not warrant the creation of an additional facies (cf. Copeland 1975). Another group of assemblages is included with the Tabun C–B type: These have a very low number of retouched tools, and a dominant Levallois component. Such are all the series recovered to date from the Carmel coastal plain (Ronen 1977), the red loam near Beirut (Fleisch 1970), and the Mousterian cave or terrace assemblages (e.g., Qafza, Sefunim, Geula, Erk el-Ahmar, and Unit V at Shovakh). Sometimes, a reduction in size is noted with time in these series, similar to that observed between Tabun C and B. At present these "Levalloisian" occurrences seem to the author as activity oriented tool kits.

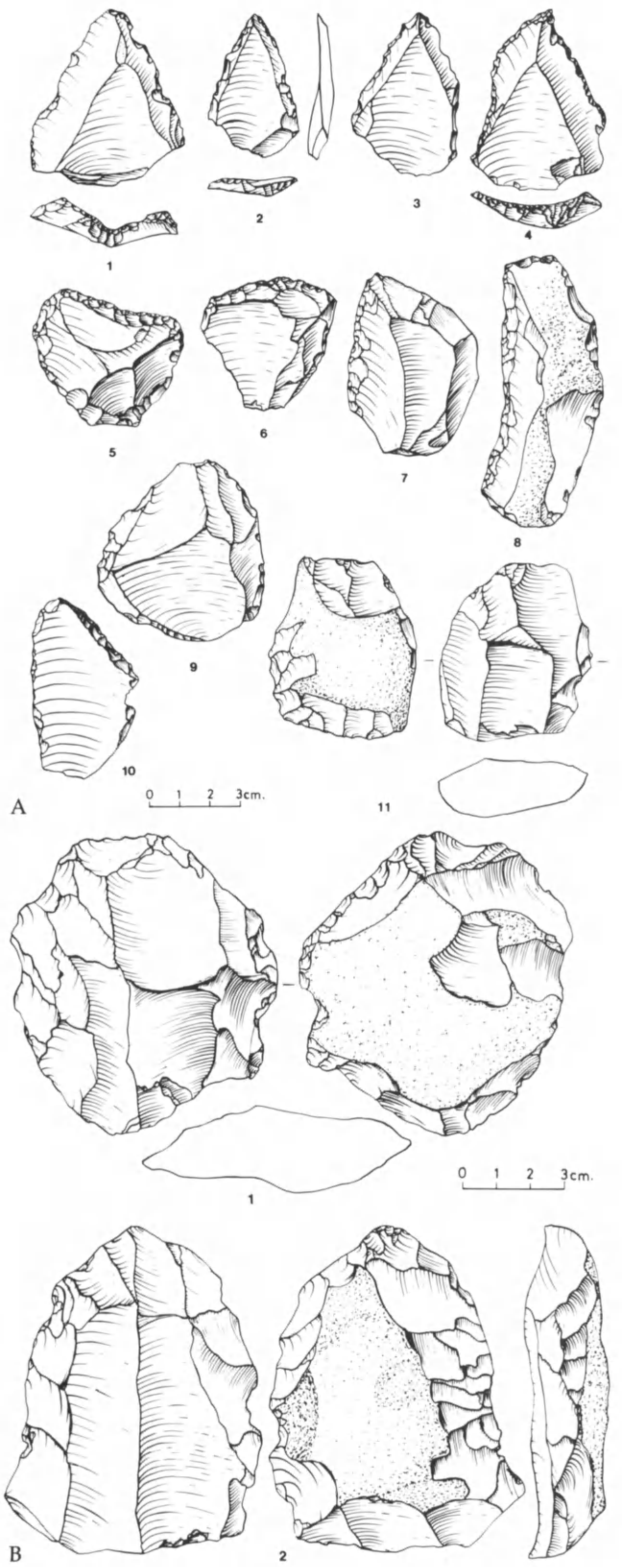

FIGURE 8.11. *Mousterian artifacts of the Tabun C–B type. (A) 1–4, Levallois points. 5–8, Racloirs. 9, 11, Levallois cores. 10, Inverse truncation. (B) Levallois cores.*

Data from the longest Middle Paleolithic sequences in Israel, Tabun, Kebara, and Qafza, are not yet published, so that the basic findings for understanding culture change within the Mousterian are not available. The forthcoming analysis of Tabun industries hopefully will throw new light on this problem. From the few sites that have been analyzed within the last few years, and for which data are available, the Mousterian of Israel can be defined broadly as a typical Mousterian with Levallois technique, according to western European terminology. None of the other Mousterian groups of the classical area has been found so far in Israel. Within this broad definition, several subtypes are clearly distinguished. The major variables are the relative frequencies of: (*a*) the Levallois technique; (*b*) sidescrapers; and (*c*) the Upper Paleolithic tool component. The Levallois technique is present in all Middle Paleolithic assemblages. Normally in fairly high percentage (about half of all flakes), it reaches up to 70–80% in some of Garrod's series from el-Wad (personal observation of the author based on the samples kept in Jerusalem). It is hard to evaluate whether these high percentages are real or perhaps are due to the selective nature of the collection. On the other hand, a Levallois index of 20 is found at Tirat Carmel (Ronen 1974). The open site Rosh En Mor, near Avedat in the Negev (Marks and Crew 1972), has a Levallois index varying between 11 and 16. For the south of Israel, however, the Levallois technique makes up a special facies, which may cause some problems in classification. This is the case with the "elongated Mousterian" of the Judean Desert type, e.g., Abu Sif (Neuville 1951), to which Rosh En Mor also belongs. This type of Mousterian exhibits a complete transition from typical Levallois points, through elongated points, to blades, all manufactured by essentially the same technique. The Levallois index will vary depending on how these blades and pointed blades are classified, a matter which still awaits agreement among scholars.

The Mousterian, rich in elongated points and blades, seems to be dominant in the south and not represented in the north, although it is present in Tabun D (Jelinek 1975). In most of the known series sidescrapers are present in fairly high proportions (25–40%). In several instances, though, the percentages drop to between 5% and 12%. Such is the case at Rosh En Mor, Amud Cave (11%), El-Wad, Layer G (11%), and Layer F (5%). For El-Wad and Amud, this is based on personal observations of samples from the Jerusalem collection. Some Mousterian assemblages in Israel have a very high proportion of the Upper Paleolithic tool category. Rosh En Mor has 21–26%, and Tirat Carmel has 20%. This character does not seem to have temporal significance since Rosh En Mor yielded a radiocarbon date of > 50,000 B.P. (Marks 1975). Curiously, it may be noted that several series claimed to be "transitional" to Upper Paleolithic are very poor in Upper Paleolithic elements, for example, El-Wad G (1%) and El-Wad F (11%). On the other hand, Upper Paleolithic elements are well represented in some far older assemblages such as the Amudian or the Acheulian of Bar'am, where they reach 25%, (Ronen *et al.* 1974). In spite of the presence of Charentian-type Early Paleolithic in Israel (Yabrudian) no Charentian type Mousterian is known at present.

The end of the Middle Paleolithic is unknown both typologically and chronologically. In many caves marked water activity reworked and redeposited upper Mousterian layers (cf. Bar-Yosef and Vandermeersch 1972). It is expected that the latest Mousterian occupation in the caves was washed away or mingled with earlier phases. The author fully agrees with Bar-Yosef and Vandermeersch that the entire notion of "Transitional Culture" (Garrod 1952) emerged from a mixture of Upper and Middle Paleolithic layers either by turbulent water or by the efforts of past excavators. As has been noted, the Upper Paleolithic element may be quite low in some "transitional" assemblages; the Emireh point, that "trace element" of the Transitional Culture, has actually been found in deposits from Upper Acheulian at Evron (Gilead and Ronen 1977) through Upper Paleolithic at Sefunim (author's excavation). The Emirah Point is perhaps of some regional significance, since its frequency seems to decrease from Lebanon southward (Copeland and Wescombe 1965). Chamfered pieces, typical elements of the earliest Upper Paleolithic in Lebanon, exist in only one Israeli site, Amud Cave, which is probably a typical Middle Paleolithic cave rich in Levallois products.

It seems to have been established that two distinct types of man are associated with the Mousterian of Israel, a Neanderthaloid in Tabun C and in Amud cave, and a morphologically modern species at Qafza and apparently also at Skhul. The earliest burials found in Israel are Mousterian, and after excavations completed in 1973, Qafza became the largest Mousterian cemetery known today, with at least 12 individuals. In the north of Israel, five open-air Mousterian sites, or rather find spots, are known, all but one in hamra (Farrand and Ronen 1974; Garrod and Gardner 1935). Since this layer is mostly buried under other sediments, the low number of sites cannot be regarded as representative. Only the site at Tirat Carmel, which is not in hamra, could be studied in detail (Ronen 1974). It is located in alluvial-colluvial deposits on the west slope of Mt. Carmel, a habitation site and a nearby workshop are known. Recently, several open-air Mousterian sites were found in the south, 19 near Avedat (Marks *et al.* 1971), and one near En Sharuhen (Collins, personal communication). The only one for which data are published is Rosh En Mor, already mentioned above. The distribution of the Mousterian open-air sites is distinctive in that it follows closely the location of present-day perennial springs (En Avedat, En Sharuhen, and Tirat Carmel, etc.). This Mousterian settlement pattern differs from that of the Acheulian. Some wide areas that were occupied by the makers of the Acheulian (Bar'am Plateau, Kissufim area) were totally or largely deserted during the Middle Paleolithic. At the same time, there are indications for a lowering of the water table since Mousterian times (as evidenced by the fossil springs in the Avedat area). On the whole, one may assume that topography and hydrology have changed little since the Mousterian, whereas a radical change occurred between the Acheulian and the Mousterian.

The only site known from Israel and assigned a Middle to Upper Paleolithic transitional industry is site D-101 in Nahal Zin, Central Negev (A. E. Marks, Dept. of Anthropology, Southern Methodist University, Dallas, *in litteris*, 1975, 1976). The artifacts are basically of later Mousterian culture, but a strong influence of Upper Paleolithic blades can be seen in the assemblage.

Mousterian sites are quite abundant in caves and in the Negev, where they were never covered subsequently by sediments. In the coastal plain and in the Jordan Valley sites are quite rare, being covered in the coastal plain by subsequent dunes and in the Jordan Valley by the expanding Lisan pluvial lake. The rare occurrences of Mousterian sites that are known from around the Jordan Valley are usually connected with fossil springs, such as Fatza'el, while some are connected with the Dan Travertine north of the Hula Valley, and some with springs south of the Dead Sea (A. Sneh, Geological Survey of Israel, personal communication 1976). Except for site D-101, a "cultural break" can be seen in Israel between the Middle and the Upper Paleolithic industries. This was explained by Horowitz (1971) as a result of the interstadial separating the Early and the Middle Würmian pluvial phases. During this interstadial the deteriorating climatic conditions probably forced people northward, while most of the former, Early Würm sediments began to be eroded. Thus the combination of these two factors, the dry climate and the erosion or nondeposition in most places, prevented any recording of the transitional phase between the Middle and the Upper Paleolithic. These cultures are, however, known from Lebanon, Syria, and farther north. Table 8.2 shows the principal indices of some Middle Paleolithic assemblages from Israel.

UPPER PALEOLITHIC

With the "Transitional Phase" eliminated, the Upper Paleolithic in Israel consists solely of the Aurignacian industry. To date, no "*çhanfreins*" phase has been discovered. It is not clear whether the erosion that had affected the Mousterian layers in caves occurred between the Middle and Upper Paleolithic or during early Upper Paleolithic times, thus possibly washing away some of the latter as well. The beginning of the Aurignacian is as yet undated. It is fairly homogeneous in Israel, with endscrapers, carinated endscrapers and burins as dominant elements. Endscrapers are normally more numerous than burins. The frequency of carinated relative to flat endscrapers is variable, with no clear temporal significance. Among the burins, dihedral types for the most part greatly outnumber truncated ones. Retouched blades are quite frequent, but Aurignacian retouch is rare. The El-Wad points (formerly Font-Yves or Krems) are, according to Garrod (1954), more frequent in the lower Aurignacian than in the upper. At present, this can be seen only at the El-Wad and Kebara caves. Other occurrences with numerous El-Wad points, for example, Qafza, Layers 9 and 8 (Ronen and Vandermeersch 1972) still await dating. In most Aurignacian assemblages El-Wad points appear in small quantities (Table 8.3; Figure 8.12). Bone tools, mainly points, are clearly shaped for the first time. Some bones were clearly used, or even flaked, in the Mousterian of Geula Cave (Wreschner *et al.* 1967) and even earlier (e.g., Ubeidiya, Holon).

The only Upper Paleolithic sites with a different aspect are Qafza (Ronen and Vandermeersch 1972) and Kebara (Ronen 1976). Typologically they lack carinated scrapers altogether and have abundant El-Wad points and micro-

TABLE 8.2
Principal Indices of Some Middle Paleolithic Assemblages (Essential)

	Tabun D[a]	Tabun C[a]	Tirat–Carmel[b]	Shovakh[c]	Rosh[d] En Mor
Levallois index	53	34	20	41	16
Facetting index	64	61	34	65	56
Blade index	57	29	15	12	22
Typological Levallois real index	60	63	16	45	60
Racloir index	19	50	33	24	12
Mousterian group	24	54	35	30	14
Upper Paleolithic group	32	8	20	15	26
Denticulate group	5	20	10	7	10

[a] Jelinek (1975).
[b] Ronen (1974).
[c] Binford (1966).
[d] Crew (1976).

TABLE 8.3
Principal Indices of Some Upper Paleolithic Assemblages

	El Wad E(249)[a]	El Wad D_2(230)	El Wad D_1(258)	El Wad C(338)	Kebara Upp. Pal. (290)	Hayonim D_3(125)	Sefunim 8(173)
Endscraper index	23	26	35	22	26	22	25
Carinated endscrapers	14	40	24	7	5	17	18
Burin index	28	11	21	52	5	13	14
Dihedral burins	20	8	15	40	2	8	12
Truncated burins	6	3	5	11	1.5	4	1.5
Retouched blades	8	12	7	3	6	10	18
El Wad points	7	0.4	1.5	—	17	—	1.5
Microliths	—	0.4	—	3	3	11	6
Sidescrapers	4	4	1	2	10	6	0.5

[a] Total number of series indicated in parentheses.

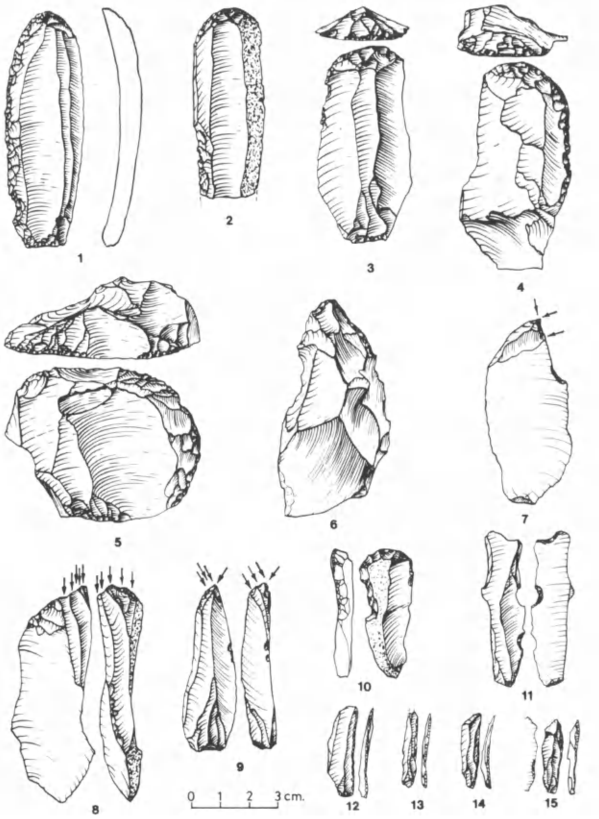

FIGURE 8.12. *Upper Paleolithic artifacts from the Central Negev. 1-4, 10, End scrapers on blades. 5, Rounded scraper. 6, Carinated scraper. 7-9, Burins. 11, Notches. 12-15, Retouched bladelets.*

liths. Although the series recently excavated by Vandermeersch are poor, the more abundant series of Neuville show the same characteristics (Bar-Yosef, personal communication). Perhaps the Upper Paleolithic of Qafza should not be included in the "Aurignacian." The Upper Paleolithic of Israel is further typified by the lack of art or ornament and by the extreme paucity of human remains. As for art, the Middle Paleolithic pattern is continued, whereby abundant fragments of ocher are the only hint of aesthetic values. In the lowest Upper Paleolithic of Qafza, a well-shaped pallet made of basalt was found that served for grinding ocher. One cannot help but wonder at the seeming absence of the custom of burial. By comparison with the abundant burials of the Middle Paleolithic, only one is known from the Upper Paleolithic, and apparently from a late stage. It is a woman, found in a semi-flexed position near a living floor at the site of Nahal En Gev in the Jordan Valley (Arensburg and Bar-Yosef 1973). Very few other human remains are known. It is assumed, but with no direct evidence, that burials in the Upper Paleolithic were outside of caves, either'on cave terraces or farther away. In fact, none of the caves in the northern part of Israel have Upper Paleolithic deposits on their terraces—Mousterian layers directly underlie Kebaran or Natufian layers. Furthermore, in the coastal plain of Mt. Carmel no deposits containing Upper Paleolithic age is known, and there are no open-air sites. At Tirat Carmel the Mousterian colluvial layers form the top of the section, with no later deposits. It is not known if they were eroded or if they are simply absent. If burials were indeed on terraces, this may account for their disappearance, at least in the Mt. Carmel area.

The distribution and pattern of Upper Paleolithic habitation seems to indicate, in the northern part of the country, some deterioration of living conditions. Eighteen caves north of Jerusalem are known to have been inhabited during the Mousterian, and only seven were inhabited during the Upper Paleolithic, with a far smaller area occupied in each cave than during the Mousterian. There appears to be no case for claiming a wealth of Upper Paleolithic sites now submerged on the continental shelf. It has been noted that occupations exist in red loams, both Mousterian and Epipaleolithic, and that, in between these red loams, soils that should date from the time of Upper Paleolithic occupation did not develop into red loam but indicate a near-shore environment. Hence there are no grounds to support the contention that the coastal plain of Israel was far wider than the present one during the Upper Paleolithic. A similar reduction in the number of Upper Paleolithic settlements occurred in Lebanon and apparently in Jordan, too. In the southern half of the country Upper Paleolithic settlements are almost as numerous (Judea 6, Negev 14) as Middle Paleolithic ones (Judea 6, Negev 20), but not necessarily in the same localities. It may be added that open-air Upper Paleolithic sites in the Negev are near present-day perennial springs and that all areas where Mousterian habitation is unknown are also devoid of Upper Paleolithic habitation.

EPIPALEOLITHIC AND NEOLITHIC INDUSTRIES

O. Bar-Yosef and E. Mintz

The aim of this chapter is to revise the Epipaleolithic and Neolithic cultural sequence of Israel, following an earlier revision of the Epipaleolithic (Bar-Yosef 1975). The industries are divided into six main chronological units, which are accepted by most students of the area (Bar-Yosef 1970, 1975, 1976; Hours *et al.* 1973; Marks 1975; Mellaart 1975). The chronology is mainly based on radiocarbon datings summarized by Henry and Servello (1974), with some additional dates (Bar-Yosef and Phillips 1977; Mellaart 1975; Singh 1974). The term "Epipaleolithic" is used presently in the Near East to include the microlithic industries that postdate the Levantine Aurignacian C and predate the Pre-Pottery Neolithic. These were known in the past as "Upper Paleolithic VI" and "Mesolithic." The term "culture" as used here implies that the archaeological data form a system in which tools, debitage, burials, structures, art objects, site sizes, and locations and sources of subsistence are incorporated as different variables subject to change and interaction. The term "industry" is used only in reference to artifacts, including both technology and typology.

The Neolithic period reflects a crucial point in human history. While in the ninth millenium B.C., people were still hunters and gatherers, living in small social units, at the beginning of the fourth millenium, a fully agricultural society was already established, which had mastered production of pottery and metal and thus founded the base for the great urban civilizations of the following periods. Excavations of large stratified sites in Israel and in adjacent countries, and an increasing number of radiocarbon dates, enable researchers to define certain developmental phases within the Neolithic and to put them in a chronological frame. Some of the details are still a matter of controversy, but a general picture can be drawn from the available data.

CULTURAL CHARACTERISTICS OF THE EPIPALEOLITHIC

During the time span of the Epipaleolithic, one may observe the development of slightly different technologies. Although these technologies have not been thoroughly studied, they seem to be a result of nonuniform development in the preceding period as well as the expression of geographical variability. In northern Israel the basic technological change following the Levantine Aurignacian is the appearance of the bladelet core, generally with one or two striking platforms. In the Geometric Kebaran A complex this tendency continues, but within the Natufian the number of striking platforms increases. The long, narrow bladelets evolve into short, broad ones. This change is pronounced as well in the retouched bladelets. We may look for the origins of this phenomenon in the industries of the Geometric Kebaran A, either in the coastal plain or in the Negev, for example, at the sites of Qiryat Arie I, Hofit, and D5. The bladelets in the Negev and Sinai are generally wider than those from the northern part of Israel, within both nongeometric and geometric assemblages. Another important event is the appearance of blades (Bar-Yosef 1970a). The early appearance of sickle blades in the Kebaran and especially in the Natufian apparently spurred the production of blades, which became much more abundant in the eastern part of Israel, such as in the sites of En Gev I-IV and Ha'On III. The technological difference between the east and the west became more apparent when new sites were discovered in Wadi Fatza'el and Wadi Malih (Bar-Yosef *et al.* 1974). The technological differences are sometimes accompanied also by typological variations. However, it seems that the Kebaran complex and Geometric Kebaran A complex in Israel present one continuum of the same basic technology. An intensive study of the Natufian technology (Henry 1973) provided a body of data ready for comparisons. Sites such as the Geometric Kebaran A En Gev IV, which is dominated by triangles, seem to support the observation that the Natufian technology is different from the Kebaran. Detailed information on the sites of Hefziba and Hadera I and II (Kaufman 1976) seem to point to the same conclusion. Another aspect of these technologies arises from the presence of the microburin technique in the Kebaran at the Yabrud III rock shelter and at Nahal Hadera V (Saxon *et al.*, in press). This seems to contradict Henry's (1974) suggestion that the origin of this technique is in North Africa. Although a high percentage of microburin technique was found in Sinai and the Negev, and was found to decrease northward within the Natufian assemblages, one should keep in mind the assemblage from En Gev IV, where the index of microburin technique as part of the tool count amounts to 55. The presence of this technique in both the Mushabian in Sinai and En Gev IV sites, points to more than a single origin.

The most important group, typologically, which characterizes the Epipaleolithic cultures is that of microlithic tools. Differences within this group suggested the division into Kebaran and Geometric Kebaran. It is possible to observe a clear tendency toward the domination of the geometric component, although such a development is not linear, but dendritic. This means that there is generally no way to place a certain industry within an accurate chronostratigraphic sequence on the basis of quantitative relationships between nongeometric microliths and geometric microliths alone (Bar-Yosef 1976). The use of radiocarbon dating is therefore essential. Quantitative typological studies are based on type lists, such as the London type list (Hours 1974), the type list used by Hours in Lebanon, and the one used by Bar-Yosef and others in Israel (Bar-Yosef 1970; Valla 1975, 1975a). In each type list an account is taken of both the kind of retouch and the final form of the bladelet. As most of the sites in Israel were studied through our type list, we may designate several subgroups within the microlithic nongeometric category as follows: retouched and backed bladelets; bladelets with inverse and alternate retouch; arched or curved bladelets, including micropoints; and retouched and obliquely truncated bladelets. The differences between the industries are presented in the quantitative relationships between these subgroups. It is notable that the subgroup of truncated backed bladelets gives the entire cultural complex its definition, following the industry uncovered in the cave of Kebara (Garrod and Bate 1937; Turville-Petre 1932). It seems preferable to the authors to use the term "Kebaran Complex" for all the nongeometric microlithic assemblages. As for the other subgroups of microliths, it is still difficult to suggest chronological meanings. Radiocarbon datings hint that some of these quantitative situations are simply local. The retouched bladelets are probably a permanent component within each assemblage, and their quantity rarely varies. Perhaps they are actually unfinished microliths.

Within the group of geometric forms the following three subgroups have been distinguished: trapeze rectangles, triangles, and lunates. The first and last appear more or less uniformly in many sites, while the triangles are known from fewer sites with a great variation in their quantities. The dominance of trapeze rectangles was suggested as the common denominator for assemblages assigned to the Geometric Kebaran A complex (Bar-Yosef 1976). Lunates characterize typologically the Natufian. It is also suggested that they are the characteristic tool of the "Geometric Kebaran B," which we will discuss later. They are made either by abrupt retouch on an anvil or by Helwan and inverse retouch. Helwan retouch is broadly accepted as a chronological indicator. The triangle is the most difficult to fit into our framework. In Yabrud III rock shelter, Layer 5, it intercalates with Kebaran layers (Rust 1950). A similar case was noted in Hayonim Cave, within layer C. A recent occurrence is their appearance at the site of Nahal Hadera V in nongeometric Kebaran layers, which may be referred to as Late Kebaran, but pregeometric Kebaran. The same phenomenon was also noted in Lebanon (Hours 1976).

The Kebaran Complex

Typologically, the Kebaran is defined on the basis of its microlithic tool group, microliths forming 50–90% of the total assemblage. On the basis of major components of the microlithic group, the known Kebaran sites (Figure 8.13) in northern Israel can be divided as follows. (*a*) The first division comprises sites with small, curved, and pointed bladelets, with narrow micropoints: Qiryat Arie II, Kefar Darom III, and Soreq 33-Q. Obliquely truncated backed bladelets are almost absent from these assemblages. The same holds for Kefar Darom 8 (Bar-Yosef 1970, 1970a, 1970b), where wide curved pointed bladelets, modified by abrupt retouch, dominate the microlithic tool group. Typologically, this assemblage seems to be younger than others and perhaps reinforces the suggestion to name this cluster of sites from the southern coastal plain the "Ashdodian" facies of the Kebaran (Figure 8.14). (*b*) The sites that make up the second category contain obliquely truncated backed bladelets, plus mi-

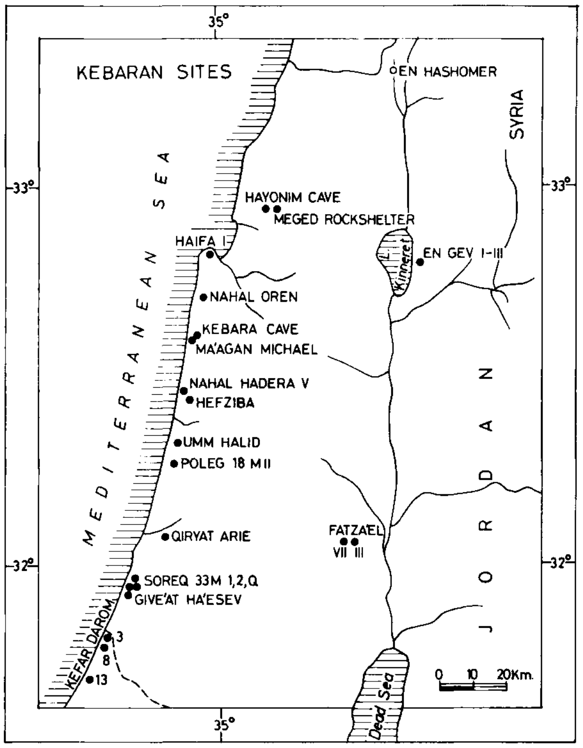

FIGURE 8.13. *Location map of the main Kebaran sites.*

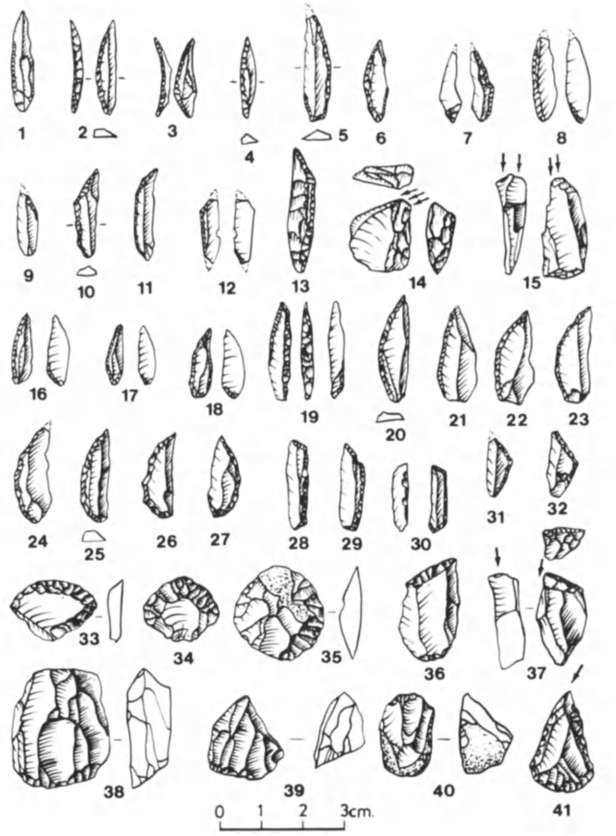

FIGURE 8.14. *The "Ashdodian" facies of the coastal Kebaran. Selected artifacts from Kefar Darom 3 (1-15), and Kefar Darom 8 (16-41). 1, Retouched bladelet. 2-8, Narrow curved micropoints. 9, Obliquely truncated bladelet. 10, 11, 13, Obliquely truncated backed bladelets. 12, Prototriangle. 14, 15, Burins. 16-18, Narrow curved micropoints. 19, Microgravette. 20-27, Broad curved micropoints. 28-30, Narrow trapeze rectangles. 31, 32, Prototriangles. 33-35, Scrapers. 36, Truncated piece. 27, Burin. 38-40, Cores. 41, Burin scraper.*

cropoints: Hayonim Cave, Layer C (Figure 8.15); Meged Rock shelter, near Hayonim Cave; Kebara Cave (Figure 8.16); Nahal Hadera VI, lower levels; Give'at Ha'Esev; Soreq 33-M-2; Poleg 18-M-II; Kefar Darom 8; Kefar Darom 13 and Fatza'el III, Layer 6. (*c*) Sites with obliquely truncated backed bladelets make up the third division: En Gev I, II; Um Khalid (Figure 8.17); Nahal Hadera V, upper levels; Fatza'el III, layer 4; Haifa I (Olami 1973) and Soreq 33-M-1.

A few geometric microliths occur in many of these assemblages and some are basically modifications of an already existing type. Scrapers, burins, truncated pieces, notches, and denticulates are well represented in Kebaran sites. Although indices may vary from one assemblage to another, there is no assemblage without those tools. Differences are known between the Kebaran and Geometric Kebaran A of northern Israel and Geometric Kebaran A and the Kebaran of northern Sinai and the Negev, such as, for example, a difference in the average width of the microliths. Backed bladelets from the north average 4-8 mm in width, while those from the south average 7-10 mm. Other typological features, such as the Falita point, may indicate a territorial division for the Kebaran, into an eastern and a western province. Other Kebaran artifacts comprise bone tools and grinding and pounding stones. Bone tools are rare, mostly points and burnishers. Pounding and grinding tools have been uncovered in several sites. En Gev I was the first Kebaran site in which a mortar and pestles were found (Stekelis and Bar-Yosef 1965), but since then pounding stones have been found in Um Khalid, Caesarea South, Hefziba, Nahal Hadera V (Ronen *et al.* 1975; Saxon *et al.*, in press), and Ha'On III (Bar-Yosef 1975). These finds are, however, subordinate when compared to the numerous mortars and pestles in Natufian sites. It would seem premature to infer early domestication of plants from these finds when such an interpretation is still dubious in regard to the Natufian economy.

The size of a well-defined Kebaran site is generally 150-400 m². En Gev I provided relatively clear evidence of a hut dug into a sandy hill, delineated by a

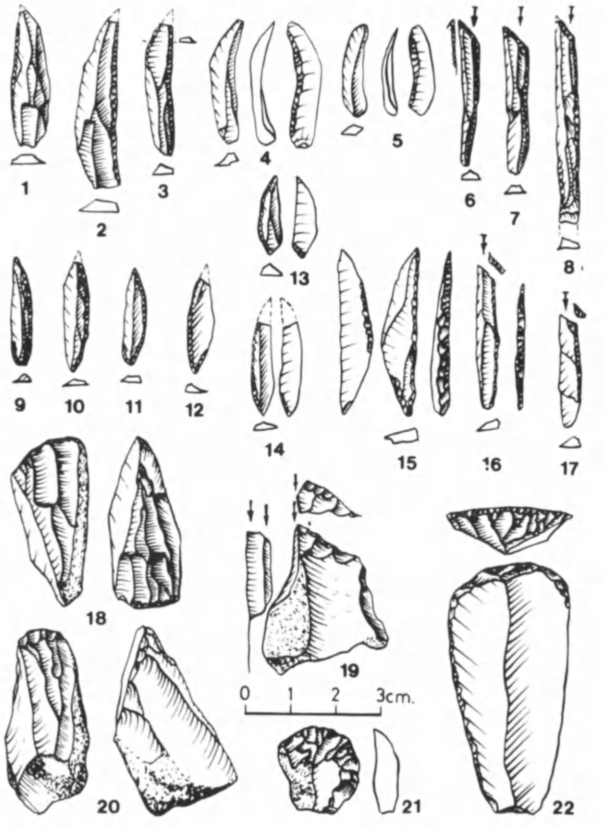

FIGURE 8.15. *Selection of tools from the upper part of the Kebaran sequence, Hayonim Cave. 1-5, Inverse and obverse retouched bladelets. 6-8, 16, 17, Obliquely truncated backed bladelets. 9-14, Narrow curved micropoints. 15, Microgravette. 18, 20, Cores. 19, Burin. 21, 22, Scrapers.*

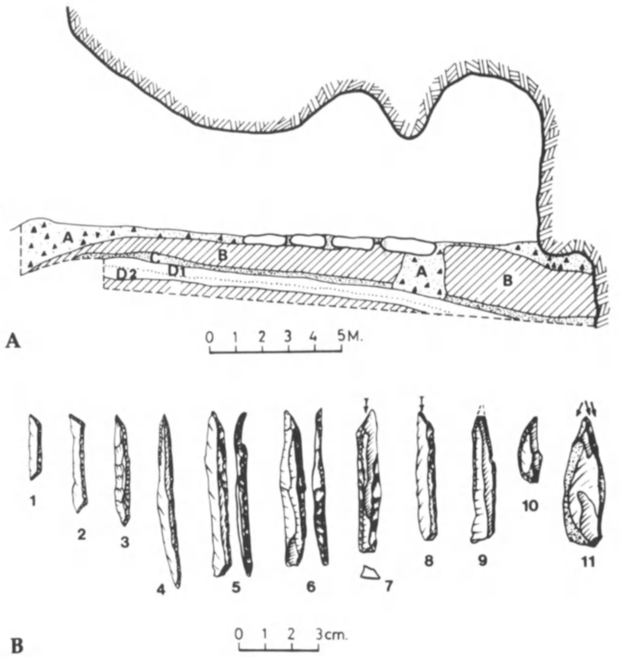

FIGURE 8.16. **A.** *Cross section at Kebara Cave. A, Neolithic through Recent. B, Lower Natufian. C, Kebaran. D, Aurignacian.* **B.** *Selected tools from Layer C (after Turville-Petre 1932). 1, 2, Narrow trapezes. 3, 5–8, Obliquely truncated backed bladelets. 4, Atypical microgravette. 9, Pointed bladelet retouched on both edges. 10, Broad micropoint. 11, Burin.*

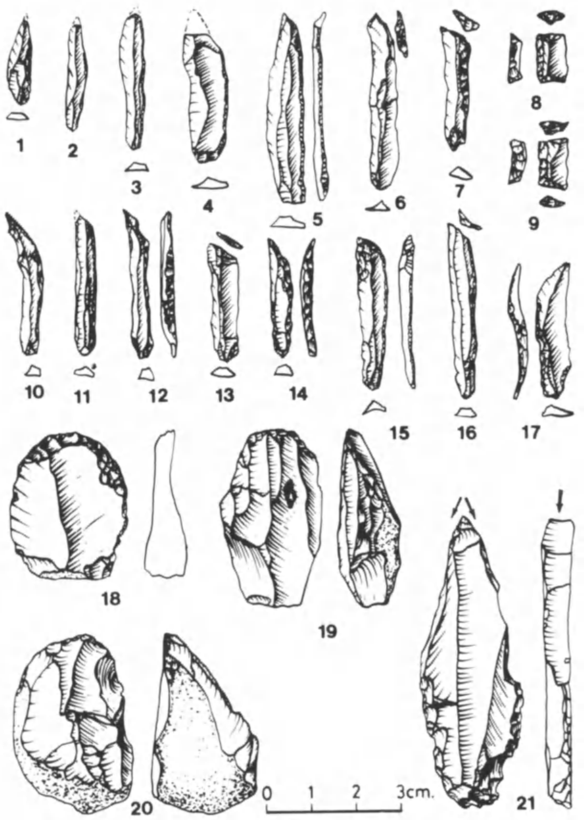

FIGURE 8.17. *Selection of Kebaran tools, Umm Khalid. 1, 2, 4, Partially retouched bladelets. 3, 5, Completely retouched bladelets. 6, 13, Obliquely truncated bladelets. 8, 9, Rectangles. 10–12, 14–17, Obliquely truncated backed and retouched bladelets. 18, Scraper. 19, 20, Cores. 21, Burin scraper.*

shallow basin, 5–7 m in diameter. This depression contained remains of several living floors which were littered with tools, debitage, bones and stones. A few pestles and one mortar were uncovered, as well as a burial of a woman (Arensburg and Bar-Yosef 1973). Wide artifactual surface scatter characterizes the coastal plain sites, which might be due to subsequent erosion. When found intact, Kebaran deposits are over one meter in thickness, and are limited to a restricted area. The size of Kebaran sites depended mainly on the band size, in our view. The principal Kebaran sites have a high density of artifacts, pounding and grinding tools, and are located near water resources, usually beside a major wadi course in a strategic, lookout position. Transitory or ephemeral camps are smaller, with low artifactual densities and are normally farther up-wadi than the larger sites. In the coastal plain, most of the large Kebaran camps are located along the first kurkar ridge, close to the outlets of the actual wadi courses. Taking into account that the coastal plain was wider at that period, these sites were actually in the central part of the plain. These sites form a north–south line with comparable camps in Mount Carmel, Nahal Oren, and Kebara (Figure 8.13). It seems that the Kebaran sites had their subsistence sources within the coastal plain and the flanks of the hilly regions. Kebaran people were basically hunters, but were also using grinding and pounding tools for processing acorns or wild cereals, or both. No fish bones have been recovered. In the Jordan Valley, a similar pattern of site location is noticed. Kebaran, as well as Geometric Kebaran A, sites are found embedded in alluvial deposits in the lower reaches and the outlets of Wadi Malih and Wadi Fatza'el (Bar-Yosef *et al.* 1974). This is the period when the Lisan Lake shrank and flat, steppic areas developed in the Central and Southern Jordan Valley.

The Geometric Kebaran A Complex

The designation Geometric Kebaran A seems to us preferable to the Bergian or the Falitian employed by Copeland and Waechter (1968) and Hours (1976). This does not rule out the possibility that several technological changes took place during the period to which Geometric Kebaran A sites are dated. Sites where Geometric Kebaran A stratigraphically overlies Kebaran remains are limited. These include Abri Bergy (Copeland and Waechter 1968), Yabrud Rock shelter III (Rust 1950), Fatza'el III (Bar-Yosef *et al.* 1974), and Nahal Oren Terrace, Layer VII (Noy *et al.* 1973) (Figure 8.18). The Geometric Kebaran A complex was found underlying Early Natufian layers at

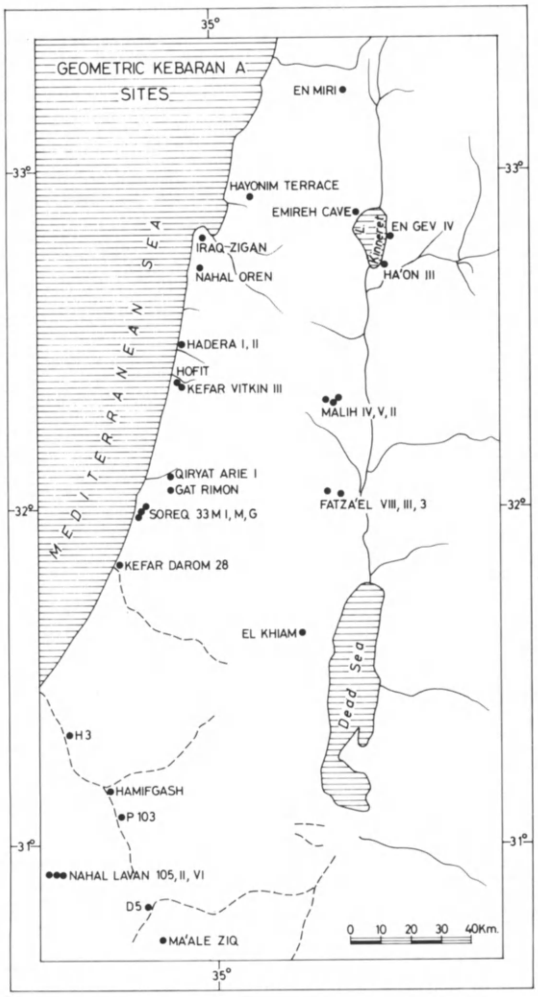

FIGURE 8.18. *Location map of the main Geometric Kebaran A sites.*

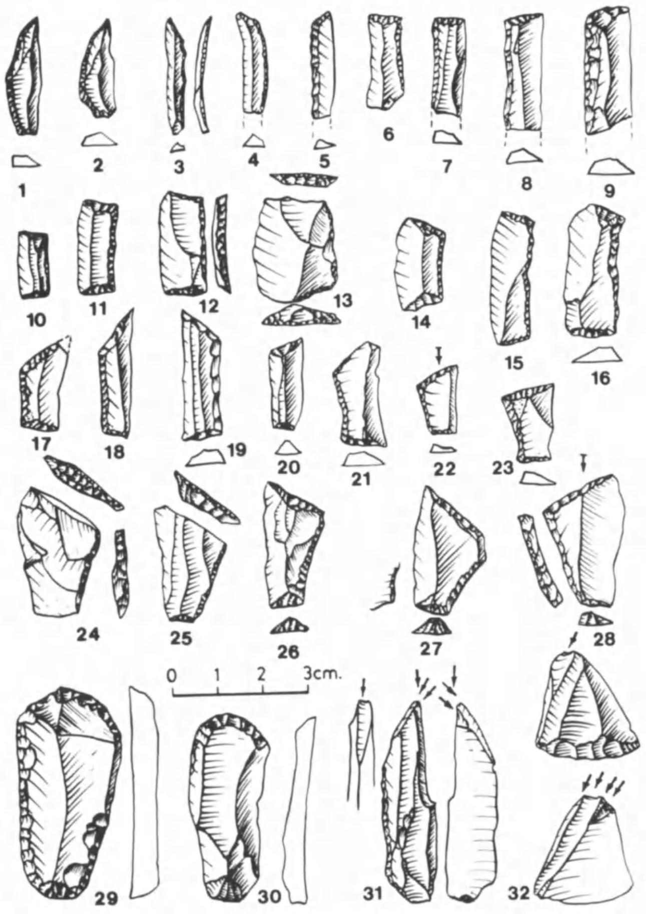

FIGURE 8.19. *Geometric Kebaran A assemblage from Qiryat Arie I, coastal Plain. 1–5, Various types of backed and retouched bladelets. 6–28, Broken and complete rectangles and trapezes. 29, 30, Scrapers. 31, Burin. 32, Burin scraper.*

Hayonim Terrace (Henry 1976). While the general stratigraphic position of Geometric Kebaran A is already known, the refined chronology is yet to be determined. The Geometric Kebaran A complex is typified by the production of narrow bladelets or the fabrication of trapezes, long or short. The production of wider trapeze rectangle in a few assemblages of this complex, such as Hofit, indicates a change in technology. Within Geometric Kebaran A there are sites in which the geometrics are more than double the number of other microliths. Most of these are in the Negev and Sinai, but sites like Malih V and Ha'On III indicate that this phenomenon occurs also in northern Israel. The type of geometrics that make up these high percentages are trapezes, rectangles, and their variants, but there are no triangles or lunates. In some sites like Soreq 33-M-I, 33-M, 33-G; Qiryat Arie I (Figure 8.19), Kefar Vitkin III and others, there are lunates and triangles, but trapeze rectangles are dominant. In En Gev IV, Kefar Darom 28, and Nahal Oren, Layer VII, the triangles are dominant. It was therefore suggested to recognize two facies in Geometric Kebaran A: A-1, with dominance of trapezes and rectangles; and A-2, with triangles and lunates, both of which precede the Natufian (Bar-Yosef 1975).

Most of the Geometric Kebaran A sites are small and located near wadi courses or lake shores. Many were deflated prior to discovery. Until now, the in situ occurrences present relatively shallow deposits in comparison to the Kebaran or Natufian sites. It seems that their size is also quite small; a rough estimate would be 50–500 sq. meters. Faunal remains are scarce in most sites, but those found in situ, such as in Nahal Oren, Layer VII, are dominated by gazelle—more than 75% (Legge, in Noy *et al.* 1973). The existing fragmentary evidence suggests that Geometric Kebaran A sites are widely distributed throughout the Levant. These are generally small sites situated on terraces near wadi courses or lake shores, rarely in rock shelters. They scarcely coincide in their exact location with Upper Paleolithic or Natufian sites. There are indications that some sites are inhabited for relatively long periods, such as Abri Bergy, Nahal Oren, and Hayonim Terrace, and these may therefore be base camps. Chronologically, the Geometric Kebaran A spans the time from about 13,000 B.C. to 10,500 B.C.

The Natufian

The Natufian industry was first recognized by Garrod during her excavations at Shukba, in 1928. Later, at El-Wad in Mount Carmel, she was able to divide up the Natufian sequence on the basis of her field observations (Garrod 1932, 1957; Garrod and Bate 1937). Neuville (1934, 1951) further subdivided the Natufian, based on his excavations at Erk el-Ahmar (in the Judean Desert), Umm el-Zuweitina, Tor Abu Zif, the terrace of El-Khiam, and some other sites in the Judean Desert. The observations of Garrod and Neuville were criticized by excavators of Nahal Oren (Stekelis and Yizraeli 1963), Eynan (Perrot 1966), Hayonim Cave (Bar-Yosef and Tchernov 1966), and sites in the Negev (Henry 1973a; Marks 1975, 1976). Sites in the Galilee were subject to more detailed studies (Bar-Yosef and Goren 1973; Valla 1975). Recently, the Natufian site at Hayonim Terrace (in front of Hayonim Cave) was excavated and a few other Natufian sites were found in the Jordan Valley (Bar-Yosef *et al.* 1974; Henry 1976; Figure 8.20). Bar-Yosef (1970) suggested that only base camps with architecture, burials, art objects, bone industries, groundstones, and a rich flint industry should be considered as Natufian. Recent discoveries (Bar-Yosef and Phillips 1977) in northern Sinai support this view.

The Natufian lasted, according to radiocarbon dating, from about 10,000 B.C. up to 8500–8300 B.C. Natufians were the first people to leave behind well-built habitations. Architectural remains are quite numerous, such as those noted at El-Wad, Nahal Oren, Hayonim Terrace, and also at Rosh Zin and Rosh Horesha in the Negev (Henry 1973; Marks *et al.* 1972). The most impressive structures were exposed at Hayonim Cave and at Eynan (Bar-Yosef and Goren 1973; Perrot 1966, 1974). One of the rounded habitations at Eynan, about 9 m in diameter, was probably roofed over with the support of wooden poles; 6 postholes from this dwelling were uncovered (Perrot 1974). The habitations were partially dug into the ground. Their walls were built like a terrace wall, slightly slanting inside the house. Fireplaces, mortars, pestles, etc., were found on the floors or in the collapsed remains. It seems that the Natufian community at Eynan comprised some 80–160 people. On typological grounds, there is a division into Early and Late Natufian (Figures 8.21 and 8.22). The Early Natufian is either dominated by Helwan lunates, lacks geometric microliths, and uses microburin technique, or has an increasing number of lunates modified by abrupt retouch, relative to the number of Helwan lunates, with other geometric microliths, and a clear use of microburin technique. These are thought to be two phases of the Early Natufian, or perhaps two contemporaneous industries. The Late Natufian sites are characterized by lunates with abrupt retouch and the use of microburin technique. Other flint tools are also quite common in many Natufian sites. Groundstone tools, made of basalt or limestone, are very common. These comprise mainly pounding tools, such as mortars and pestles, a few grinding stones, shaft straighteners, rare pendants, whetstones made of sandstone, chopping tools, and hammerstones, and finally, the mysterious "stone pipes." These heavy, 80–150-kg artifacts, with a conical hole about 60–90 cm deep, generally breached at their bottoms, were found standing upright as tombstones in Nahal Oren terrace (Stekelis and Yizraeli 1963). They might have been used as mortars, but what seems to have been their primary context, in graves, or in Jericho, around a platform, indicates a nondomestic use (Bar-Yosef 1970; Kenyon 1960).

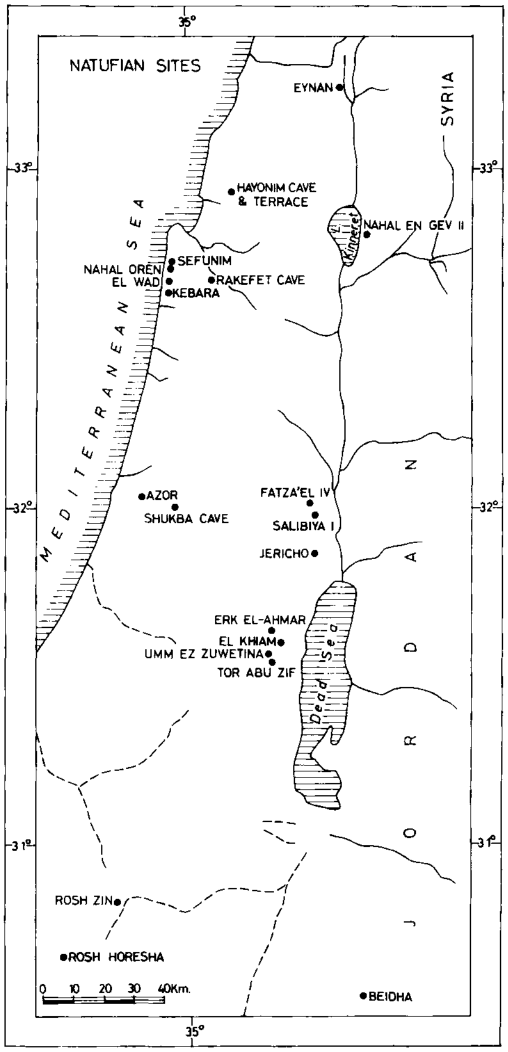

FIGURE 8.20. *Location map of the main Natufian sites in Israel.*

Natufian base camps in northern Israel provided rich bone industries (Bar-Yosef and Tchernov 1970). Among

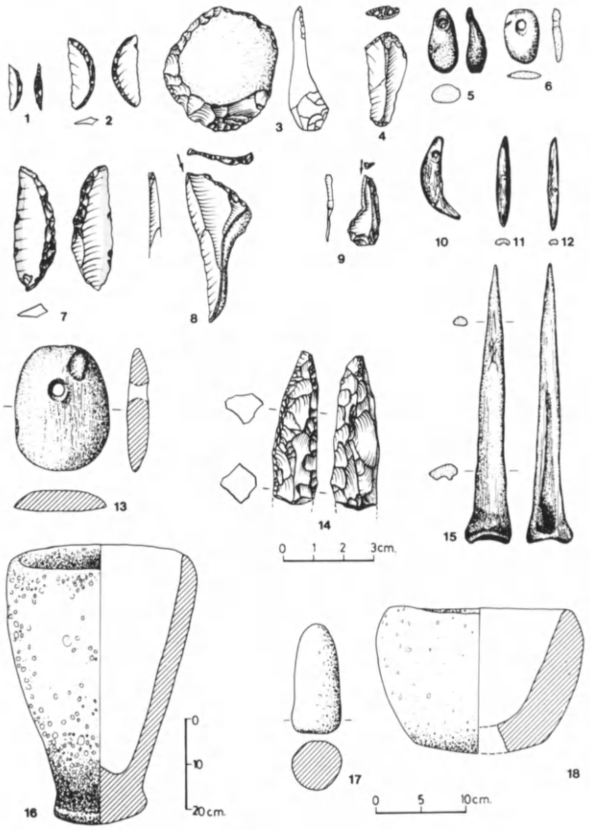

FIGURE 8.21. *Hayonim Cave, selected Lower Natufian artifacts. 1, Lunate, abrupt retouch. 2, Helwan lunate. 3, 4, Scrapers. 5, 6, Bone pendants. 7, Sickle blade. 8, 9, Burins. 10, Tooth pendant. 11, 12, Gorgets. 13, Bone pendant. 14, Broken flint pick. 15, Bone point. 16, Basalt mortar. 17, Pestle. 18, Limestone bowl.*

the major tool types are awls and points, spatulae, sickle hafts, gorgets, and rarely, harpoons and fish hooks. Bone was also used for the production of combs or ornaments. These were also made quite frequently from teeth and seashells. Natufian mobile art objects are quite rare, but some schematic decoration or naturalistic figurines of carved animals and human figures are known (Cauvin 1972). One of the most important traits of a Natufian base camp, in our view, is human burials. These were found at Eynan, Hayonim Cave, El-Wad, Nahal Oren, Kebara, Shukba, and Erk el-Ahmar. The graves were dug into earlier deposits in each site. Some of them are built up of undressed stones, others are plastered or just given an oval shape. The graves were marked and in many cases, more skeletons or corpses were added to the original contents of the grave (Bar-Yosef and Goren 1973).

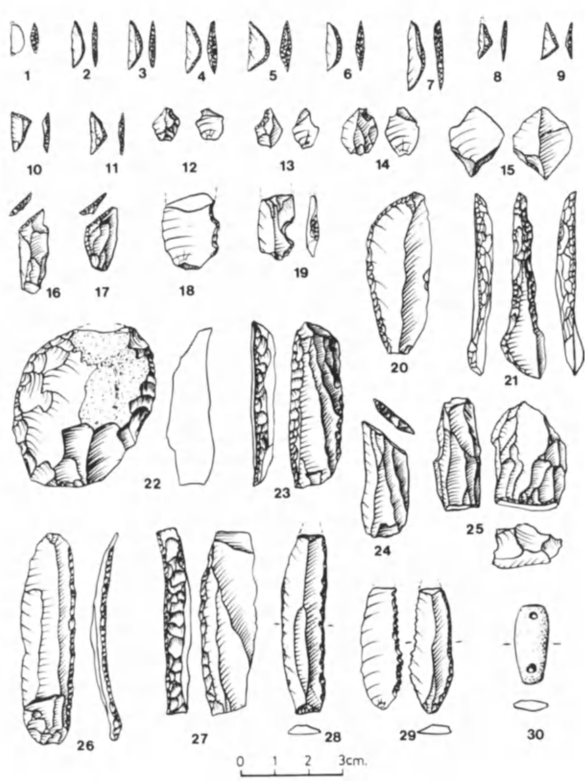

FIGURE 8.22. *Fatza'el IV, selected Late Natufian artifacts. 1-7, Lunates. 8-11, Triangles. 12-15, Microburins. 16, 17, Truncations. 18, Denticulate. 19, Notch. 20, Backed blade. 21, Borer. 22, Rounded scraper. 23, 26-29, Sickle blades. 24, Truncated blade. 25, Core. 30, Spacer made of greenstone.*

Other Industries of the Eleventh to Ninth Millennia

The term "Geometric Kebaran B" was first suggested for only a few assemblages different from, yet reminiscent of, the Natufian, such as En Gev IV, Kefar Darom 38, Layers 8-6 of the El-Khiam terrace, Matred 141 and 190 (Yizraeli 1967), and Poleg 18-M (Bar-Yosef 1970; Prausnitz 1970). New sites discovered or those reexcavated and studied further (Marks 1975, 1977) have shown that the Geometric Kebaran B could be considered as a complex or cultural group that includes the industries described from Jebel Maghara and Har Harif (Bar-Yosef and Phillips 1977; Marks 1977; Marks *et al.* 1971), which are generally contemporaneous with the Early Natufian from northern Israel. The role played by the desertic parts of Israel seems not to be limited to the eleventh and tenth millenia; occupation occurred during the ninth as well. During the late tenth and early ninth millenia, the Negev highlands were occupied by a Natufian population (Henry 1976; Marks *et al.* 1972). Later, in the second part of the ninth millenium, a new industry appears in the Negev and northern Sinai, the Harifian. The Harifian was defined by Marks at the site of Abu-Salem in Har Harif, where circular structures were exposed that had been used both for habitations and for storage. Game was mainly gazelles and ibex. Cereals were probably cultivated at this time (Horowitz, in press). Radiocarbon dates for the Harifian from Abu Salem cluster around the last centuries of the ninth millenium, which means that this culture is contemporaneous with at least a part of the pre-Pottery Neolithic A sequence.

STRATIGRAPHY AND CHRONOLOGY OF THE NEOLITHIC

Toward the end of the ninth millenium a change occurs in the archaeological record. In the Negev and Sinai a new microlithic industry appears, the Harifian which, being in the Epipaleolithic tradition, was discussed above. At the same time the first Neolithic settlements are built further north. The proto-Neolithic layers in Jericho and Layer 4 in Nahal Oren suggest an intermediate, transitional phase between the Natufian and the Neolithic. Two phases were defined in the Pre-Pottery Neolithic in Jericho (Kenyon 1960). Very few sites belong to the earlier phase, the Pre-Pottery Neolithic A (PPNA), which, apart from Jericho, was recognized in Nahal Oren, Layers III–II; Mureibet, Layers 1–8, or "phase one" of the new excavation; El-Khiam, Layers IV and III, and recently at Gilgal (Cauvin 1974; Echegaray 1966; Kenyon 1960; Noy 1976). Radiocarbon dates (Mellaart 1975) assign this phase to the time from about 8300 B.C. through the second half of the ninth millenium. The second phase, Pre-Pottery Neolithic B (PPNB), encompasses a much larger number of sites. PPNB settlements are known from Jericho, Nahal Oren, Beidha, Munhata, Abu Gosh, and many other sites throughout the Levant, from northern Syria through southern Sinai.

The change from PPNA to PPNB culture may point to some foreign influence apparently derived from the north, combined with local development. Most of the PPNB settlements date to the seventh millenium B.C. At the beginning of the sixth millenium, most of the PPNB settlements were abandoned. Some of the sites, like Beidha and Nahal Oren, were never inhabited again. Others, such as Munhata and Jericho, are resettled after a period of having been deserted. Sites disappeared from the Negev and Sinai, but the coastal plain was heavily settled (Figure 8.23). In contrast to the southern part of the country, there was continuity of settlement to the north. The basis for this abandonment is often given as climatic deterioration, however, the exact cause is still unclear. The period of abandonment is suggested by some archaeologists to be as long as 1000–1500 years (Moore 1973; Perrot 1968). Radiocarbon dates for the following period, the Pottery Neolithic or Yarmoukian, designated at Sha'ar HaGolan (Figure 8.24) are quite rare, and therefore no definite age is assigned. Three cultural units were found in Munhata. The earliest is the "Sha'ar HaGolan phase," or Yarmoukian, as defined by Stekelis (1973). Then follows the "Munhata phase," which resembles the first in many aspects. Latest is the Wadi Rabah, which apparently defines the beginning of the Chalcolithic period.

Architectural Remains

PPNA sites, although still very few, show a continuation of the domestic architecture of the Natufian tradition, of round, single room structures. The building materials differ according to geographical location of the site, as followed also in the PPNB. In Jericho, rounded structures were dug into the soil and were entered by means of a few passageway steps. Walls were built of hogback bricks and were plastered. Traces of wooden poles and reeds are visible. Floors were made of beaten earth (Kenyon 1960). Fourteen almost similar structures built of undressed stones were excavated at Nahal Oren by Stekelis and Yizraeli (1963). Evidence from this site points to a very high degree of coordinated social organization, which made the building of a complex village like this possible (Flannery 1969). More impressive evidence for a higher social organization is found in the massive fortification system found in Jericho, which includes a wall and a tower 10 m in diameter and 8.5 m in height, solidly built of

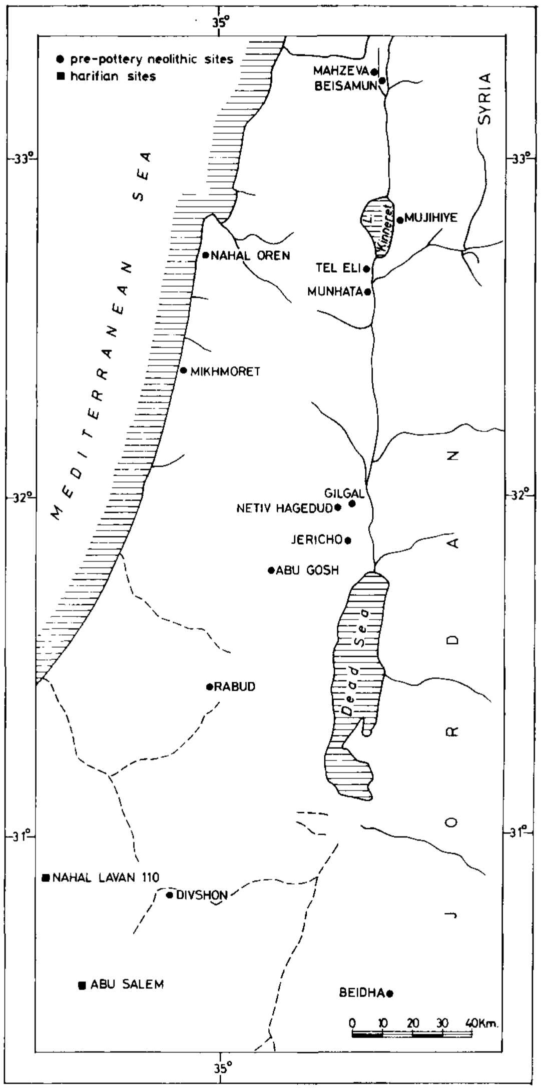

FIGURE 8.23. *Location map of the main Pre-Pottery Neolithic and Harifian sites in Israel.*

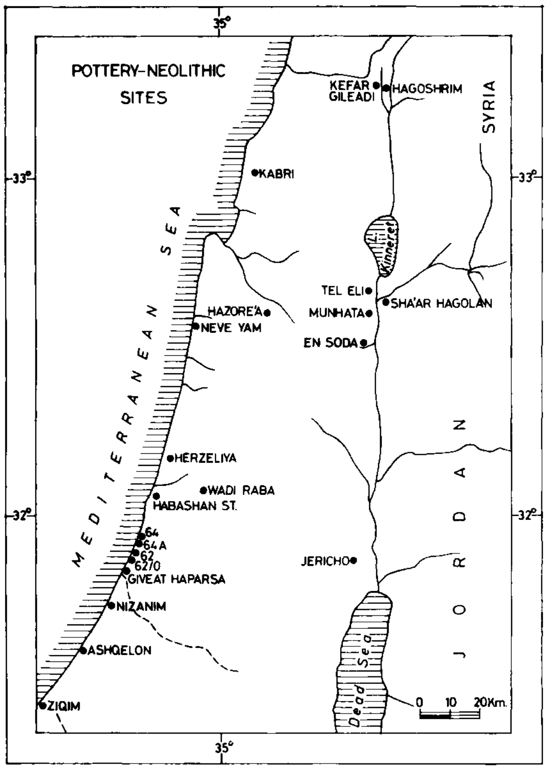

FIGURE 8.24. *Location map of the main Pottery Neolithic sites in Israel.*

stone. The population in Jericho was estimated as about 3000 inhabitants. The most characteristic feature of domestic architecture of the PPNB is a rectangular house with a polished, plastered floor, sometimes decorated with red paint. This architectural tradition is new in Israel, but is well known from Anatolia and the Zagros as early as the eighth millenium. This may hint at a strong cultural influence from this area in the seventh millenium. Remains of such structures were found in many PPNB sites such as Jericho, Beidha, Abu Gosh, Munhata, and others. Except for these, most of the houses are of the rounded type during the PPNB, as in Beidha (Dollfus and LeChevallier 1969; Kenyon 1960; Kirkbride 1966; LeChevallier 1977). The site of Beidha, after a long abandonment, was settled by PPNB people for at least 500 years (Mortensen 1970, 1973). In Jericho a structure consisting of a large central room, 6 × 4 m, with annexes on both sides, probably served some public function. The PPNB site in Jericho, like its predecessor, the PPNA, was surrounded by a wall built of massive stones, preserved to a height of 2.5 m.

During the Pottery Neolithic the nature of settlement changed. The common form of habitation was the pit dwelling, about 3 m wide and about 1 m deep. Later there is some evidence for above surface structures constructed of bricks. Various domestic installations, hearths, silos, and floors, indicate that the use of these pits was for dwelling as well as for storage. This type of building seems to point to a seminomadic way of life.

Lithic Industries

The most important new tool of the Neolithic, which in fact serves as a "fossil directeur" of the period, is the arrowhead (Figures 8.25, 8.26, and 8.27). The typical arrowhead for the PPNA is the El-Khiam point, a triangular point notched on both edges near the base, with or without the basal truncation (Cauvin 1974; Echegaray 1966). At the beginning of the PPNB many new types of arrowheads appear. The tanged point becomes a common feature. Pressure flaking is introduced, probably derived from the northern areas where obsidian was the main raw material. Toward the end of the PPNB willow leaf arrowheads become more and more common. Pressure flaking becomes dominant in the Pottery Neolithic culture and such scars cover the entire face of the arrowhead. Small barbed arrowheads are dominant in the coastal plain (Noy 1976) and long, leaf-shaped arrowheads, known as Amuk points and Byblos points

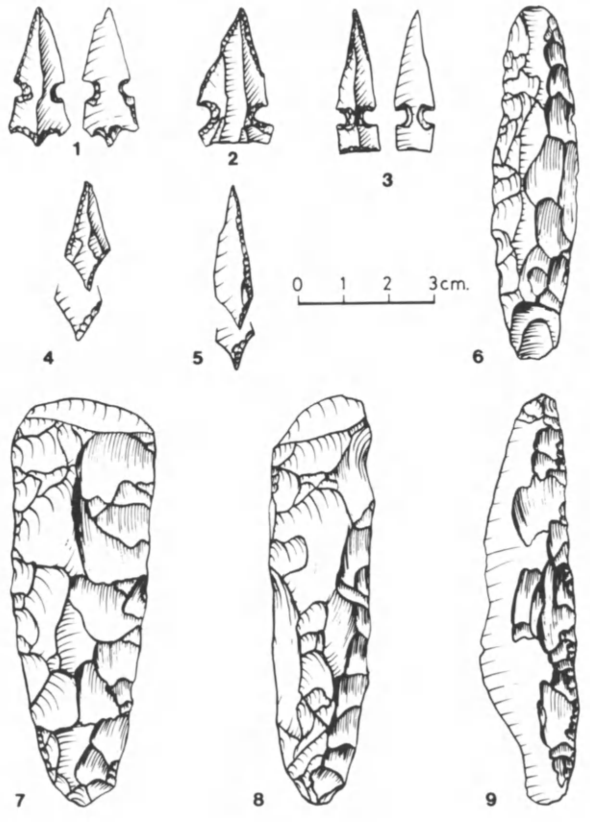

FIGURE 8.25. *Selected Pre-Pottery Neolithic A and Harifian artifacts. 1–3, Arrowheads. 4, 5, Harif points. 6, Chisel. 7, 8, Axes with transverse blow. 9, Bet Ta'amir knife.*

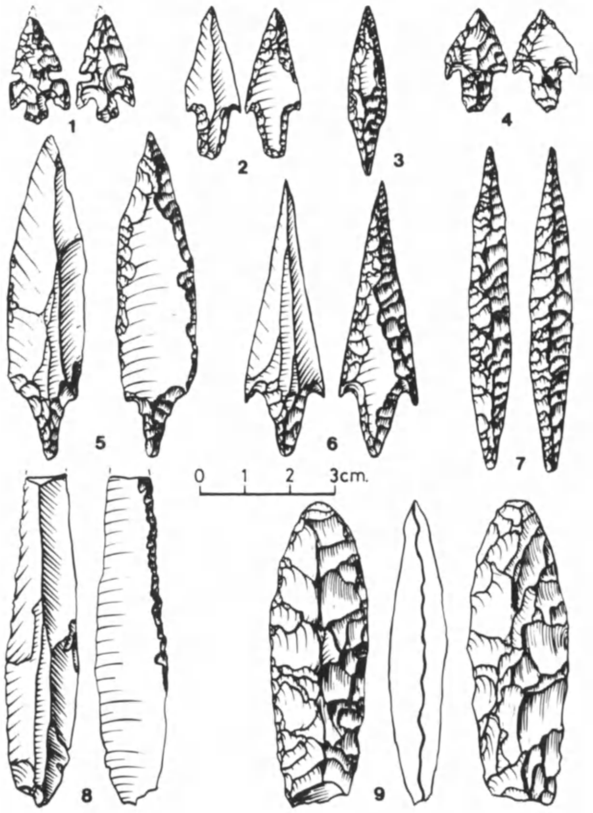

FIGURE 8.26. *Selected Pre-Pottery Neolithic B lithic artifacts. 1–7, Arrowheads. 8, Sickle knife. 9, Axe.*

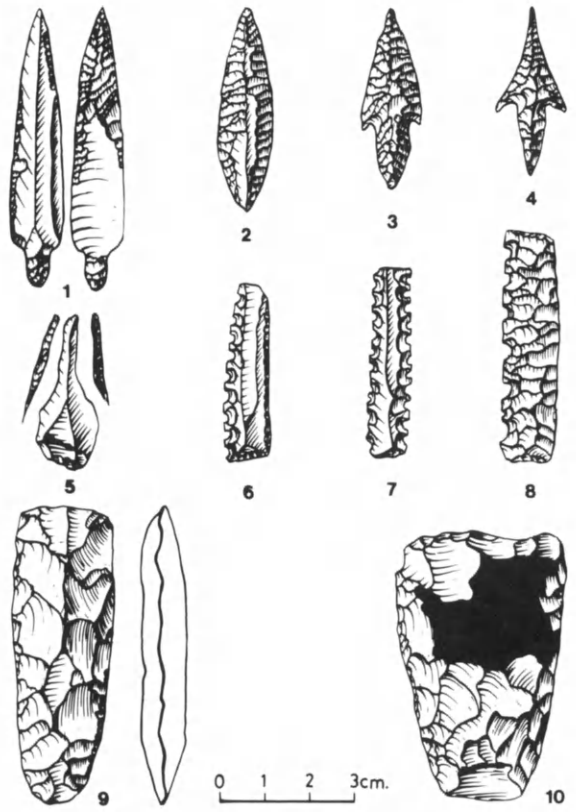

FIGURE 8.27. *Selected Pottery Neolithic lithic artifacts. 1–4, Arrowheads. 5, Awl. 6–8, Sickle blades. 9, 10, Axes.*

(Cauvin 1968), occur to the north. The percentage of arrowheads declines towards the end of the period; they are altogether absent from Chalcolithic assemblages.

The axe is another tool that is highly characteristic of Neolithic assemblages. The tranchet axe makes its first appearance in the PPNA and continues to the PPNB. Basalt and limestone axes are also found at this time. The flint axe, with a polished working edge, seems to appear toward the end of the seventh millenium and the beginning of the sixth. Small, almond-shaped axes become numerous, together with small polished axes. In the Pottery Neolithic, the transversal blow disappears and polishing becomes a major technique for shaping the working edge. The short, oval, and amygdaloidal shapes become dominant. Trapezoid axes become more common during this phase. The major type of sickle blade in the PPNA continues the Natufian tradition. Another type is a large blade, bifacially backed. In the PPNB, long narrow blades, often finely serrated, are common. In the Pottery Neolithic, short sickle blades reappear, and often have a rectangular form achieved by backing one edge and truncating both ends and the denticulated edge. A change in the technique for making sickle blades is in the use of pressure flaking. Sickle blades with bifacial pressure flaking scars and without serration occur as well. During the fifth millenium, simple rectangular blades are being used, sometimes with arched backs and often with fine serrations. These resemble types found later in the Ghassulian.

The rest of the PPNA lithic assemblages clearly show a continuation of Natufian tradition. An important change is made in the PPNB with the introduction of opposed platform blade cores and the dominance of blades and blade tools in the industry. Microliths disappear, while scrapers, burins, and perforators form an important part of many PPNB assemblages. In the Pottery Neolithic the opposed platform core disappears and the industry becomes poor, but interesting are a few scrapers made on tabular flint that begin to appear in the Wadi Rabah phase, or possibly earlier, and become an important component in Ghassulian and Early Bronze times. Grinding stones and querns are common while the deep mortars of the preceding periods almost disappear. This may reflect a shift in food processing practices; grinding seems to replace pounding as a common food preparation practice. The saddle-shaped quern is introduced in PPNB times, together with numerous bowls and rubbing stones. Most of the groundstone tools are made of basalt, but limestone is also quite common. These tools continue also to the Pottery Neolithic.

Pottery

Clay was used in the Levant as early as the ninth millenium (Schmandt-Besserat 1977) for various purposes, such as making figureines, adding facial features to plastered skulls, plastering floors, etc. However, the first clay vessels were found in Israel only in the Yarmoukian of Sha'ar HaGolan, Munhata, Jericho and in some coastal plain sites. These include small and large bowls, both shallow and deep, sometimes with handles, and sometimes decorated by incisions and red paint. In the Munhata phase of the Pottery Neolithic, the number of painted vessels increases while the incised decoration continues (Perrot 1968). Imprints of mats appear on the bases of vessels. In the Southern Jordan Valley, decorations of bands, zigzag lines, and triangles painted red and burnished seem to be more important. There is no meaningful change in the shapes between the Yarmoukian and the Munhata phases and continuity seems apparent. The pottery of the Wadi Rabah phase, which rather belongs to the Chalcolithic, continues the early traditions but shows a strong northern influence in the shapes and especially by the introduction of red, brown, and black burnish. New shapes include the bow ring neck on jars, carinated bowls, and plastic decorations describing a snake or a human figure (Kaplan 1959, 1969). Ledge handles appear on jars. Incised decoration decreases and painted decorations are sometimes done in a net pattern on triangles. These assemblages may be related to the last phases of the Halaf Culture and to the "Middle Neolithic" of Byblos.

Art Objects

Neolithic art is known from Israel exclusively in the form of mobile objects, which fall into four categories: human figurines, animal figurines, pendants, and other decorative objects and stamps. Figurines are the most common of these, and express two major elements in the life of Neolithic peoples: the importance attached to fertility and the domestication of animals (Cauvin 1972). Only two human figurines are known from PPNA deposits, one from Nahal Oren and one from El-Khiam, carved and incised in limestone. Large figurines describing human heads and the upper part of the body were found in Jericho, related to the plastered skulls recovered from this site. Fragments of human figurines were also recovered from Munhata and Beidha. Animal figurines are mostly of herbivores, from Munhata and Beidha (Kirkbride 1966). Numerous human figurines were found in the Pottery Neolithic, most of them attributed to the Yarmoukian. These are of two types: schematic human figures, incised on pebbles, and figurines made of clay. Both types display large eyes, nose, and sometimes arms and legs with exaggerated and emphasized sex organs. Animal figurines are subordinate in the Pottery Neolithic, such as domestic animals incised on pebbles, found at Sha'ar HaGolan (Stekelis 1973). Among other ornamental objects are incised pebbles bearing various designs such as zigzags, crosses, net designs, etc. Pendants and beads are common, and are made of Mediterranean and Red Sea shells such as *Dentalium* and cowry, and have been found in different areas, some quite remote from their sources. Beads made of green and black stone and also of bones occur in many sites. These artifacts seem to point to an early trade during Neolithic times.

Burials

The Pre-Pottery Neolithic, like the preceding Natufian culture, is rich in evidence attesting to treatment of the dead, and which seems to cast some light on the spiritual aspects of that prehistoric society (Cauvin 1972). Special attention was given to the skulls, which were removed from the body in the grave. Headless burials were found under floors of houses in many PPNB sites such as Jericho, Nahal Oren, Beidha, Abu Gosh, Tel Eli, Beisamun, and Tel Ramad. The most exciting find concerning the funerary customs of this period is the plastered skulls. These are known from Jericho, Tel Ramad, and Beisamun (Kenyon 1960), where skulls are coated with clay in which facial features were moulded. Shells were inserted in place of the eyes. In contrast to the Pre-Pottery Neolithic very little information is available from the Pottery Neolithic. A burial under a tumulus built of river pebbles was found at Sha'ar HaGolan (Stekelis 1973). In general the Pottery Neolithic burials are single individuals, usually flexed or semiflexed.

ORIGINS OF AGRICULTURE IN ISRAEL

James L. Phillips

Throughout the years, several major hypotheses have been presented concerning the origins and development of agriculture. They can be grouped under two headings; why it began and how it began. One of the first in the former category is that of Childe (1952), who postulated that agriculture occurred as the direct result of the drying up of the Levant at the end of the last Pluvial (Pleistocene), about 10,300 B.P. His argument is known as the Oasis, or Desiccation Theory, for he felt that, as the region dried up, animals and men were driven to areas where water was always available, such as the oasis of Jericho. As animals, humans, and plants came into intimate contact in these rather limited areas, man learned to exploit animals and plants through agriculture and animal domestication, thereby to insure adequate food resources. Braidwood and his colleagues refuted this hypothesis (Braidwood 1960; Braidwood and Reed 1957), by showing that no significant climatic change occurred in the Near East at the end of the Pleistocene, and therefore man, plants, and other mammals were not "forced" together into an intimate relationship they never had before. Most recent evidence indicates some deterioration of climatic conditions at the end of the Pleistocene, but no evidence exists that shows the human population being forced into enclaves. Braidwood further stated that the origin and development of agriculture was a culmination of the "ever increasing cultural differentiation and specialization of human communities [1960, p. 134]." This "culmination" would have naturally occurred in those areas where the wild plant and animal ancestors were most abundant, and was a natural result of cultural evolution. The next most favorite hypothesis, more recent than Childe's, is that of Binford (1968). Essentially, Binford postulates that human populations increased to such an extent as a result of the first exploitation of cereals and legumes that they were forced to find more and better sources of food. They therefore began to plant grain to insure a year-round food supply. He, however, doesn't predict how this was accomplished, or what advantage cultivation would have over the collection of the wild forms. Binford also rejects Childe's hypothesis of climatic change being the prime mover behind the development of agriculture in the Levant.

D. Zohary (1960, 1963, 1969, 1971, 1973; Harlan and Zohary 1966; Zohary and Spiegel-Roy 1975) discussed the genetic requirements of plants, and has provided a hypothesis concerning the advantages domestic plants have over their wild progenitors. *Triticum dicoccum* and *Triticum dicoccoides*, domesticated and wild emmer wheat, are both tetraploids, "and hybrids between them are fully infertile [Zohary 1969, p. 49]." Wild emmer has the brittle spike rachis characteristic of all wild cereals "and the individual spikelets serve as the seed dissemination units. In cultivated emmer the mature ears stay intact; they are separated only by threshing, and are thus fully dependent on man for their survival [Zohary 1969]." [p. 63] *Hordeum spontaneum* and *Hordeum vulgare*, wild and domestic barley, are a bit different from the wheats. They are diploids, and hybrids between them are fertile. The seed dispersal is the same for the wild variety as it is for wild emmer wheat, while the cultivated variety needs man for its survival. In each wild wheat and barley field one could find both plants with the brittle and the hard rachis, as the change from brittle to hard occurs as a mutation, from one gene and one locus, in every generation. Thus a harvester of the Epipaleolithic period would, if he wasn't careful, collect plants of both varieties. According to Zohary (1969, 1971), the collection of the wild forms tends to maintain the system spontaneously, for this system would actively select for the brittle variety. Under a system of cultivation, only the seed is placed in the ground, and this system would select for the nonbrittle variety. "Nonbrittle mutants, which were lethal in the first situation, become advantageous in the second [Zohary 1969, p. 60]." Genes for nonbrittleness would thus be selected for by planting. Another important factor concerning these plants is that the wild and the cultivated forms are predominantly selfpollinated. This factor makes them different from most other plant species, which are cross-pollinated. Zohary feels that this makes these particular plants "preadapted" to domestication. Thus the very plants that seem to have been first cultivated are those which appear to have been the most abundant in the wild state, the most easily adapted to varying climatological conditions, and the easiest to harvest. Zohary's thesis, of the inadvertant cultivation by man of the nonbrittle varieties, seems quite plausible, as we would otherwise have to assume that the inhabitants of Israel not only were able to differentiate between the two varieties, but they also had to realize the potential of the nonbrittle wheats and barley. We feel that the latter is the real question to be answered. The last major hypothesis which we will consider is that of Flannery (1968, 1969, 1973). Flannery rejects, as did Braidwood and Binford, the Childe claim of post-Pleistocene climatic change as the causative factor in the development of agriculture. He also rejects Braidwood's "settling in" claim. Flannery maintains that agriculture would *not* occur in those areas where the natural stands of wheats and barley occur. Rather, the people must have taken the seeds out of this zone and planted them elsewhere. As evidence for his hypothesis, Flannery cites the site of Ali Kosh in southwestern Iran, where the earliest occurrence of systematic cultivation has been discovered (Flannery 1969; Hole *et al.* 1969).

It becomes clear that there are two ideas concerning *why* agriculture occurred; the first, because of population pressure, and the second, because of pressure on certain resources in particular habitat zones, such as the Oak-Pistacio forest belt of the slopes of the northern Jordan Rift, the Galilee, and Mt. Carmel. Why would population pressure occur? Most likely population would increase as a response to additional food supplies, which would probably lessen the amount of disease. It seems clear, however, that Israel was not witness to a population explosion at any time during the Epipaleolithic. In fact, there may even have been a *decrease* in population, especially during the Natufian and PPNA times. Thus a major causative factor must be rejected. The second proposition, however, has merit. There does seem to be evidence suggesting that groups moved away from certain areas, as Binford suggested (1968), and concentrated their food procurement regimes on much smaller zones. The changes in size between the Kebaran and Natufian sites might be an example of groups coming together to exploit wild plant resources in a more efficient way. Of course a different social system must have become operative, so that the various groups would become integrated into these larger, more sedentary units. We might suggest that the depth of Natufian deposits at various sites should also be taken into account, for the evidence is suggestive that the permanancy of occupation is directly correlated with the effort put into building structures and silos, manufacturing groundstone tools, etc. The structures help to make the deposits thicker, as at Mallaha, Jericho, Nahal Oren, Hayonim Cave and Terrace, and Mureibet. Additional evidence of the semisedentary nature of these sites is the fact that certain microfaunal elements, which represent commensalism, are first found in Natufian levels, such as at Hayonim. These elements, *Passer domesticus* (house sparrow), *Mus musculus* (house mouse), and *Rattus rattus* (common rat), only occur where man lives in relative sedentism, as they feed off the discards of the food supply (Tchernov 1975a).

If wild cereals and legumes began to be intensively exploited by Natufian times, and if over the next several thousand years the relatively small territories were frequently harvested, it is conceivable that by PPNA times the yield of these crops would diminish, especially if there was a slight decrease in the amount of rain. This would put pressure on the local population, in terms of assuring the annual crop, to find some way to provide enough food for the year. Two ways the people could deal with this problem were: to move away from the small areas into a broad spectrum hunting and gathering strategy, and begin again the seminomadic way of life that was previously known from the Epipaleolithic period, or to add to the food supply by supplementing it with additional acreage, by planting the seeds in zones where they were not indigenous, as Flannery has suggested. The first choice is not so farfetched, for even in the Akkadian and Old Babylonian periods in Mesopotamia (ca. 4300–3500 B.P.), during hard times or droughts, townsmen left their cities and assumed a nomadic way of life. It can also be seen today in the Sahel, of Western Africa. This might account for the lack of large sites (except for Jericho and Abu Salem) until the PPNB period. A further complication might have been the competition between wild animals and man for similar food sources, with the addition of the introduction of domesticated grazers and browsers by the late eighth Millenium.

CONCLUSIONS

The development of agriculture in Israel was most probably a process of experimentation in more effective food procurement, which began by hunting and gathering groups near the end of the Pleistocene. The process was completed by the seventh millenium B.C. Throughout this period many different factors, including climate, the nature of the plants and animals used as food, and the nature of the Epipaleolithic and Neolithic inhabitants, contributed to this process. If at first humans were unwitting participants in this process, by PPNB time they controlled, or at least learned how to control, the animals and plants that provided the food and clothing for their existence.

POST-NEOLITHIC SETTLEMENT PATTERNS

R. Gophna

Beginning with the Neolithic, agriculture played a major role in the economy of people in Israel, so that the inhabitants were considerably dependent on both soil and availability of water. People inhabited entire regions in the country, in a pattern depending on natural, as well as cultural conditions.

CHALCOLITHIC SETTLEMENT

The first post-Neolithic assemblages, dating to the fifth millenium B.C., may be defined as "Pre-Ghassulian." Such are Munhata 2A, Jericho PNB (VIII), Bet She'an "pits," Esh-Shuneh I, etc. (Mellaart 1975). This is the first cultural phase in which large parts of the country were inhabited, from the Upper Galilee down to a line connecting Nahal Soreq and the northern Dead Sea shore. Settlements of this stage are known from the Western and Upper Galilee, Yizre'el Valley, Central Jordan Valley, the vicinity of Jericho, the Sharon, the northern parts of Pleshet, and the Shefela. Some settlements are also known from the mountainous areas, connected with intermontane valleys. Not many sites have been excavated to date, and very little is known about architecture, but it seems clear that all sites are connected with alluvial soils and water sources, for example, the numerous sites of the Central Jordan Valley, around Bet She'an Lake and the considerable number of springs in the area. This is also true for mountainous sites, connected with the alluvial plains of the intermontane valleys.

The Ghassulian Chalcolithic, which follows, flourished during the fourth millenium, when great numbers of large and small settlements were scattered all over the country (Perrot 1968). The inhabitants cultivated the soil, but to a great extent were seminomadic shepherds of sheep, goats, and cattle. Settlements of this period are very abundant in the northwestern Negev and the Be'er Sheva-Arad loess areas, which are presently semiarid, but were then the most densely populated areas of Israel. Less extensive habitation is known from the coastal plain, the Shefela, Yizre'el, and Jordan Valley. Many of the Chalcolithic settlements are only temporary encampments, connected with the seminomadic way of life. Some sites, however, were settled for long periods, serving as village foci for the seminomads. Such a site is, for instance, Teleilat Ghassul, northeast of the Dead Sea. The rugged mountains are almost devoid of any Chalcolithic settlements, but some scattered artifacts indicate temporary encampment. This might be due to the extensive tree coverage during the time of the Atlantic (Horowitz 1974d) climatic optimum, unsuitable for pastoralism. In the Shefela settlements are more abundant, where the people probably cultivated rendzina areas, but were also dependent on grazing. These are connected with water sources, mostly high groundwater level or streams. In some cases, where water was remote, water holes dug into chalk were used, mainly in the eastern Shefela foothills. Only a single Chalcolithic cave occupation is known from the Central Negev. Some Ghassulian sites are known from En Yahav and Timna in the Arava, and also from southern Sinai, but these are connected with copper and turquoise mining (Beit-Arieh and Gophna, in press).

EARLY BRONZE SETTLEMENT

The transition to the Early Bronze Age occurred during the last third of the fourth millenium B.C., and the land of Israel began to play an important role in the Near Eastern history. In this time Mesopotamia and Egypt became the centers of civilization of the Near East. The Early Bronze period lasted in Israel about a thousand years, during most of the third millenium, when sound commercial relations between the country and the neighboring civilizations were established (de Vaux 1971). All the Chalcolithic settlements were abandoned, and a new settlement pattern was established by the new culture. The Early Bronze Age people lived in large agricultural villages, some of which developed into walled cities with highly organized internal life. Early Bronze Age agriculture, based on cereals, olives, and vines, pertained in Israel during most of the historical periods of this time with no irrigation used. This is in contrast to the Chalcolithic, during which the people depended mostly on pastoralism.

Early Bronze Age settlements are for the most part restricted to the northern parts of the country. Only sporadic settlements are known from the northwestern Negev. The southern boundary of substantial, enduring Early Bronze settlements in the coastal plain was Nahal Shiqma. A walled town is known from Arad. During the second stage of the Early Bronze a network of unwalled villages flourished in the Central Negev down to southern Sinai, exploiting copper there. It seems that the great number of sites known from the south is a result of many short occupations at different places, which, taken together give an apparent picture of dense occupation. The people seem to have been shepherds, also cultivating some cereals. The nature of the Early Bronze II settlements of the Central Negev is totally different from the walled cities to the north. The Jordan Valley was more densely inhabited in comparison to the Chalcolithic, to which the cities of Jericho, Bet She'an, and Bet Yerah bear evidence. To the north, Dan and Hazor are known, as well as settlements in the internal valleys of the Upper Galilee, such as Qadesh. Early Bronze Age population was also dense in the Akko plain. The coastal plain was intensely settled, the sites connected with water sources, such as Aphek and Tel Poran. Other sites are situated on kurkar ridges or on the marsh shores, while no site is connected with hamra soils, apparently not used for cultivation at this time (Gophna 1974). The mountains became extensively inhabited, both in connection with intermontane valleys and the rugged landscapes. It seems that the Early Bronze Age people preferred areas of chalky rocks or limestone, probably due to their better water storage. Olives and vines also prefer the chalk. One of the largest cities of this period, north of Jerusalem, is Ai. To sum up, the Early Bronze Age people were the first to develop the typical Mediterranean agriculture of cereals, olives, and vines, with some pastoralism, which completely changed the face of the country.

MIDDLE BRONZE I SETTLEMENT

Middle Bronze I people inhabited the country in the last two centuries of the third millenium, after a total destruction of the Early Bronze Age settlements and cities. These were poor, seminomadic shepherd tribes, who mostly built unwalled villages. They also practiced some agriculture and hunting (Dever 1971). MB I settlements are known from all over the country, including the Central Negev, but the northwestern Negev was almost deserted. The MB I settlements continue through northern Sinai to Egypt. The MB I pattern of the Central Negev is very much like the former, EB II, but southern Sinai was not inhabited and copper was not exploited there by these people. Many of the MB I sites are located in places which have never been inhabited before, and some were never inhabited afterward. The differences between the EB II and MB I pattern of the Central Negev is probably one of exploitation of economic resources, the people of EB II being mostly farmers, while the latter are goat shepherds. On the other hand, it seems that the rarity of Ghassulian Chalcolithic settlements in the Central Negev was due to their dependence on sheep breeding, while the MB I people were goat breeders, more adaptable to the arid region.

MIDDLE BRONZE II AND LATE BRONZE SETTLEMENT

At the beginning of the second millenium B.C. a new settlement pattern appears with the Middle Bronze Age II culture. This pattern persisted during the Late Bronze Age culture, altogether some 800 years. It was dictated by the needs of a stable farmer society, and very much resembles the Early Bronze Age. The centers of population were again walled cities, politically acting as city-states ruled by "kings" (Mazar 1968). This system divided the country into many small districts. Hundreds of unwalled agricultural settlements were connected economically and politically with the larger cities (Gophna, in press). The MB II and LB settlements were never totally destroyed, and the basic pattern continues until the Hellenistic period. The greater number of MB II, compared with EB settlements, probably indicates larger areas cultivated by these people, and most likely a larger population as well. During MB II, areas that have never been inhabited before are settled, such as parts of the coastal plain and the mountains. MB II sites are known along the present-day coastline, but some of their structures, such as in Tel Michal north of Tel Aviv, are submerged. Some of these sites were ports, such as Akko, Atlit, Tel Michal, Jaffa, Yavne-Yam, and Ashqelon. The Sharon becomes more heavily settled by MB II people, and mountainous areas dominated by limestone and dolomite become inhabited for the first time in history. This resulted from development of the plastering technique for water storage systems, which overcame the porosity problem (Gophna and Porat 1972). Land use also became much more extensive in MB II times. The northwestern Negev and Be'er Sheva Valley, almost deserted since the Ghassulian Chalcolithic, became inhabited once more. Several large, walled cities are known, such as Tel el Ajjul, Tel Jemme, Tel Sharuhen, Tel Haror, and Tel Masos. The Central Negev and Sinai, on the other hand, were not settled by MB II or LB people.

This settlement pattern continues also into the Late Bronze Age, when the country was ruled by Egypt. Some difference is noted in the south: The Arad and Be'er Sheva Valleys were not inhabited by LB people, but new walled cities were erected in the loess areas of the northwestern Negev such as Tel Shera, accompanied by unwalled villages. New settlements are also known from the coastal plain, such as Dor, Tel Borgatta, and Hadid. The number of mountainous settlements considerably decreased during the Late Bronze Age. The copper resources of Timna, in the southern Arava, were exploited in this period by the Egyptians.

IRON AGE

The Iron Age begins with the conquering of the country by the Israelites and the Philistines, during the twelfth and eleventh centuries B.C. Following the Israelite settlement, the MB II–LB Canaanite system, which had prevailed in the country for 800 years, began to disintegrate. The city-states gave way to large areas occupied by tribes, which later became a single national state, Israel. The southern coastal plain was ruled by the Philistines, continuing the Canaanite city-state system. Israelite settlements were abundant in the mountainous areas of the Galilee, Samaria, and Judea down to the Shefela foothills (Aharoni 1967). This was made possible by the introduction and development of the terrace agriculture, by which erosion was controlled and water supplied. Sophisticated agriculture methods and elaborate water storage systems also enabled settlement of the desert areas of eastern Samaria, the Dead Sea area, and the Central Negev. This is the first time in the history of the country when physical–natural conditions are controlled, and together with the developing agriculture, a prosperous society emerged, consequently despoiled by successive conquerors.

9

Conclusions

The present chapter deals with two aspects of our subject, both ensuing from the facts and discussions presented previously, the Quaternary development of Israel and some general implications concerning Quaternary chronology and paleoclimatology. The first part sums up the evolution of landscape in Israel throughout the Quaternary, the depositional and erosional processes, the development of environments, and the interaction between man and his surroundings during the period in which he inhabited the region. The second part is more general in nature, and aims at understanding the peculiarities of the Quaternary period, its boundary and subdivisions, the correlation between Quaternary sequences of Israel and other parts of the world, and the distinctiveness of the Quaternary—its climate and climatic changes. The development of ice ages in general and the Quaternary ice age in particular is discussed, and a mechanism is suggested to delineate the Quaternary paleoclimates and their global distribution.

QUATERNARY MORPHOTECTONIC EVOLUTION OF ISRAEL

In order to discuss the Quaternary morphotectonic evolution of Israel one must bear in mind the late Pliocene landscape and structure of the country. Two principal tectonic lineaments were already well developed at the end of the Pliocene: the Levantine Fold Belt (Figure 3.3), which mainly evolved during early Cenozoic times, and the Erythrean Fault System (Figure 3.5) which was principally active during the transition from the Miocene to the Pliocene, some 5.5 million years ago. The Levantine Fold Belt was responsible for the main landscape characteristics until the termination of Miocene times. Rivers have mainly developed in the synclines, and the river valleys were (Figure 4.3) consequently filled by sediments during the middle Miocene transgression, while during both the preceding Oligocene and the Miocene the higher, anticlinorial ranges underwent considerable erosion, becoming an almost total peneplain. This rather flat landscape changed abruptly during the latest Miocene due to the activity of the Erythrean Fault System and the renewal of the relief, accompanied by the Tabianian and Piacenzian sea level rises, which caused another cycle of basin filling with sediments and peneplanation of the higher areas (Figure 4.5). It should be noted though that these higher areas were not considerably elevated above average sea level, and in fact, except for some rare localities like the Dead Sea Basin, the Pliocene landscape had low relief.

At the end of the Pliocene, with the regression following the Piacenzian transgression, the following picture emerges. The center of the country was eroded rather flat, while the downfaulted parts of the Jordan–Arava area and the coastal plain were filled with Pliocene sediments. Some volcanic intercalations within these sediments in the northeastern part of Israel, in the coastal plain and in the Negev, helped date these fillings at around 3.5–5 MY (Siedner and Horowitz 1974; Siedner *et al.*, in preparation; Steinitz *et al.*, in press). The sea, which had regressed from the rather flat land in late Pliocene times, initiated channeling processes (Figures 5.63 and 5.65) across the country in a general east–west direction. The area occupied by the present-day Jordan Valley was only somewhat lower than the central part of the country, and therefore the channels running to the Mediterranean easily captured the drainage system that led to the Pliocene Dead Sea embayment area, thereby helping to create the latest Pliocene channel system toward the Mediterranean, which served as the principal base level in these times. The area of the "proto-Bay of Elat" also served as a base level, toward the regressing Red Sea. The processes involved were almost similar in both systems, and erosion channels began to evolve at the end of the Pliocene, leading southward to the area of the present-day Red Sea. It should be noted that the Bay of Elat itself is a younger phenomenon, connected with the north–south lineated Jordan–Arava Rift Valley, which was not active as yet in those times. In fact, the area occupied presently by the Bay of Elat served during the Pliocene, as well as during Miocene times, only as an erosion channel (Figure 5.5), which drained the southern part of the Arava and some of the adjoining areas. This base level had never influenced a large area in Israel, both due to the relative aridity of the Southern Negev that had already developed during the Pliocene, and perhaps during part of the Miocene as well, and due to the remoteness of the base level in the Red Sea area.

Thus, the latest Pliocene landscape of the area presently occupied by Israel was a rather extensive flatland occupied by two drainage systems, the main one leading to the Mediterranean, and a subordinate one leading to the Red Sea. These drainage systems were both rather flat, meandering with relatively wide river channels, which traversed the entire country, connecting (except for the subordinate system of the Bay of Elat area) the Transjordanian Plateau with the Mediterranean. The regression at the end of the Pliocene was rather considerable, as even the boreholes drilled on the Mediterranean continental shelf show a rather pronounced hiatus between the Pliocene and Quaternary sediments. Two principal factors therefore controlled the landscape at the end of the Pliocene. The first is the Tabianian and Piacenzian transgressions, which caused filling of the internal basins and of the coastal plain with sediments, whether they were marine, lagoonal, lacustrine, or fluviatile. During this period a considerable peneplanation took place over the entire country, reducing the landscape to a flatland not much elevated above the average sea level which, compared with the present day, was approximately 200 m higher. The other factor was the late Pliocene regression, which led to non-deposition in these areas and initiated channeling by wide, meandering rivers toward the retreating sea.

This flatland morphology persisted also throughout the Preglacial Pleistocene, consequently influenced by the Calabrian and Sicilian ingressions, which caused deposition in the preexisting channels. The average Pliocene sea level, about 200 m above that at present, was succeeded by the Calabrian and Sicilian transgressive sea levels, averaging between 120 and 80–90 m above the present level, which considerably influenced the entire area of Israel. Deposition of marine sediments resumed on the continental shelf. In the littoral areas, the Ga'ash Formation (Figure 5.6) was accumulated while the river valleys leading to the Mediterranean were filled by the Bethlehem Conglomerate in the center of the country, the HaMeshar Conglomerates in the Negev and Arava areas, and the Garof Conglomerates in the drainage system leading toward the Red Sea. In the north of the country, however, the picture was somewhat different, and the principal influence on the landscape became the outpourings of the Cover Basalt (Figure 5.129). The Cover Basalt filled and flattened the areas of the Northern and the Central Jordan Valleys and the area of the Yizre'el Valley. No manifestations of this volcanic stage are known in the coastal plain or in the Negev. On the Transjordanian Plateau, the Cover Basalt is known quite far south, reaching areas opposite the present-day Dead Sea. The Cover Basalt, together with the continued activity of the erosion channels leading to the Mediterranean, sealed the Pliocene connection between the present-day Dead Sea area and the Mediterranean through the Central Jordan and Yizre'el valleys. The result was that the present-day Dead Sea area became an intermediate basin in the way of rivers flowing from the Transjordanian Plateau through the Judea and Hebron areas, to the Mediterranean. In this intermediate basin the Ghor el-Qatar Series was deposited.

The coastal plain was almost totally submerged under the Calabrian and the Sicilian seas (Figures 5.40 and 5.41), while during the regressive phases pedogenic and erosional processes prevailed in this area (Figures 5.39 and 5.56). The Calabrian transgression had deposited beachrocks up to elevations of 130 m above present sea level. Fossil dunes connected with this transgression, the Hirbet Harev Ridge, attain elevations up to 200 m above present sea level. The regression separating the Calabrian and the Sicilian ingressions caused formation of the Ze'elim Hamra Member of the Gaza Formation in the coastal plain, while the following, Eyal Ingression, of Sicilian age, caused deposition of beachrocks up to elevations of 80–90 m above the present sea level, and fossil dunes, the Yakhini Kurkar Ridge, up to elevations of 140–150 m above the present sea level. The regression separating the Calabrian and the Sicilian went as far as 20–30 m below present sea level, and dunes deposited during the standstill of this regression are presently buried under the Mediterranean.

The flatland morphology then changed rather abruptly at the transition from the Preglacial to the Glacial Pleistocene. The reason for change was the beginning of tectonic activity along the Levantine Rift System. This tectonic activity acted in two directions, through downfaulting of the Jordan–Arava Rift Valley and uplifting of the neighboring country, more or less along parallel lines. Downfaulting along the Jordan–Arava created several subbasins in which subsidence was considerable (Figure 5.90), separated by thresholds in which subsidence occurred, but to a much lesser extent. The principal subbasins are, from south to north, the Bay of Elat, which is very deep, attaining depths of 1800 m below present sea level. This subbasin extends north to the Southern Arava and is separated from the succeeding one by the relatively elevated area of Gav Ha'Arava, presently about 200 m above sea level. The valley grades to the north, to the Dead Sea subbasin, which is at present approximately 400 m below sea level. At least 2 km of Quaternary sediments were penetrated by boreholes in the area. The Dead Sea subbasin floor gradually elevates to the north, to the area of Merma Feyyad, which is presently about 200 m below sea level. Next comes the Central Jordan Valley which is the shallowest subbasin. It only contains several hundred meters of Glacial Pleistocene sediments, which are separated to the north by the elevated Korazim-Gadot Block, about 100 m above sea level, from the succeeding Northern Jordan Valley sector, or the Hula Basin. The Hula is the smallest of the subbasins, but is rather deep. Its present-day elevation is 70 m above sea level, but 1700 m of Glacial Pleistocene sediments were encountered, filling this basin. The Metulla-Marj Ayyun Block separates the Lebanon from the Anti-Lebanon mountains. It is quite interesting to note that the deeper subbasins occur in places where the rift valley transects former anticlinal or anticlinorial ridges, while synclinal areas of the Levantine Fold Belt are only subordinately influenced by the faulting, and in some places, such as the Merma Feyyad area, are not faulted at all. The areas of Gav Ha'Arava and the Beqa'a, which are synclines, do not presently form a true rift valley but in fact are bordered by only a single fault.

The upwarped shoulders of the rift valley constitute the mountainous backbone of Israel to the west, and the Transjordanian Plateau to the east. The uplifting along these two lines is differential, and while approaching the rift valley, the shoulders are subsiding. This can clearly be seen around the Bay of Elat by the submerged wadis (Figure 5.44) and by the lack of Quaternary raised beaches along the northern part of the Bay. Even the Miocene beachrocks, which crop out along the Bay of Elat on both sides, are not much elevated above sea level at present. In Israel they reach elevations of up to 400 m above sea level, while along the Bay of Elat they reach only about 50–60 m above sea level, and have probably been subsiding since the time of their deposition. The tectonic activity along the Levantine Rift System created an endoreic drainage system that captured parts of the former drainage systems running toward the Dead Sea. The wide, meandering river systems that led across the Negev, Judea, and Samaria toward the Mediterranean, draining the present-day Transjordanian Plateau, ceased to exist, and a local drainage system began to develop (Figure 2.29) toward the new base level of the Dead Sea. To the west, the drainage system leading to the Mediterranean began to incise deeply into the uplifting mountains. The limited area drained to the Bay of Elat also acted in the same way and the wadis leading toward the newly created bay, submerged ever since by the Red Sea waters, incised quite deeply into the previous rather flat landscape (Figure 5.84).

The uplifting of the Transjordanian Plateau, to the east, resulted in rather strong erosion and incision in the wadis leading to the Dead Sea Basin and to the Bay of Elat, while to the east of the uplifting line two regimes were created. The northern part of Transjordan is drained to the Persian Bay through the Wadi Sirhan drainage system, while the southern part became an internal drainage system, draining toward the shallow endoreic basin of El-Jafr (Figure 5.125). To the south of Transjordan, many wadis previously leading to the Arava were captured by Wadi el-Yutm, which presently leads to the Bay of Elat near Aqaba; this wadi made its way from east of the uplifting line through a less uplifted area to the Bay. It presently drains most of the southern part of the Transjordanian Plateau which is not drained to the El-Jafr internal basin, while most of the former wadis became very short, and almost ceased activity.

The central and southern coastal plain was probably rather stable throughout the Glacial Pleistocene and was not so much affected by the Levantine Fault System or by the uplifting along the mountainous backbone. This is suggested by the relative position of the fossil dune ridges along the coastal plain (Figures 5.58 and 5.16). The series of submerged ridges (Figure 5.39), as compared to the series of ridges preserved inland, display eustatic ingressions of almost the same magnitude throughout the Glacial Pleistocene. The difference in elevation between any ingression and a successive regression is always approximately 150 m (compare Table 5.2), which indicates that tectonic activity along the coastline is rather subordinate. This is true from the south up to the northern tip of the Carmel. The areas north of the Carmel display a totally different picture. The Haifa Bay area and the Zevulun Valley continuously subsided throughout the entire Glacial Pleistocene, as can be seen by the buried Glacial Pleistocene sediments (Figure 5.10) penetrated by many boreholes in the area. North of Akko, however, subsidence occurred during the Glacial Pleistocene but to a lesser extent, which can be seen by the occurrence of fossil dune ridges, the oldest of which does not attain elevations of much more than 30 m, as compared to 200 m to the south of the country.

The tectonic subsidence of Zevulun Valley–Haifa Bay and the Western Galilee coastal plain must be related to the uplifting and upwarping of the Galilee throughout the Glacial Pleistocene. This uplifting renewed the activity on the previous, Erythrean faults, and also created new faults (Figure 2.77). The basis for this assumption lies in the absence of Preglacial Pleistocene marine sediments in the Zevulun Valley and the Western Galilee coastal plain. Apparently these areas were elevated in the same manner as the Carmel and stood as cliffs against the Preglacial Pleistocene sea. The subsequent subsidence of Glacial Pleistocene times resulted in Glacial Pleistocene marine sediments directly overlying the Pliocene rocks in these areas (Issar and Kafri 1972; Kafri and Ecker 1964). The coastal plain, therefore, continued to be influenced mainly by eustatic sea level changes throughout the Glacial Pleistocene, namely, the interglacials (or interpluvials, depending on the local climate), which are recorded by high sea levels, pushing forward of dune ridges and deposition of beachrocks on the coastal plain. On the other hand, the regressive phases, corresponding to the glacials (or pluvials) are characterized by a rather wide, flat coastal plain on which red soils were formed, presently preserved as hamra paleosols (Figure 5.58). The regressions were also accompanied by some erosion. The mountainous areas were influenced by incising processes of the wadis, following the continuous uplifting of the mountainous backbone throughout the Glacial Pleistocene. The style of erosion was, however, dictated by the climate. During the pluvials, erosion was milder and gentle slopes were formed, covered by colluvial soils and gravel (figures 5.72–5.76), as a result of abundant mild rains and rich vegetation. During the interpluvials erosion was rather strong due to scarce vegetation and torrential floods initiated by cyclonic thunderstorms, bringing rains that poured down rather large quantities of water during a short period. The alternation of these two erosive styles created a typical landscape of benches (Figure 5.70) along most of the wadis leading from the mountainous backbone both to the Mediterranean and to the Dead Sea. The same picture can also be seen in the wadis leading toward the Bay of Elat (Figure 5.86). The Bay of Elat was occupied by the Red Sea waters, which fluctuated according to the global eustatic sea level changes during the Glacial Pleistocene. Only limited evidence of these changes (Figure 5.9) can, however, be seen along the Bay of Elat, due to the continued subsidence of both its sides throughout the Glacial Pleistocene. To the north, the Beqa'a sector of the rift valley, in Lebanon, is drained to the Mediterranean through two principal rivers, the Orontes draining its northern part and the Litani its southern part. The changing climate during the Glacial Pleistocene resulted in the formation of river terraces along these two rivers.

In the endoreic system of the Dead Sea, the three subbasins were occupied by lakes (figure 5.90), depending on local tectonics and climate. The Dead Sea area was almost always occupied by a terminal lake, rather large during the more humid pluvial periods and turning to restricted sebkhas or salt lake during the dry interpluvials. The Central Jordan Valley, an intermediate basin in the drainage system running from the north to the Dead Sea, was occupied by lakes only during the humid pluvial phases, except for the Rissian, for reasons discussed later. The Hula sector was almost always occupied by lakes, spreading over most of the valley during the pluvials, while during the interpluvials the lakes shrank and became for the most part peat bogs.

Two rather severe tectonic phases influenced the Jordan Rift Valley during the Glacial Pleistocene. The first of these is known only from the Central and Northern Jordan Valley, while in the Dead Sea, if it was active, its results are probably buried under subsequent sediments. In both the Central and Northern Jordan Valley tectonic activity considerably influenced sediments of Mindel age and older, the Erk El-Ahmar and Ubeidiya formations in the Central Jordan Valley and the Gadot and Mishmar HaYarden formations in the Hula Valley. Basalts that overlie these sedimentary formations in both subbasins, the Yarda Basalt in the Hula Basin and the Yarmouk Basalt in the Central Jordan Valley, were also influenced by this tectonic phase, which helps to date the faulting. These basalts were dated at 560,000 years (Siedner *et al.*, in preparation), 640,000 years and 680,000 (Horowitz *et al.* 1973; Siedner and Horowitz 1974). Formations of Rissian age, the Naharayim Formation of the Central Jordan Valley and the Benot Ya'akov Formation of the Hula Valley, were not affected by this tectonic phase and overlie it intact. The age of this tectonic activity is therefore placed somewhere between the latest Mindel and the beginning of the Rissian. It should be noted that a tectonic phase that might correspond to this one affected sediments of Mindel–Riss Interglacial age in the Orontes Valley (Clark 1967). If these two tectonic phases are correlatable, which is quite possible, we may assume that this tectonic activity influenced the Jordan Valley sometimes near the end of the Mindel–Riss Interpluvial. It is, however, quite difficult to assess this in the Jordan Valley itself due to the scarcity of sediments of Mindel–Riss age. In the Central Jordan Valley no interpluvial sediments crop out, and apparently previous sediments were subject to erosion during the dry interpluvial. No lake was formed during this time in the Central Jordan Valley. In the Hula Valley, Mindel–Riss sediments of the Ayyelet HaShahar Formation are only known from boreholes, and therefore no information as to their structural setting is available. An upper limit for the age of the post-Mindel tectonic phase was observed while analyzing the basalts of the Golan Plateau. The lower part of the sequence, including the "Undivided Cover Basalt" and the Dalwe Basalt, is faulted by this tectonic phase. The age of the Dalwe Basalt is around 1 million years, but since the Yarmouk Basalt, which yielded an age of 560,000 years, is also faulted, this gives the maximum age for the faulting. The minimum age for this faulting is given by the Muweisa Basalt. Flows of this phase overlie the faults of the previous Dalwe Basalt on the fault scarp facing the Hula Valley (Mor 1973). The Dalwe Basalt was dated (Siedner *et al.*, in preparation) at around 350,000 years. The post-Mindel tectonic phase can therefore be placed between these dates, namely, between 560,000 and 350,000 years. The post-Mindel faulting of the Central Jordan Valley ended its role as an intermediate basin occupied by lakes. As a consequence of this faulting, the Rissian sediments of the Valley are no longer of lacustrine nature and represent only the stronger activity of the Yarmouk and the Jordan, flowing to the Dead Sea, by large-scale deposition of river gravels intermingled with paleosols, known as the Naharayim Formation. During the Würmian period as well, the Central Jordan Valley did not act as an independent basin, but was strongly connected with the Dead Sea when both were flooded by the waters of the Lisan Lake.

The second tectonic phase that is known along the Jordan Valley occurred only 18,000 years ago (Neev and Emery 1967). This phase considerably influenced the morphology of the Valley during the last Würmian Pluvial phase. It caused downfaulting and created the northern Dead Sea basin to the south, presently about 400 m below the Dead Sea surface, and the Kinneret basin to the north. As a consequence, the Lisan Lake, which occupied almost the entire Jordan Valley during the Early and Middle Würm, from somewhat north of Tiberias down to about 40 km south of the present southern tip of the Dead Sea, ceased to exist as such. The Dead Sea and Lake

Kinneret, more or less in their present-day configurations, came into existence. This tectonic phase is also known from the Hula Valley, faulting sediments of the Würmian Ashmura Formation and the Dan Travertine, but without considerably influencing the landscape. A still younger tectonic phase is known from the Hula area, faulting sediments which are radiocarbon dated at about 4500 years ago. This phase is also known from the Central Jordan Valley, but was not recognized in the Dead Sea area.

Late Pleistocene or Holocene tectonic movements along the Israeli coastal plain were recently advocated by several authors, and mainly by Neev *et al.* (1973). They are, however, opposed by other authors, and the picture is presently not so clear. It is quite evident that beachrocks of early Versilian age are uplifted along some parts of the Israeli coastal plain, which suggests some faulting or some differential block movement along the coast. The evidence is, however, far from conclusive and needs much further research. For details, see Chapter 2.

Volcanic activity considerably influenced the country in Preglacial Pleistocene times, when the Cover Basalt was poured over the northern and especially the northeastern parts of the country. The centers of vulcanism have later, during the Glacial Pleistocene, migrated further east and large-scale Glacial Pleistocene vulcanism is only known from the Golan Plateau and sometimes from the Transjordanian Plateau. Some subordinate manifestations of this vulcanism also reached the Central and the Northern Jordan Valleys during two phases. One, at the end of the Mindel Pluvial, deposited the Yarmouk Basalt of the Central Jordan Valley and the Yardā Basalt of the southern Hula Valley, and the other, during the Riss–Würm Interpluvial, deposited the Raqqad Basalt of the Central Jordan Valley and the Hasbani Basalt of the northern Hula Valley. Radiogenic datings of these basalts, discussed later, have considerably aided chronological assessment of the sedimentary formations.

—QUATERNARY PALEOENVIRONMENTS AND HUMAN SETTLEMENT—

The Quaternary paleoenvironments of Israel are described in stratigraphic order, according to the terminology set forth in Chapter 1. We shall not enter into great detail in this discussion since most of the details concerning the stratigraphy, lithology, fauna, and flora are to be found in the preceding chapters. For the earlier part of the Quaternary, only natural conditions are discussed since hominid settlements are not known from this time in the area. For the later part, the discussion will focus on the paleoenvironment and the connection of human settlement with natural conditions. A general reference is made here to Table 5.2, which presents correlations between Quaternary formations in different areas of Israel, and also to conclusions in Chapters 6 and 7 on the development of the flora and fauna of Israel during the Quaternary period.

Throughout the Quaternary climatic changes took place rather quickly, so that processes involved in transitional climate or sea levels have only subordinate influence on sediments and morphology. This will be discussed in more detail later, but it should be noted that most of the influences of pluvial and interpluvial climates or of low and high sea levels, respectively, were in periods of stabilization of these processes, either of a pluvial climate and low sea level or of an interpluvial climate and high sea level. It is extreme conditions that occupied a considerable time throughout the Quaternary rather than the transitions between one state and another, either climatic or eustatic, which were rather short and subordinate in time and influence on the landscape and environment. The discussion presents the consequences of these stabilizations of climate and of sea level, on the sediments, erosional processes, and paleoenvironments.

PREGLACIAL PLEISTOCENE

The Preglacial Pleistocene was a period in which the flatland, low morphology inheritance of late Pliocene times is the principal environmental factor. The country was crossed by several large river systems flowing to the Mediterranean and the Red Sea, while to the north eruptions of the Cover Basalt took place. The changing climate and sea level influenced the entire region as a single entity, with no pronounced differences between the various areas. No hominid settlements are known as yet for this period in the Levant.

Pre-Calabrian Glaciation: The Biber

The Biber Glacial period is probably the first considerable cooling of the northern hemisphere, designating the beginning of the Quaternary period. Its climax occurred about 2.8–3 million years ago (Beard, 1969), corresponding in time to the regression which terminated the Pliocene. The final Pliocene regression seems to be a combined result of both geotectonic activity and some eustatic lowering of sea level, due to the Biber Glaciation. The glaciation itself cannot have been responsible for the entire regression at the end of the Pliocene since the average sea level dropped more than 300 m during this time, which is much more than the average eustatic sea level lowering for the succeeding glacial periods. It should also be noted that the Biber was not a major glaciation and therefore only the superposition of eustatic regression with geotectonic activity gave the late Pliocene regression such a marked expression in the stratigraphy. Very little is known of what happened in Biber times in Israel for two reasons. No sediments are known from this period because even if they were deposited in some areas of Israel they were later eroded or covered by subsequent, younger sediments. On the other hand, the amount of such sediments could not be considerable, due to the low sea level and the rather flatland morphology, inherited from the middle Pliocene peneplain of the elevated areas, and the sedimentary filling of the Erythrean basins. Both low sea level and flat morphology initiated erosional and channeling processes which shaped the country in Biber times. The result of these processes was formation of a new hydrographic network of rivers connecting the Transjordanian Plateau to the Mediterranean, crossing over the previously taphrogenic areas of the present-day Dead Sea and the presently uplifted mountainous backbone. A similar picture, although to a much smaller scale, can be seen around the present Bay of Elat, where the retreating late Pliocene Red Sea created a shallow hydrographic network in which the Garof Conglomerate was subsequently deposited.

The ensuing landscape in Biber times is therefore as follows: the country was rather flat, crossed by several main rivers: the Bethlehem System in the central part of the country, the HaMeshar System in the Arava and the Negev areas, and the Garof System in the Elat area. These systems were mainly subjected to erosion in Biber times. The sediments that filled them constitute fluviatile formations deposited subsequently, when sea level rose again in Calabrian and Sicilian times. To the north of the country the same picture prevails, of channeling of late Pliocene sediments towards the retreating Mediterranean. The main difference is, however, that in the north these channels were later filled by Cover Basalt flows and not by fluviatile sediments. The average maximum elevation of the country must have been on the order of 250–300 m above the Biber sea level. The coastal plain was very wide, which can be seen by the unconformity at the base of the Calabrian sediments on the Continental shelf, presently under about 100–120 m of sea water. The morphology was rather low, as can be seen from the nature of the river systems that developed. The channels were mostly wide and meandering in great curves, which shows that the rivers flowed over vast floodplains of a flatlying country. No lakes are known for the Biber period from Israel, except perhaps for a restricted lake that might have existed in the present-day area of the Dead Sea and somewhat north of it, as an intermediate lake in the course of river draining Transjordan to the Mediterranean, the Ghor El-Qatar Lake. However, no conclusive evidence is available for this assumption. Practically nothing is known about the vegetation and fauna of this period. Due to the lack of marine sediments from the continental shelf no material was available for palynologic or paleontological examination. No conclusions can therefore be made in respect to paleoclimate, and it is not known to what extent the Middle East was affected by the Biber Glaciation, except for the considerable rate of marine regression.

Calabrian

The Calabrian Transgression is the first Quaternary sea level rise, which took place at about 2.8 to 2.4 or 2.5 million years ago (for its age see later discussion), corresponding to the Biber–Donau Interglacial. The average sea level rose to about 110–130 m above the present level, which indicates that the Calabrian cannot be regarded as of purely eustatic nature, but was probably also connected with some geotectonic activity, combined with a warming up of the climate during the interglacial. The previous landscape, of a rather flat country during Biber times, crossed by several large, wide, meandering rivers, was maintained also throughout the Calabrian, but the wide coastal plain was almost totally submerged under the Calabrian sea, which deposited the lower part of the Ga'ash Formation. East of the coastline dunes were pushed up to form a series of ridges, reaching a present height of about 200 m above sea level, and designated as the Hirbet Harev Ridge. The aeolian sand comprising these dunes was later solidified into calcareous sandstone, comprising the Haruvit Kurkar Member of the Gaza Formation, which is known from the southern coastal plain. The central coastal plain and the Carmel areas, in which the Calabrian sea transgressed up to the Cenomanian and Turonian mountainous formations, show a different picture. Sand was not accumulated here and only beachrocks are known from the Carmel, at elevations of 105–115 m above present sea level. No Calabrian sediments are known in the Zevulun Valley and the Western Galilee coastal plain, which were probably elevated areas in these times, and beachrocks are to be sought farther west of the present-day coastline.

The main river systems continued their activity, draining the Transjordanian Plateau to the Mediterranean through the Bethlehem and HaMeshar Systems. The southernmost part of the country was drained to the Red Sea through the Garof System. The considerably elevated Calabrian sea level caused diminution of the erosive energy of these channels, and as a consequence they were filled with fluviatile sediments, to comprise the lower parts of the Bethlehem Conglomerate, HaMeshar Formation, and Garof Conglomerate. The Dead Sea area and the southern part of the Southern Jordan Valley probably comprised an intermediate lake in the way of a river system draining the Transjordan Plateau to the Mediterranean. In this lake the lower part of the Ghor El-Qatar

Series was deposited. The difference in thickness of the correlative sediments, the Ghor El-Qatar Series attaining several hundred meters and the Bethlehem Conglomerate 20-30 m, calls for a local intermediate basin in the Dead Sea area. To the north conglomerates are not known for this period, but the first three flows of the Cover Basalt, of normal paleomagnetic polarity, filled the preexisting erosional relief in the northeastern Galilee, the Hula Valley, and the Central Jordan Valley.

The malacofauna and microfauna recovered from the lower part of the Ga'ash Formation indicate that the Calabrian sea was somewhat cooler than the present-day Mediterranean. Not much is known about the terrestrial fauna of this time. Pollen grains recovered from the lower part of the Ga'ash Formation indicate a rather dry climate, similar to that of the present day. Almost no arboreal pollen, except for some pine, were recovered from this part of the section, indicating that the mountainous type of forest did not exist in these times. The fauna of the overlying beds still bears a rather strong African stamp and it seems reasonable to conclude that the general landscape resembled the East African dry savanna flatlands, and covered by Gramineae and other grasses, and possibly *Acacia* trees. A single enclave of *Acacia albida* from the western foothills of Judea might be a relic of Preglacial Pleistocene times. *Acacia* is almost always underrepresented in the pollen spectra, even in places where it grows abundantly, so that the pollen spectra for the Calabrian period cannot yield any evidence for its occurrence or nonoccurrence in these areas. No human remains are known from the Calabrian in Israel. Although the site of Bethlehem was thought by its early excavators to include artifacts, later studies showed that these are natural in origin and do not constitute evidence for hominid occupation of the country in those times.

Donau

The Donau Glaciation, separating the Calabrian from the Sicilian, took place from about 2.4 to 2.1 million years ago. The sea level regressed down to 20–30 m below that of the present day, and a rather wide coastal plain was exposed to erosional and pedogenic processes. The typical pluvial climate paleosol, hamra, was formed on the coastal plain and presently comprises the Ze'elim Hamra Member of the Gaza Formation. Only rare outcrops of this hamra are known from southern Israel, due to subsequent erosion and to coverage by younger sediments. The flatland morphology and the wide, meandering rivers continued to act as such also during the Donau. Apparently there were some differences in the erosional and depositional regimes of these rivers, but no detailed petrological studies of the conglomerate formations are available. Pockets and beds of red clays, very rich in titanium and consisting almost solely of kaolinite, are intercalated with the conglomerates, especially those of Bethlehem. These most probably indicate a more humid climate during the Donau. In the Dead Sea area the Ghor el-Qatar Series continued to be deposited, possibly in a more clayey facies.

The Cover Basalt continued to be poured to the north, and synchronous with the Donau are probably the first or perhaps also the second flows of reversed paleomagnetic polarity. It seems that the Bethlehem fauna should be ascribed to this stage. The animals mentioned by Hooijer from the Bethlehem bone-bearing bed all require ample quantities of open water. The crocodiles recovered by Horowitz from the Bethlehem Conglomerate also point to the same conclusion. Stratigraphically, the Bethlehem fauna could be assigned, in comparison with Tobien's definition (1970), to the middle and upper Villafranchian. This span corresponds to the entire Preglacial Pleistocene, with no possibility of differentiating between its stages by means of large animals. It is only vertebrate microfauna that can be used to distinguish between the middle and the late Villafranchian, and these unfortunately were never unearthed from the Bethlehem bone-bearing bed, possibly due to their bad state of preservation. Some locally restricted lacustrine phases within the HaMeshar Formation conglomerates may also be tentatively assigned to the Donau, mainly on negative evidence. It is inconceivable to have lakes, even of a rather restricted extent, in the southern Negev under the Calabrian or Sicilian interpluvial climates. Except for assignment of the Bethlehem fauna to the Donau no other faunal remains are known from this stage. The Ze'elim Hamra Member did not yield any fauna; nor are pollen spectra available. The ensuing paleogeography in Donau times is therefore of a rather wide coastal plain, a flat country occupied by meandering rivers, which in some places have turned into intermediate lakes with presumably rather rich vegetation and animal life. To the north, basalts and basaltic soils constituted the landscape. The savannah type landscape still prevails, but this time it is the more humid savannah, comparable to the lowlands of Eastern Africa. No hominid remains are known for this period, although at an early stage some flint implements and fractured bones were thought by Stekelis to be man-made, which later proved to be of natural origin.

Sicilian

The Sicilian stage, which took place from about 2.1 to 1.8 million years ago, is recorded in Israel by the Eyal Ingression of the Mediterranean, which reached elevations of 80–90 m above present sea level. The Eyal Ingression pushed forward dunes that formed the Yakhini Kurkar Ridge, reaching elevations now 140–150 m above sea level. The sand dunes later solidified into calcareous sandstone, comprising the Gerar Kurkar Member of the Gaza Formation, overlying the Ze'elim Hamra. In Haifa Bay and the Western Galilee coastal plain the Eyal Ingression is not recorded, possibly because these areas were above the average sea level and only subsided later, during the Glacial Pleistocene. The landscape in Sicilian times was quite similar to that of the Calabrian. The hinterland still comprised a vast flatland with rivers coming from Transjordan and crossing the country to the west, while in the Elat area the Garof System was still active. The rising Sicilian sea level renewed deposition of gravel in the drainage systems of Bethlehem, HaMeshar, and Garof, overlying the clays deposited during the preceding, Donau Glacial times. Most of the coastal plain was covered by the Eyal Ingression sea and the upper part of the Ga'ash Formation was deposited in this area. Beachrocks, at elevations of 80–90 m, are known from the Negev, eastern Sharon, and the Carmel. To the northeast, in the Central and Northern Jordan Valleys and in the Upper Galilee, the last flows of the Cover Basalt, with reversed paleomagnetic polarity, were outpoured. In the Dead Sea area, the upper part of the Ghor el-Qatar Series was deposited by the Bethlehem river system. The upper part of the Garof Conglomerate was deposited at the Elat area. Pollen assemblages for the Sicilian period from the Mediterranean coastal plain indicate climatic conditions that were quite similar to those of the Calabrian and not so much different from those of the present, namely, a rather warm and dry interpluvial climate, and characterized by very little arboreal pollen. The pollen spectra represent a dry savannah landscape for this time in Israel. The marine malacofauna and microfauna both indicate that the Sicilian sea was somewhat cooler than the sea at present, but somewhat warmer than during the Calabrian. No hominid occupations are known from the Sicilian of Israel.

PREGLACIAL PLEISTOCENE: CONCLUSIONS

During the Biber, Calabrian, Donau, and Sicilian stages of the Preglacial Pleistocene, the most striking aspect of the landscape of Israel was the flatland morphology, with wide, meandering rivers leading across the entire country to the Mediterranean and the Red Sea. No signs of rift activity are apparent in the present-day Jordan–Arava and Bay of Elat areas. The mountainous backbone of Israel to the west and the Transjordanian Plateau to the east were not yet uplifted in these times, thus rivers flowed directly from east to west. Rivers, originating in Transjordan, crossed the area with only a single intermediate lake at the present-day Dead Sea Region, the Ghor el-Qatar Lake. The Preglacial Pleistocene was a period in which Israel was a vast, flat savannah. During the interglacials, the transgressing Calabrian and Sicilian seas covered almost the entire coastal plain and conglomerates were deposited in the river channels. The interpluvial climate of these times made the country look like the dry savannah of Eastern Africa. However, during the Biber and Donau pluvial periods the sea regressed considerably, somewhat west of the present-day Mediterranean coastline, while a more humid climate resulted in a type of wet savannah, reminiscent of present-day lowland savannahs of Eastern Africa. Similar processes took place in the Bay of Elat area, which was drained to the Red Sea by the Garof River System. Deposition along the Garof rivers was also mainly controlled by sea level changes, with incision during the Biber and Donau regressions, and gravel filling during the Calabrian and Sicilian ingressions. At the same time, throughout the entire Preglacial Pleistocene, the northeastern part of the country was inundated by extrusions of Cover Basalt lavas.

GLACIAL PLEISTOCENE

The onset of the Glacial Pleistocene brought considerable changes to the morphology of the Levant, due to the beginning of tectonic activity in the Levantine Rift System. The influence of this activity was twofold in Israel. The subsiding Jordan–Arava Rift Valley created the endoreic system of the Dead Sea, while to the south, the Red Sea entered the now open Bay of Elat. The uplifting mountainous backbone further divided the country longitudinally. As a consequence, the flatland morphology of Preglacial Pleistocene times ceased to function and new river systems began to incise into the elevated areas, flowing to the Mediterranean, the Dead Sea, and the Bay of Elat. The country comprised four regions at this time: the coastal plain, the mountainous backbone, the Jordan Rift Valley, and the Bay of Elat, each subject to different erosional and depositional processes.

Günz

The Günz Glacial stage took place approximately 1.8 to 1.5 million years ago. Some subdivisions of this stage are known from Europe, but due to the scarcity of data in Israel, the entire stage will be dealth with as a single temporal interval. During the Günzian stage, the Mediterranean regressed down to about 40–50 m below present sea level, where it left a fossil dune ridge presently buried under seawater and later sediments. The newly exposed coastal plain consisted mainly of sandstones and calcareous sandstones, deposited by the preceding Eyal Ingression, which were subjected to two processes during the Günz: fluvial processes, which comprised both erosion and gravel deposition, and pedogenic processes, which resulted in the formation of red, hamra type soils. Both the fluviatile sediments and paleosols of Günzian age are designated as the Hasi Member of the Gaza Formation.

The flatland morphology and long, meandering rivers of Preglacial Pleistocene times ceased to exist due to taphrogenic activity along the Levantine Rift System, which opened and created the Dead Sea endoreic system. As a result, the uplifting mountainous backbone was eroded toward two base levels, the Mediterranean to the west and the Dead Sea to the east. The ensuing new wadis and rivers cut through the flatland Preglacial Pleistocene morphology, incising the peneplains, the Bethlehem, HaMeshar, and Garof conglomerates, and the Cover Basalt, creating new hydrographic networks. The pluvial climate considerably influenced the form of erosion. Due to the weaker erosion, the availability of rainwater, and the ensuing rich vegetation, gentle slopes were developed and rather wide, gently sloping valleys began to develop both toward the Mediterranean and to the Dead Sea. Similar phenomena could be observed in the drainage system leading to the Bay of Elat, as well as in that leading to the Dead Sea from the eastern, newly elevated Transjordanian Plateau. The Bay of Elat was formed at this time, while the erosion channels no longer flowed as far south as the Red Sea, but were met by the new erosion base level quite closely, at the area of Elat–Aqaba. As a result, the previous Preglacial Pleistocene Garof Conglomerate was deeply incised by the Günzian wadis, but these developed rather gentle, wide valleys due to the pluvial climate. Although the present form of environmental gradient from north to south existed also during the pluvials, the rainfall pattern was different during the pluvials as compared to the present day and to the interpluvials. The main difference was the occurrence of some quantity of summer rains, with the rainfall mainly dependent on the occurrence of warm fronts rather than the cyclonic thunderstorms of the interpluvial periods. As a result, torrential erosion was uncommon, and even around the Bay of Elat the differences in the wadi profile morphology between pluvial and interpluvial periods are quite striking. Unfortunately, no way of dating the respective benches and terraces in the wadis leading to the Bay of Elat is available, and therefore only the general character of the landscape can be inferred at the present stage. In the mountainous backbone, however, the problem of dating was partially solved and the first, highest gentle slope morphology which cuts into the Preglacial Pleistocene Plateau is tentatively regarded as of Günzian age.

The Jordan Valley had been divided by Günzian times into its three subbasins. The Dead Sea basin, the deepest, continued to be filled with the middle part of the Upper Dead Sea Group. The sediments are mainly lacustrine and apparently the Günzian Dead Sea lake occupied an area considerably larger than the present-day Dead Sea, down to Hazeva, where the lake shore deposited the Fourth Lakeshore Terrace of this area. The Günzian sediments of the Central Jordan Valley comprise the Erk el-Ahmar Formation, which was laid down in a rather shallow lake that occupied a considerable part of the valley. The exact extension of the Erk el-Ahmar Lake cannot be delineated due to the scarcity of outcrops, resulting from the fact that in most cases the Formation is deeply buried under younger rocks. The Günzian correlative of the Erk el-Ahmar Formation on the eastern side of the Central Jordan Valley was designated as the Abu Habil Series. It should be noted that the Abu Habil Series is probably correlative both to the Erk el-Ahmar Formation and to the overlying Ubeidiya Formation. Therefore, only the lower part of the Abu Habil Series is correlative to the Günzian Erk el-Ahmar Formation. The Hula Valley was occupied by the Gadot Lake, which deposited the chalky Gadot Formation. Rivers that led to the Gadot Lake deposited conglomerates of the Hazor Gravel to the south and especially to the southwest of the lake, while rivers coming from the north deposited gravel of the lower part of the sequence, penetrated by Hula I borehole.

Pollen analyses of Günzian sediments are available only for the lacustrine formations of the Jordan Rift Valley. The three formations of Günzian age, the Gadot, Erk el-Ahmar, and the corresponding part of the Upper Dead Sea Group, have yielded pollen spectra of typical pluvial vegetation, comprising quite a rich oak forest of the northern Mediterranean type. Fossil fauna is hardly known for the Günzian period. The malacofauna of the Erk el-Ahmar Formation was studied in detail and comprises several species that are reminiscent of the Pliocene freshwater malacofauna, together with some new species. The charophytes of the same formation have similar nature, and rather strong affinities with those of the Pliocene. Vertebrate remains are hardly known from the Günzian except for a long bone recovered from the Hasi Member, possibly belonging to a camelid or a giraffe. The ensuing environment is as follows. The coastal plain was rather wide and occupied by streams and rather fertile soils. The elevated mountainous backbone was incised by gently sloping wadis and considerable parts probably were covered by thick oak forests of the northern Mediterranean type, developed on the terra rossa soils. The Jordan Valley was occupied by three lakes, the Gadot Lake to the north, the Erk el-Ahmar Lake in the Central Jordan Valley, and the "Fourth Lake" in the Dead Sea area, all of them of considerable areal extent. The Erk el-Ahmar was a freshwater, intermediate lake. The Gadot Lake might have been blocked at some time and there are indications, like the higher percentage of Chenopodiaceae in the pollen spectra, that periods of slight salinity occurred during Günzian times in the Hula Valley. The "Fourth Lake" of the Dead Sea area was most likely a saline one, although admittedly almost no information is available on the matter. In the Elat area, the newly created Bay of Elat influenced morphology and drainage, but essentially the pattern did not change much. The most important change was the dissection by the new Günzian wadis of the Garof peneplain, with incision due to the uplift of adjoining mountains. On the eastern side of the Bay of Elat and the southern Arava the change in the hydrographic pattern was more acute. Most of the wadis, previously leading to the southern Arava from the Transjordanian Plateau, and which deposited the eastern correlatives of the Garof Conglomerate in the form of huge alluvial fans of the southeastern Arava, were severed from their former heads by the uplifting Transjordanian Plateau. As a result, a single wadi developed, draining the area to the south, which captured all those heads, and has fed into the Bay of Elat since Günzian times. Presently this wadi is known as Wadi el-Yutm, and joins the Bay near the town of Aqaba. Somewhat to the north, on the Transjordanian Plateau, the internal basin of El Jafr was probably formed at the beginning of the Glacial Pleistocene, but no Günzian sediments have been reported from this area.

The only signs of human settlement in Günzian times in Israel are a single chopping tool which was found *in situ* in the Hasi Member of the southern coastal plain, near Nahal Shiqma and several artifacts recently found *in situ* in the Erk el-Ahmar Formation. However, at least two sites of this age are known from Lebanon, both embedded in river gravels of the Orontes Valley. One is Sharia, in which bones and teeth of *Archidiskodon meridionalis* were found, and the other is Rastan, not far from this same locality. The artifact assemblages of these two sites were designated as "Para-Acheulian." It seems premature to talk about the environment of hominid settlements of Günzian age, but the four find spots, the two sites in Lebanon and the sites in Israel, were found embedded in river gravels together with bones of rather large mammals. It might be tentatively said that the Günzian hominids probably dwelled on river banks, where large and perhaps also small game were available as food. One of the interesting problems concerning Günzian paleogeography is the northward extension of the Hula Valley. it is not yet clear whether the Metulla-Marj Ayyun Block system was fully elevated in Günzian times, and in fact even during Mindel times, since the malacofauna of the Günzian and the Mindelian formations of the Hula Valley show strong connections with the Orontes system. The Beqa'a was connected with the Hula Valley and the Central Jordan Valley in late Pliocene times. The Cover Basalt of the Preglacial Pleistocene might have brought about an end to this connection, but it is not clear to what extent, and it is plausible to assume that during the more humid early pluvial periods of the Glacial Pleistocene some hydrographic connection with the Orontes system still existed, and totally ceased only when the Metulla-Marj Ayyun Block became fully elevated, as it is today.

Milazzian

The Millazian stage is sometimes called late Sicilian or Sicilian II, due to its faunal similarities with the earlier Sicilian *s. str.*, and corresponds to the Günz-Mindel Interglacial, which took place at about 1.5-1.2 million years ago. The Mediterranean sea level rise is known in Israel as the En Besor Ingression, which reached elevations in the order of 50-60 m above the present-day sea level. The En Besor Ingression deposited the lowermost member of the Yarkon Formation, M1a Member, on the coastal plain of Israel, and left remnants of beachrocks at elevations of 50-60 m along the entire coastal plain, from the northwestern Negev to the northern tip of the Carmel. The sea also considerably ingressed into the now-subsided rift of the Zevulun Valley, depositing corresponding littoral-marine sediments, which were penetrated at depths of 60-80 m below present sea level. The dunes, which were pushed eastward of the En Besor Ingression created the Nir'am Kurkar Ridge, and at present reach elevations of approximately 120 m above sea level. The sand dunes were later solidified into calcareous sandstone of the Tell Fara Kurkar Member of the Gaza Formation, which is known through the entire country, except for the Zevulun Valley area, where its correlatives are probably buried. The Tell Fara Kurkar Member is also known from the Western Galilee coastal plain, comprising the first and easternmost kurkar ridge of this area. The mountainous backbone rivers leading to the Mediterranean, to the Dead Sea, and to the Bay of Elat have cut rather steeply into the preexisting gentle slopes of the land cover from the previous Günzian Pluvial. As a result, a morphologic bench was formed along most of these wadis, which can sometimes be clearly seen even today, in places not attacked by subsequent erosion to a great extent. Erosional processes prevailed in the mountainous areas and the previously laid colluvial soils were washed down toward the lower areas. No sediments are known for this period from the mountainous backbone, and it seems that the rate of erosion was considerable, in the fashion prevailing in these areas at present.

The only lacustrine sediments known for the Milazzian were penetrated by Melekh Sedom I borehole, at the southern basin of the Dead Sea. These represent a hypersaline lake or sebkha, very restricted in area. In the Central Jordan Valley, the Erk el-Ahmar and older formations were subject to erosion and no lake is known for this period. In the Hula Valley, the Milazzian is represented by a gray paleosol, about 2 m thick, separating the Gadot from the overlying Mishmar HaYarden Formation of Mindelian age. A very restricted lake or peat bog might have existed in the deeper parts of the Hula Valley during this period, but the sediments were never penetrated by boreholes. Pollen spectra for this period, recovered from the Mediterranean ingressive sediments of the M1a Member, indicate a rather poor, interpluvial Mediterranean vegetation. The microfauna of this member represents some warming of the seawater by disappearance of the cooler elements, which were typical for the Preglacial Pleistocene Ga'ash Formation. Due to the scarcity of sediments from this period no other faunal or floral remains are known. The climate, according to the pollen spectra and modes of erosion, was interpluvial. Rains were limited to a rather short winter, and poured down under the influence of cyclonic thunderstorms. These rains, resulting in torrential floods, were responsible for the rather steep erosion recorded in the mountainous areas. The Jordan Valley was rather dry and only a small, hypersaline lake is known from the terminal base level at the Dead Sea. In this area too, erosion processes prevailed during the Milazzian. Only rare pedogenic processes are known for this period, which resulted in paleosols like the one known from the Hula Valley. The difference between this paleosol and paleosols forming under humid climates is considerable. While the pluvial paleosols are mostly red and quite well washed of their carbonates, the Milazzian paleosol is gray and very carbonatic, of the rendzina type.

No hominid settlements are known for this period from Israel, most probably due to both the interpluvial semiarid climate, which could not support considerable food supplies in the form of edible plants and game, and to the considerable rate of erosion, which removed rather quickly any soil that might have been formed in the mountainous areas and the Jordan Valley. The coastal plain, on the other hand, was for the most part submerged by the sea or by the dunes, and could not support a favorable environment. Only a single occupation from this stage has been found in the Levant, in Lebanon, on an elevated beach some 95 m above the present-day sea level, which corresponds there to the Milazzian. This is the site of Borj Qinnarit, southeast of Sidon, from which only 17 artifacts were recovered. Due to the scarcity of data it is hard to say anything about the environment of this site.

Mindel

The Mindel Glacial was apparently a rather long stage, which took place approximately from 1.2 million to about 600,000 years ago. As a result, extensive sedimentary and pedogenic processes took place in the country and are quite widespread presently, despite subsequent erosion and coverage. The Mindel Glacial separates the Milazzian from the subsequent, Tyrrhenian Ingression. The average Mediterranean sea level had dropped to about 55–60 m below that of the present and created a fossil dune ridge, which is presently buried under the sea. As a result, the coastal plain was rather wide and subject to erosional and pedogenic processes. The Dorot Hamra Member of the Gaza Formation was formed during this stage and comprises both paleosols and paludine deposits. Some gravel horizons interfinger with the Dorot Hamra but are subordinate. The mountainous backbone rivers flowing to the Mediterranean, the Dead Sea, and the Bay of Elat again shaped their shoulders rather gently in the uplifting terrains, and colluvial soils were probably accumulated in the valleys. The Jordan Valley was again occupied by lakes in each of its three subbasins. In the Dead Sea area, the "Third Lake" left lakeshore terraces near Hazeva, in the northern Arava, some 30–40 km south of the present-day southern tip of the Dead Sea. In the Central Jordan Valley the Ubeidiya Lake deposited the lacustrine sediments of the Ubeidiya Formation and the corresponding upper part of the Abu Habil Series. In the Hula Basin the Mishmar HaYarden Lake spread over a considerable area, occupying most of the basin floor. Rivers running to these lakes left gravel, which was deposited in the channels and in their outlets to the lakes. These river gravels are mainly prominent in the Central Jordan Valley, in which they comprise part of the Ubeidiya Formation, and in the northern sector of the Hula Valley, where they comprise the lateral conglomerates of the Mishmar HaYarden Formation, penetrated by several boreholes. The Mishmar HaYarden was a freshwater lake, which probably graded southward into peat bogs. It seems, according to its malacofauna, that it had some connections with the Beqa'a and Orontes systems, the nature of which is unknown. The Ubeidiya was mostly a freshwater lake, but short phases of higher salinity are known from the deposition of clays rich in gypsum. The "Third Lake" of the Dead Sea basin was most likely saline, although less than the lake of Milazzian times.

Toward the end of the Mindel two basaltic phases, which were probably extruded on the Golan (on which volcanic activity was almost continuous throughout the Glacial Pleistocene) reached the Jordan Valley. The Yarmouk Basalt reached the Central Jordan Valley, but did not extend far into the basin. The Yarda Basalt inundated the southern sector of the Hula Valley and the northern sector of the elevated Korazim-Gadot Block. The last mentioned area might have been the source for some of the flows of the Yarda Basalt, but this is not yet fully ascertained. These basalts have normal paleomagnetic polarity and together with their dates—680,000, 640,000 and 560,000 years ago—indicate that they cooled at the beginning of the Brunhes Normal Epoch. Floral remains of the Mindel stage are known from a considerable number of pollen spectra, recovered from lacustrine sediments of the three subbasins of the Jordan Valley. These are quite rich in arboreal pollen; in fact, in comparison with the pollen spectra of other pluvial climates in Israel, they are the richest. Arboreal pollens attain up to 80 or 90% of the total pollen count, and are derived almost exclusively from oak, probably *Quercus ithaburensis.* Some leaves of other Mediterranean elements were also recovered from the Ubeidiya Formation, such as *Pistacia* and *Rhus tripartita.* The faunal record of this period is very rich and comes mainly from the Ubeidiya Formation. It is discussed in detail in Chapter 7. Some scarce vertebrate remains are known also from the coastal plain, notably a

Leptobos, and from the Mishmar HaYarden Formation, mainly *Hippopotamus.* The flora, the fauna, and the modes of erosion indicate a rich vegetational cover and extensive wildlife. The northern and central parts of the country were covered by a very well-developed oak forest, most probably of the type prevailing at present in Turkey or in northern Syria. The composition of the fauna indicates for the first time an important influence of European elements, especially in the occurrence of animals such as deer and horse. Some African elements also still lived in the country, especially in ecological niches of locally favorable climate, such as the Central Jordan Valley. The southernmost extension of the oak forest is not known due to lack of data, but it seems that it reached at least the area of the present-day northern Negev, as concluded from the type of paleosols formed during the Mindel in these areas, being red and very well washed of lime.

Habitations of Mindel age are known in Israel from two localities: first, the well-known site of Ubeidiya in the Central Jordan Valley; second, some occurrences of Ubeidiya-like artifacts recently recovered from the Dorot Hamra Member at the Nahal Shiqma area of the northwestern Negev indicate the presence of man there as well. Some pieces of questionable basalt flakes were recovered from the Mishmar HaYarden Formation, south of Lake Hula. Sites of Mindel age are also known from Lebanon and from northern Syria, such as the sites at south Beqa'a, along the Orontes Valley, of Nahr el-Kebir, and several sites that were found embedded in the Euphrates terraces. The Mindel sites of the Near East represent a very similar environmental context. They are all situated along rivers or lake shores, in places that are very rich in water, vegetation and game. It seems, from the richness of the excavated sites, and especially Ubeidiya, and from the occurrences of living floors in these sites, that the Mindel habitations were basically sedentary, connected with water and availability of game. The Mindel inhabitants of the Near East were probably hunters, and settled at the very places where game was richly available. The idea of carrying water bags or carrying the hunted food from far away to their sedentary camp probably did not yet occur to peoples at that time.

Tyrrhenian

The Tyrrhenian stage took place from about 600,000 up to 300,000 years ago. During this stage warm water fauna penetrated the Mediterranean, some of which, notably *Marginopora,* and more rarely *Strombus bubonius,* reached the eastern Mediterranean. Warm water fauna have persisted in the Mediterranean almost up to the present; therefore, the subsequent ingressions were sometimes also named "Tyrrhenian." We are presently dealing with the stage originally called Tyrrhenian, but known also as "Paleo-Tyrrhenian," "Early Tyrrhenian," or "Tyrrhenian I," corresponding to the Mindel–Riss Interglacial. The Tyrrhenian sea level rise caused the Azor Ingression to deposit the M2 Member of the Yarkon Formation on the submerged coastal plain. The Azor Ingression reached elevations of 35 to 45 m above present sea level and left a series of beachrocks at this elevation, from the south of the country north to the Carmel. In the subsiding Zevulun Valley, Tyrrhenian sediments were penetrated 50–60 m below present sea level by a series of boreholes. The Azor Ingression pushed forward a dune ridge, the Erez Ridge, which presently reaches elevations of up to 80 m above sea level in the central and southern parts of the country. On the Carmel, only beachrocks are known. In the Zevulun Valley, the sandstones are probably buried under subsequent sediments, while in the western Galilee coastal plain the Erez Ridge is known as the "Sar'ar-Evron Ridge," attaining an elevation of about 30–35 m above sea level. The dune sand comprising the Erez Ridge later solidified into the calcareous sandstone of the Gedera Kurkar Member of the Gaza Formation. Consequently, most of the coastal plain was covered in Tyrrhenian times either by the Mediterranean or by dune sands. Only the eastern part of the wide coastal plain of the northwestern Negev was not covered by the sand dunes of the Azor Ingression, and this is probably the reason why sites of Mindel age are exposed in this area.

In the mountainous areas, the gentle slopes of Mindel times were cut rather steeply by strong erosion in Tyrrhenian times, without depositing any gravel or colluvium in these areas. Moreover, most of the colluvial soils deposited during previous pluvial climates on the mountains were washed away by floods. As a result, a second bench along the mountainous backbone wadis was formed in the entire country, in wadis leading to the Mediterranean, the Dead Sea, and the Bay of Elat. In the Jordan Valley only restricted lakes occurred, in the Dead Sea and the Hula Basin. In the Dead Sea the lake was hypersaline, while in the Hula Valley it was very restricted in area and in fact frequently graded into peat bogs. The lacustrine sediments and peat deposited in the Hula Valley are only known from boreholes and do not crop out on the Basin's rims. These comprise the Ayyelet HaShahar Formation. It seems that erosion prevailed in the Jordan Valley during Tyrrhenian times and the lakes are only subordinate in the system. Some rare occurrences of river gravel denote the existence of rivers, which in some instances have deposited sediments, while most of the rivers were subject to strong floods that carried their loads down to the Dead Sea. Some time during the Tyrrhenian the Jordan Valley was subject to considerable tectonic activity, which tilted the former strata and deepened the subbasins, strongly connecting the central and southern sectors.

Tyrrhenian pollen spectra are available for the Dead Sea, the Hula, and the Mediterranean areas. The spectra are mostly nonarboreal pollen, in which Gramineae, Chenopodiaceae, and *Artemesia* are quite common. Arboreal pollen are rather rare, comprising several percent only of oak in the Jordan Valley and some pine in the coastal plain. In general they resemble the present-day pollen spectra and consequently suggest a similar vegetation and climate. The marine Tyrrhenian fauna is quite rich, comprising a variety of species that prefer warm water. It was concluded that the Mediterranean was somewhat warmer than at the present day. Vertebrates are only known from a single site, Evron, in the Western Galilee coastal plain, comprising warthog, hippopotamus, and elephant embedded in a yellow-green clay that probably represents floodplain deposits of a small river which flowed in the close vicinity. The climate was interpluvial, not different basically from present-day conditions. Rains were restricted to a short winter season and were brought to the country by cyclones and thunderstorms. As a consequence the vegetation was rather poor, and erosional processes, creating steeply dipping slopes, prevailed in the mountains and also to some extent in the Jordan Valley. Sediments from running water are only known from the north of the country, at Evron. The coastal plain was occupied by seawater and dunes.

Only a single occupation is known for this period in Israel, the site of Evron, which was a hunting-butchering site close to a river. Several other sites are known for the Tyrrhenian stage in Lebanon and Syria, of which the best known is Latamne, situated on the bank of the Orontes River. All these sites seem to bear the tradition of Mindel habitation, namely, sedentary, permanent sites very close to water courses and to places where game was available. Pollen analyses from Latamne and the constitution of its vertebrate fauna indicate that the environment in Tyrrhenian times in the vicinity of Latamne, some 200 km north of Israel, was more or less similar to a pluvial environment in Israel, which means that in interpluvial times the climatic belts had moved northward at least 200 km. As a consequence hominids followed the suitable climatic and environmental conditions and were settled more to the north, as compared to the preceding Mindel and the succeeding Riss pluvial stages. The scarcity of settlements of Tyrrhenian age in Israel might also be a result of the morphology and erosional processes. Since most of the elevated areas were subject to erosion, no sediments that could bear evidence of possible habitations were preserved from this time. The coastal plain, covered by the sea and dunes, did not favor any habitation, except for the site of Evron, which was situated at the back of the Tyrrhenian dune ridge, where most likely the river coming from the Galilee was blocked by the dunes to form marshes in which game was available. In the Jordan Valley, on the other hand, where local conditions could have been suitable for habitation, all the sediments corresponding in age to the Tyrrhenian stage are buried under succeeding sediments. As a consequence, even if sites had been present in the Jordan Valley in Tyrrhenian times, they could not be found. In this case, even if we assume some sites connected with the Ayyelet HaShahar lake, they still must bear the same paleoenvironmental consequences.

Riss

The Riss Glacial stage took place from about 300,000 up to about 120,000 years ago. It was divided in the Hula Valley into early and late pluvial phases, separated by an interstadial. Unfortunately, in most of the other Rissian occurrences in the country, the sequences have not been studied in great detail, or were not so well preserved as to show this subdivision, and the stage will be therefore mostly treated as a single unit. The Rissian Glacial stage separates the Tyrrhenian from the Monastirian ingressive stages of the Mediterranean. During Riss times sea level dropped down to 70–80 m below m.s.1. and the fossil sandstone ridge that was formed on the Rissian beach is now covered by the sea. The coastal plain was considerably wider than at present and pedogenic and paludine processes accompanied by some fluviatile activity took place over it, creating the Holon Hamra Member of the Gaza Formation. The Holon Hamra Member mostly comprises paleosols, but in some places grades to paludine deposits, representing extensive marshes that occupied the wide coastal plain in Rissian times. The uplifting mountainous backbone was further incised by the Rissian rivers and wadis, forming gentle shoulders. On these shoulders colluvial soils, conglomerates, and gravel have accumulated, designated as the Baqa'a Conglomerate. Considerable spring activity is known for the Rissian times in Israel, creating three principal travertine formations, the Ga'ton Travertine in the Western Galilee, the Kefar Yuval Travertine in the northern Hula Valley, and the Seif Travertine, south of the Dead Sea.

The Jordan Valley during the Riss was occupied by lakes and rivers depositing lacustrine and fluviatile formations. The Benot Ya'akov Formation was deposited in the Hula by a rather large lake which covered the entire valley. The Seif Lake covered the Dead Sea area, extending down to the Hazeva area, where lakeshore terraces are present, connected with the Seif Travertine. In the Central Jordan Valley, the Yarmouk and Jordan Rivers spread over wide floodplains on which gravel was deposited and paleosols were formed. No lake is known for the Rissian period in the Central Jordan Valley, most probably as a result of the Tyrrhenian tectonic phase, which opened strong connections between the Central Jordan Valley and the Dead Sea Basin, therefore draining all the waters down to the Dead Sea. However, the extensive fluviatile Naharayim Formation, which covers considerable areas in the Central Jordan Valley, proves that water activity was stronger than at the present. The Benot Ya'akov was a freshwater lake, while the Seif was hyposaline. Rissian pollen spectra indicate that the country was covered by a rather dense, northern Mediterranean vegetation, comprising mainly oak forests that went down probably to the northern Negev. An interesting element of these forests is *Fagus* (beech), which migrated to the country from the north, and is known only from Rissian times. During the interstadial separating the early from the late Riss the vegetation cover was less extensive and thermophilous elements, such as olives, penetrated. Still, the vegetation was richer than at present. The fauna was quite rich and large vertebrates such as elephant, equids, rhinoceros, deer, and others are known from the Jordan Valley at the Gesher Benot Ya'akov area down to the northwestern Negev, where their remains were recovered from paludine sediments of the Holon Hamra Member. Elephant is also found at the site of Holon near Tel Aviv. The freshwater malacofauna, especially from the Benot Ya'akov Formation, represents the strong influence of northern elements, among which the invasion of *Viviparus apameae* is very conspicuous. Like *Fagus*, the intrusion of *Viviparus apameae* is only known from the Rissian period in Israel.

The climate in Rissian times was pluvial, which could maintain the rich vegetation and fauna. Rainfall was of the warm front type and the country apparently enjoyed some amount of summer rains as well. As a consequence the mountainous areas were subject only to mild erosion, creating gentle landscapes. The coastal plain was wide, covered by soils and marshes, most probably maintaining a rich vegetation and wildlife. The Jordan Valley was occupied by lakes to the north and to the south, while the Central Jordan Valley was occupied by the wide floodplains of the Yarmouk-Jordan System. The Bay of Elat area also enjoyed a mild erosion, and gravel, intermingled with colluvial materials, accumulated in many of the wadis. It is quite difficult to assess the amount of vegetation cover in the southernmost Negev, but it seems that it was considerably richer than at present. The environment was therefore quite favorable for plants, animals, and human settlement.

Human settlement in Israel, as well as throughout the entire Levant, was rather dense during the Rissian Pluvial stage. Two cultural phases are known for the Riss: the Middle Acheulian, which is known from several rather large sites in the country, and the Upper, or Late Acheulian, which is very common all over Israel, as far south as the central and possibly also the southern Negev. The transition phase between these two cultures is known only from a single site in northern Israel, Ma'ayan Barukh in the northern Hula Valley. The Middle Acheulian sites are dominated by crude, rather large handaxes made in the Early Acheulian tradition, while the Late Acheulian sites (or rather find spots) are characterized by the predominance of fine, thin handaxes, which are much lighter than the former ones. Several Middle Acheulian sites, Bar'am and Yir'on in the Upper Galilee mountains, Repha'im-Baq'a in Jerusalem, and Oumm Qatafa E, are known from the mountainous backbone of the country. This, it seems, is the first invasion of human settlers to the mountainous areas and the first indication of the usage of a cave as a sedentary base: the cave of Oumm Qatafa in the Judean Desert. Middle Acheulian sites are also known from Holon, in the coastal plain near Tel Aviv, and at Gesher Benot Ya'akov in the Jordan Valley, embedded within the Benot Ya'akov Formation. These are all sedentary, permanent sites which have in common the tradition of the Early Acheulian site pattern, except for the invasion of the mountains, which is new. All the sites seem to be intimately connected with water sources. Oumm Qatafa Cave, which is presently situated quite high above the thalweg of Wadi Hareitun, was in Rissian times at a totally different position. If one assumes the gentle slope of Rissian times to be connected together on both sides of the wadi, the ensuing Rissian thalweg is not much lower than the cave's level and therefore the settlers of Oumm Qatafa Cave could enjoy water from this wadi. The settlers of the Bar'am-Yir'on Plateau were probably connected with the numerous karstic sinkholes in the area, which up to the present contain water and were most likely used as water holes by game. The site of Holon was situated near a large marsh, once more an ideal place for game. The site at Gesher Benot Ya'akov was situated at the southern tip of the Benot Ya'akov Lake in the Hula Valley, and once more game was available. We do not know much about the site at Repha'im-Baq'a in Jerusalem, for two reasons: first, most of the artifacts, or at least a considerable part of them, were rolled in water, and therefore the site does not necessarily indicate *in situ* settlement of the area; second, present-day construction around the site prevented a search for the source of the archaeological material.

All the sites of the Middle Acheulian culture were probably connected with the first pluvial phase of the Rissian, which took place from about 300,000 to about 200,000 or 220,000 years ago. The transition to the Late Acheulian is known only from Ma'ayan Barukh. In this site, the handaxes are still rather crude, and are embedded in a paleosol interfingering with the Kefar Yuval Travertine. It is very probable that the paleosols were formed in this area due to some diminution in the water output of the springs, which corresponds to the drier interstadial separating the early from the late Riss pluvial phases, approximately 200,000 years ago. The interstadial climate, which resulted in shrinkage of the lakes, stronger erosion in the mountains, and possibly also some propagation of sand over the coastal plain soils, seems to be responsible for the scarcity of sites of this culture in Israel. They are much more abundant in Lebanon.

Late Acheulian sites are much more abundant over the entire country, down to the central and southern Negev. Handaxes were even found near Elat. Typical for the Late Acheulian settlement pattern is the rarity of large, permanent, sedentary base camps, and the large number of find spots in which single tools or small groups of tools, handaxes mainly, were found. Even the larger concentrations of handaxes, such as at Kissufim or Nizanim, do not seem to constitute real sites. They are not connected with bone material for the most part; at least the association of bones with the finds of handaxes is quite rare and limited. Gilead (1975) indicated no connection of the distribution of find spots of Late Acheulian handaxes with the present-day morphology. These handaxes are quite common in many areas of the country, especially where the Rissian sediments and paleosols of the Holon Hamra Member crop out. Occurrences of these handaxes in the mountainous areas are not rare. Gilead noted also that the Late Acheulian find spots are more restricted to the eastern side of the coastal plain, while the westernmost several kilometers yielded none. This conclusion must be viewed in the perspective of sedimentary processes of the succeeding Monastirian Ingression. The dune sands and beachrocks deposited by this ingression covered the Rissian paleosols in areas that were penetrated by the sea and covered by dunes. This gives the apparent picture of no Late Acheulian settlement in the western part of the coastal plain. In fact, the coastal plain in Rissian times was much wider than at present, and it might well be that Late Acheulian handaxes are still to be found, perhaps even buried under the Mediterranean.

The change in settlement pattern from the Early to the Late Acheulian is therefore quite striking. According to the pollen spectra, there is not much difference in the landscape of the country during the early and the late Rissian. We must therefore seek the reason for a different settlement pattern in the culture of the people. The Middle Acheulian people apparently hunted in the Early Acheulian tradition, living permanently in sedentary camps that were situated at the very places where game was available, namely, those localities where animals came to drink water. On the other hand, the Late Acheulian people made a considerable step forward. They no longer waited for game to come to them to be hunted, but went out in search for it. This change involved both a new concept and a new technology (cf. Bar-Yosef 1975a). These nomadic or seminomadic hunters considerably increased their food supply, which can be seen in the large number of sites and find spots. Hunted now were not only the big, heavy animals like hippopotamus and elephant, but deer, horses, and gazelles, which had added considerably to the menu since Early Acheulian times. The basic change in technology involved apparently two changes. One was the diminution in size of handaxes and the development of the pointed handaxe, which was much more useful in hunting small game; it could be thrown a longer distance and was much easier to carry along. On the other hand, moving some distance away from permanent water sources probably involved invention of water carrying equipment. This equipment was most likely made of leather; thus our sites would yield no evidence of it. It seems though that the wide scatter of the Late Acheulian handaxes and other implements over the different environments in Israel should hint at the invention of some equipment for water transport. To sum up the settlement pattern in Rissian times, the Middle Acheulian sedentary bases are known from many localities in the early Riss pluvial phase, connected with permanent water sources, and enjoying the favorable pluvial climate. The interstadial, drier climate had pushed the people to the north toward the Lebanon, and only a single site in the north of Israel is known for that period. The Late Acheulian people did not live in sedentary camps, but were rather nomadic hunters spread across the entire country in late Rissian times, once more under favorable climatic conditions. During the Rissian stage, therefore, one can envisage how, under similar climatic conditions, totally different settlement patterns evolved, due to cultural evolution. Another rather important cultural development of Rissian times was the invasion of mountainous areas, which also included the first use of caves as shelter, opening a new environment for human settlement.

Monastirian

The Monastirian, "Eu-Tyrrhenian" or "Tyrrhenian II" stage corresponds to the Riss–Würm (or Eemian) Interglacial and took place from approximately 120,000 to 70,000–65,000 years ago. The average Mediterranean sea level rose to about 18–20 m above that at present, causing the Poleg Ingression to inundate the western part of the coastal plain. In the submerged areas, the M2a Member of the Yarkon Formation was deposited, while beachrocks at elevations of 18–20 m above m.s.l. are known from the northern tip of the Carmel, southward along the entire coastal plain. In the Zevulun Valley the Poleg Ingression deposited littoral-marine sediments, encountered at depths of 15–30 m below sea level, penetrated by many boreholes. In the Western Galilee coastal plain, the Poleg Ingression reached somewhat west of the present-day coastline, probably because the area was more elevated than it is today. The Poleg Ingression pushed eastward dunes that constitute the Yad Mordekhay Ridge, attaining presently elevations of up to 60 m in the central and southern coastal plain. In the Carmel only beachrocks are known, while in the Zevulun Valley dunes are buried under the subsequent sediments of the subsiding rift. In the Western Galilee coastal plain, these dunes constitute the Akhziv Ridge, which runs along the present-day coast. The dune sands later solidified to form calcareous sandstone of the Ramat Gan Kurkar Member of the Gaza Formation.

A new development appears in Monastirian times in the northwestern Negev. Due to the fact that the ingression did not reach far landward, the remote parts of the northwestern Negev began to be covered with loess of the Ruhama Loess Member of the Gaza Formation, which has been deposited ever since in these areas. Stronger, torrential erosion processes deepened the mountainous backbone wadis and created rather steep slopes, cutting into the more gentle Rissian Baq'a Conglomerate and morphology, thereby creating the third bench running along most of these wadis. Lakes of the Jordan Valley shrank considerably, to form a small hypersaline lake in the Dead Sea area and peat bogs in which the Hulata Formation was deposited in the Hula Basin. The Central Jordan Valley basin only was subject to erosion during these times. At the end of this period, two basaltic formations were extruded and reached the Jordan Valley: the Hasbani Basalt of the northern Hula Valley, which came from the north and east and inundated some parts of the basin, and the Raqqad Basalt of the Central Jordan Valley and the Dead Sea area, extruded on the Transjordanian Plateau, where it is quite widespread. Several flows of the Raqqad Basalt reached the Jordan Valley and interfinger with the sediments, separating the Rissian conglomerates from the overlying Würmian lacustrine sediments. The areal extension of these basaltic flows on the Golan and the Transjordanian plateaus is quite considerable, but only subordinate shares have reached the Jordan Valley.

Pollen spectra of this period were recovered from the M2a Member, from the lower part of the sequence in the Tabun Cave, from the Hulata Formation in the Hula Valley, and from the Dead Sea Basin. The spectra indicate a rather poorly developed Mediterranean maquis of mixed elements—oak, pistachio, olive, and cypress—which was hardly developed in the northern part of the country, even less than at present. To the south, the country became a desert. The microfauna of the M2a Member indicates a rather warm sea, more or less of the same type as the present-day Mediterranean. No faunal remains are known from the Jordan Valley. The vertebrate fauna was studied in detail from the Tabun Cave and discussed in Chapter 7. The climate, as concluded from the pollen spectra, was interpluvial and the climatic belts moved far northward in comparison to the preceding Rissian times, even more to the north than their present position. Rains were limited to a short season during the winter and came to the country as the result of cyclonic thunderstorms. As a consequence of the poor vegetation and the cyclonic torrential rains, the rate of erosion in the mountainous backbone wadis was quite considerable, creating steeply sloping wadi shoulders. The environment in general was poor: mountains almost completely bare, a coastal plain covered by sea and dune sands, and an almost dry Jordan Valley.

As a consequence, most of the country was evacuated by the rich Rissian population, which moved northward to Lebanon and Syria. Many settlements of this age are known from the northern areas, but in Israel in fact only two are known—at the caves of Tabun and Amud, in which the Yabrudian culture was found. The Yabrudian people were hunters and sought shelter in caves, which were used as base camps. Deteriorating climatic and environmental conditions had some impact also on the culture. The great achievement of the Late Acheulian people, becoming seminomadic hunters actively looking for food, was abandoned, and the only sites known from Israel are permanent base camps in caves. It should be noted though that this is the situation only in Israel. In Lebanon, where the climate was more favorable, many sites and find spots of this age are known, showing a much more evolved culture than in Israel. The fine craftsmanship of the delicate and useful handaxes of the Late Acheulian period was abandoned in Israel, and the entire assemblage of the Yabrudian artifacts recovered from the caves of Amud and Tabun has a kind of degenerate appearance. This is the main reason why these cultures were thought of for some time as of Middle Acheulian or Early–Middle Acheulian affinity, predating the Late Acheulian, which looks much more evolved in terms of technique and craftsmanship. The stratigraphic relations and the palynological investigations of these sites proved that stratigraphically, the Yabrudian is younger than the Late Acheulian, and in fact represents a regression of the cultural achievement of Late Rissian times. It is quite conceivable that more habitations occurred in the country during Monastirian times, but due to the strong erosion, apparently nothing was preserved. If sites existed in the Jordan Valley, and especially in its northern part, they have been totally covered by subsequent sedimentary formations. Radiogenic ages of the Hasbani and Raqqad Basalts helped to date the end of the Monastirian to approximately 70,000 years ago. Marine sediments dated on the Lebanese coast, deposited by the same ingression, yielded ages of around 90,000 years ago.

Würm

The Würmian Glacial stage lasted from 70,000–65,000 to about 11,000 years ago. Climatically and eustatically, five phases were discerned within the Würmian stage in Israel: the Early, Middle, and Late Würmian pluvial phases, each separated by an interstadial. The Early Würm pluvial phase lasted from 70,000–65,000 to about 40,000 years ago. The sea level was rather low, down to about 90 m below that of the present, depositing a sandstone ridge that is presently buried under the sea. Pedogenic processes prevailed in the wide coastal plain, forming the Nahsholim Hamra Bed of the Shefa'yim Member of the Gaza Formation. The mountainous areas were subject to rather mild erosion, and colluvium accumulated in the wadi courses, forming the Nahshon Conglomerate, which comprises the "Upper Terrace." The Nahshon Conglomerate, which corresponds to the Hasa

Formation described from the Transjordanian wadis flowing to the Dead Sea. In the central and northern parts of the country it is quite difficult to distinguish between the different stages of the Nahshon Conglomerate, and this formational name is applied to the entire Würmian colluvial sequence of the wadis. To the south, however, loess was accumulated on the highlands. Colluvial wadi terraces were formed only during the pluvial phases, and were consequently eroded during the interstadial phases. The Early Würmian is therefore manifested in many of the northern and central Negev wadis by a distinct colluvial terrace and on the highlands by loess accumulations. This is apparently the picture also in the Elat area, but since no detailed studies were done no further information is available.

In the Jordan Valley lakes developed. In the Hula area the Hulata peat bogs extended to form the Ashmura Lake, which covered almost the entire Hula Valley. To the north, extensive spring activity commenced deposition of the Dan Travertine. The Central Jordan Valley and the Dead Sea Basin were both covered by the extensive Lisan Lake, which deposited its lower, Hamarmar Member during the Early Würmian pluvial phase. The Lisan Lake extended from about midway of Lake Kinneret down to about 30–40 km south of the present-day southern tip of the Dead Sea. The Ruhama Loess Member was continuously deposited during the Würmian in the northwestern Negev. During the more humid pluvial phases, the deposition extended also to the central Negev highlands, while during the drier interstadials these areas were subject to erosion and wind deflation, and loess deposition continued only to the north. During the more humid pluvial phases, pedogenic processes converted parts of the Ruhama Loess Member of the northwestern Negev into paleosols. Pollen spectra for the Early Würm are known from the coastal plain, the cave of Tabun, the Hula Valley, Birket Ram on the Golan Plateau, the Hamarmar Member of the Lisan Formation, and from the central Negev colluvial and loess deposits. The pollen spectra indicate that the vegetation was quite rich. A well-developed oak forest covered most of the country down to Judea, while Mediterranean maquis was developed down to the central Negev. The fauna of this period, described from many Mousterian sites, is discussed in detail in Chapter 7. The fauna, flora, and gentle erosional and considerable depositional processes in the wadis indicate that rainfall was rather mild. Its quantity was higher than at present, and some amount of summer rains were available.

The environment was favorable for human occupation and settlement. Extensive forests and woods provided a lot of game, while the extensive soil and marsh covered coastal plain provided a favorable environment for settlements. The caves were also settled in these times, and Mousterian occupations, which characterized the Early Würm in Israel, are known down to the central Negev. Most of the people were hunters and the game was predominantly gazelles to the south and cervids to the north. The Mousterian settlements show a somewhat different pattern than those of the Late Acheulian, since the people hunted out of well-developed base camps. To the north, most of the base camps were situated in caves, which provided shelter from the abundant rains, while to the south, numerous open-air sites are known, many of them connected with springs that are no longer active. This also proves that the general groundwater table was considerably higher in Mousterian times than at present, particularly in the central Negev highlands. It seems therefore that the Mousterian settlement pattern comprised both permanent base camps situated near water sources and ephemeral camps, from which hunters went out to the field, carrying water with them. Water carrying equipment was probably in abundant use during Mousterian times.

The Early–Middle Würm Interstadial, which took place from about 40,000 to about 32,000 years ago, provided a totally different environment. The Late Monastirian sea level rose nearly 15 m above that at present. The early Yarkon Ingression deposited the M3 Member of the Yarkon Formation and beachrocks in the Carmel coastal plain, which are known at elevations of 12–15 m above m.s.l. The terrestrial correlative, the dune ridge of the early Yarkon Ingression, is the lower part of the Ziqim Kurkar Ridge, which at this time reached elevations of up to 30 m above sea level. This lower part, when solidified, comprises calcareous sandstone of the lower part of the Dor Kurkar Bed of the Shefa'yim Member. Not much is known of this interstadial in the mountainous areas, but it seems that erosion was stronger and deposition of the Nahshon Conglomerate ceased, while some parts of it might have been eroded. In the Hula Valley, the Ashmura Lake shrank somewhat, but still occupied a considerable area of the basin. In the Central Jordan Valley and the Dead Sea areas, the Lisan Lake shrank, thereby causing an unconformity between the Early Würmian Hamarmar Member and the Middle Würmian Ami'az Member. The loess and colluvial accumulations of the central Negev highlands were subject to erosion during this interstadial. Practically nothing is known of this period in the Elat area.

Pollen spectra from the Mediterranean and the Jordan Valley basins indicate that vegetation was quite poor during the interstadial, although somewhat richer than at present. It seems that the somewhat higher arboreal pollen percentage during the interstadial, as compared with the present day, might represent relics of the forest which found refuge in some areas. Very little is known of the fauna in these times, except for the marine fauna, which indicates that the sea was quite cool, cooler than the preceding Monastirian stage. This is clearly shown by the drop in the relative percentage of *Marginopora,* a thermophil foraminifer. Almost no settlements are known in Israel from these times and there seems to be a gap between the Mousterian and Upper Paleolithic industries. This gap is somewhat filled by settlements known from the northern part of Lebanon and Syria. A single site which shows a transitional phase from the Mousterian to the Upper Paleolithic in the Negev, D-101, is quite old and dates to the beginning of the interstadial. It seems that when the interstadial climatic conditions came to their maximum, no settlements were present in Israel at all.

The Middle Würmian pluvial phase, which took place between 32,000 and 22,000 years ago, is again characterized by a regression of the sea, down to about 100 m below its present position. On the wide coastal plain paleosols were formed, comprising the Tel Barukh Hamra Bed of the Shefa'yim Member. Due to the relative short duration of this pluvial phase, the erosion during the consequent interstadial, and the coverage by younger sediments, the Tel Barukh Hamra Bed is not so widely exposed on the coastal plain. In the mountainous areas of the Nahshon Conglomerate and the corresponding Hasa Formation of Transjordan resumed, while in the Hula Valley, the Ashmura Lake once more extended over the entire basin area. To the north of the Hula Valley deposition continued of the Dan Travertine, by extensive spring activity under Middle Würmian pluvial climate. The Lisan Lake extended in the Central Jordan Valley and the Dead Sea area, depositing the Ami'az Member. In the central Negev highlands colluvium, gravel, and loess again accumulated down to Makhtesh Ramon. Pollen spectra for the Middle Würmian indicate a southward propagation of the Mediterranean forests, which reached somewhat north of their extension in Early Würmian times, down to the area of Judea or the Hebron mountains. Some stands of trees were present in the central Negev, but in general the central Negev in the Middle Würmian times had the landscape of the present-day Shefela. The favorable climatic conditions encouraged settlement in the country down to the Negev and Sinai by Upper Paleolithic peoples. Their economy and settlement pattern seems to be very much like the Mousterian pattern of hunters. They settled in permanent base camps, and maintained ephemeral camps in many places where they went to hunt. The common game was gazelles and ibex in the southern parts of the country and in Sinai, and deer and gazelles to the north. Sites of Upper Paleolithic settlements are quite rare in the north of the country due to the scarcity of Middle Würmian sediments, but to the south they are quite widespread. Settlements seem to be more restricted; at least the permanent base camps are more restricted to the wadi courses than those of the Mousterian people.

The Middle–Late Würm Interstadial, which corresponds to the Epi-Monastirian stage, occurred from about 22,000 to about 18,000 years ago. In these times, the late Yarkon Ingression again flooded the coastal plain, depositing the M3a Member of the Yarkon Formation and beachrocks on the Carmel coastal plain and in other areas, at elevations of 6–8 m above m.s.l. Dune sands connected with this ingression form the upper part of the Ziqim Ridge and later solidified into the upper part of the Dor Kurkar Bed of the Shefa'yim Member. In the mountainous areas and the central Negev highlands erosion prevailed, and loess was only accumulated in the southwestern coastal plain, where the Ruhama Loess Member of the Gaza Formation was continuously deposited. The Jordan Valley lakes again shrank. The Ashmura Lake became a peat bog, while the shrinking Lisan Lake caused some erosion and unconformity, separating the Ami'az Member from the overlying Fatza'el Member. Pollen spectra for this period, both from the coastal plain and the Jordan Valley, indicate vegetation in the same style as during the preceding interstadial, that is, a rather poor Mediterranean maquis, although somewhat better developed than at present. Faunal remains are only known from marine sediments, indicating by the low percentages of the thermophil *Marginopora* that the ingressive sea was rather cool. The climate was probably of the same type as at present, with torrential winter rains and a long, dry summer. These climatic conditions did not favor human settlement, and in fact there is a gap in the country between the Upper Paleolithic and Epiplaeolithic industries.

Towards the end of the Middle–Late Würmian Interstadial, about 18,000 years ago, a tectonic phase considerably reactivated the Jordan Valley, creating the deep basins of the northern Dead Sea and Lake Kinneret, and somewhat deepening the Hula Basin. As a consequence the former Lisan Lake was drained into the new, deeper basins, and ceased to exist as a large lake occupying the entire Jordan Valley. The Late Würmian pluvial phase, which lasted from about 18,000 to 11,000 years ago, again brought about a considerable drop in sea level, down to nearly 140–150 below m.s.l., leaving a fossil dune ridge that is presently buried under the sea. On the wide coastal plain pedogenic and paludine processes created the Netanya Hamra Bed paleosols and marsh deposits. In the mountainous areas the Nahshon Conglomerate resumed deposition on gentle slopes, while in the central Negev highlands loess, gravel, and colluvium were again deposited in the wadi courses and on the highlands. The Ashmura Lake in the Hula Valley again extended considerably to occupy a large part of the basin. In the northern part of the Central Jordan Valley, the Tabgha Formation began to be deposited in the newly created Lake Kinneret, while the "Unnamed post-Lisan Sediments" began to be deposited in the newly created Dead Sea, as they still are today. On the exposed areas of the previous Lisan Lake, the Fatza'el Member of the Lisan Formation was deposited by rivers, coming from the mountains on both sides of the Rift Valley. Considerable spring activity is known for the Late Würm in the northern Hula Valley, resuming deposition of the Dan Travertine, and in the Central Jordan Valley, creating the Bet She'an Travertine. This spring activity is partly attributed to the pluvial climate, especially to the north, but in the Bet She'an area, it followed fault lines of the last tectonic phase.

Pollen spectra for the Late Würmian again indicate spreading of the northern Mediterranean forest more or less to the middle of the country, and the Mediterranean maquis south to the Be'er Sheva Valley. The central Negev highlands were occupied by steppe vegetation of the present-day northwestern Negev and Shefela type. The fauna was quite rich and has been studied in many Epipaleolithic sites, discussed in detail in Chapter 7. The climate was again pluvial, that is, with rather mild winter rains, some amount of summer rains, and in general higher rainfall than at present. These climatic conditions again resulted in spreading of human settlements over the entire country, down to the central Negev and Sinai. The coastal plain was densely inhabited, and the areas around the Jordan Valley lakes also supported several large settlements. Details of the settlement pattern of this time, comprising the Kebaran, Geometric Kebaran, and Natufian cultures are discussed in detail in Chapter 8. Termination of the Würm pluvial stage coincided in the area with the development of agriculture and the first processes of human control of the environment. These developments are also discussed in Chapter 8.

Holocene

The Holocene stage, which lasted from about 11,000 years ago up to the present day is divided in Israel into three substages: the Versilian, which lasted up to about 7000 years ago, the Atlantic, which lasted from 7000 to 4500 years ago, and the Recent, which lasted since then until the present. The Versilian substage is characterized by the postglacial sea level rise, which attained elevations of 2–3 m above the present-day sea level, depositing the L4 Member of the Yarkon Formation in the western coastal plain. Dune ridges were rarely developed by this ingression due to its short duration, and the coastal sediments comprise calcareous sandstones of the Tel-Aviv Kurkar Bed of the Shefa'yim Member. In the northwestern Negev, loess was deposited until the present. In the mountainous areas erosion was quite severe, cutting into the Würmian Nahshon Conglomerate and forming the "Upper Terrace." In the central Negev highlands the previously laid loess and colluvium were deflated and eroded. The same processes most likely prevailed also in the Elat area. In the Hula Valley the Ashmura Lake considerably shrank, while deposition of the Dan Travertine by springs of the Würmian period had totally ceased. In the Central Jordan Valley the Tabgha Formation continued to be deposited in Lake Kinneret, which also shrank somewhat, thus exposing the lower part of the Tabgha Formation on its shores. In the Dead Sea area the "Unnamed post-Lisan Sediments" were still deposited in the Dead Sea. The pollen spectra indicate that the vegetation in Versilian times was more or less comparable to the present. Very little is known of the fauna, but it seems that many of the Würmian species had migrated to the north, never to return, while Saharan elements entered the coastal plain. The climate was interpluvial, corresponding more or less to that of the present, with only minor fluctuations. These minor fluctuations, however, considerably influenced human habitation of the country. In Versilian days, human habitation was not controlled solely by environmental conditions, but also by the application of rather sophisticated economic processes such as agriculture and pasturing. The settlement pattern of the Neolithic cultures of this period is discussed in detail in Chapter 8.

The Atlantic substage, which lasted from about 7000 up to 4500 years ago, experienced some regression of the Mediterranean, down to about 5 or 6 m below its present level. The coastal plain was again wider, and pedogenic and paludine processes deposited the Ta'arukha Hamra Bed quite extensively. In the mountainous areas, gravel and colluvium began to accumulate in the wadi valleys, while in the central Negev loess and colluvium were again accumulated. In the Hula Valley, the Ashmura Lake expanded somewhat, while in the Central Jordan Valley the Tabgha Formation is still deposited in Lake Kinneret, which also expanded. In the Dead Sea the "Unnamed post-Lisan Sediments" were deposited. A local lake was formed in the Bet She'an area, which covered considerable parts of the Hula Valley. This was a very shallow, freshwater lake, rich in *Mealenopsis* shells. Pollen spectra for the Atlantic period from many parts of the country indicate that the vegetation was considerably richer than at present and the northern Mediterranean forest once more penetrated the country. Oak and olive pollen grains were recorded in the Negev and in the southern parts of Sinai. As a consequence, human habitation of the Chalcolithic and Early Bronze cultures again became extensive, as discussed in detail in Chapter 8. The climate of the Atlantic is again pluvial, with some summer rains and mild brief winter rains.

The Recent period, which began about 4500 years ago, was accompanied by a slow rise of the sea level up to its present level. This "Actue'l" Ingression deposited the recent sediments of the Mediterranean and pushed forward the Hadera Dune Bed, constituting the Recent dunes of the coastal plain, which attained elevations of up to 40 m above sea level. In the mountainous areas the preceding Atlantic colluvial sediments were cut by the rather strong erosion, forming the "Lower Terrace." The Negev highlands were eroded and wind deflated, while the deposition of the Ruhama Loess Member was continuous only in the northwestern Negev areas. In the Hula Valley, the shrinking Ashmura Lake gave place to widespread peat bogs to the north, in which the Mallaha

Formation is deposited. Lacustrine sediments of the Ashmura Lake were in fact deposited up to the present in the lake presently known as the Hula Lake. In the Central Jordan Valley, the Bet She'an Lake ceased to exist due to the combination of both the drying climate in post-Atlantic times and to a minor tectonic phase which faulted the area about 4500 years ago. In Lake Kinneret, the Tabgha Formation sediments continue to be deposited, as are the "Unnamed post-Lisan Sediments" in the Dead Sea. The pollen spectra and fauna indicate that plant and animal life became more or less of present-day character, with only minor fluctuations.

The settlement pattern during the last five millenia, discussed in Chapter 8, depended on several factors: the culture and the type of economy, the people being either farmers or shepherds, the development of commerce, mining, and connecting roads with neighboring countries, and also to some extent the climate. It is quite notable that in periods in which the climate deteriorated, nomadic tribes penetrated the country, while in periods in which the climate was more favorable, agriculture flourished. Newly developed, rather sophisticated agricultural techniques considerably helped in conquering new areas of the country. Such was the development of terraces in the hilly and mountainous areas, mainly used for olives and vines by the Israeli Iron Age people. It is quite notable that these sophisticated agricultural techniques have enabled the Israelis, from ancient times up to the present, to settle parts of the country which would otherwise be uninhabitable environments.

CLIMATE

GLOBAL PALEOCLIMATES

The changing Quaternary climate seems to be the most prominent feature of its chronology, stratigraphy, and subdivisions. Since the recognition, in the mid-nineteenth Century, of the Great Ice Age, Quaternary stratigraphy became intimately connected with climatic changes. The principal features of Quaternary stratigraphy, the eustatic sea-level changes on the one hand and the glacials and interglacials on the other, became the cornerstone for Quaternary stratigraphy. Many theories have appeared during the last 100 years to explain the changing Quaternary climate, of which apparently the most important is the astronomical theory, suggested by Milankovitch (1941). The basic principles of this theory are well known: Variations in the relative positions of the sun and earth in space caused periods of maxima and minima in the amount of radiation received by the earth from the sun. Milankovitch neglected to enter into his calculations another factor, which is not yet fully understood, variations in the amount of radiation emanating from the sun itself. It is quite well known nowadays that solar radiation is not constant, but at present we can follow only short-time variations, and almost nothing is known about long-time ones. These probably have had some effect on geological periods. The Milankovitch theory explains quite well the changing Quaternary climates and the occurrences of glacial and interglacial periods. However, the greatest flaw in his theory lies in the fact that he tries to explain only the Quaternary climatic changes. If the astronomical explanation itself could account for the climatic variations and the setup of glacials and interglacials, then these should have been present throughout the entire history of the earth.

Analyses of geological data show that this is quite far from being the case. When discussing the geological record of the paleoclimate of the earth we must restrict ourselves to the period from the Cambrian up to the present, which is about 12–15% of the known geologic history of the Earth. This is quite unfortunate, but this is the only period for which we have enough evidence from fossil fauna and flora on one hand, and from sedimentary rocks on the other. In the Precambrian all we know is mostly from magmatic and metamorphic rocks. Only very rarely do we find rocks that have not undergone serious metamorphism, and in these we sometimes do find fossils. However, with these we cannot reconstruct an overall picture of the earth in Precambrian times. We know of Precambrian tillites in many places of the world, but the sense of their occurrences is not yet clear. During the last 550–600 million years, which constitute the Paleozoic, Mesozoic, and Cenozoic eras, we know, however, of global glaciations that took place in only three periods, namely in the Silurian, in the Permo-Carboniferous (or rather in the Permian), and in the Quaternary. When the rest of the Phanerozoic, about 90% of the time span, is considered, the picture is totally different. As far as we know, the earth enjoyed a fairly uniform climate over this enormous expanse of time, and almost any fossil community which is found for periods besides those mentioned above indicates general conditions of a rather warm climate all around the world. Another interesting point is that during these periods, not only has the world climate been warm, but the differences between the equatorial and polar areas were negligible, that is climatic belts were hardly developed.

It seems therefore that when one comes to explain the Quaternary glacials and interglacials, one must consider also the basic difference between this climate, which is in fact an abnormal climate, and the "normal" climate of the earth, rather uniform and generally warm. The phenomena that are common to the ice ages, the Silurian, the Permian, and the Quaternary, are therefore not only the glacials and interglacials, but also the climatic belts, which depend on the existence of Hadley Cells in the atmosphere. It seems that these cannot be attributed only to solar influence but are rather a local phenomenon generated by the atmosphere in response to geological processes. A comparison of global geological processes throughout the last 550 million years with the earth's climate reveals a strong connection between the appearance of ice ages, climatic belts, and the existence of major orogenic processes. The Silurian ice age followed the Caledonian orogeny, the Permian followed the Hercynian orogeny, and the Quaternry follows the Alpine orogeny. During the rest of the time, except for local phenomena that involved only mountain building in restricted areas of the globe, the climate was warm and uniform. The warm and uniform climate of the earth in these periods is also connected geologically with the rather flat, lowland, peneplained surface of most of the earth, and consequently, a considerable enlargement of the areas occupied by seas; in other words, the great extension of epicontinental seas. Sediments of these epicontinental seas are well known on most of the continents.

Horowitz (1977) suggested a trigger mechanism to explain the occurrence of ice ages during the geological past, and the contrast between them and the rather uniform "normal" climate of the Earth. The basic principle was that the orogenic belts forced the atmostpheric circulation to form Hadley Cells by convective rising of air masses, when these arrived at the mountain ranges. The principal influence, naturally, would be that of the latitudinal mountain ranges like the present-day Alpine belt, stretching from western Europe to eastern Asia. Relics of Hercynian and Caledonian orogenies are also known along these lines, more or less parallel to the Alpine chain. Another principle involves acceptance of the Milankovitch theory, but in a wider sense: the astronomic variations have occurred not only during the Quaternary, but throughout geologic history. This, of course, is quite sensible, considering the astronomical data. A third principle involves the albedo of different areas on the earth. Deserts and snow fields have a much higher albedo than vegetated lands and the oceans, therefore amplifying their existence (see discussion further on). Evidence to prove these principles was found in several cases. The connection of mountain ranges with climatic belts and consequently Hadley Cells can be checked geologically. It was found that in the periods in which there were no mountain ranges, or at least no considerable latitudinal orogenic belts, the climatic belts are very much subordinate on the earth, giving place to a rather uniform climate all around the globe. Some indirect evidence was indicated by Horowitz (1977) from other planets, comparing the atmospheres of Venus, Earth, and Mars. Venus has a very thick atmosphere, and its relief is subordinate. It was noted long ago, and in recent years it has been measured by spacecraft, that energy exchange over the entire surface of Venus' atmosphere takes place very rapidly. In fact, it is a matter of only 2-3 hours until higher energy concentrations, sometimes known as red spots, are transferred from the equatorial to the polar areas of this planet. On the other hand the relief of Mars is considerably more pronounced than that of the Earth. Mountains tower up to elevations of 17–18 km; great canyons cut through the planet, while the atmosphere is rather thin, about 1/100 of the earth's atmosphere. The climatic belts of Mars are well known and its ice caps can be seen with almost any telescope. It should be noted that the evidence gathered from other planets is not really conclusive, but does support the situation known from the earth's geological past.

Neither Venus or Mars have water in the form of seas or oceans. It seems therefore that the factor responsible for Hadley Cells is the relief, without any role for oceans, as is probably the situation on Earth. If this hypothesis is true, it can explain the rather uniform climate of the earth by means of fast energy exchanges between the equatorial and the polar regions, energy exchanges that are not interrupted by convectional currents. However, there is still another phenomenon to account for, the rather warm climate in these periods. This is explained by the much larger areas occupied by epicontinental seas in the "normal" periods of the Earth. The water surface has a much lower albedo than the land; therefore much more solar radiation could be absorbed by the Earth in these times than today. Only the combination of these two phenomena, which are both related to the nonexistence of mountain ranges, can therefore explain the climate of the earth throughout most of the geological past, namely, a warm, rather uniform climate. We must still bear in mind the existence of the Milankovitch theory. The theory states that by differences in the relative attitudes of the earth and sun, temperature changes of up to 5 or 6°C. could be generated on the earth. In times of a warm, rather uniform climate these changes would not do much to the biogeography of the earth. If we take an average temperature of 21–23° all over the Earth, with oscillations in the range of 18–24°, this still could not precipitate an ice age, and would be quite subordinate in its influence on organisms. In fact it is worthwhile stressing that these temperature fluctuations can be seen in the fossil record. Oxygen isotope analyses of fossils from almost any period indicate the existence of these variations, but with no connection with ice ages.

To explain the ice ages, we must get back to the orogenic belts, which lead to the formation of Hadley Cells and climatic belts. Another consequence is a considerable drop in the amount of radiation that the entire Earth receives from the Sun due to the diminution in the area occupied by epicontinental seas. As a result of all this, the average temperature in the equatorial regions would not vary much, but at the poles the temperatures would drop considerably, depending on the climatic belts. If we take as an example an ideal globe, with climatic belts, we might expect in the polar areas average temperatures in the order of only 2–3°C. If we apply the Milankovitch curve to this situation, we get two extreme cases. If the temperature drops only 3 or 4° we pass the critical limit of the eternal snow fields. These snow fields, once formed, would generate and amplify themselves by a positive feedback mechanism caused by their very high albedo, thereby accumulating more and more snow, until glaciers are formed. The areas occupied by snow and later by ice, would considerably enlarge themselves and push from the polar areas toward the temperate zone, thereby also pushing the other climatic belts toward the equator in glacial times. The equatorial areas would be considerably influenced by the drop in the amount of radiation; since most of the rains depend on solar radiation, the consequent amount of rain would considerably drop in the equatorial areas during the glacials. As a result, the tropical rain forests might totally disappear, which in fact was proved for certain periods by E. M. Van Zinderen-Bakker (Institute for Environmental Sciences, University of the Orange Free State, personal communication 1975). Due to the decrease of solar radiation in the equatorial areas, the Intertropical Convergence Zone would almost disappear, and the planetary deserts would enjoy a much more humid climate during the glacial phases. This was shown, for example, by Van Campo (1975) for the Sahara. It should be noted that due to amplification processes these changes are rather rapid, and although the solar radiation curve is more or less sinusoid, the reactions, once the critical limit has been passed, would be very rapid, as would be the transition between glacial and interglacial climates.

During the interglacial periods of radiation maxima, the picture would be inverted. The snow and ice in the polar areas would melt. The climatic belts would move toward the poles and the tropical rain forests, and consequently planetary deserts, would again develop. The critical point naturally depends also on the elevation. Therefore the ice cap on the Arctic Ocean would be formed much later than the ice cap on Antarctica during the Cenzoic, as a result of the elevation of this continent. In fact the Alpine orogenesis commenced at the beginning of the Cenozoic period, while the ice sheet on Antartica had already developed in Oligocene times. In the Arctic Ocean the ice cap was considerably developed for the first time only following the Late Pliocene regression. This regression, primarily of geotectonic origin, apparently also helped in forming the first ice cap on the Artic Ocean by considerable lowering of the average global sea level, thereby lowering the amount of radiation received by the Earth, due to increased albedo. It can be seen therefore that this theory explains not only the Quaternary Ice Age, but also the former ice ages, the "normal" climate of the globe, and the occurrences of both glacial and interglacial periods within an ice age.

QUATERNARY CLIMATES OF THE LEVANT

The Quaternary climates of the Levant depend on two principal factors: the relative position of global climatic belts and the role played by the Mediterranean. Throughout this book the Quaternary climates of Israel were regarded as of a pluvial or interpluvial nature. The first task to be undertaken while analyzing these climates is to correlate them with the European climatic sequence. Rossignol (1969) has shown that the eustatic Mediterranean ingressions on the Israeli coast are typified by interpluvial pollen spectra, with very low percentages of arboreal components. The stratigraphically interfingering sediments were shown to contain pluvial spectra, with a considerably higher percentage of arboreal pollen. The Mediterranean eustatic ingressions have been correlated by many authors in Europe, in the northwestern Mediterranean, and in the Atlantic with interglacials (see, for example, West 1968). It is therefore quite clear that the interpluvial climates in Israel correspond to the interglacials of Europe, while the pluvials correspond to the glacials. An interpluvial climate, of which that at present in Israel is quite a good representative, is characterized by several factors. Rains are restricted to the winter and approach the Levant as cyclonic thunderstorms, which cause large quantities of rainwater to fall in a relatively short time. This results in floods, strong erosion, and steep incision by the wadis, and consequently, most of the water is not available for plant life. Due to the poor vegetation, wind deflation is prevalent in the south of the country. Pedogenic processes are limited to those areas in which erosion is less active, forming gray, lime-rich soils. When the interpluvial conditions were fully developed, as, for example, during the Riss–Würm Interpluvial, the climatic belts were pushed even more to the north and most of the country became a desert. During pluvial periods, however, the picture was totally different. The rich vegetation, the extended lakes in the Jordan Valley, the considerable pedogenic processes forming red, well-washed soils, the loess accumulation to the south, all indicate that rainfall was higher and milder, that is, not brought by cyclonic thunderstorms but rather by warm fronts, which made most of the water available to plant life and did not invoke severe erosion.

The elevated regions of the Levant, the Persian and the Turkish high plateaus, had a totally different climate during times corresponding to the pluvials in Israel or the glacials in Europe. Most of these areas became rather dry, cool steppes (Farrand 1971; Leroi-Gourhan 1973; van Zeist 1967; Wright *et al.* 1967). The same climatic condition of cold steppes also existed during the last glacial in

Greece and Italy (Bottema 1967; Bonatti 1966; Frank 1969; Wijmstra 1969). The difference between the pluvial climate of Israel, Syria (van Liere 1961), Lebanon (Leroi-Gourhan 1971), and the elevated regions to the north was discussed by Butzer (1975). It seems that when climatic belts were pushed to the south the elevated regions became periglacial cool steppes, while the southern areas enjoyed the more favorable temperate climate.

The role played by the Mediterranean in determining the climate of the Levant is discussed by Horowitz and Assaf (1978). The present situation, which it is suggested corresponds also to the interglacials (or, locally, interpluvials), is controlled by the negative water balance of the Mediterranean and the high pressure area over the Sahara. The barometric pressure over the Sahara is higher and extends more to the north during the summer, due to the higher amount of solar radiation north of the equator. In winter the higher solar radiation moves south of the equator, the western trade wind belt moves south and influences the Mediterranean, while the barometric pressure over the north pole increases, pushing cold air masses further south than in the summer. As a consequence, only winter rains arrive at the Levant. The negative water balance of the Mediterranean causes water from the Atlantic to flow eastward through the Strait of Gibraltar to the eastern Mediterranean, where the evaporation is most excessive. Arriving at the eastern Mediterranean, the Atlantic waters become progressively more saline and heavier, and begin to sink to the bottom. The sinking causes mixing of the entire water volume, thus storing considerable solar energy. Consequently, no thermocline is formed presently in the eastern Mediterranean, and oxygen is present down to the bottom of the sea. The sediments are brownish, oxidized, with almost no pyrite, very little organic material, and rich benthos. Cold air masses approach the Mediterranean only in winter, mostly by way of Greece, where the Alpine chain is lower and acts less as a barrier. These cold air masses are heated by the energy stored within the entire water body of the Aegean and Ionian seas, and cyclones are generated. These cyclones, accompanied by thunderstorms, arrive at the Levant by combination of the southward moving cold air and the westward trade winds. These cyclonic thunderstorms are responsible for the style of winter rains in the Levant and all their biological and geomorphological consequences.

In glacial times, corresponding to pluvials in the Levant, the picture is totally different. Due to a considerable drop in the amount of solar radiation received by the earth (Milankovitch Curve), the Intertropical Convergence Zone is much less developed, and consequently the barometric pressure in the Sahara is lower than during the interglacials, and does not play an important role in preventing the western trade winds from arriving at the Levant, even in summer time. The extended ice cap at the north pole pushes the trade wind belt to the south, and these winds become the principal factor in the climate of the Levant, bringing summer rains of the western European style to the region. The Mediterranean, on the other hand, no longer acts to store energy. Due to excess freshwater, coming mainly from the higher amounts of rain and also from the higher runoff in countries around the Mediterranean, accompanied by a decrease in the amount of solar radiation and thus in evaporation, the net water balance becomes positive. Freshwater flows on the Mediterranean surface, through Gibraltar to the Atlantic. Consequently, no mixing of the water body occurs, a thermocline develops, and no oxygen reaches the sediments. The basin no longer stores energy, and the Levant enjoys rains of the western European style, that is, mild summer rains, winter rains due to warm fronts, and no thunderstorms. This type of rain results in the pluvial phenomena already described for Israel: rich vegetation, spreading considerably further south than during interpluvials, with consequently rich fauna; pedogenic processes resulting in red soils, well washed of lime, down to the Negev; loess deposition in the now-vegetated areas of the central Negev; almost no wind deflation, due to lack of thunderstorms; accumulation of colluvium and gravel in the wadi and river courses, on rather gentle slopes; only subordinate erosion in the mountains, and no floods; a higher groundwater table, with considerable spreading of lakes, especially in the Rift Valley, and new springs appearing in various localities.

The formation of a thermocline and the cessation of mixing considerably influenced sedimentary processes in the Mediterranean, by turning it into an euxinic basin. The typical Mediterranean sediment of glacial times is a black, highly organic, rich in pyrite sapropel. The sapropel beds occur throughout the Quaternary record of deep sea cores from the Mediterranean, and their climatic significance has been differently interpreted by various authors. Vergnaud-Grazzini *et al.* (1977) believe that the sapropels represent periods of deglaciation, while Thunell *et al.* (1977) believe that they have been formed during the interglacials. Both opinions are based on the composition of foraminiferal assemblages and fractionation of their oxygen isotopes. Unfortunately, no dates are available and no correlation is possible with continental processes. It seems to Horowitz and Assaf (1978) that the sapropels correspond to the glacial episodes, and their deposition is mainly influenced by the totally different rainfall regime. Conclusions based on the foraminifers and oxygen isotopes could in fact indicate only the salinity, which everybody agrees was lower at the Mediterranean surface in times of sapropel deposition. Palynological analyses of the sapropels (Rossignol and Pastouret 1971; Rossignol-Strick 1976) yielded rich pollen spectra of a pluvial nature. Good control was possible in the study of Rossignol and Pastouret (1971), who analyzed the uppermost, radiocarbon dated part of the sequence. The Atlantic stage, which is characterized in Israel by pluvial pollen spectra and apparently some summer rains (Horowitz 1971; 1974d) proved to be a period of sapropel deposition in the eastern Mediterranean. The rich pollen spectra, although ascribed by Rossignol and Pastouret to better transportation, seem to corroborate the pluvial climate, and correlate well with similar spectra around the Mediterranean, much richer in arboreal pollen than at present.

It is quite interesting in this respect to analyze the vegetation of the Levant and especially Israel. Annual vegetation can react much more rapidly to changes in the rainfall regime. Therefore, the present-day (interpluvial) annual vegetation is of the type which basically conforms well with climatic conditions, that is, most of the annual plants grow during the humid rainy winter, while during the summer, most of them are dry. The trees, however, have a much longer process of adaptation, and in fact most of the trees that grow in Israel are probably remnants of pluvial times. Almost all the trees of Israel, and in fact those of the entire Levant, have their growing season in the spring and summer. Moreover, fifty percent of them are winter deciduous! If one takes into account the seven plant species mentioned by the Bible, the picture is really striking. The date palm depends for its growth only on groundwater. Wheat and barley are winter annuals, but the rest, the fig tree, vine, pomegranate, and olive, grow only in the spring and summer. The first three are winter deciduous. In fact, the only group of trees that seems to be well adapted to present-day conditions are the acacias. This is not surprising since the source area of the acacias is subtropical Africa. These trees grow only in winter time, when they have enough rainwater, and are summer deciduous. Acacias, however, form a minority among the tree species of the Levant.

The temperature drop of pluvial times in Israel is regarded differently by various authors. Early workers suggested no drop at all. Luz and Bernstein (1976) suggested a drop of only 2°C, based on oxygen isotope composition of foraminifers collected offshore from Israel. It seems, however, that these authors have analyzed Atlantic, rather than Würmian sediments. Horowitz (1968, 1973) and Butzer (1975) suggested a temperature drop of about 4–5°C, based on inferred composition of the vegetation from pollen spectra, and on geomorphological processes. Gvirtzman (1975, 1976) suggested a drop of the average summer temperature by 15°C, based on recognition of glacial cirques in the Hermon to the north and in the high mountains of Sinai to the south. Both recognition of the geomorphic features and the methods by which Gvirtzman arrives at a drop of 15°C do not seem plausible to this author. Moreover, even if one accepts Gvirtzman's assumptions for the two extreme cases, these might have been a result of local amplification processes, with only a subordinate influence on the entire area between the points. According to Gvirtzman, the 15°C temperature drop would cause the entire area of Israel to be covered by sub-Alpine vegetation. Numerous pollen spectra for the Würmian indicate that the vegetation was of the northern Mediterranean type, quite unlike the sub-Alpine. A recent study of the size variation of Würmian foxes from Israel (Davis 1977) also suggested a temperature drop of about 15°C, based on the application of Bergmann's Rule. However, analyses of the faunal spectra of this period by Tchernov (see Chapter 7) indicate that these foxes are of the Mediterranean type, and another mechanism should be sought to explain this size variation, like better food availability or less competition.

CHRONOLOGY

Quaternary chronology depends to a great extent on the definition of the Quaternary period and on the method used to date it. Classical definitions for the Quaternary period are numerous, among which three suggestions are the more widespread. The Pliocene–Pleistocene boundary was defined by its faunal successions (see, for example, Haug 1911; Tobien 1970), who defined the lowermost boundary of the Quaternary by the appearance of the genera *Elephas–Leptobos–Equus* in Europe. On the other hand, Gignoux (1955) defined the beginning of the Quaternary by the first appearance of man and his cultures. This view is basically accepted by many workers and especially those concerned with appearance of early hominids in the East African rift valley system. Bishop and Miller (1972) regard the first appearances of *"Pithecanthropus"*-like creatures as the beginning of the Pleistocene, and date it by potassium–argon to about 3 million years ago. Tobien (1970), based on potassium-argon datings of volcanic ashes interbedded within sediments containing the *Elephas-Leptobos-Equus* group, also dates the beginning of the Quaternary to about 2.8–3 million years ago. The third group of workers is mainly concerned with the marine Quaternary and regards the Pliocene–Quaternary boundary as the first severe cooling of the oceans of the northern hemisphere, on the base of the Calabrian in Le Castella, Italy. Dates given to this cooling phase will be discussed shortly, and are either clustered around 1.8 or 2.8 million years ago.

The occurrence of continental glaciations in the northern hemisphere as characteristic for the Quaternary period is accepted by most of the workers. It seems that the concept of the first severe cooling of the oceans, which corresponds to the latest Pliocene regression, and also to the onset of the first considerable continental glaciation, the Biber in the Alps, the Nebraskan in the United States, and the Pretiglian in northwest Europe, is presently accepted by more and more researchers as the lowermost boundary of the Quaternary. The advantage of this boundary is that it involves considerable sea level changes and can therefore be distinguished in many parts of the world, regardless of their connection with continental glaciations. Continental processes of erosion and deposition would respond to the latest Pliocene–earliest Quaternary considerable sea level drop and to its succeeding Calabrian Ingression. This boundary therefore can be easily discerned wherever either continental or marine deposits are encountered. Correlative basalts of the lower part of the Cover Basalt have cooled in Israel and its vicinity at the end of the Gauss Normal Epoch, therefore indicating an age of approximately 2.8 million years for the beginning of the Quaternary. The Günzian sediments of northeastern Israel were laid down on top of the sequence of the Cover Basalt, which was dated to 1.7 million years ago. Therefore the Preglacial–Glacial Pleistocene boundary should be drawn at around 1.6–1.7 million years ago. Other potassium-argon dates for the Quaternary sequence of Israel are available. Basalts that cut the upper part of and overlie the Mindel deposits in the Central and Northern Jordan Valley were dated at 560,000, 640,000, and 680,000 million years ago. This age should represent the upper part of the Mindel Glaciation. Sediments of Günz, Mindel, and Mindel-Riss Interglacial, including the above-mentioned basalts, were faulted in the Jordan Valley, and basalt flows that cover these faults were dated at about 350,000 years. These unfaulted basalts are in turn covered by Rissian sediments. The time span between 560,000 and 350,000 years should approximately correspond to the Mindel-Riss Interglacial. Basalts overlying the Rissian sediments, high in the Riss–Würm Interglacial sequence, were dated at about 70,000 years ago, indicating an upper limit for the Riss-Würm Interglacial. The Würm Glacial began more or less at this date and numerous radiocarbon and ionium datings span the Würmian sequences between 70,000 and 11,000 years ago. It seems that there is not much dispute as to the dating of the last glaciation and the Holocene. Therefore these will not be discussed further.

Various figures were given for the Glacial Pleistocene sequence, from a total length of about 300,000 years, suggested by Emiliani (1955), to an age of 1.6–1.7 million years, suggested in this work and elsewhere (Siedner and Horowitz, 1974). The radiogenic age of the lowermost boundary of the Quaternary is a matter of great dispute. Ages of around 2.8–3 million years were suggested by students of the marine sequences (Beard 1969), of the vertebrates (Tobien 1970), and of the hominids (e.g., Howell 1972; Isaac 1972). On the other hand, most researchers studying deep sea sediments and the Calabrian marine transgression, especially in the Mediterranean (e.g., Haq *et al.* 1977; Venzo 1975), but also in other areas, such as the Atlantic (Shackleton and Heusser 1977) and the Arctic and the Antarctic oceans, have suggested the figure of 1.8 million years for the first cooling of the oceans and for the first appearances of *Hyalinea balthica,* which designates the base of the marine Calabrian in the Mediterranean. An analysis of the background to this age, 1.8 million years, yields an interesting result. All of the marine sediments were dated as 1.8 million years old due to their occurrence just above or within the upper part of a normal magentic event, assigned to the Olduvai Event, and therefore were given the radiogenic age of 1.8 million years. Several samples of basalt from Israel and its vicinity that yielded ages from 1.7 through 2 million years are of a reversed magnetic polarity, and it seems that the Olduvai Event was not recorded in our area. This could, of course, be due to the short length of this event, about 150,000 years (Darlymple 1972). But an analysis of worldwide occurrences of the Olduvai Event shows an interesting fact (Darlymple 1972, p. 130). From 16 samples that were potassium-argon dated and are regarded as of reliable ages by Darlymple, lying within the range of 1.78–1.98 million years ago, a period in which the Olduvai Event should have been recorded, only 7 have normal magnetic polarity, while the rest, 9 samples, have reversed polarity. This author would like therefore to put in question the validity of the worldwide occurrence of the Olduvai Event and its use for dating.

It seems that the deep sea sediments which encountered the normal magnetic period at the depth where *Hyalinea balthica* first appeared in the Mediterranean, and the first cooling of the oceans indicated in many deep sea cores, probably indicate the Gauss Normal Epoch, which corresponds in age to about 2.8–2.7 million years ago, and not the Olduvai Event. All the dates that cluster around 2.8–3 million years ago for the beginning of the Quaternary were accepted on outcrop, potassium-argon dated material, which is interbedded either within faunal bearing sediments, such as in Europe, faunal and hominid bearing sediments, as in East Africa, or the climatostratigraphically controlled sequence of the Near East. All the 1.8 million year clustered dates were accepted only by comparison with the far from complete paleomagnetic record. It should be noted that a preliminary date of 2.5 million years, made by the fission track method on a volcanic glass, was accepted for a sample near the middle of the 60-m Vrika sequence, spanning the Pliocene–Pleistocene boundary stratotype, about 16 km northeast of Le Castella, Italy (Boellstorff 1977). This date confirms the suspicion that the 1.8 million years suggested for this boundary (Venzo 1975) is too young. This is a rather crucial date since the area of Le Castella is suggested as the type area for the Pliocene–Pleistocene boundary of the Mediterranean (Venzo 1975). It seems therefore that the 2.8–3 million years cluster is presently much more reliable.

The termination of the Preglacial Pleistocene, which corresponds to the termination of the Villafranchian Faunal Stage in Europe and to the beginning of the

Günzian Glaciation, is given by Tobien as around 1.8–1.9 million years ago, based on several potassium–argon dates, especially from the Massif Central by, for example, Bout (1968) and Savage and Curtis (1968). Van Couvering *et al.* (1972, p. 471) regard the period from 2.7 through 1.5 million years as a period of cooling, while at 1.5 million years the glacial cycles begin. These figures correspond very well to the definitions of the Preglacial and Glacial Pleistocene and to the dates accepted for the Levant. The radiogenic age accepted for the Mindel Glaciation in Israel, older than 600,000 years ago and beginning at about 900,000 years ago, also needs some consideration. It appears much older than the classical ages for the Mindel Glaciation of Europe, but an analysis of the dates given to the Mindel in Europe shows that all these dates are based only on estimates of rates of deposition and erosion and none of them on radiogenic dates. The only potassium–argon dates from Europe, for deposits presumably of Mindel and Günz age, were carried out on the Laacher See Volcanics in Germany, which are incorporated in Rhine terraces (Vrechen and Lippolt, in Isaac 1972). These, according to Isaac (1972), are "alleged to be correlatable with named climato-stratigraphic entities," and place the Mindel II at about 220,000 years, the Mindel I at about 300,000 years, and the Günz at about 420,000–340,000 years. Isaac doubts the correlation of these volcanics with the named climato-stratigraphic units, and it seems that until much more evidence is gathered in support of these dates, they should be regarded as very questionable, that is, not the potassium–argon dates themselves but their correlations with the climato-stratigraphic units.

On the other hand, a very thorough study of Mindel deposits in Russia was carried out by Nikiforova *et al.* (1970). These authors suggested the site of Tiraspol as a type locality for the Mindel of eastern Europe and correlated the faunal remains from this site with the classical Mindel faunal assemblages of western Europe. A paleomagnetic study of the sediments cropping out at Tiraspol showed that the Matuyama–Brunhes boundary lies in the upper part of the sequence, which corresponds very well to the dates accepted for the Levant, namely, that at least part of the Mindel is older than 700,000 years. Industries that are equivalent to the Developed Olduvan cultures of Ubeidiya, attributed to the Mindel, yielded in East Africa ages in the range of 800,000–700,000 years, ane even older.

To conclude, it seems that the Glacial Pleistocene should be extended to cover the last 1.8 or 1.7 million years, thereby accounting for many of the stratigraphic "gaps" that were encountered while discussing hominid migration and settlement in Africa, Asia, and Europe (cf. Isaac 1972). Consequently, the site of Choukoutien in China should be considered as much older than the suggested age of 300,000 years attributed to it. It seems therefore that hominids were migrating from Africa by the termination of the Preglacial Pleistocene, and had arrived in the Middle East, southern Europe, and probably also in southeast Asia, by the beginning of Günz Glaciation times, that is, about 1.7 million years ago. When correlating the African and European sequences, one should bear in mind the "longer" Glacial Pleistocene record, and one could in fact use to advantage the occurrence of pluvial and interpluvial sediments in the Near East, which correspond to glacial and interglacial sediments of Europe, the latter having been potassium–argon dated by their interfingering basalts.

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