INFORMATION TO USERS

This reproduction was made from a copy of a document sent to us for microfilming. While the most advanced technology has been used to photograph and reproduce this document, the quality of the reproduction is heavily dependent upon the quality of the material submitted.

The following explanation of techniques is provided to help clarify markings or notations which may appear on this reproduction.

1. The sign or "target" for pages apparently lacking from the document photographed is "Missing Page(s)". If it was possible to obtain the missing page(s) or section, they are spliced into the film along with adjacent pages. This may have necessitated cutting through an image and duplicating adjacent pages to assure complete continuity.
2. When an image on the film is obliterated with a round black mark, it is an indication of either blurred copy because of movement during exposure, duplicate copy, or copyrighted materials that should not have been filmed. For blurred pages, a good image of the page can be found in the adjacent frame. If copyrighted materials were deleted, a target note will appear listing the pages in the adjacent frame.
3. When a map, drawing or chart, etc., is part of the material being photographed, a definite method of "sectioning" the material has been followed. It is customary to begin filming at the upper left hand corner of a large sheet and to continue from left to right in equal sections with small overlaps. If necessary, sectioning is continued again—beginning below the first row and continuing on until complete.
4. For illustrations that cannot be satisfactorily reproduced by xerographic means, photographic prints can be purchased at additional cost and inserted into your xerographic copy. These prints are available upon request from the Dissertations Customer Services Department.
5. Some pages in any document may have indistinct print. In all cases the best available copy has been filmed.

University
Microfilms
International

300 N. Zeeb Road
Ann Arbor, MI 48106

El-Moslimany, Ann Paxton

HISTORY OF CLIMATE AND VEGETATION IN THE EASTERN MEDITERRANEAN AND THE MIDDLE EAST FROM THE PLENIGLACIAL TO THE MID-HOLOCENE

University of Washington PH.D. 1983

University
Microfilms
International 300 N. Zeeb Road, Ann Arbor, MI 48106

History of Climate and Vegetation in the Eastern Mediterranean and the Middle East From the Pleniglacial to the Mid-Holocene

by

Ann Paxton El-Moslimany

A dissertation submitted in partial fulfillment
of the requirements for the degree of

Doctor of Philosophy

University of Washington

1983

Approved by Matsuo Tsukada
(Chairperson of Supervisory Committee)

Program Authorized
to Offer Degree Botany

Date May 12, 1983

DOCTORAL DISSERTATION

Ann P. El-Moslimany

Ann P. El-Moslimany

May 12, 1983

Date

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

Number Page

LIST OF TABLES

LIST OF TABLES (continued)

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

وَهُوَ ٱلَّذِىٓ أَرْسَلَ ٱلرِّيَٰحَ بُشْرًۢا بَيْنَ يَدَىْ رَحْمَتِهِۦ ۚ وَأَنزَلْنَا
مِنَ ٱلسَّمَآءِ مَآءً طَهُورًا ﴿٤٨﴾ لِّنُحْۦِىَ بِهِۦ بَلْدَةً مَّيْتًا وَنُسْقِيَهُۥ
مِمَّا خَلَقْنَآ أَنْعَٰمًا وَأَنَاسِىَّ كَثِيرًا ﴿٤٩﴾ وَلَقَدْ صَرَّفْنَٰهُ
بَيْنَهُمْ لِيَذَّكَّرُوا۟ فَأَبَىٰٓ أَكْثَرُ ٱلنَّاسِ إِلَّا كُفُورًا

In the name of God, the Merciful, the Kind

It it He who drives the winds as harbingers of His mercy and sends down pure waters from the sky, so that He may give life to dead lands and quench the thirst of man and beast.

The Holy Quoran

Acknowledgements

It is with deepest gratitude that I acknowledge the help of my professors, friends and family. My supervisory chairman, Professor Matsuo Tsukada, generously shared his knowledge and his facilities and has patiently dealt with my frequent changes of direction during the first years of my graduate work. The other members of my reading committee, Professor Bastiaan Meeuse and Dr. Linda Brubaker, have both given valuable criticism and help, as has Professor Zaghlool Naggar of the University of Petroleum and Minerals in Dhahran, Saudi Arabia.

I thank the members of the Botany and Microbiology Department of Kuwait University who extended to me full use of their facilities during my years in Kuwait and in particular to Professor Kamal Al-Kaisi, Professor Ahmad Kabarity and Professor Riad Halwagy, who helped me in many ways. Professor Riad Halwagy and Professor Ali Al-Rawi have given me access to their personal libraries and have helped me to develop my understanding of and appreciation for the desert ecology of the Middle East. Professor Salah Behiery provided my husband and myself with warm hospitality and first-hand information about the Quaternary geomorphology of Jordan during my field work in that country.

The help of Mrs. Vivian Armer of the Kuwait University Herbarium has been of great value and I thank her sincerely. Ms. Ruba Al-Jalili, Mrs. Wafa Abdel Jawad and Mr. Ibrahim Mohammed

Ibrahim have all given generously of their time. Mr. Mohammad Ahmad Mohammad was always ready to help me in the laboratory and his kindness is gratefully acknowledged. Special thanks are due to Ms. Lisa Thomas not only for her superb typing and word processing but also for being such a sympathetic, responsible, and cheerful person.

I also thank Dr. Matti Eronin, who identified the diatoms of the Bubiyan peat sediments, and Mr. Abdulla Al-Zamel, Mr. Harold McClure, Mr. J. Mandaville, Mr. S. Shehab, Mr. G. Chapman, Dr. A. Garrard, Dr. Ridha Al-Hassan and Dr. Mohammad Halwagy, all of whom provided me with unpublished information.

Most of all I am grateful to my family, who has shared in every aspect of my work and has given me their total support and cooperation. My children, Samia, Ramsey and Rasheed, have grown to adulthood waiting for their mother to finish her Ph.D. I only hope that their sometimes reluctant sacrifices will be partly compensated by the qualities of independence and responsibility which they developed at an early age. I can never adequately express my appreciation for my husband Dr. Mohammad El-Moslimany. He has for the past several years willingly subordinated his own career and personal comfort to the attainment of my goals. He has never faltered in his enthusiasm and has often renewed my own. Without his advice, understanding, encouragement, and patient support, my work could never have been completed.

INTRODUCTION

Current Concepts of Quaternary Climates in the Middle East

The Quaternary climatic history of the Middle East has been widely studied (Butzer, 1958; Farrand, 1971, 1981; Brice, 1978, Bintliff and van Zeist, 1982), for here western civilization had its origins when the domestication of plants and animals occurred. Moreover, it has been appreciated that an understanding of the climatology of these latitudes is essential to the understanding of the large-scale features of the atmospheric circulation and the relationships of global climate to sea-surface temperatures, ice extent and other boundary conditions. Nevertheless, the paleoclimatic evidence for this region often appears contradictory and inconclusive and a generally accepted history of climatic change has yet to emerge.

Many geomorphological studies indicate that during the last glacial period the Middle East was moister than at present (Butzer, 1958; Wright, 1961, 1969; Farrand, 1971, 1981; Roberts, 1982), while early evidence from palynology apparently suggested that the reverse was true, that the glacial period was arid with moisture increasing during warming trends (van Zeist, 1967; Wijmstra, 1969). In a review of pollen evidence it was stated:

> "The most astonishing fact is that these changes, reflected at the transition from forest to steppe and vice versa, are perfectly synchronous with the changes based primarily on temperature in Northwestern Europe. The only explanation seems to be that changes in humidity depend directly on changes in temperature as a primary cause for changes of the world's climatic pattern as a whole" (van der Hammen *et al.*, 1971).

Since then there has been a rapid increase in the number of available pollen diagrams (Niklewski and van Zeist, 1970; Bottema, 1974, 1979; van Zeist et al., 1975; van Zeist and Bottema, 1977; van Zeist and Woldring, 1978, 1980). However, instead of eliminating the apparent lack of correspondence between palynological and other data, inconsistencies in the interpretation of the palynological data themselves have appeared. Van Zeist and Bottema (1982), in referring to the moisture curves obtained from these diagrams, remarked, "Even if one ignores smaller fluctuations and if one accounts for uncertainties in the dating, the humidity curves cannot possibly be brought into line with each other." And in discussing two diagrams from sites separated by only 300 km, they have stated, "The Huleh and Ghab diagrams suggest a more or less opposite climatic development in the Late-Glacial and in the lower Postglacial." Although it is certainly possible that one site would have been affected to a different degree than another, the suggestion that trends over long time periods were opposite seems unlikely. Winstanley (1973) has demonstrated that precipitation trends throughout North Africa and the Middle East are similar for the period 1950-1970. He stressed that this is only to be expected, because they are subject to the same incursions of westerly storm tracks. This same causal mechanism was operating in the past and if moisture curves differ strongly from place to place it may be more appropriate to question the method by which these curves were obtained than to suspect rainfall anomalies. Some differences reasonably can be expected to have occcurred between those regions dependent solely on winter precipitation and those on the fringes of the Middle East where summer rainfall may occur. The tendency for palynology to be taken as the most definitive of the Quaternary sciences has resulted in the various pieces of contradictory evidence being forced into alternative explanations or simply overlooked. Faced with some incontrovertible evidence for a generally moist pleniglacial, two slightly different explanations have been considered. The first of these is the "thin band of moister climate" hypothesis which essentially states that a strip of wet climate, including north-central Palestine, stretched across the middle of a much larger arid zone (Butzer, 1978; Goldberg and Bar-Yosef, 1982). A modified version of this hypothesis was suggested by Bintliff (1982), "Cyclonic depressions seem to have survived along the central Saharan axis and either across the Nile headwaters and Arabia or veered northeast into the Levant."

Although new diagrams appear almost every year, even the most basic questions concerning Quaternary climatic change have continued to go unanswered. Clearly, of more fundamental importance than the accumulation of new data is the adequate processing of the ample information already available. It is a major purpose of this paper to analyze these previous studies and to attempt to resolve the apparent dichotomy which exists.

Scope of This Work

Since long segments of many diagrams are composed almost entirely of non-arboreal pollen it seemed obvious that climatic information for the periods of time represented by these segments could only become available through careful study of the ecology and biogeography of the herbaceous pollen-producers applied to the fluctuations of their pollen in the diagrams. The ratio between two of these pollen types (Chenopodiaceae and *Artemisia*) was found to be useful as a relative moisture indicator and could be used to demonstrate moisture trends which were similar throughout the region.

Once a working model which reconciled the apparent anomalies in the existing data had been constructed, it was possible to concentrate on some of the important questions which remained. Palaeoclimatological studies of low latitudes demonstrate increased precipitation 30,000-25,000 B.P. and 10,000-6,000 B.P. How far north did this influence extend? If the more recent period was due to the increased solar radiation which occurred at that time and caused a strengthening of the monsoons, was the earlier period due to a similar phenomenon as suggested by Kutzbach (1981), or was it due to a southerly shifting of the zone of westerlies (Rognon, 1980, 1981), or to interacting climates (Flohn and Nicholson; 1980;

Maley, 1981). The Chenopodiaceae-Artemisia (C/A) ratio-derived moisture curves indicate increased precipitation 22,000-16,000 B.P. If real, how far south did this effect extend?

A limitation of the sites represented in most of the existing diagrams is that they are in mountainous regions or in regions surrounded by mountains. The great differences in altitude, topography, climate, and vegetation within short distances make it particularly difficult to distinguish between changes controlled by moisture, those controlled by temperature, and those related to interactions. The decision was made to concentrate on desert sites (Fig. 1) in regions of more uniform topography where moisture was accentuated and could be recorded accurately, while other factors were minimized.

The disadvantage of desert sites with pollen records is, of course, their lack of availability. In arid and semiarid regions lakes are usually ephemeral, forming during a storm or a rainy season, only to evaporate when normal moisture conditions reoccur. The fossil pollen is then exposed to oxidation or may even dry up and blow away as the sediments turn to dust. Nevertheless, regions of perennial water supply do exist or have existed in the past, even in very xeric regions. Over the past few years, numerous potential sites in desert regions of the Middle East and various types of sediment were investigated including alluvial and deltaic

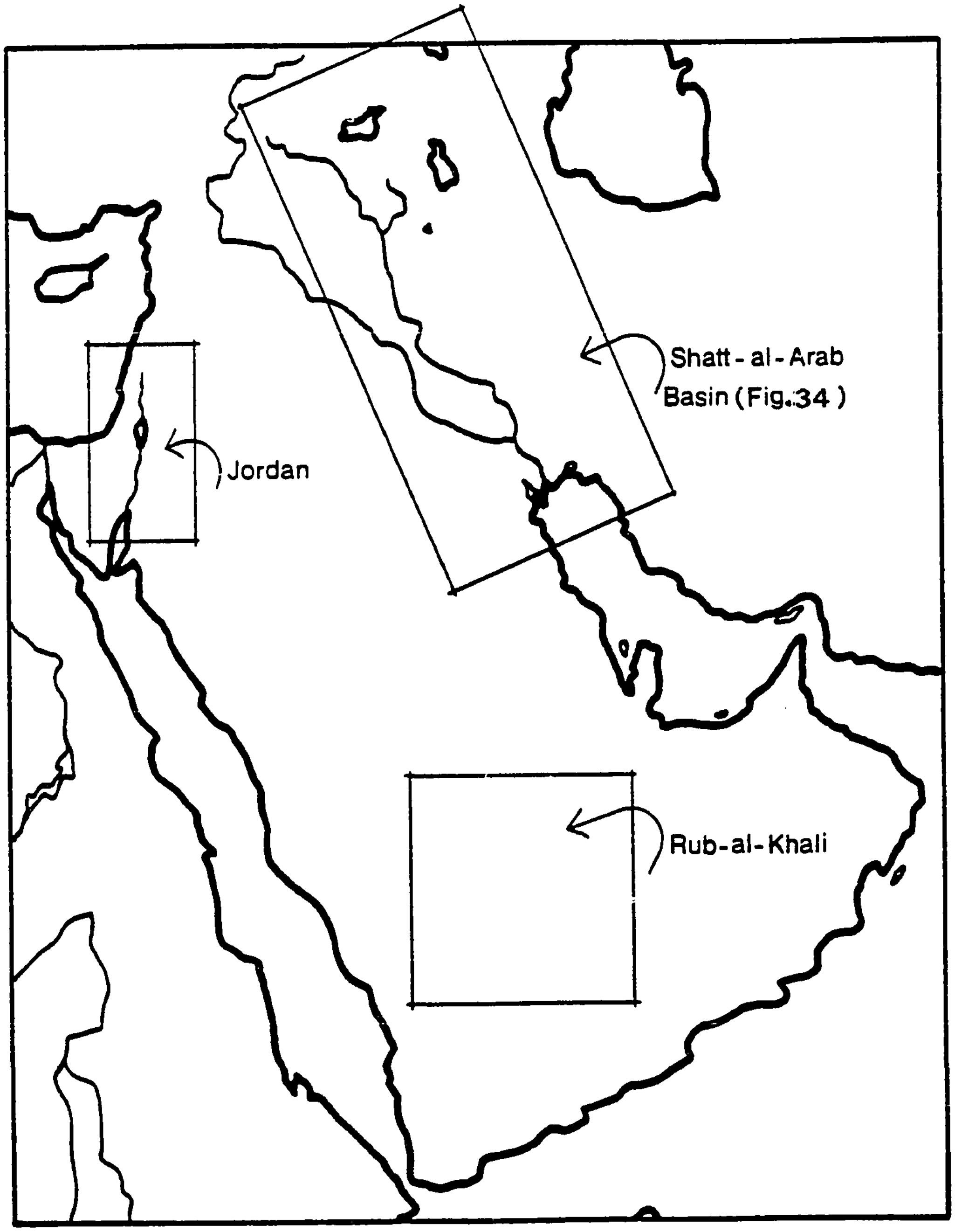


Fig. 1. Regions studied by the author.

deposits, sabkhas (saline regions of high water-table) and lakes in an effort to locate pollen-bearing materials.

Fortunately, dated sediments, some of which yielded ample pollen were eventually obtained from two regions in connection with ongoing geomorphological studies. At each site, Bubiyan Island, at the head of the Arabo-Persia Gulf in Kuwait, and the Rub'al-Khali in Saudi Arabia, both Holocene and Pleistocene sediments were investigated.

As a first step it was necessary to identify and collect plants to establish a pollen reference collection. Nearly two hundred pollen types were described, classified and photographed. A key to the regional pollen, much of which had not been previously described, was prepared.

It was also essential to obtain samples of present-day surface pollen assemblages from as many different plant communities and depositional environments as possible. It was fortunate that most regions which were inaccessible for political reasons had previously been studied by other palynologists. Desert areas had been largely neglected and it was left to the author to explore the accumulating pollen assemblages of Southern Iraq, Kuwait, Jordan and Saudi Arabia.

Low production and poor preservation rendered classical methods of palynology futile, both for modern assemblages and for sediments. However, when pollen was present at all, adequate concentration was eventually obtained by means of repeated fine sieving and/or centrifugation.

CHAPTER I

OVERVIEW OF REGIONAL CLIMATIC CHANGE

Any investigation of Quaternary climatic change must draw on evidence from several disciplines. Each specialist, therefore, has a responsibility to analyze critically results obtained in the context of other Quaternary sciences. This is not an easy task as each of these fields is highly specialized and, except in the attempt to answer similar questions, so different from one another, that expertise in one specialty does not qualify one as expert in any other field. With this in mind, the evidence from various disciplines is presented here in some detail, while in a later chapter previously published material is synthesized with my conclusions into an illustration of regional climatic history.

Pluvials and Their Relationship to Glacial Periods

There is ample geomorphological evidence that the Middle East has experienced times of greater rainfall in the past, but just how these rainy or pluvial periods are related to the recurring glacial periods of higher latitudes and to the general atmospheric circulation is only beginning to be understood. It was in this region that Lartet (1865) noted lake deposits in the Dead Sea Basin far above the present-day level of the lake. His observations with those of Jamieson (1862) and Whitney (1865) in western North America led to the concept of periods in the past which were moister than today. These moist periods were given the name

"Pluvials" by E. Hall in 1884. Russell (1885) at Lake Lahontan, Gilbert (1890) at Lake Bonneville, and Blankenhorn, among others, in the Middle East, further developed the concept that pluvials and glacials were contemporary (Butzer, 1961).

Over the next 75 years the notion of low-latitude lakes rising and falling synchronously with the expansion and contraction of glacial ice became firmly entrenched. This model, however, did not go unquestioned. As early as 1913 Penck suggested that tropical pluvial-glacial synchroniety was not likely on climatological grounds. He argued that world atmospheric conditions would only tend to be weakened or strengthened with glaciation and deglaciation. In general, climatic belts would be expected to migrate toward the equator during glacial periods and towards the poles during the interglacials. The reduction in evaporation, the displacement of the tropical high-pressure belts toward the equator and the reduction in strength of the monsoons should result not in increased rainfall, but in increased aridity (Fairbridge, 1962).

Nevertheless, it was not until the late sixties and early seventies that the concept of rain increasing and decreasing along with polar ice began to be rejected. At that time an almost overwhelming accumulation of evidence demonstrated pleniglacial aridity and increased Holocene precipitation at low latitudes. The data came primarily from Africa but also from India, Australia, and South America (Bigarella and de Andrade, 1965; Kendall, 1969;

Damuth and Fairbridge, 1970; Singh et al., 1972; Livingston, 1975; Bowler et al., 1976).

This is not to say, however, that glacials and tropical pluvials are negatively correlated with one another. The situation is much more complex than that, for although the tropics were dry at the glacial maximum there was apparently increased moisture during the preceding period of 30,000-25,000 B.P. (McClure, 1976, 1978; Street and Grove, 1979; Gasse et al., 1980). Furthermore, the westerly-controlled precipitation regime of the mid-latitudes of the eastern Mediterranean and Middle East differs fundamentally from that of the monsoonal precipitation of the tropics. It is not surprising that relationships between the two are lacking at their geographical extremes and highly complicated in the intervening regions where interaction between the two systems can be expected to have occurred.

Since the term "pluvial" carries with it certain erroneous stratigraphic connotations, left over from its long association with the glacial periods, and since it has never been adequately defined, it has outlived its usefulness. Most paleoclimatologists prefer to place moist periods of the past into a specific time frame and to describe them as quantitatively as possible in relation to present-day conditions.

Marine Sediments

A number of studies of planktonic organisms in Mediterranean cores have been made in attempts to estimate the Pleistocene climate (Emiliani, 1955; Parker, 1958; Reiss et al., 1971; Herman, 1972; CLIMAP, 1976; Cline and Hays, 1976; Luz and Bernstein, 1976, 1977; Cita et al., 1977; Almogi-Labin and Reiss, 1977; Thunell et al., 1977; Thiede, 1978; Thunell, 1979). The more recent studies have utlized the transfer function method of Imbrie and Kipp (1971) whereby surface temperature and salinity are related to assemblages of planktonic Foraminifera which are then applied to assemblages in dated sediments (CLIMAP, 1976; Cline and Hays, 1976; Luz and Bernstein, 1976; Thiede, 1978; Thunell, 1979).

Unfortunately, this has not resulted in the precision which might have been expected; the reason is that transfer functions were used whose basis is derived from North Atlantic data. One effect of this apparently has been to underestimate the seasonality of the Mediterranean because of the low seasonality of the North Atlantic. In the earlier of these studies, (CLIMAP 1976; Cline and Hays 1976; Luz and Bernstein, 1976) inconsistency in the taxonomy as well as generally subjective selection of the 18,000 B.P. level in the cores further reduced the reliability of the results (Thunell, 1979).

Thunell (1979) relied to a greater extent than previous authors on Mediterranean-derived transfer functions, using North

Atlantic assemblages only when no analogs existed in the modern Mediterranean. Therefore, it is primarily his results that will be considered here (Fig.2). Thunell (1979), and also Thiede (Fig. 3) (1978) have demonstrated that the temperature gradient in the Mediterranean assumed a north-south trend during the glacial period. Today the trend is west to east. The lowest glacial temperatures were in the Aegean sea with a tongue of cold water extending to the south. This suggested to both authors that meltwater run-off was entering the Mediterranean via the Aegean Sea. It is remarkable, however, that both the steepness of the gradient and the southerly deflection were greater in winter when meltwater run-off would be at a minimum. Therefore I suggest that consideration should be given to the likelihood that freshwater influx was due to higher (winter) precipitation rather than to glacial meltwater.

Surface salinities during the glacial period also trended north-south with lowest salinities in the region of the Aegean Sea, further indicating a large influx of freshwater. However, Luz (1982) pointed out that the quantity of meltwater needed to cool the sea to that extent would also require a substantial lowering of $\delta^{18}O$ in the same vicinity. In actuality a uniform $\delta^{18}O$ occurred throughout the basin suggesting that the temperature gradient was not due to glacial run-off. However, no explanation was suggested.

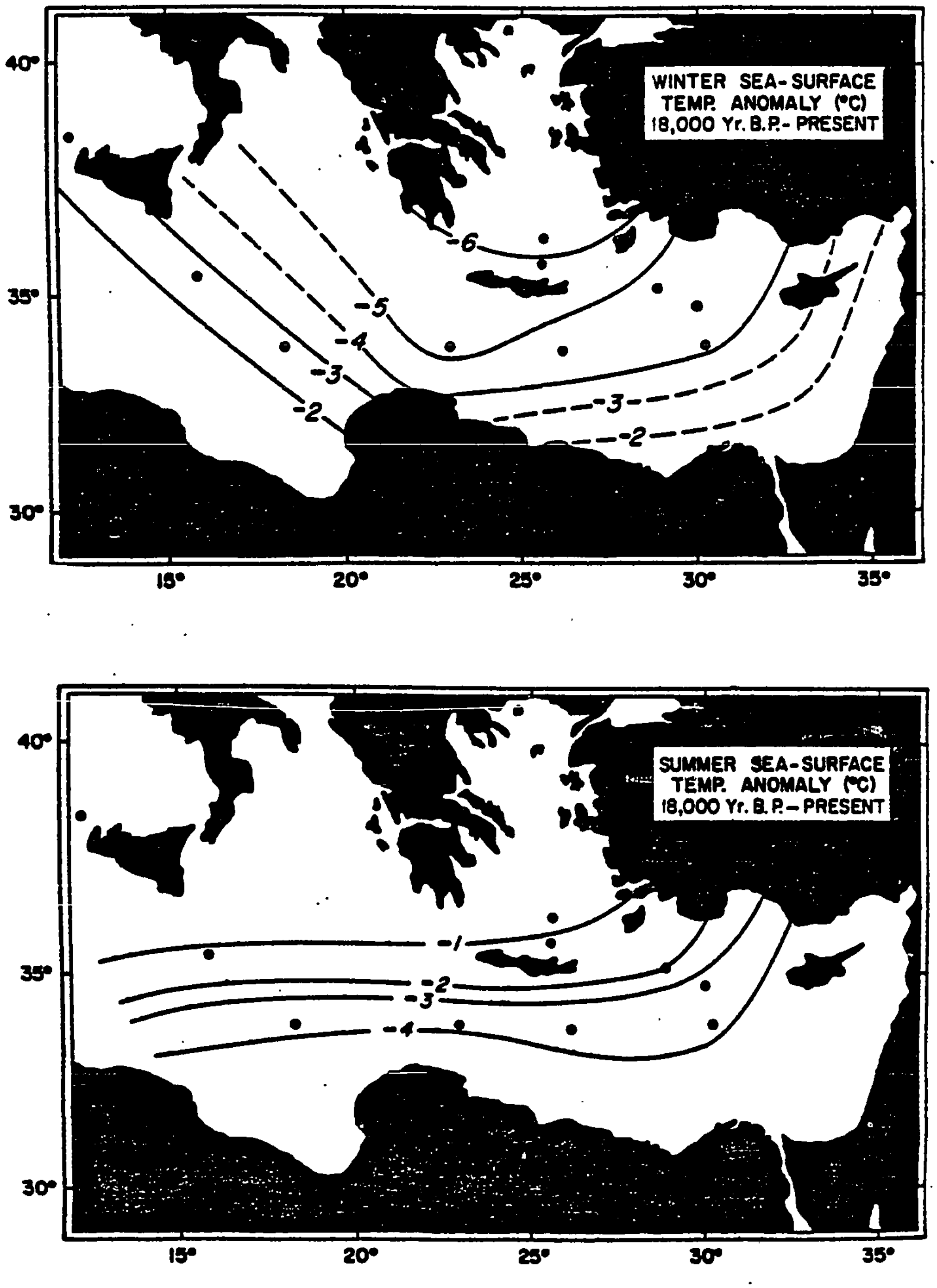


Fig. 2. Thunell's (1979) estimate of the difference between modern and glacial period sea-surface temperatures in the Mediterranean.

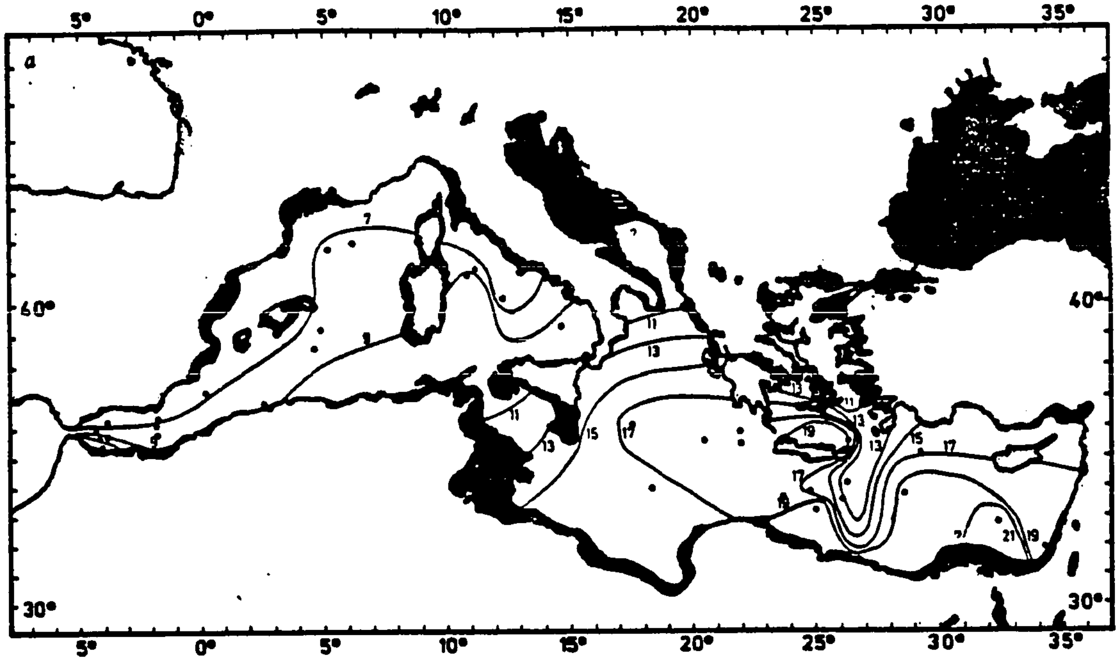


Fig. 3. Winter sea-surface temperatures (°C) 18,000 B.P. according to Thiede (1978).

More evenly distributed sources of freshwater would account for the similar $\delta^{18}O$ throughout the basin as well as for the steepness of the temperature gradient. If it is assumed that the low sea-surface temperature was primarily due to low air temperature, no massive influx of icy water would be required. The gradient could be explained by assuming a relatively cold sea which was cooled still further by the addition of colder run-off from winter precipitation in the regions of the Aegean, and warmed by the addition of increased run-off from the south via the Nile. Indeed in Thiede's (1978) reconstruction (Fig. 3), winter sea-surface temperatures off the Nile are shown as slightly warmer than today. Moreover a northerly extension of warm water extending from the region where the Nile enters the Mediterranean is apparent, as well as the tongue of cold water extending south from the Aegean. Neither Thiede (1978) nor Thunell (1979) have given serious consideration to the Nile as an important source of freshwater influx during the glacial period.

A study of $\delta^{18}O$ and of sapropel layers in a closely sampled 50 cm of core have enabled Rossignol-Strick et al. (1982) to precisely describe the environment of the Eastern Mediterranean between 20,000 and 5,000 B.P. (Fig. 4). A higher ratio of $^{18}O/^{16}O$ isotopes occurs in the calcitic shells of *Globigerinoides ruber* during glacial periods. This is partially related to temperature but a more important factor is the preferential evaporation of the

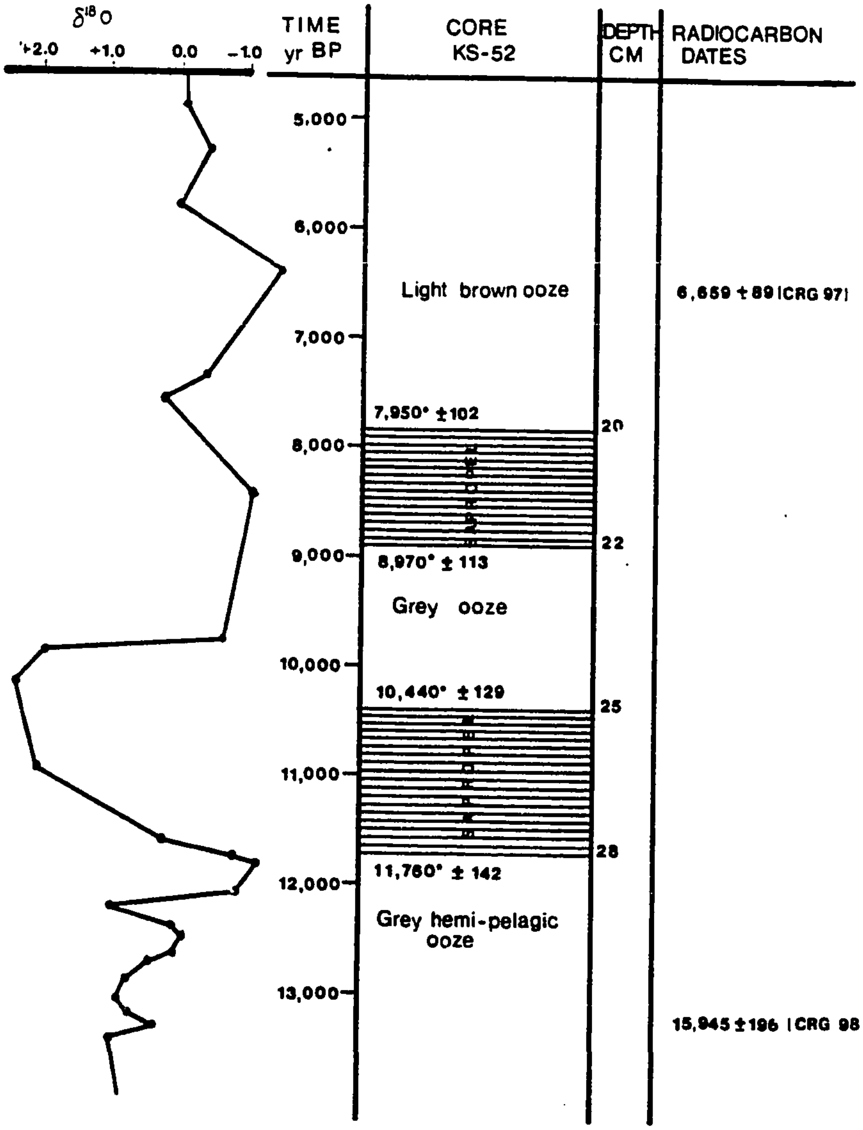


Fig. 4. Deep sea core from Mediterranean showing sapropels and $\delta^{18}O$ curve.

^{16}O isotope and its accumulation in glacial ice resulting in the enrichment of the heavier isotope in the ocean. Sapropels are black organic-rich mud that results from reduction of the pelagic material under conditions of stagnation. They occur periodically in the sediments of the deeper parts of the Mediterranean basin and are caused when a combination of high-salinity bottom water and a low-salinity surface layer stratifies the water column, preventing oxidation of the bottom sediments. At the time of their formation $\delta^{18}O$ levels of the epipelagic Globigerinoides ruber are drastically reduced.

Between 17,000 - 11,800 B.P. $\delta^{18}O$ decreased 2% with several sharp oscillations after 14,000 B.P. This decrease was probably due to a combination of rising temperatures and, until 13,500 B.P., of increased meltwater via the Bosporus, causing partial stagnation and the deposition of a grey protosapropel layer. The sharpest decrease of $\delta^{18}O$ occurred just prior to the deposition of the first sapropel layer between 12,600 and 11,700 B.P. This is attributed entirely to increased tropical rainfall which was discharged into the Eastern Mediterranean by the Nile. This influx of low-salinity water triggered the formation of sapropel after a 230 year lag. Between 11,000 and 10,000 B.P. $\delta^{18}O$ suddenly increased resulting, after about 600 years, in the deposition of an oxygenated ooze, during which time the maximum $\delta^{18}O$ occurred. Since the period of increased $\delta^{18}O$ was synchronous with the cold Younger Dryas of northwest Europe it is assumed that renewed tropical aridity, glacial build-up and lowered temperatures were responsible. After 10,000 B.P. $\delta^{18}O$ again decreased rapidly due primarily to resumption of the Nile floods. Sapropel formation was delayed 800 years, presumably due to the very high sea-surface salinity prior to the flooding. The minimal values of $\delta^{18}O$ occurred between 8000 and 6000 B.P., the formation of the sapropel layer, 8970 ± 113 to 7950 ± 102 B.P. Subsequently $\delta^{18}O$ increased to present-day levels. Corresponding to the low $\delta^{18}O$ and sapropel formation in the Mediterranean are low $\delta^{18}O$ values about 8000 B.P. in cores from the Red Sea and the Gulf of Aqaba about 8000 B.P. (Schoell and Faber, 1978).

Further indications of regional climatic change are available from studies of the Arabo-Persian Gulf. Kassler (1973) showed that during the last glacial period the drop in eustatic sea level emptied the Gulf, transforming it into an extended river valley of the Shatt-al-Arab which ended only at the Gulf of Oman. During this time tributaries joining the main valley from Arabia and Iran eroded the slopes, leaving submarine channels which have been mapped by sparker profiles and echograms. The maximum development of these channels coincided with the maximum retreat of the sea. Their formation is due to both structure and erosion. Baselevel lowering must have played a role but increased rainfall has to be invoked to account for their level of development. Platforms carved into the channels on both sides of the Gulf apparently mark stands of sea level of the Holocene transgression (Kassler, 1973).

Based on the study of relict sediments by Sarnthein (1972) and of radiocarbon-dated cores by Stoffers and Ross (1979) a sequence of sedimentation in the Gulf has been established. Throughout the period of rise in sea level following the last glacial period (12,000 B.P. to 6000 B.P.), sediments were dominated by aragonite, a carbonate which today is formed only near the very arid coasts of the south and southwest where no rivers enter the Gulf. Apparently, the Zagros mountains were much drier and the rivers which drain them much less active than they are today. By 6000 B.P. a more marly carbonate had begun to be deposited, its higher clay content indicating an increase in terriginous sediments delivered by the Zagros rivers (Sarnthein, 1972). SEM studies on the quartz crystals indicate a predominance of wind-transported grains prior to 6000 B.P. and an increase in fluvially-transported grains after that time, supporting the climatic interpretation of the change in sediment types (Georgiev and Stoffers, 1980).

Mountain Glaciation and Snow-line Lowering

Features indicating the presence or extension of mountain glaciers often have been used to estimate climatic conditions during the recent glacial period. Messerli (1967) has estimated a 1000 m snow-line depression in the circum-Mediterranean area based on his extensive studies of glaciation in that region. He has related this to a temperature depression of 6-7° C.

Wright (1960) identified fresh moraines below 1325 m in the large valleys of the Iraqi Zagros and small cirques as low as 1700 m in some protected locations, indicating that the snow line was lowered by 1200-1800 m, This conflicts with Bobek's (1940) estimate of a lowered snow line of 775 m, but Wright (1960) believes that Bobek's (1940) estimates may have come from retreatal phases and so do not represent the maximum extent of glaciation. The degree of snow line lowering reported would have required a 12°C drop in temperature unless, as Wright suggested, an increase in precipitation is also assumed.

Such a large lowering of snow line is also difficult to reconcile with the much smaller depression in the Mediterranean region. If both estimates are correct, the temperature reduction for the Zagros Mountains must have been considerably greater than in the region closer to the Mediterranean as the increase in winter precipitation in the Zagros Mountains cannot be expected to have greatly exceeded that of the mountains closer to the moisture source.

Even more surprising than the 1800 m lowering is the 1300-1400 m and 1440-1540 m depressions identified on Shir Kuh and Kuh-i-Jupar of the south central Iranian plateau (Kuhle, 1974; Grunert _et_ _al_., 1978) implying considerable decrease in temperature and increase in precipitation in spite of their low latitude and their isolation from northwesterly sources of precipitation by the Zagros mountains to the west and the Elzburg mountains to the north. The validity of the various methods used in determining past glaciation, as well as the validity of the assumption that the extent of small isolated glaciers is equivalent to climatic snow line, has been questioned by Brooks (1982). He has stressed the problems of large asymmetry of glaciation due to local variation in aspect and topography, lack of agreement on lapse rate, inadequate dating, and the relatively small area of elevations above the present and glacial period snow lines.

Lake Level Changes

Fluctuating lake levels have been shown to be useful indicators of regional changes in effective precipitation (Street and Grove, 1979). However, well-documented changes are few for Middle Eastern lakes as compared to those in other semi-arid regions of the world. (Table 1).

Roberts (1982), in a regional classification of lake levels, has demonstrated that consistent trends are exhibited by the existing data, while pointing out the potential information available from many additional lake basins yet to be studied. In some regions, changing levels may be affected by non-climatic factors such as tectonics, as in the Jordan Valley, or by

TABLE 1

LOCATIONS OF RADIOCARBON DATED SEDIMENTS USED FOR ESTIMATING LAKE-LEVEL CHANGES OR OTHER PALEOCLIMATIC INFORMATION

(for Rub'al-Khali sites see Ch. 7)

	N. LAT./E. LONG.
Wadi ar-Rimah	20°00'/43°30'
Wadi Ranyah	21°14'/42°46'
Wadi Birk	23°30'/46°50'
Wadi al-Luhi	24°26'/46°30'
Bahrain	25°06'/50°06'
The Sulb Plateau	26°30'/47°30'
Jubbah	28°02'/40°56'
El Jafr	30°30'/35°30'
Lake Lisan	31°30'/35°30'
Damascus	33°37'/36°31'
Palmyra	34°30'/38°10'
Zeribar	35°32'/46°07'
Konya	37°30'/33°00'
Ioannina	39°40'/20°51'

underground karstic outlets, but if such factors are noted and accounted for, even these lakes can be useful as climatic indicators.

In northwest Greece, Lake Ioannina apparently reached its highest level 22,000 to 20,000 B.P. (Higgs, 1978; Vita-Finzi, 1978) , but note that Bottema (1974) questioned this on palynological grounds. Studies of fluctuations of Turkish lakes have been summarized by Erol (1978). Since most of Turkey today experiences rather cool, moist climates, Erol's research has centered on the warm, drier region of south central Anatolia. In general, highest lakes occurred prior to 13,000-11,000 B.P. By 10,000 B.P. a period of extreme aridity had set in followed by an increase in moisture some time after 7000 B.P.

A recent series of radiocarbon dates from Konya basin, Turkey (Roberts *et al*., 1979), shows a high lake level 23,000-17,000 B.P. and a later one 12,000-11,000. Terraces above Lake Van in eastern Turkey reach up to 80 m above the present level, joining glacial moraines in the mountain valleys above the lake. The +22m level has been radiocarbon dated at 24,000-23,000 B.P. A drastic fall in lake level occurred before 10,000 B.P. (Roberts 1982).

In western Iran, indications of variations in the level of Lake Zeribar come from studies of the chemistry (Hutchinson and Cowgill, 1963), Cladocera (Megard, 1967), and plant macrofossils (Wasilikowa, 1967) of cores. Plant macrofossils indicate that the lake was high between 22,000 and 14,000 B.P. but fluctuated strongly from 14,000 to 6000 B.P. During this period low water levels are also suggested by the presence of sediments without fossil Cladocera. Also Chydoridae had disappeared completely, perhaps due to increased salinity, while diatom species are those representative of alkaline conditions (Megard, 1967). In addition, high chloride and carbonates in the lake sediments are indicative of a decreasing tendency to overflow (Hutchinson and Cowgill, 1963). By about 6000 B.P. conditions within the lake had stabilized to the extent that perennial swamp vegetation became established (Wasylikowa, 1967) and the lake regularly overflowed (Hutchinson and Cowgill, 1963). Dramatic Bosminia increases also indicate greater depths and volumes of water.

Lake Lisan, the extension of the Dead Sea, occupied the rift valley during the late Pleistocene. It must be emphasized that this region is subject to tectonic movement. Horowitz (1979), in fact, attributes the demise of the lake after 17,000-15,000 entirely to a phase of increased tectonics. Neev and Hall (1977), on the other hand, suggest a drying trend beginning after 20,000 B.P. A later moist period is thought to have redeposited salt from Lake Lisan into the Dead Sea.

Radiocarbon dates of lacustrine sediments have been obtained from various sites where no lakes occur today (Fig. 5). Sediments in the Damascus basin dated between 23,605 ± 565 (HV-4470) and

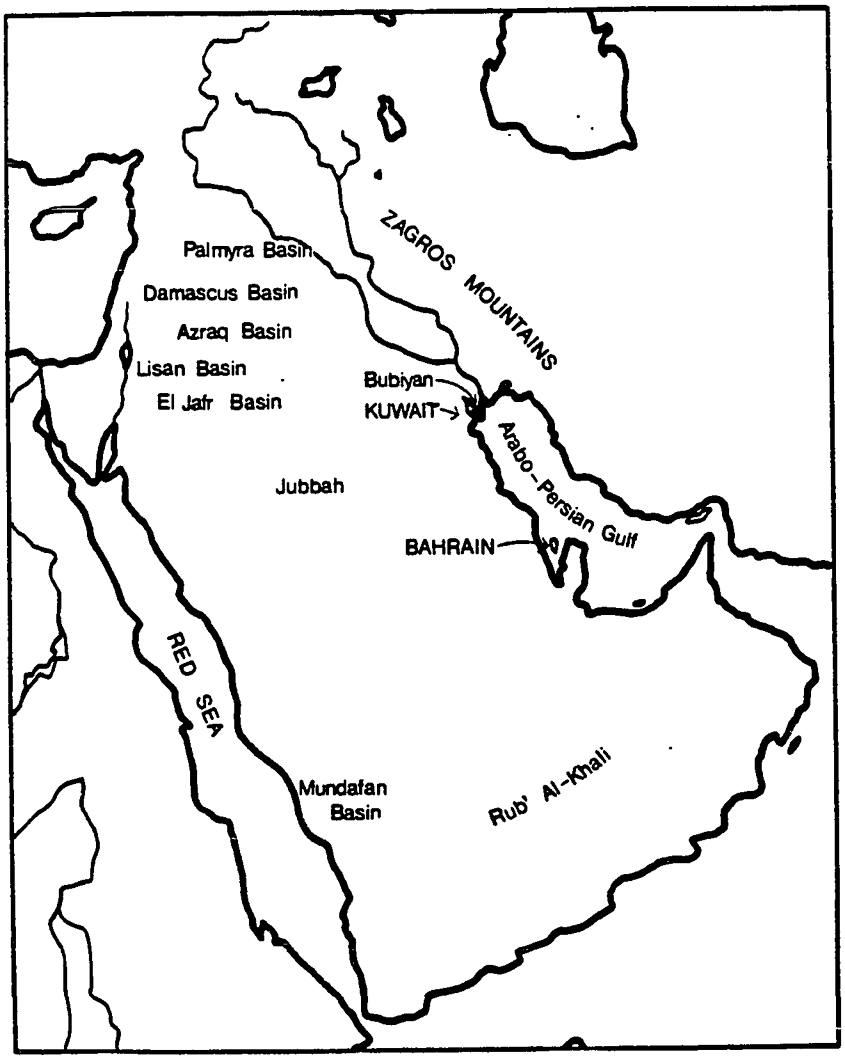


Fig. 5. Sites of lacustrine sediments in dry regions of the Middle East.

18,990 ± 520 (HV-4471) (Kaiser et al., 1973) and from Palmyra basin between 19,410 ± 150 (GRN 7597) and 18,900 ± 200 (TK-150) (Sakaguchi, 1978). From the upper part of the lake marl deposited in the Al Jafr basin of eastern Jordan, a date of 26,400 ± 870 B.P. (HV-1719) has been reported (Huckriede and Wiesemann, 1968). Following the lacustrine period was a time of extreme dryness. Later during a moister phase, dissolution of the upper lake marls occurred and a playa was formed. There are no dates from the Azraq basin farther to the north, but the sequence of changes is similar (Garrard and Stanley Price, 1977).

At Jubbah in the Nafud of northern Saudi Arabia, Garrard et al. (in press) studied a former lake basin which had been protected from burial by a chain of sandstone hills to the west. A lacustrine diatomite was dated to 25,630 ± 430 B.P. (Q-3117). This was followed by a period of fine-to-medium aeolian sand deposition and a later moist period during which an organic silty sand (6685 ± 50 B.P.) was deposited.

A similar sequence of deposition has been reported from lake sediments in the Rub'al-Khali (Empty Quarter) of Saudi Arabia (McClure 1976, 1978). The most extensive of these deposits are located in the Mundafan Basin on the western edge of the Rub'al-Khali at the base of the Wajid Plateau. A large number of radiocarbon dates have been obtained. The earlier series clusters primarily between 30,000 and 21,000 B.P. An intensely arid period separated these deposits from a more recent series (9000 - 6000 B.P.). Contemporary lake formation occurred on the island nation of Bahrain in the Arabo-Persian Gulf (Doornkamp et al., 1980). In Wadi al-Luhy, Saudi Arabia, gastropods in lake deposits were dated to 8400 ± 140 B.P. (VR1-384) (Hötzl et al., 1978).

Other Radiocarbon Dated Materials

Several other radiocarbon dates have been reported from scattered sites in Saudi Arabia (Table 1). In lower Wadi Birk charcoal in aeolian sands and silts characteristic of arid environments was dated to 2170 ± 130 B.P. (VRI-503) while sinter pebbles from the same region yielded dates of 27,140 ± 1940 B.P. (IRM-4240) and 6880 ± 290 B.P. (IRM-4,241) (Hötzl and Maurin, 1978). At Wadi Ar-Rimah crumbs and pebbles encrusted with calcium carbonate were found embedded in a few centimeters of a terra rossa-like soil which forms under moist conditions. The carbonate was dated to 28,900 ± 1300 B.P. (VR1-442) (Hötzl et al., 1978).

Large areas of eastern Arabia are covered by calcareous duricrust. The crust is formed by precipitation moving downward into the soil and later, in response to evaporation, moving upwards. Its formation requires a rainfall considerably higher than that which occurs in Arabia today, interacting with a high evaporation rate. As the rain percolates through calcareous sand, siltstone or limestone, it dissolves the matrix and loosens the grains. During evaporation the supersaturated solution of $CaCO_3$ cements the surface into a hard pan. The oldest duricrusts directly overlie Tertiary strata, and are believed to have had their primary formation during the Pliocene-Pleistocene humid period. On the other hand, younger crust formations date from 30,000 to 25,000 B.P. and calcareous weathering horizons from about 1 m below the surface in the Maqamil loam pit in Wadi Ranyah showed ages of between 26,000 and 29,000 (Hötzl and Zötl, 1978).

The Sulb Plateau is a strongly karstified region. Radiocarbon measurements were made of deposits from within caves. A small "warty" calcite deposit was dated to 5060 ± 250 B.P. (IRM-3660). Stalactites were found not to contain ^{14}C and are thus older than 37,000 years. Duricrusts were also dated, and corrected dates of 30,500 to 32,000 B.P. were obtained (Felber et al., 1978). It should be noted that calcareous pans, encrusted pebbles and other sinter deposits do not form today even under sporadic episodes of heavy rainfall.

Radiocarbon measurements of ground water in eastern Arabia yielded dates of 22,000 to 34,500 B.P. but it should be pointed out that ground water is particularly susceptible to "contamination" by modern water. Other isotopic measurements indicate that considerably lower temperatures and rainy conditions prevailed during the dominant time of water infiltration (Moser et al., 1978).

Palynology

Cores of several Middle East lakes have been studied palynologically over the past several years. Location of diagrams discussed are shown in Figure 6. The majority of diagrams have been interpreted as indicating a dry glacial period with moisture increasing in the Holocene. It should be emphasized that although the conclusions reached differ greatly from mine, the original interpretations will be presented here.

Three pollen diagrams, extending well back into the Pleistocene, have been published for Greece. The first of these came from Tenaghi Philippon in the Drama plain of eastern Macedonia at an altitude of 40 m (Wijmstra, 1969) (Fig. 7). The second was from Lake Ioannina (alt. 470 m) in the Pindus mountains of northwestern Greece (Bottema, 1974) (Fig. 8), and the third from drained Lake Xinias in east-central Greece at 500 m altitude (Bottema, 1978) (Fig. 9). Several other shorter diagrams have also been obtained (Bottema, 1974; Turner and Greig, 1975).

At Xinias and Tenaghi, arboreal pollen (AP) was very low throughout most of the glacial period, and steppe vegetation prevailed. At Ioannina, however, AP never dropped below 15% and was, at times, as high as 45%. It has been concluded that a glacial tree refuge occurred in the Pindus mountains and perhaps elsewhere at higher elevations where precipitation would have been

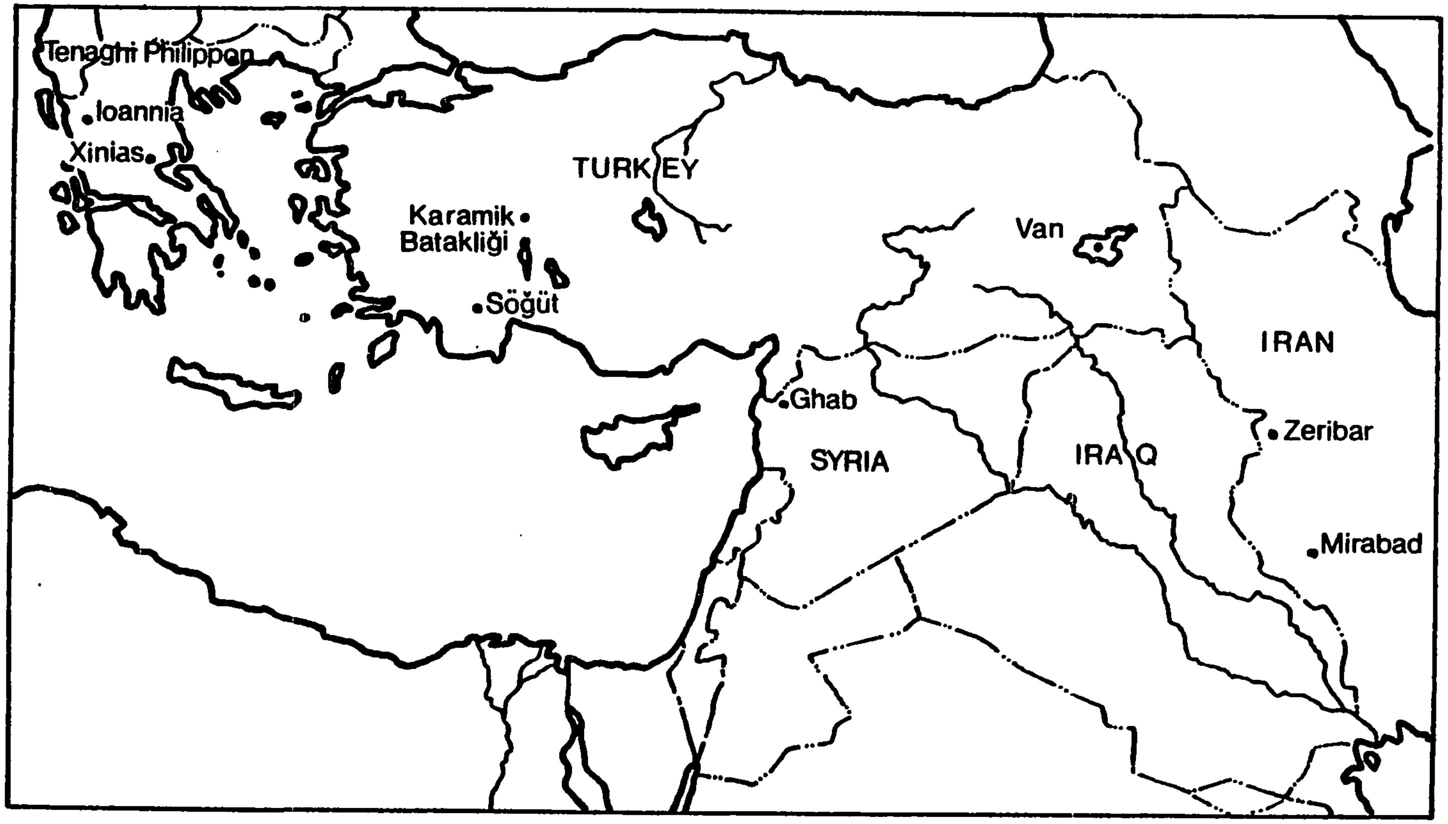


Fig. 6. Locations of pollen diagrams reproduced and discussed in the text.

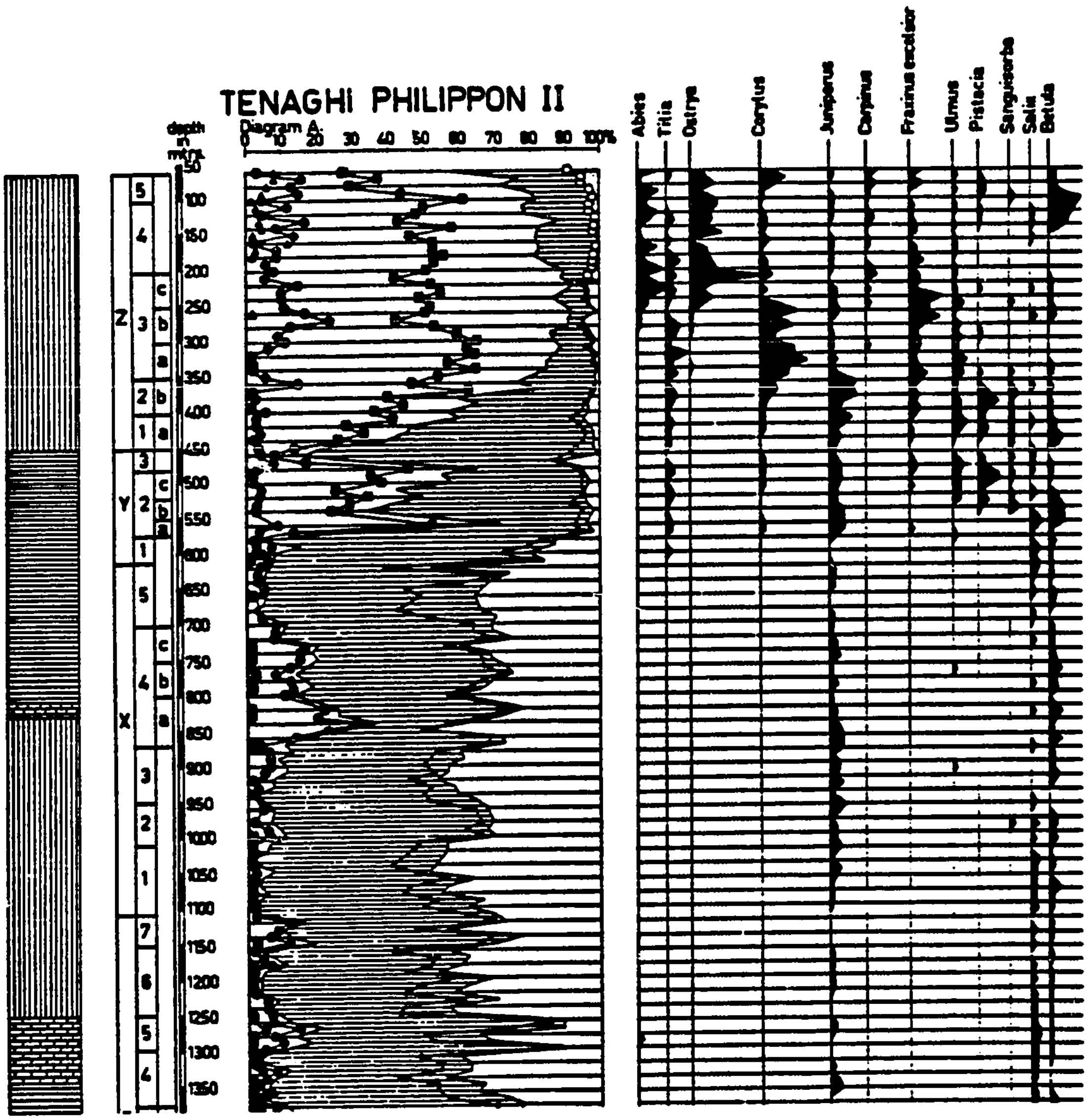


Fig. 7. Pollen diagram of Tenaghi Philippon, northeastern Greece (Wijmstra, 1969).

IOANNINA I

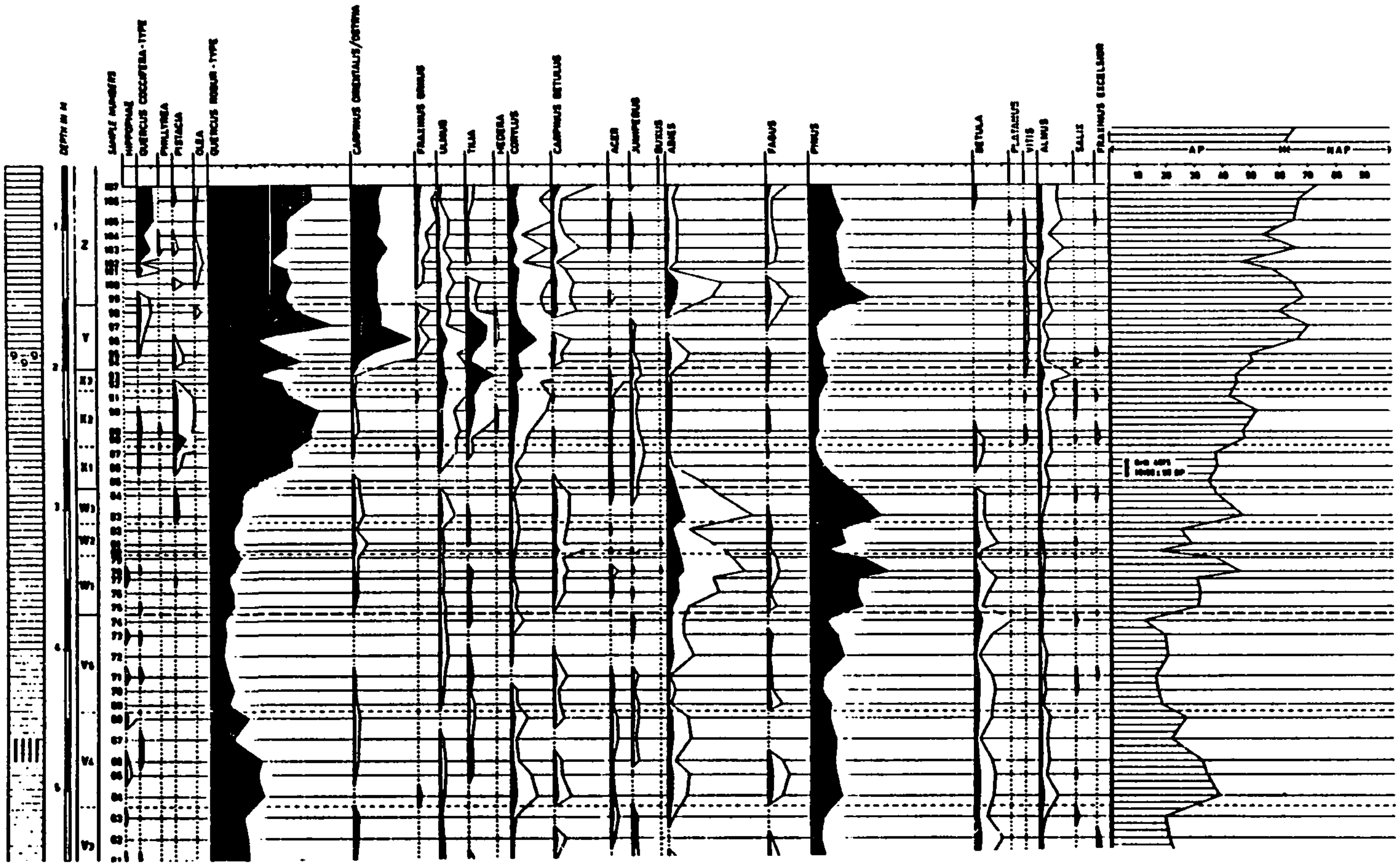


Fig. 8. Pollen diagram of Lake Ioannina northwestern Greece (Bottema, 1974).

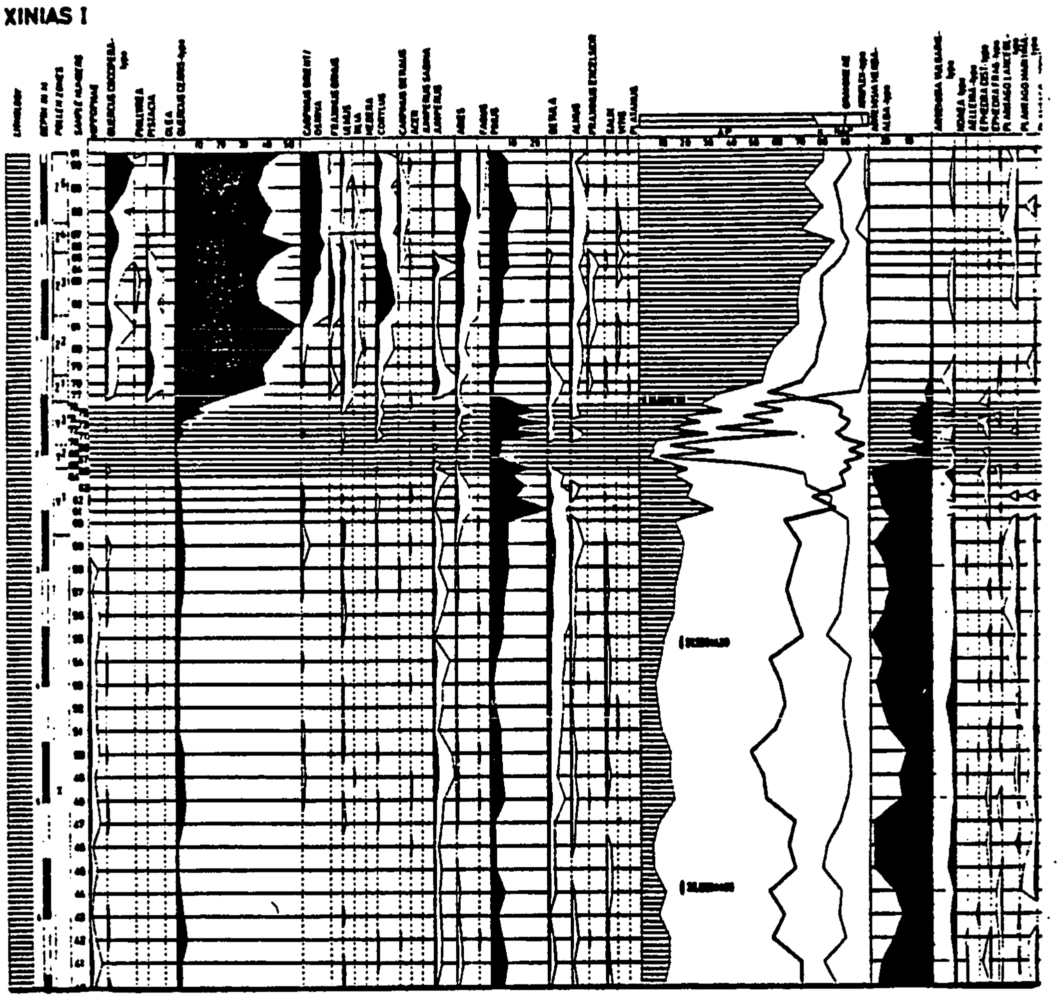


Fig. 9. Pollen diagram of Lake Xinias, east-central Greece (Bottema, 1979).

higher. At lower altitudes trees were assumed to have been limited by glacial-period aridity, a later increase in moisture permitting establishment of forests throughout the country, after about 10,000 B.P.

Diagrams from a series of three lakes provide data for interpretation of climatic change in the Kurdistan region of western Iran (van Zeist and Bottema, 1977) and southeastern Turkey (van Zeist and Woldring, 1978) (Figs. 10, 11, 12). At Lake Zeribar (elev. 1300 m), the only one of these diagrams which extends back into the Pleistocene, conditions were apparently even more severe than in Greece, for tree pollen remained almost nil throughout the glacial period. The *Quercus* (oak) forest began to return very slowly after about 10,000 B.P. but did not reach its peak until 5500 years ago, while at Lake Van in southeastern Turkey (elev. 1650 m) the *Quercus* forest was not established until 3400 B.P. (van Zeist and Woldring, 1978).

Two other diagrams from southern Turkey are long enough to indicate changes in climate from the glacial period to the Holocene (van Zeist *et al.*, 1975). At Lake Söğüt (elev.1393 m) glacial period vegetation apparently alternated between steppe and steppe-forest. The only date available is at 9180 ± 95 B.P. and so it is impossible even to estimate the times of these fluctuations. Tree pollen (mainly *Quercus* and *Pinus*) increased after 9000 B.P. and again this is assumed to be due to an increase in moisture

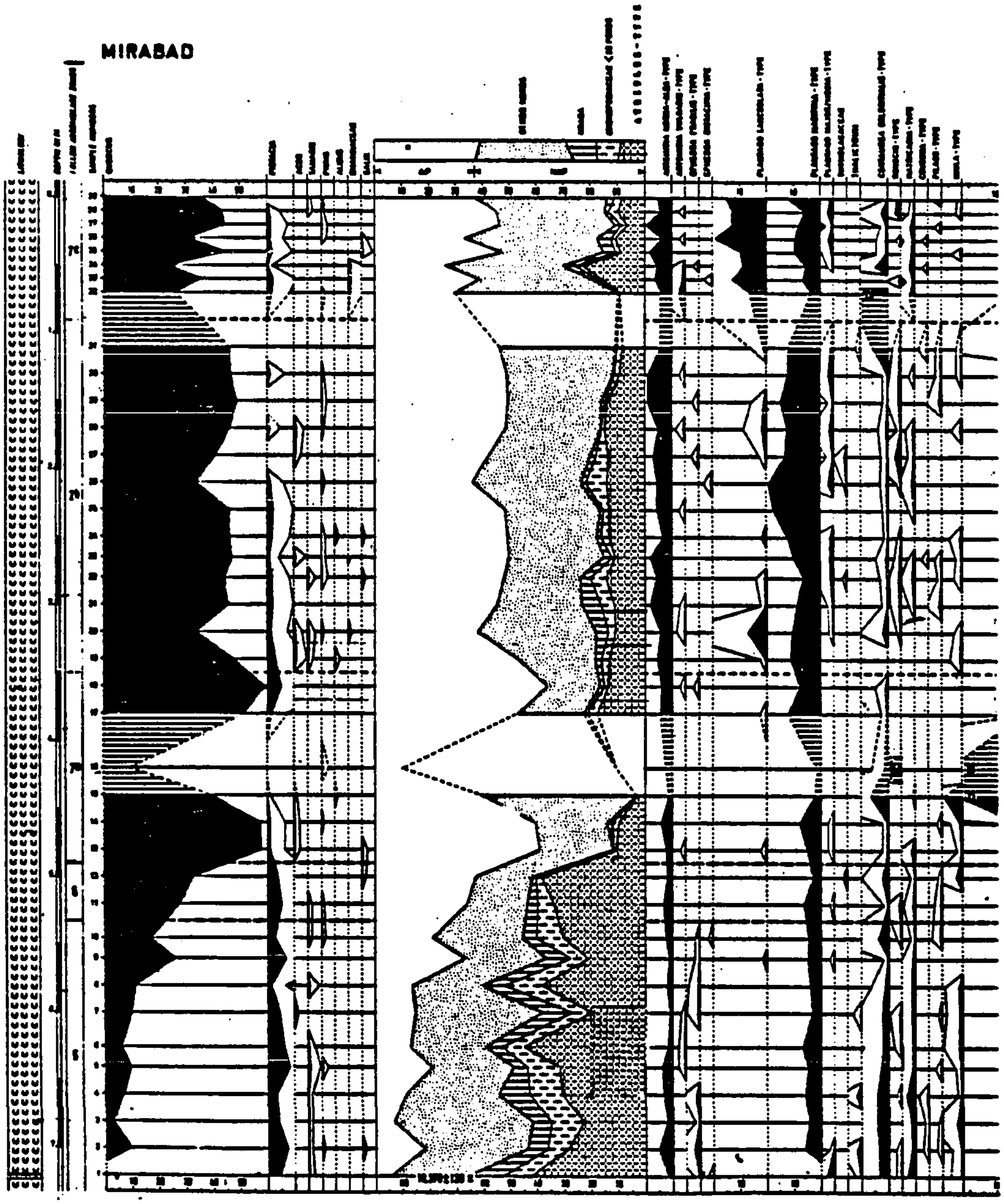
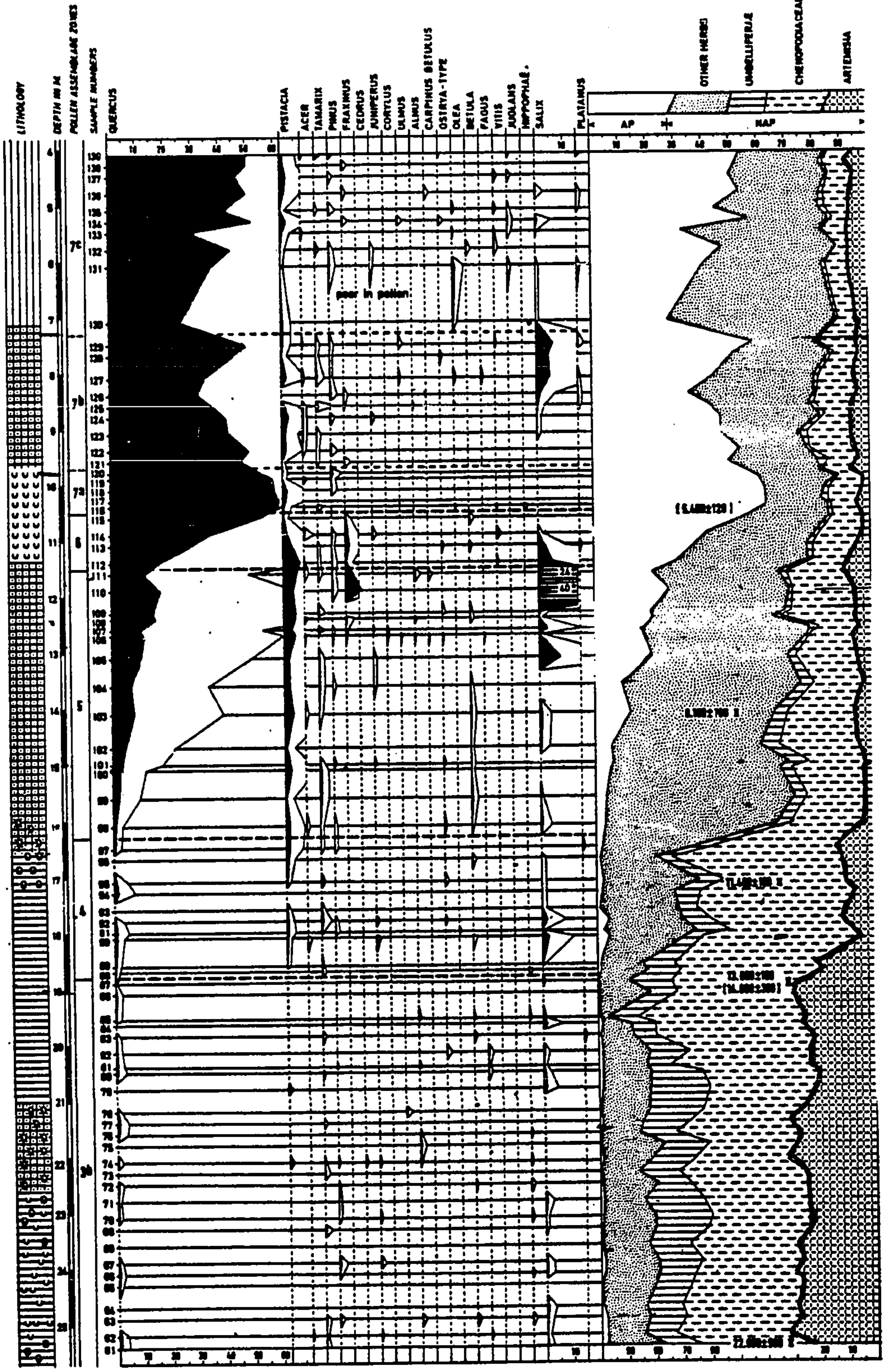


Fig. 10. Pollen diagram of Lake Mirabad, western Iran (van Zeist and Bottema, 1978).

Fig. 11. Pollen diagram of Lake Zeribar, western Iran (van Zeist and Bottema, 1977).

ZERIBAR I^{b} (1963-J)



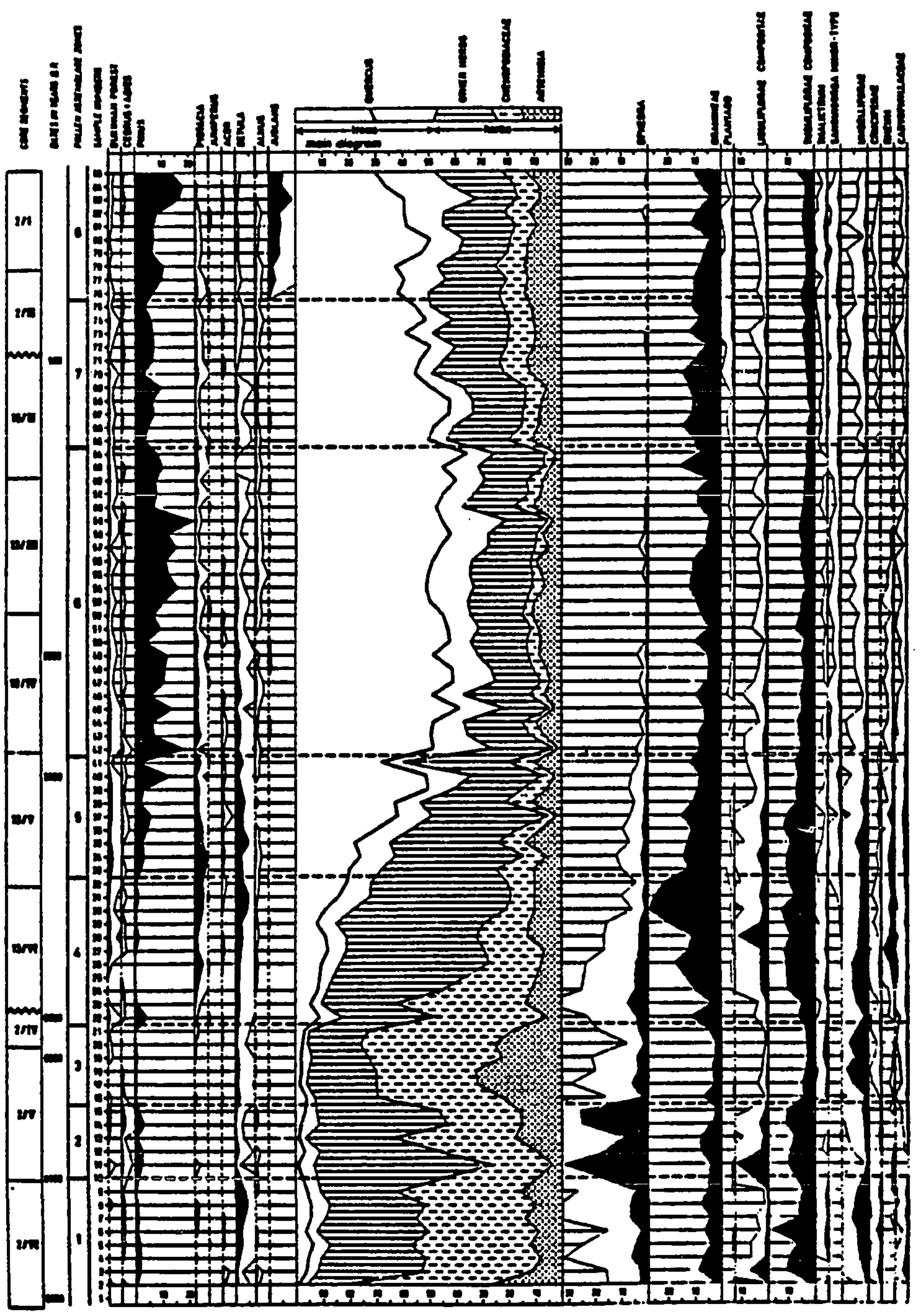


Fig. 12. Pollen diagram of Lake Van, southeastern Turkey (van Zeist and Woldring, 1978).

(Fig. 13). At Karamik-Batakliği (elev. 1000 m) in the levels dated 20,130 ± 290 B.P. (GrN-6881) low values of arboreal pollen occur, but soon after, Pinus and Cedrus (cedar) begin to increase rapidly. The two genera continue to fluctuate during the length of the diagrams, presumably in response to moisture (Fig. 14).

A pollen diagram has been prepared from cores in the Ghab Valley of northwestern Syria (Niklewski and van Zeist, 1970) (Fig. 15). Arboreal pollen, primarily of deciduous oak, was present throughout the glacial period. It fell to a low of around 10% just before rapidly increasing to a maximum about 10,000 B.P. At the same time, pollen of Pistacia, evergreen Quercus and Olea (olive) first appeared. The value of arboreal pollen soon fell to a lower level and although fluctuations continued it never again attained the percentages that it had reached between 10,000 and 8000 B.P. It has been concluded that moisture increased to its highest level during this time and then decreased again afterwards (Niklewski and van Zeist, 1970; van Zeist and Bottema, 1982).

Summary

Studies of paleotemperature and paleosalinity of the Mediterranean suggest that either meltwater or precipitation caused a low-salinity layer of water to form on the surface during the pleniglacial (Thiede, 1978; Thunell, 1979). Later, after 12,000 B.P. low salinity occurred due to increased precipitation at low

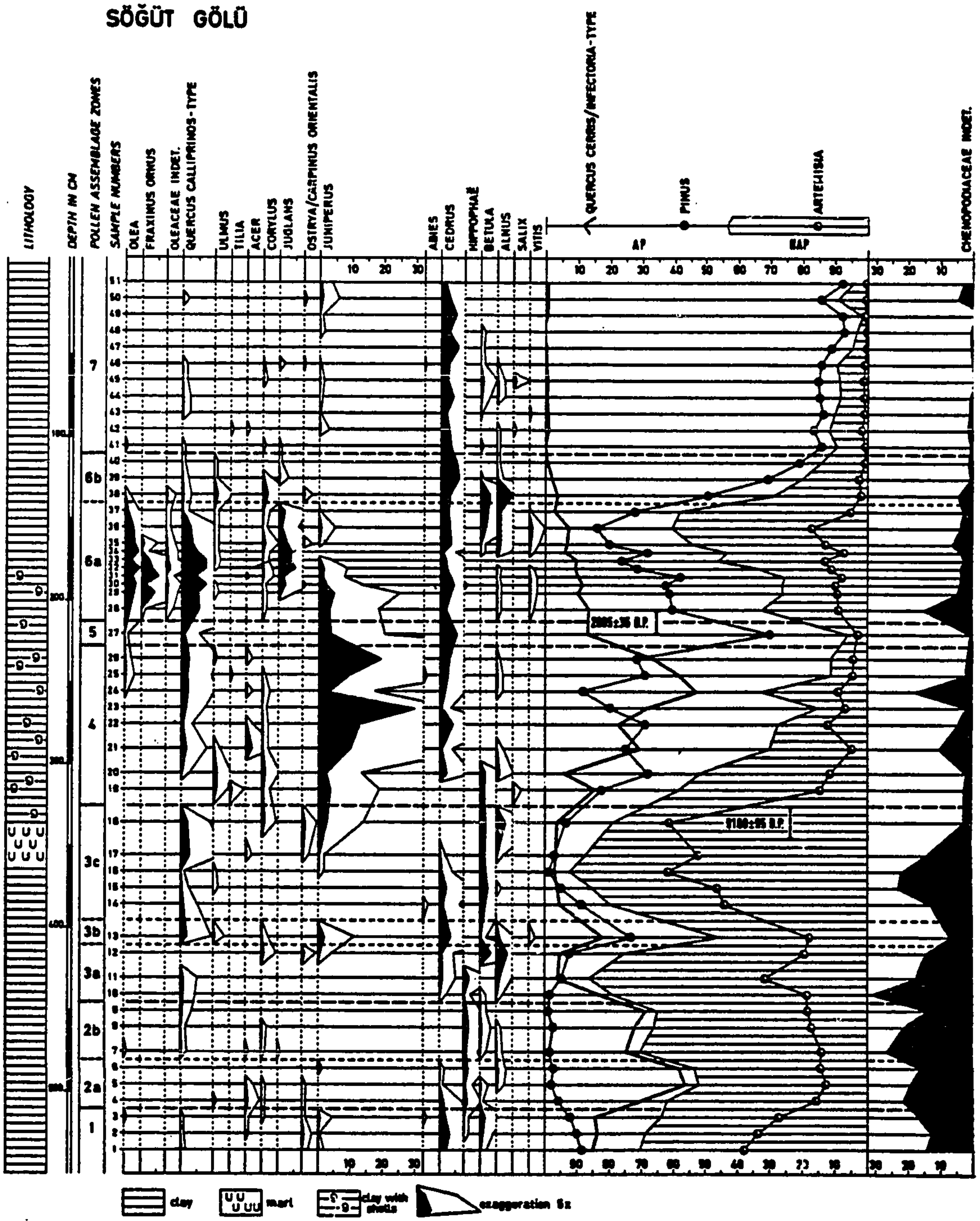


Fig. 13. Pollen diagram of Lake Söğüt, southeastern Turkey (van Zeist *et al.*, 1975).

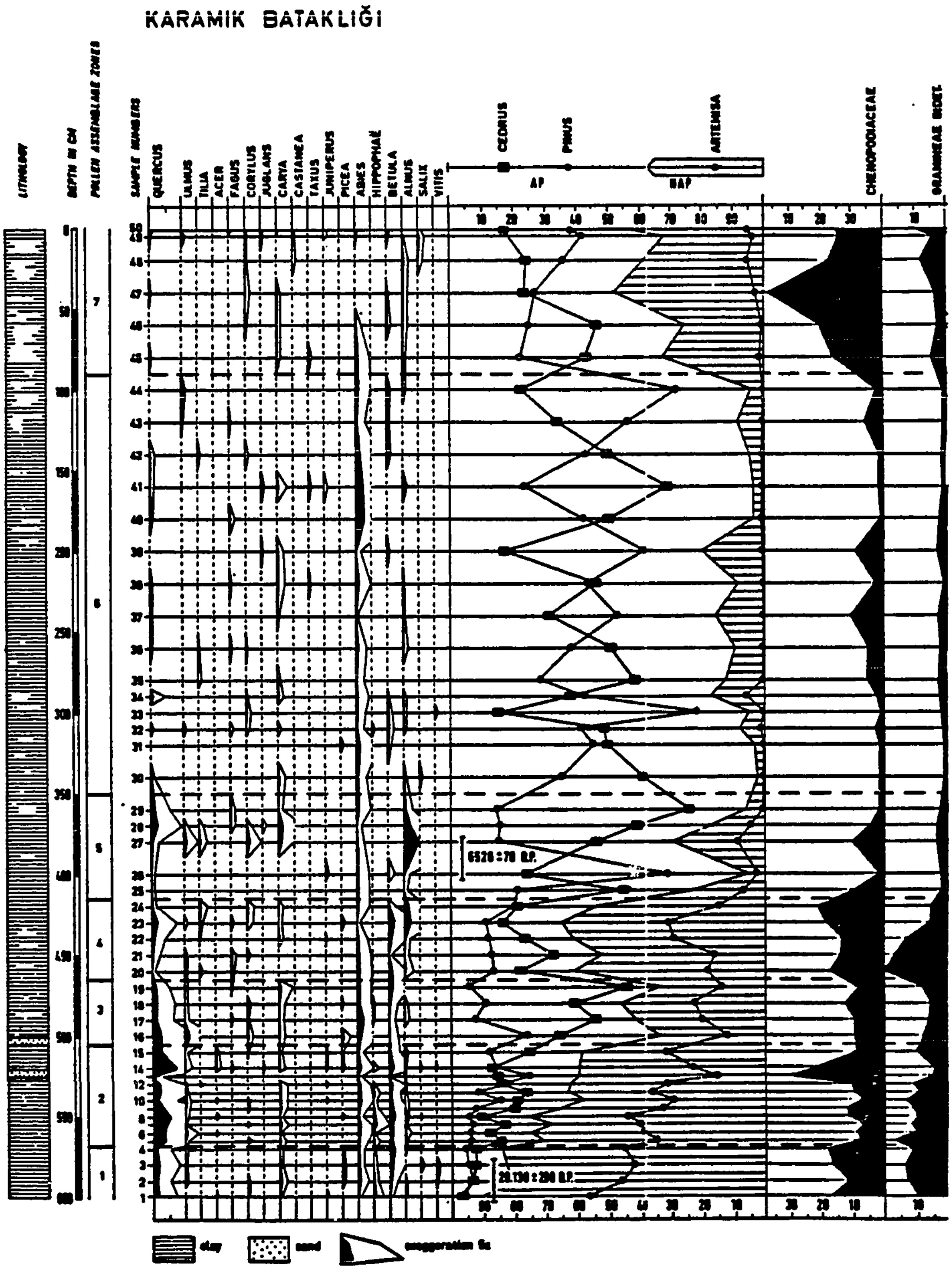


Fig. 14. Pollen diagram of Karamik Batakliği, southwestern Turkey (van Zeist <u>et al.</u>, 1975).

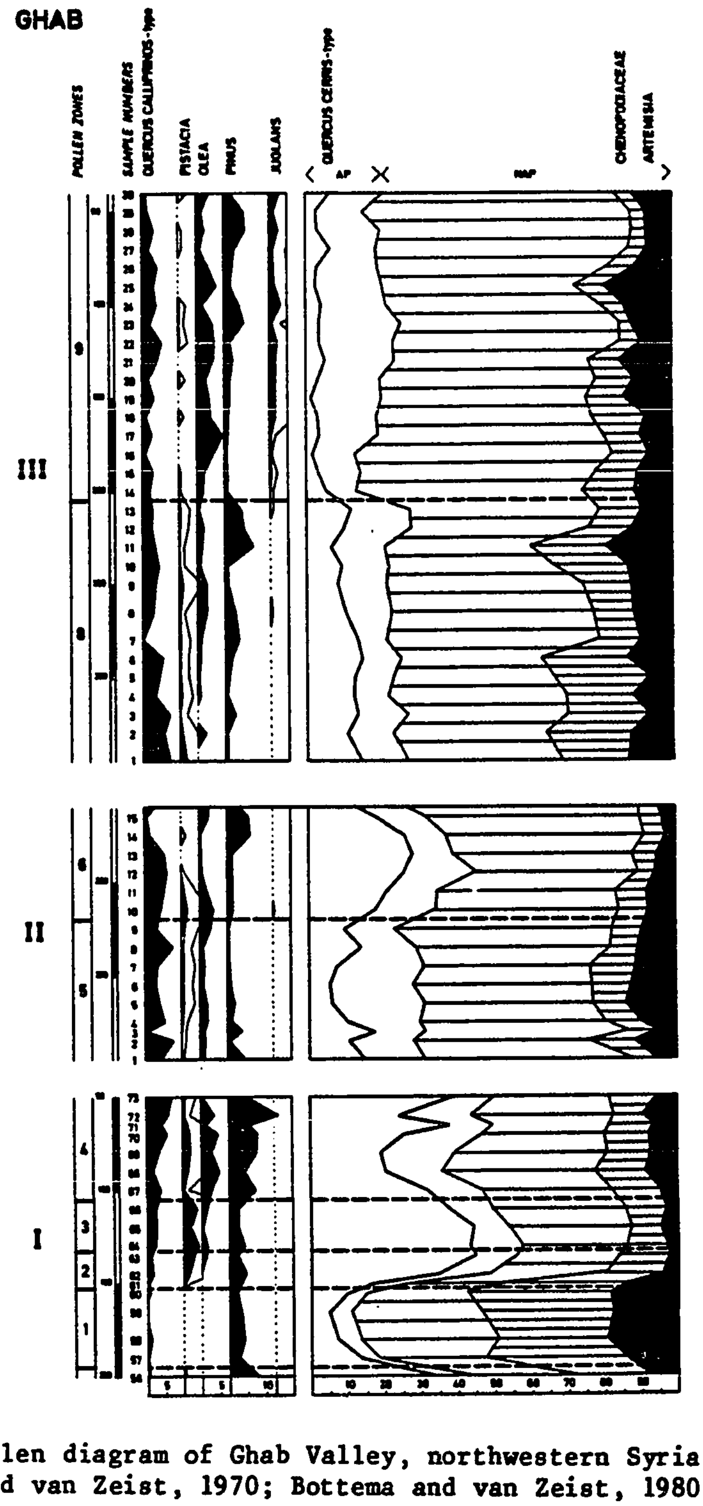


Fig. 15. Pollen diagram of Ghab Valley, northwestern Syria (Niklewski and van Zeist, 1970; Bottema and van Zeist, 1980).

latitudes which reached its maximum 9000 to 8000 B.P. This period of increased precipitation is also recorded in the Red Sea (Schoell and Faber, 1978). Evidence from the Arabo-Persian Gulf indicates higher rainfall during the glacial period (Kassler, 1973), aridity during the rise in sea level (Sarnthein, 1972), and increased precipitation after 6000 B.P. (Stoffers and Ross, 1979; Georgiev and Stoffers, 1980).

Evidence of the lowering of glaciers and snow line also implies an increase in precipitation as well as a decrease in temperature (Bobek, 1940; Wright, 1960; Messerli, 1967; Kuhle, 1976; Grunert *et al.*, 1978). The presence of lacustrine sediments in arid regions where no lakes occur today, and evidence of higher levels of existing lakes also suggests increased moisture during the Pleistocene (Street and Grove, 1979; Roberts, 1982). Fluctuations or low lake levels occurred after 14,000 - 12,000 B.P. In low latitudes high lake levels occurred again between 9000 - 7000 B.P., but at higher latitudes they did not rise until 6000 - 5000 B.P. (Roberts, 1982).

Pollen diagrams are interpreted as demonstrating low moisture throughout the glacial period but increasing in the Holocene (van Zeist and Bottema, 1982). The period of assumed moisture increase differs widely from site to site, however. In addition, the pollen evidence does not agree well with the evidence from other fields. The assumption that arboreal pollen curves are equivalent to moisture curves and the failure to fully utilize potential information from within the non-arboreal pollen spectra may be the cause of this lack of agreement.

CHAPTER II

SURFACE POLLEN INVESTIGATIONS

Previous Work

Modern pollen assemblages from surface samples have been studied in Greece (Bottema, 1974), southeastern Turkey (van Zeist *et al.*, 1968), southwestern Turkey (van Zeist *et al.*, 1975), Lebanon and Syria (Bottema and Barkoudah, 1979) and western Iran (Wright *et al.*, 1967). In Israel, modern pollen has been studied in connection with Quarternary investigations at various sites, including the off-shore Mediterranean (Rossignol, 1961), Aqaba (Horowitz, 1966), Hula Basin (Horowitz, 1971), Lake Kinneret (Horowitz, 1969) and the Dead Sea (Rossignol, 1969). According to Horowitz (1979) pollen analyses of soils and other terrestrial sediments have been attempted unsuccessfully by various investigators. A study of surface pollen carried out by Singh *et al.* (1973) in India provides information applicable to the Middle East.

All of the comprehensive surface studies have been done in semi-arid to mesic regions, where annual precipitation is greater than 200 mm. None has been reported from regions with rainfall of 150 mm or less. The alpine regions have also been neglected. The palynological study of these sites would greatly increase the understanding of Quarternary palynology at montane lakes, but unfortunately no information is available.

Some of the gaps in the knowledge of modern pollen deposition in desert environments will be filled in the survey presented here.

Samples for the study of modern pollen accumulation were obtained from Jordan, Kuwait, and Saudi Arabia (Fig. 16). Samples were taken from a variety of environments including marine mud, saline depressions, soil and surface litter.

Procedure

The procedure for treating the samples was modified from Cwynar *et al.* (1979). Samples ranged in size from 10 to 20 grams of muddy sediments to up to 500 grams of surface soil where pollen was likely to be much less concentrated. Samples were first suspended in a hot Calgon solution and the larger particles were allowed to settle out. The suspension was then poured through a 200 μ sieve to remove large fragments of plants, etc.

Next the sample was passed through a 7μ sieve to rid it of the small particles of silt and clay. For most samples this was very time-consuming as they were usually primarily composed of these very fine grained sediments. It was not possible simply to pour the sample through the sieve as described by Cwynar *et al.* (1979), as the pores very quickly became clogged. It did not help to move the container back and forth or to tap the bottom of the sieve. Several different ways were tried to prevent clogging and the most efficient method was to use a funnel and a piece of sieve considerably larger than the funnel. By holding two corners of the sieve in one hand and the other two corners in the other and

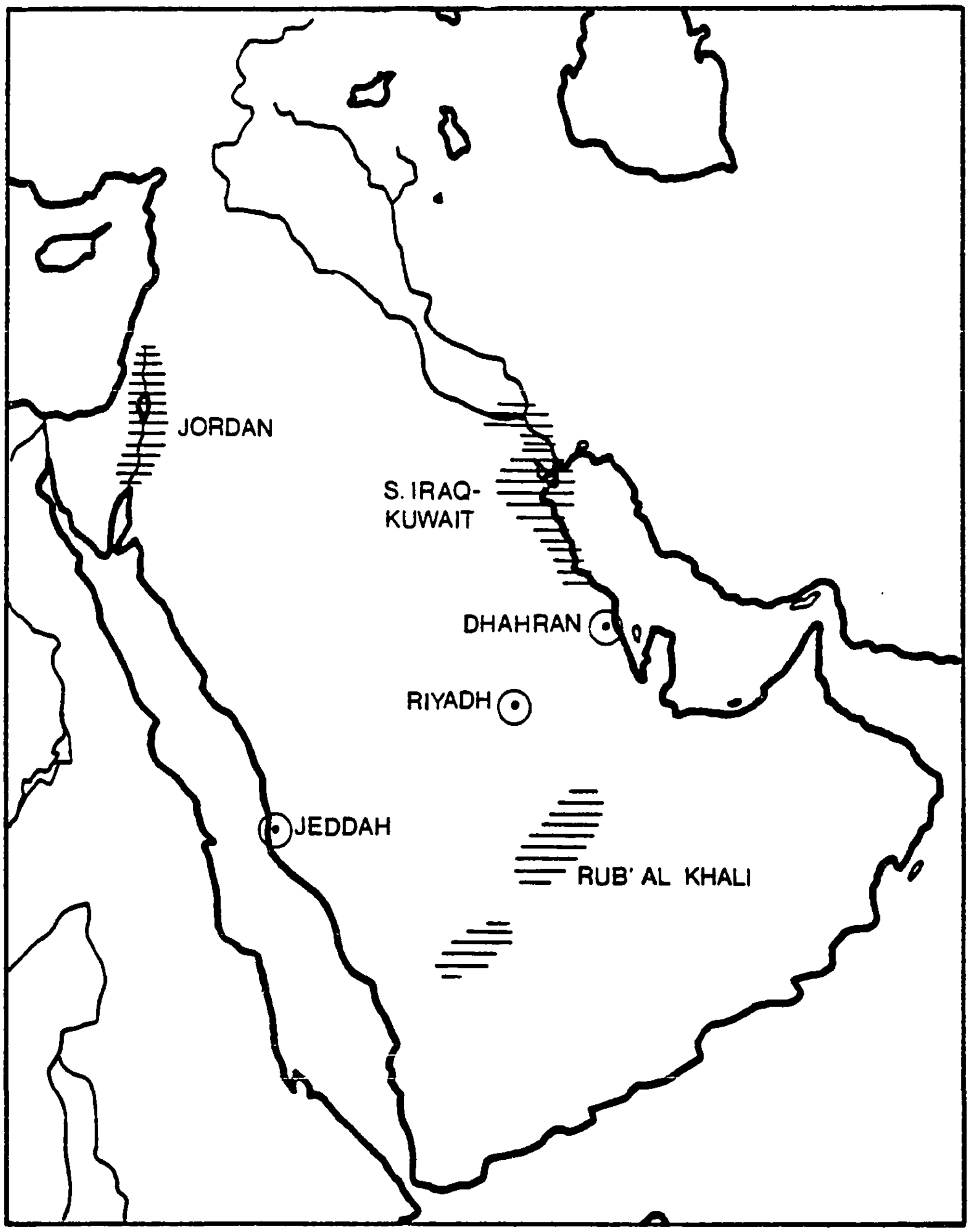


Fig. 16. Regions sampled for surface pollen.

pulling up first on one side and then the other so that the sieve moved over the inner surface of the funnel, the material was kept in suspension and the pores did not become clogged easily. Eventually the pores did become clogged, and the sieve was washed into a container and the process begun again. This was continued until the solution passing through the sieve was clear.

An alternative was to centrifuge the sediment,but this process was also slow, as some samples had to be centrifuged repeatedly - up to 100 times - before the fine sediments were removed. Chemical treatment before sieving was prohibitive because of the large size of the sample needed in order to obtain sufficient pollen. Samples were all rich in carbonates, and could be reduced substantially by first treating in HCl; however, this caused flocculation to occur and the material had to be washed several times before the fine particles began to filter through the sieve. For this reason, treatment with HCl, as well as acetolysis and HF treatment were delayed until the fine matter had been eliminated. After chemical treatment, the residue was sieved again before staining with safranin and mounting in glycerine jelly.

Although time-consuming, sieving was found to be the only suitable method for dealing with these sediments. A combination of chemical treatment and heavy-liquid separation used on several alluvial samples yielded almost no pollen, but sieving the same sediment resulted in a concentration of pollen adequate for analysis.

Kuwait and Southern Iraq

Vegetation

The zones of vegetation in southern Iraq and Kuwait (Fig. 17) are determined primarily by salinity, soil depth, moisture, temperature, and the effect of human populations. The saline coastal habitats are dominated by the halophytic chenopod *Halocnemon strobilaceum* closest to the shore; it is replaced by *Nitraria retusa* and *Zygophyllum coccineum* inland. The saline depressions are bare or covered with *Halocnemon*, with *Zygophyllum* around the sandy edges.

The non-saline environments are dominated by *Rhanterium epapposum*, *Hammada salicornica*, *Cyperus conglomeratus* or *Panicum turgidum*. Soil depth may be the most important factor in defining the boundaries between these communities. *Cyperus* requires at least 200 cm of loose sandy soil, *Rhanterium* dominates on moderately deep soil overlying a hard pan, while *Hammada* can grow on very thin soils (Halwagy and Halwagy, 1974b).

Climate is also of importance in determining the distribution of communities. *Rhanterium* tolerates high temperatures and low precipitation. Although it occurs on wind-blown drift sand, it cannot grow on dynamic dunes and prefers very compact sandy soil (Vesey-Fitzgerald, 1957; Guest and Al-Rawi, 1966). It is not found

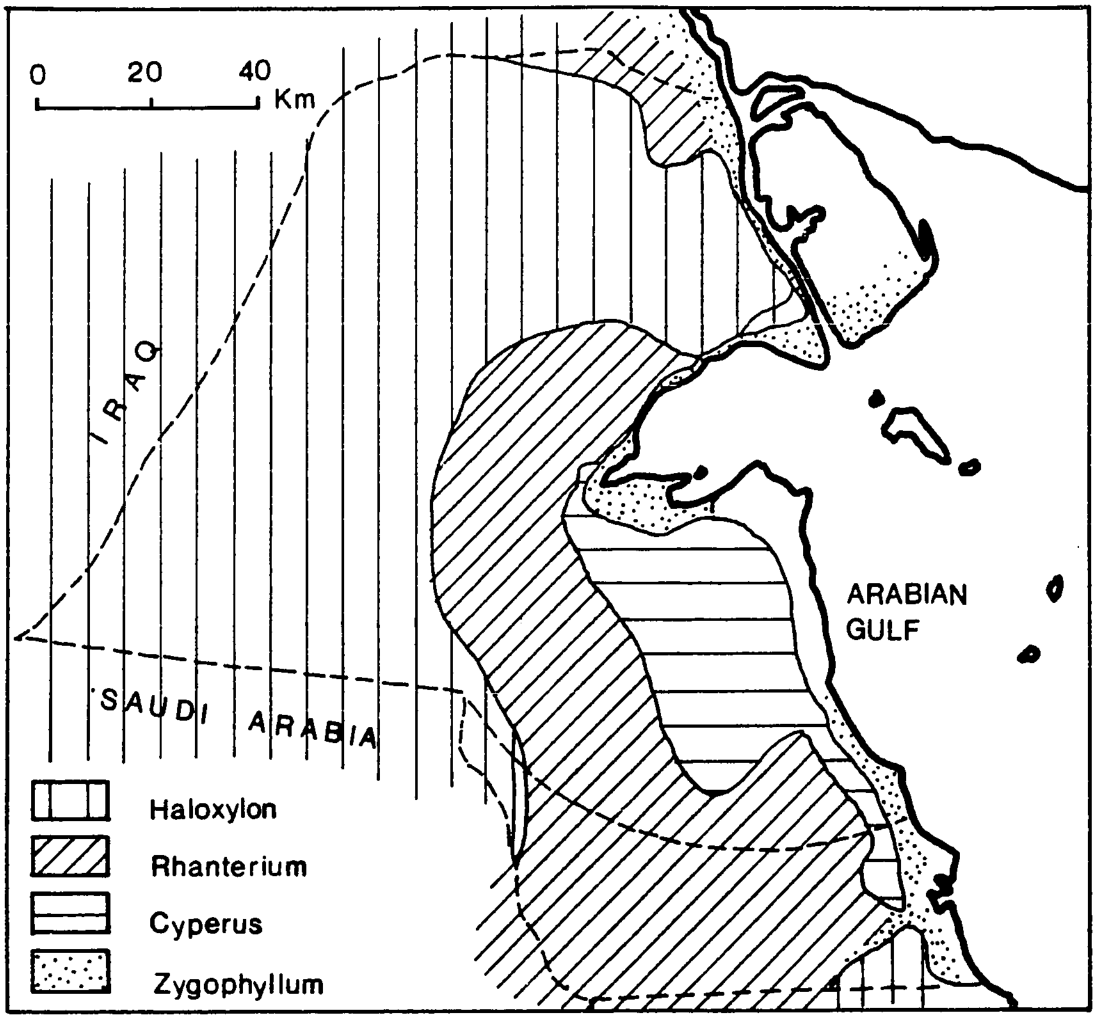


Figure 17. Vegetation Map of Kuwait and Southern Iraq. (Halwagy and Halwagy, 1974).

on hard limestone or gravel. The restriction of Rhanterium to latitudes south of 34-35°N (Guest and Al Rawi, 1966; Thalen, 1979) indicates that it is limited by low temperatures. Hammada is said to require higher precipitation (Thalen, 1979). However where Rhanterium is destroyed it is generally replaced by Hammada which is less desirable for fuel and fodder (Guest and Al-Rawi, 1966). Hammada extends farther north than Rhanterium but this may be due to a greater resistance to low temperature rather than to a need for increased precipitation. Farther north in Iraq, Hammada is largely replaced by Artemisia herba-alba. Although Artemisia herba-alba may require low winter temperatures (Walter, 1971), the limit here is apparently defined by precipitation because it extends into the Hammada community where silty, non-saline depressions provide greater moisture locally. It is not confined to such habitats farther north where precipitation is greater (Guest and Al-Rawi, 1966).

The Cyperus community is probably not limited by precipitation. On deep sand it can survive for years on moisture sealed within the sand (Thesiger, 1949) so that it is widespread throughout the hyperarid Rub'al-Khali. Cyperus ceases to form communities north of Kuwait (Halwagy et al., 1982). Since it produces abundant pollen it would be useful to know if it is limited by temperature, but there is no specific indication that this is the case. Panicum turgidum occurs in non-saline coastal habitats in Kuwait. In Iraq it shares its dominance with Haloxylon ammodendron = H. persicum which probably requires higher precipitation than occurs in Kuwait. Apparently Panicum has retreated considerably in Kuwait since first reported by Dickson in 1955, due to overgrazing.

The Pollen Assemblages

The surface samples studied for pollen came from within all of the important zones of vegetation in Kuwait (Table 2 , Fig. 17, Fig. 18). In some regions samples were taken from different environments for comparison.

The modern-pollen assemblages are dominated by pollen of the family Chenopodiaceae. Pollen of this type composes 46% of the total pollen counted. Plantago pollen (17%) and Compositae pollen (10%) are also high. No other group shows consistently high percentages, although specific taxa are sometimes high within individual samples (Table A1).

Although Chenopodiaceae pollen is high throughout the region, it is somewhat higher in the samples from saline regions, samples 9 11, 12, 13, 16, 17 and 18, than in those from non-saline regions 10, 14, 15, 8, and 7. The group of saline samples are 56% Chenopodiaceae pollen while the non-saline samples are 41%. A better way to distinguish between these two environments would be to distinguish among the various pollen-types of Chenopodiaceae. In particular, it would be useful if widespread, non-halophytic

TABLE 2

SOURCES OF SURFACE SAMPLES STUDIED IN S. IRAQ AND KUWAIT

	LOCATION	MATERIAL
1	Hor-al-Hammar	mud
2	Hor-al-Hammar	mud
3	Shatt-al-Arab	mud
4	Irrigation ditch	muck
5	Bubiyan	mud-cracks
6	Subiya	soil
7	*Hammada* community	soil
8	*Astragalus*-*Convolvulus* community	soil
9	*Nitraria* community	soil
10	*Panicum turgidum* community	
11	Failaka Island	tidal mud
12	Failaka Island (annual vegetation)	soil
13	Sulaybiya	tidal mud
	a. high tide zone	
	b. 5 m from shore	
	c. 100 m from shore	
	d. 150 m from shore	
	e. 200 m from shore (lowest tide zone)	
14	*Cyperus conglomeratus* community	soil and litter
15	*Rhanterium epapposum* community	soil
16	Khiran Tidal hole	mud
17	Khiran Khor	
	a. Algal mat	Algal mat
	b. mud (upper 10 cm)	mud
	c. mud (lower 10 cm)	mud
18	Khiran - *Artemisia scoparia* community	soil
19	Gulf sea water midway to Um-al-Muradim	water
20	Um-al-Muradim	soil

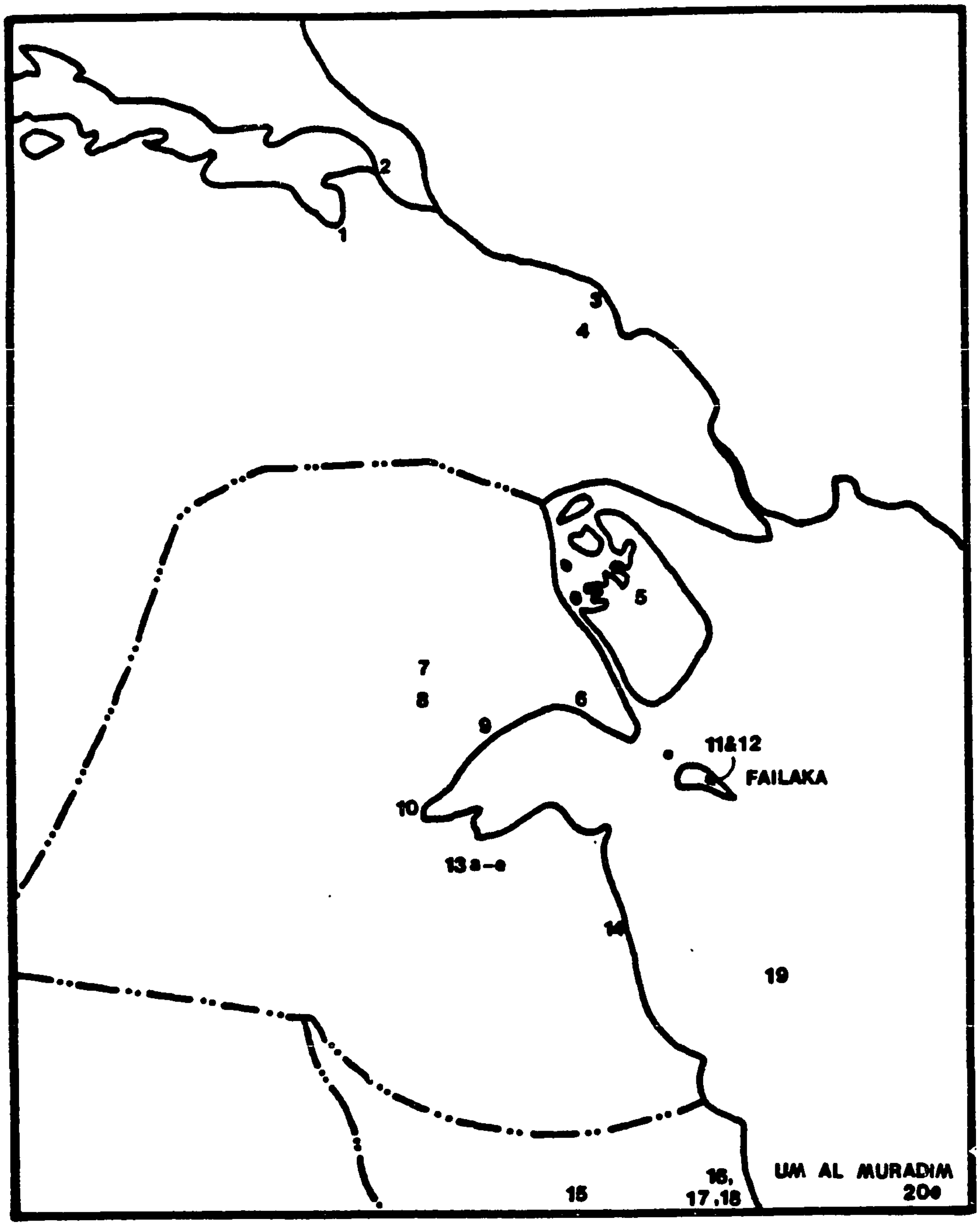


Fig. 18. Surface sample locations - Kuwait and Southern Iraq.

Hammada salicornica could be separated from the other groups. The pollen of Hammada is small, about 15 microns and has about 20 pores. These characteristics are similar to the pollen of two other members of Chenopodiaceae which occur in Kuwait, Seidlitzia rosmarinus and Cornulaca leucacantha. Neither of these species is strongly halophytic. Cornulaca is considered by M. Halwagy (1977) to be a desert plant. When it occurs in saline regions it occupies only the higher ground. Seidlitzia occupies intermediate sites between saline and non-saline environments. Higher percentages of Hammada-type pollen as compared to other Chenopodiaceae types should be indicative of non-saline environments and therefore Chenopodiaceae pollen was classified either as Hammada-type or other Chenopodiaceae. In non-saline environments the ratio of Hammada- to other Chenopodiaceae pollen is 0.8 while in saline environments it is 0.17 (Fig. 19).

In addition to salinity the sampled environments can be classified according to the source of the sediment. Some of these were aeolian deposits while others were water-laid (Fig. 19). Water-deposited samples are characterized by Typha, Sparganium, Potamogeton and Nuphar. They are highest from the freshwater deposits, samples 1-4. These pollen types are also found in somewhat lower perentages in 12 marine samples. They are lacking in the soil samples, although Sparganium has been reported from soil samples in western Iran (Wright et al, 1967) and Syria

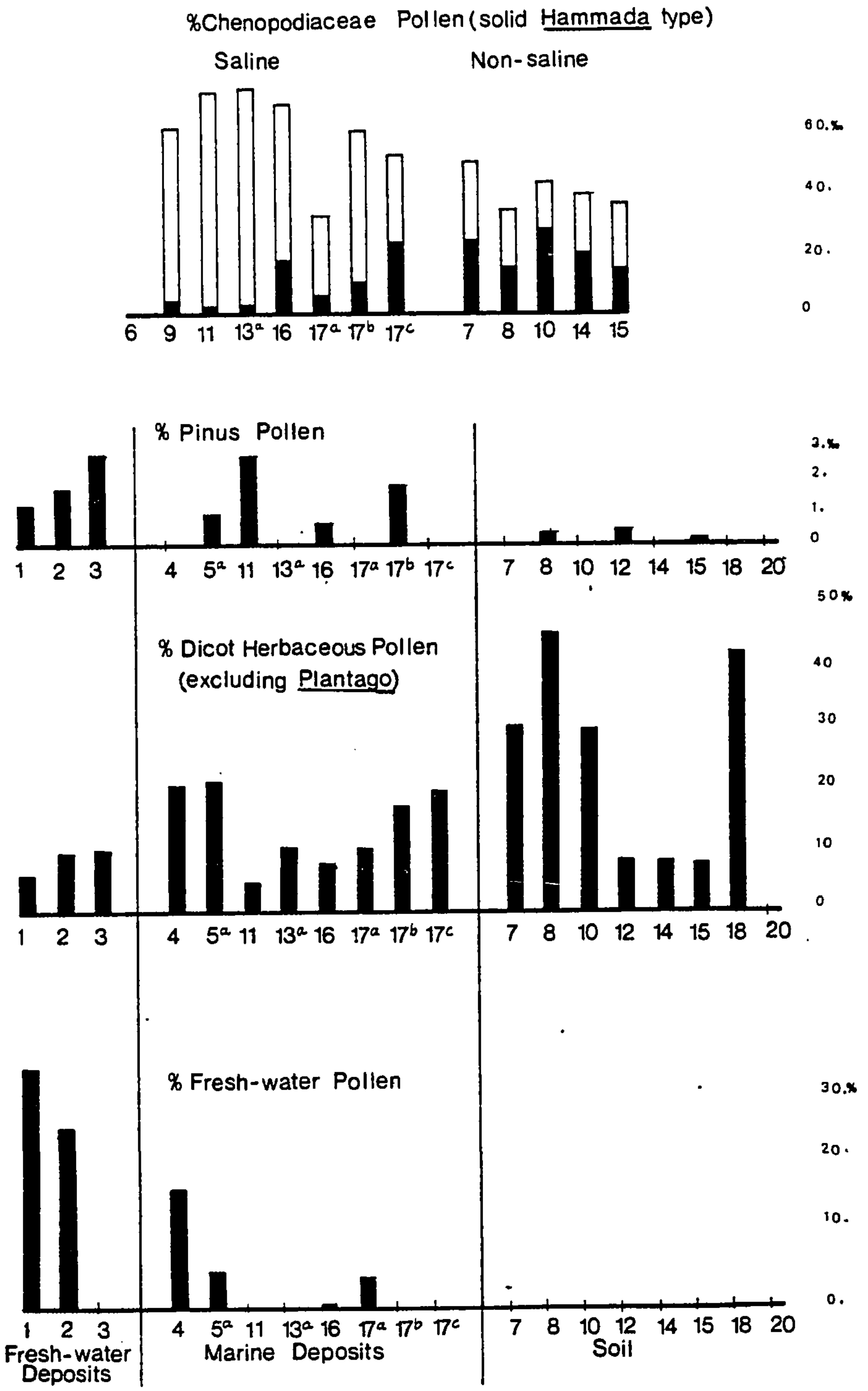


Fig. 19. Comparison of pollen from various environments in Kuwait and southern Iraq.

(Bottema and Barkoudah, 1979). Hystrichospheres are characteristic of brackish or marine conditions, but they were found also in the freshwater deposits and in one soil sample. Although Pinus pollen percentages were low in all samples they were considerably lower in the soil samples than in the water-laid deposits. The average Pinus pollen percentage on land was only 0.2%, while it reached 1.5% of the total pollen in the water-borne sediments. This pollen type is apparently mostly dependent on river transport from Turkey. In samples of daily pollen deposition observed over a two-year period Pinus was only .02% of the total pollen counted (M. Halwagy, 1978).

Even in the south of Kuwait the pollen assemblages suggest that water-transported pollen is an important component of the spectra. About twenty gallons of sea-water was filtered (sample 19) to determine the pollen content. No pollen was found. Perhaps this was due to the time of year in which the sample was obtained, late February before most plants were in flower.

Cyperus conglomeratus has a long slender pollen grain easily distinguishable from other Cyperaceae pollen of this region. Low but dependable percentages of its pollen occur within the region where it may dominate. It does not occur at any sites north of the Gulf. Its presence in the marine sediments of Bubiyan and Failaka Island may be due to transport from the south.

The terrestrial sediments also differ from the marine and freshwater deposits in the amount of herbaceous entomophilous pollen, Compositae, Umbelliferae, Leguminosae, etc. These average 2.8% of the total pollen in the Iraq samples and 27% in the terrestrial Kuwait samples (Fig. 19). However, this does not appear to be due to overrepresentation of these plants in soil, as these percentages are high in the sample from Bubiyan, which has none of these taxa, and are also high in the four marine samples at Khiran. Apparently the soil samples are representative of the pollen rain. The high percentages on Bubiyan where only Chenopodiaceae grow can only be explained by water- or wind-transported pollen. Perhaps the low percentages of these herbaceous pollen types in the freshwater samples of Iraq are due to the larger number of exotic types carried down by the rivers and classified "unknown." Also, the presence of the date-palm groves may limit the open environment which most of these plants require.

Relatively high percentage of Gramineae pollen (14%) in the sample taken from mud at the bottom of an irrigation ditch in the date groves of Iraq (number 4) can partly be explained by the grasses which grew along its bank and partly by cultivation of cereal crops nearby. More than half of this pollen was cereal-type. Four percent was Zea (Corn) and another four percent was of an unidentified cereal-type, perhaps Hordeum (barley).

The relative importance of wind-transported pollen was assessed by the pollen sample obtained from Um-al-Muradim, a small island about twenty-five miles from Kuwait in the Gulf. The island is obviously very young; the eastern shore is of very fresh-appearing coquina recently uplifted from the sea floor. Only three species of plant have colonized the island, Sueda vermiculata, Mesembryanthemum nodiflorum, and Malva parviflora. One thousand sixty-three pollen grains were counted, only two of which were exotic, one small unknown tricolpate grain and one grain of Liguliflorae. In addition there were two grains of Mesembryanthemum and two of Malva. The remaining pollen was all of Sueda.

The series of 13^{a-e} was obtained along a transect through tidal mud between the high tide zone and about 200 m onto the tidal mud-flats. The sample farthest from shore, 13^{e}, was the most diverse and representative of the regional vegetation. Pollen was not found in samples 13^{c} and was low in 13^{d}. These were taken from a zone that is densely populated by mud-skippers, burrowing fish that maintain elaborate systems of tunnels just below the surface of the mud. Perhaps it is the continuous disturbance and oxidation of the sediments that prevents pollen from being preserved. The sample closest to shore, 13^{a}, was strongly influenced by the local halophytic vegetation. Chenopodiaceae pollen was 76%, higher than in any other sample of the region. Sample 13^{b} was also high in the local shore pollen. Apparently with greater distance from shore pollen becomes more representative of the regional pollen rain.

Daily pollen counts were obtained from two Kuwait locations over a period of two years (M. Halwagy, 1978). Total percentages differ in predictable ways from the pollen of the terrestrial and water-laid samples (Table 3).

Some of the differences are probably due to the sampling-sites being within urban areas. Eucalyptus and Leguminosae tree species are widely planted. Gramineae and Cyperus may be higher due to their ability to be wind-transported as compared to the pollen of insect-pollinated species which are lower than in the surface samples. Dr. Halwagy is currently studying daily pollen deposition in the north of Kuwait and there Cyperus pollen is absent just as in the surface samples.

Jordan

Vegetation

The climate of lowland Jordan differs from Kuwait primarily in its warm winters. The hills and mountains east of the coastal plain and west of the Dead Sea rift are wooded with Pinus halepensis, Quercus and Pistacia. Much of this vegetation is degraded into a dense, shrubby "maquis" or degraded still further into a less dense, shrub vegetation known as "garique." The Jordan valley itself is characterized by xerophytic and tropical vegetation. Communities are dominated by desert shrubs such as Hammada, Anabasis, Zygophyllum and Retama. In the wadis Tamarix,

TABLE 3

TOTAL PERCENTAGES OF POLLEN COLLECTED OVER A TWO-YEAR PERIOD IN AHMADI AND KUWAIT CITY

Chenopodiaceae	49.0%
Leguminosae	13.0%
Plantago	3.2%
Gramineae	11.0%
Compositae	0.7%
Cyperus conglomeratus	19.0%
Cruciferae	2.3%
Pinus	.02%
Eucalyptus	.13%

Acacia and *Zizyphus* are found, while drier microhabitats may be completely lacking in perennial vegetation. During the winter the desert is lush with the growth of small annual plants, but by summer there is no sign of these drought-avoiding species and only the few scattered perennials can be seen (Zohary, 1962).

Pollen Assemblages

The samples were taken along a transect from north of the Dead Sea to the Gulf of Aqaba (Fig. 20). The pollen assemblages were very different from those obtained in Kuwait (TABLE A.2, Fig. 21). Chenopodiaceae pollen was low with the exception of a few samples, 2^b, 10, and 20 which were 46%, 76%, and 67%. If these samples are excluded, the percentage of Chenopodiaceae pollen is only 3.75%. Numerous tropical species are unrepresented or underrepresented. No indication of obvious trends from north to south or from dry regions to moister regions appear, perhaps due to the varied topography which causes plant distribution to be more dependent on edaphic moisture than on precipitation. Samples were often high in arboreal pollen (1, 3, 4 and 7) and in the pollen of small, annual, insect-pollinated plants (1, 2, 6, 9, 11, 13, and 15). Often one or more species of these plants was strongly overrepresented in the pollen. Local overrepresentation is almost always a problem in surveys of modern surface pollen, particularly if the only material available for studying the pollen rain is surface litter or soil. To correct for overrepresentation is difficult, since it is based

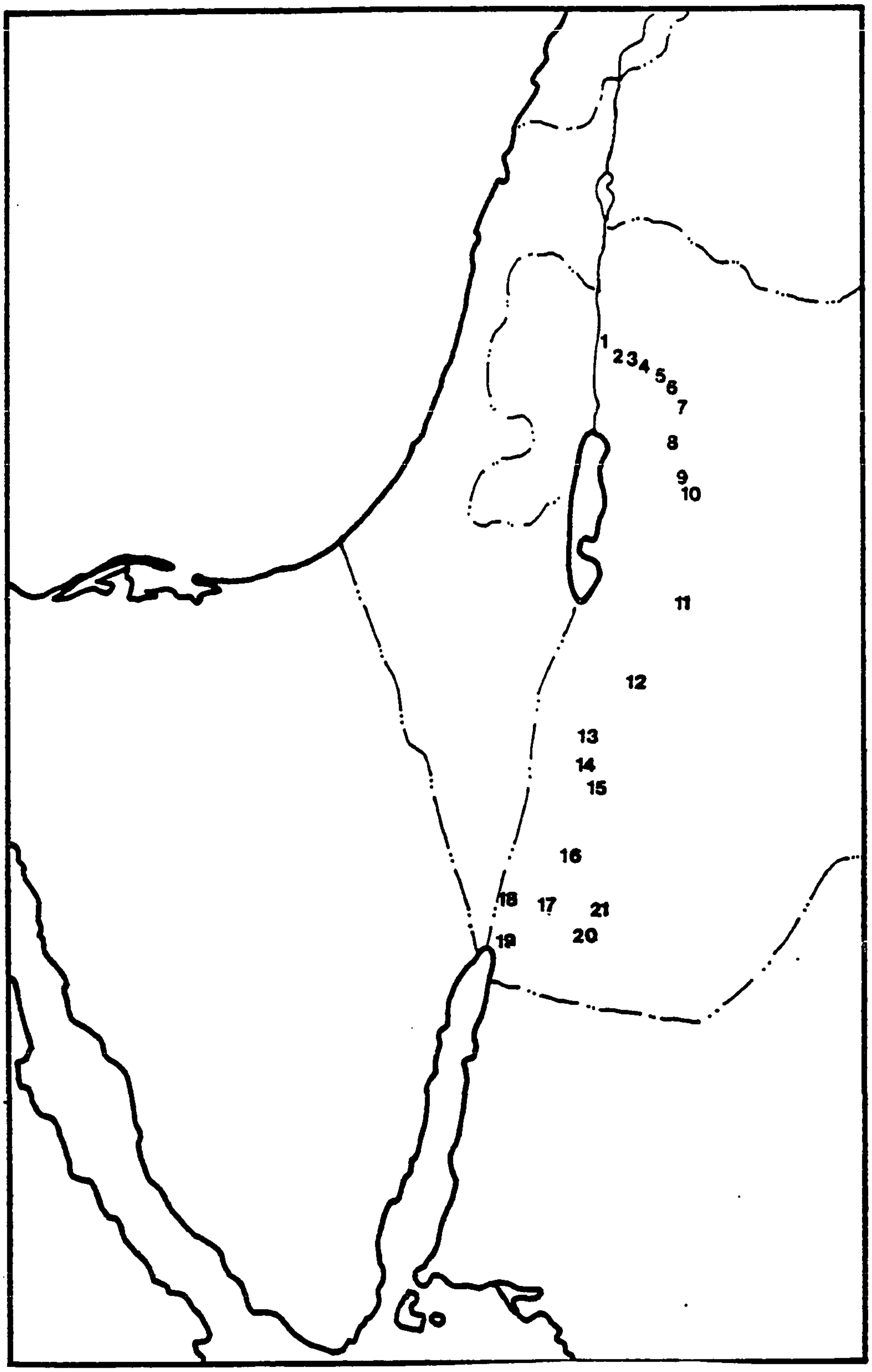


Fig. 18. Surface sample locations - Jordan.

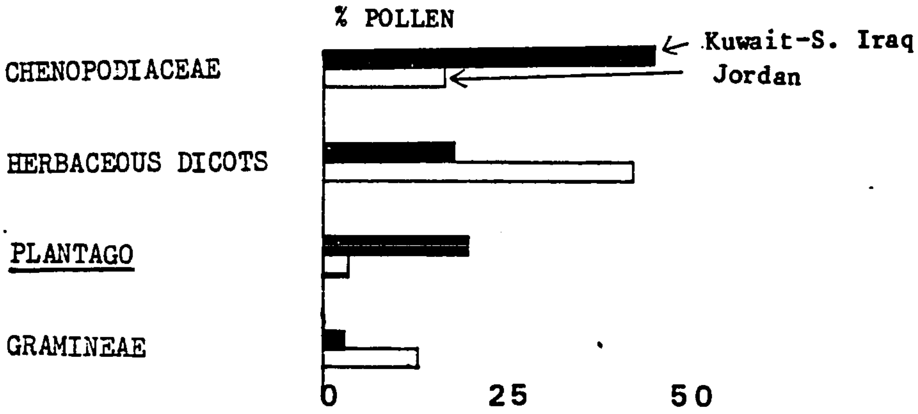


Fig. 21. A comparison of pollen types in Kuwait - S. Iraq and in Jordan.

on an arbitrary estimate of the extent of overrepresentation. By averaging the pollen percentages of all the samples within a given climatic of vegetational zone, the problem of local overrepresentation can be largely controlled.

One explanation for the overrepresentation in Jordan, as well as for the much higher percentages of pollen of ephemeral groups as compared to southern Iraq and Kuwait, is the difference in the growing seasons in the two regions. Ephemeral plants in Palestine and Jordan flower throughout the warm winter, dependent only upon rainfall (Zohary, 1962). The farther south into the desert, the warmer the winter weather becomes, and the more pollen can be produced by the ephemerals, some of which may germinate after each rainfall. In addition many larger annuals grow vegetatively all winter and flower in the spring. In Kuwait, on the other hand, the climate is more continental and the winters are colder. It is unusual for most annuals to bloom before February or March. Winter is definitely a time of restricted plant growth.

Topochory, mechanisms which restrict the dispersal of seeds to the vicinity of the parents, is common in the desert of Israel and Jordan (Zohary, 1962). In this desert 85% of the plants are characterized by this adaptation. Because of the varied topography microhabitat is of great importance. If a parent plant is growing at a specific site, it is advantageous for the seeds of the next generation to be retained at the same site, particularly in the case of annuals where the parent plant is likely to be dead before the next generation germinates. The clumping caused by topochory would contribute to the problem of overrepresentation. In Kuwait there is little relief and therefore less variety of microhabitats. One can travel for great distances across a landscape which differs very little from one part to another.

The Rub'al-Khali

The vegetation of the Rub'al-Khali is described in Chapter VII. Material for surface study of pollen is very rare. However, wind-blown chaff accumulates at the base of the dunes, and upon investigation, was found to be an efficient pollen trap. The general location of the samples can be seen in Figure 16. The location of each sample and the percentages of the important pollen groups is shown in Table 4.

With the exception of one sample, which was especially high in Chenopodiaceae, samples were similar, dominated either by *Calligonum* or, more often, *Cyperus*. These species are both common on the dunes. The sample high in Chenopodiaceae was collected at the edge of one of the extensive sabkhas among the red-sand mountains. At this particular site an unusual occurrence of *Sueda* suggests that this plant was the producer of the Chenopodiaceae pollen. In the Rub'al-Khali, as well as in Kuwait, the *Hammada*-type pollen has been distinguished from that of other

TABLE 4

LOCATIONS OF RUB' AL-KHALI CHAFF SAMPLES AND PERCENTAGES OF FIVE POLLEN GROUPS

(for complete pollen count see Table A.4)

Sample	Location E. Long./ N. Lat.	Cyperus	Chenopodiaceae	Calligonum	Cistaceae Type	Graminae	Other
1	50°00'/22°55'	0	99.0	0	0	0	1.0
2	49°00'/19°56'	50.	1.8	31.	9.0	0.9	7.3
3	47°38'/19°5'	0	0	25.	41.	2.2	19.3
4	47°32'/19°00	80.	0.2	0	4.4	1.9	5.5
5	47°08'/18°28'	69.	6.4	0	13.	0.6	11.
6	46°58'/18°18'	25.	5.5	9.	27.	0	33.5
7	46°30'/18°21'	19.	11.	0.4	37.	0.9	31.7
8	45°45'/18°50'	50.	1.05	38.	0	0	12.0

Chenopodiaceae.

The dominance of _Cyperus_ _conglomeratus_ and _Calligonum_ pollen in the Rub'al-Khali surface samples is significant. Both species grow in sandy regions. Swain _et_ _al_. (1983), using pollen-climate calibration functions, demonstrated a negative correlation between this pollen and summer precipitation in India. However, a more immediate cause of _Calligonum's_ absence may be the lack of dunes in regions of high summer precipitation.

Ecological and Climatic Significance of Pollen Types in Middle Eastern Deserts

Within a specific region, Chenopodiaceae pollen tends to increase with decreasing moisture. This trend is clearly seen in Iraq (Wright _et_ _al_., 1967) and Kuwait, in Syria and Lebanon (Bottema and Barkoudah, 1979) and in Jordan (Fig. 22). However, in Jordan percentages of Chenopodiaceae pollen are low, in spite of the fact that members of this taxon are important - even dominant - members of the desert communities. Chenopodiaceae pollen from the Jordanian sites with less than 200 mm of precipitation averaged only 15%. In ten of these twelve sites it was less than 8%. The samples from sites with precipitation greater than 300 mm had an average of only 1.95% Chenopodiaceae pollen (Fig. 22). This can be compared to the equivalent precipitation zones of Syria where the percentages are 31% and 13% respectively (Bottema and Barkoudah,

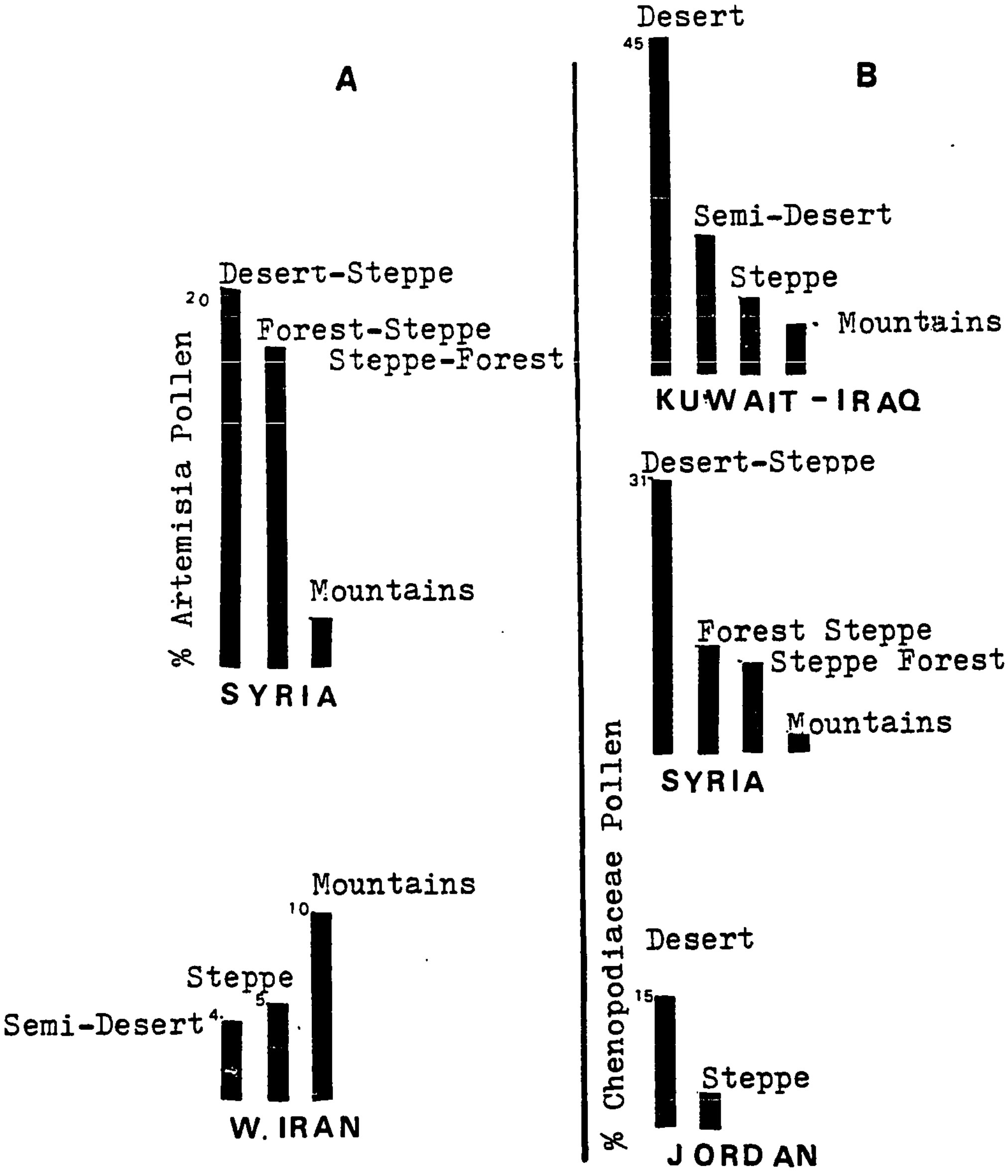


Fig. 22. Percentages of Artemisia pollen (A) and Chenopodiaceae pollen (B) in modern pollen assemblages.

1978). In Iraq the region with rainfall between 300 and 400 mm has 18% Chenopodiaceae pollen, while in a region of similar rainfall on the Irani Plateau the average is 45% (Wright _et_ _al_., 1967). Chenopodiaceae pollen is apparently positively correlated with cold winters as well as with aridity. The low Chenopodiaceae pollen percentages in dry regions with warm winters must be due to several factors:

(1) the many communities of tropical perennials which compete favorably with the shrubby Chenopodiaceae

(2) the ephemerals which characteristically flower from December to February and

(3) the other longer-growing annuals which grow vegetatively all winter, building up food resources which allow them to bloom profusely during the spring. In Jordan, still another factor is the topography which allows a generally low rainfall to be concentrated in favorable sites where vegetation which ordinarily requires higher precipitation can thrive. These conditions are reflected in the high percentages of pollen from such annual plant groups as Compositae, Umbelliferae, Cruciferae, Boraginaceae, Labiatae and Leguminosae.

The significance of Chenopodiaceae pollen is very important to the interpretation of pollen diagrams from desert regions. Le Roi-Gourhan (unpublished) has noted from her studies of pollen from archeological sites that Chenopodiaceae and Tubuliflorae pollen were replaced by a great variety of other herbaceous pollen at the end of the Pleistocene. She suggested that this demonstrates moisture increases synchronous with phases of warming. The surface data, however, suggest that this kind of change may be directly attributed to warming, particularly during the winters, allowing the growth of annuals throughout the rainy season.

Although moisture availability is by far the most important factor affecting the distribution of plants in the Middle East, it is not the only factor. The correlation of pollen of a specific plant group with moisture does not in itself prove a cause-and-effect relationship. It is essential that the entire ecology of the pollen producers be considered before judgement is made. Thus Chenopodiaceae pollen is generally associated with aridity, but depending on the location an increase in this pollen may signify colder summers (Jordan _vs_ Syria, Iran, Kuwait) or as will be seen in Chapter VII, even increased moisture.

Artemisia can serve as another example (Fig. 22). In Syria, _Artemisia_ pollen decreases from 20.5% in the steppe and desert regions to 17% in the Forest-Steppe and Steppe-Forest to 2.2% in the mountains (5.3% in the disturbed mountain regions) (Bottema and Barkoudah, 1979). This seems to imply that _Artemisia_ decreases with moisture. However, trees increase along this same gradient and _Artemisia_ requires open, treeless environments which is presumably why it is higher in the degraded (deforested?) region.

In western Iran pollen was sampled along a similar moisture gradient (Wright *et al.*, 1967). In the semi-desert *Artemisia* was 4%. It increased to 5% in the Savannah and to 10% in the mesic, but completely deforested zone. In India, Swain *et al.* (1973) have also shown *Artemisia* to be positively related to moisture.

Gramineae pollen was low throughout the region. In Kuwait the sample taken from within the community of a dominant Gramineae perennial (sample 10) had no grass pollen at all, although grass was in flower at the time. Wright *et al.* (1967) found Gramineae to be underrepresented in the pollen rain of western Iran also. Pollen evidence of other dominant vegetation was also often unrecorded, *Rhanterium* in Kuwait, *Acacia* in Jordan. *Zygophyllum*, *Nitraria* and *Zizyphus* are all important dominants which are seriously underrepresented.

The results of this study suggest that changes in the relative proportions of *Artemisia*, Chenopodiaceae, herbaceous dicots, *Cyperus conglomeratus* , *Calligonum*, *Plantago*, *Pinus*, freshwater groups and Gramineae can be useful in demonstrating climatic or other environmental changes. The potential use of fluctuations between Chenopodiaceae and *Artemisia* is discussed in Chapter III.

CHAPTER III

THE *ARTEMISIA*-CHENOPODIACEAE STEPPE

Characteristics

It has been widely assumed that pollen studies have demonstrated a region-wide aridity in the eastern Mediterranean-Middle East during the Pleistocene with woodland and scrubland being replaced by vegetation of a much drier environment (Kukla, 1977; Butzer, 1978; Thiede, 1978; Thunell, 1979; Bintliff, 1982; Rossignol-Strick *et al.*, 1982).

This interpretation is based on the inferred "*Artemisia*-Chenopodiaceae" or sometimes "Chenopodiaceae-*Artemisia*" steppe. This expression has been used extensively to characterize Pleistocene vegetational units based on pollen diagrams of the Mediterranean and Middle East as well as of other widely separated regions of the world. It is therefore appropriate to consider this landscape in more detail. Where are its analogs found today? What were its climatic causes? What spatial and temporal variations occurred within it and how can these variations be discerned from the pollen diagrams?

Today the communities dominated by *Artemisia herba-alba* occur in inland regions adjoining the Mediterranean. Although experiencing the same rainfall regime as the Mediterranean region, the continentality of these environments imposes severe restrictions on the vegetation. In Mediterranean climates the proximity to the sea provides a moderating influence on vegetation.

Winters are mild and the summers quite humid. In inland regions, particularly where separated from the coast by mountain ranges, this influence is lacking. Winters become bitterly cold and summers extremely hot and dry, eliminating the vegetation of the coastal region and allowing the dominance of cold- and drought-hardy *Artemisia herba-alba* and shrubby Chenopodiaceae species (Fig. 23).

In analyzing the vegetational changes which occurred during the Pleistocene, two questions must be considered. (1) What factors are likely to have caused the elimination or restricted the occurrence of the modern vegetation and (2) what climatic conditions would have allowed *Artemisia*-Chenopodiaceae steppe to develop.

The fact that modern communities differ greatly from one another indicates that the limiting factors may also have differed from one region to another and from one period to another. In regions where *Artemisia* and Chenopodiaceae are important components of the vegetation today but where pollen evidence indicates they were more wide-spread during the Pleistocene, emphasis obviously should be placed on whatever vegetation they replaced. Focus on the ecological requirements of the present-day vegetation can provide important clues as to the conditions which prevailed during the time of its absence. On the other hand in regions where *Artemisia* and Chenopodiaceae are of minor importance today but

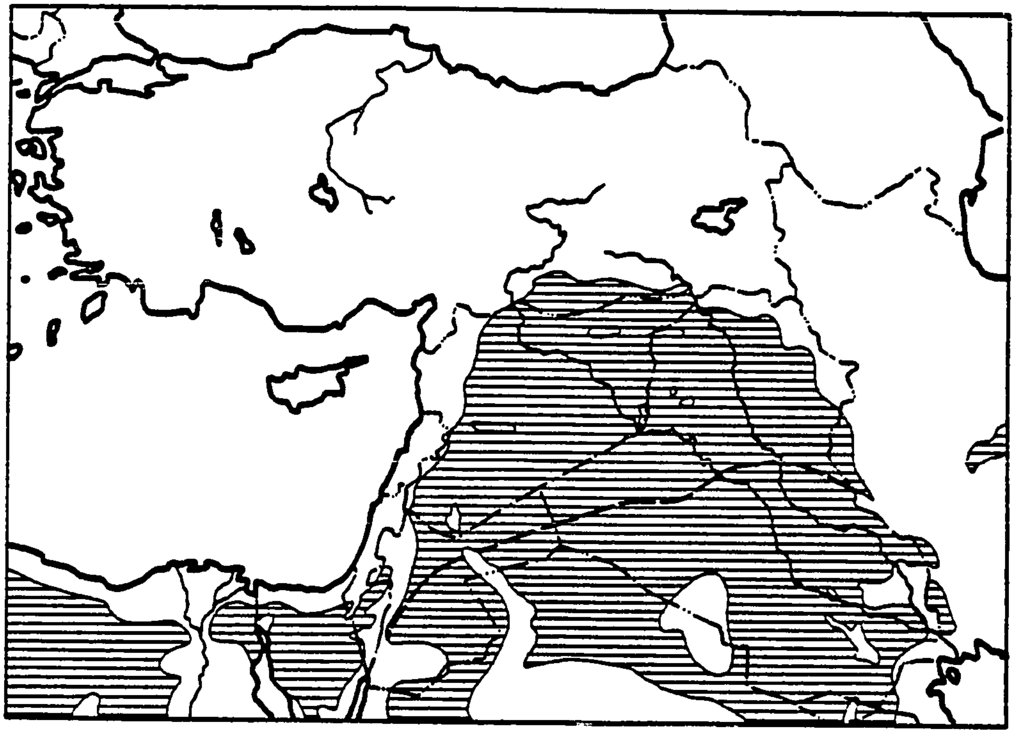


Fig. 23. Region of "Artemisia-Chenopodiaceae Steppe" in the Middle East. Dashed line denotes approximate boundary between Artemisia-dominated vegetation (to the north) and Chenopodiaceae-dominated vegetation (to the south).

where their pollen dominates the Pleistocene sediments, attention must be placed not only on the ecology of the vegetation which was eliminated but on the specific climatic conditions which characterize the modern *Artemisia*-Chenopodiacae steppe, summer drought and low winter temperatures.

The *Artemisia*-Chenopodiaceae steppe has been defined on the basis of the pollen which it produced. In addition to the groups for which it is named, relatively high percentages of Gramineae pollen and other herbaceous pollen types are also often recorded. Besides these elements, tree and/or shrub pollen may have occurred to a greater or lesser degree.

Due to the wide ecological amplitude of both Chenopodiaceae and *Artemisia* and to their strong overrepresentation in the pollen rain, it is likely that a large variety of landscapes falls into the category of *Artemisia*-Chenopodiaceae steppe of the palynologists. In some cases these two groups may not have been dominant or even among the most important members of the community since their pollen can so easily outnumber the pollen of more numerous plants which are underrepresented in the pollen rain. During a survey of vegetation and surface pollen in western Iran, Wright, *et al.* (1967) found the Chenopodiaceae and *Artemisia* to be overrepresented in the pollen rain. Bottema and Barkoudeh (1979) compared the plant communities and pollen assemblages of 85 sites in Syria and Lebanon. Thirty-two of the samples had low arboreal pollen, and in each of these Chenopodiaceae and Artemisia, pollen dominated. However, at twenty-two of the sites from which these samples were taken, neither Chenopodiaceae nor Artemisia was mentioned as having been present in the vegetation. Investigations of surface pollen carried out by the present author in Kuwait and southern Iraq (Chapter II) consistently showed percentages of 35-50% Chenopodiaceae pollen, even in communities in which no Chenopodiaceae were present. On the other hand, as was shown in Chapter II, a climate which allows small annual plants to flourish throughout the winter may cause an overrepresentation of the pollen of these plants even where shrubby Chenopodiaceae species occur.

Increasing the total number of grains counted and identifying the uncommon pollen types should result in a more precise characterization of the vegetation. Unfortunately, in this region, the results of such effort do not seem to have been in proportion to the work involved because many of the less common pollen types are not distinctive enough or are so widely distributed that they cannot be related to a specific vegetation. Moreover, it is often difficult to conclude much from the presence of a few unusual pollen grains in a sample of hundreds. In addition, the diagrams of this region are almost all from sites surrounded by such diverse topography that to distinguish from among the various plant communities which supplied pollen to the sediments is virtually impossible.

While it may not be possible to identify precisely the vegetation of a particular region it is of utmost importance that palaeoecologists not regard the *Artemisia*-Chenopodiaceae steppe as a monolithic unit. As an example, the nature of the vegetation of Pleistocene Tenaghi Philippon and that of Lake Zeribar undoubtedly differed greatly from one another even though pollen diagrams from each indicate steppe-like vegetation of *Artemisia*, Chenopodiaceae and grasses.

The Use of the Chenopodiaceae-Artemisia Ratio

The inability to reconstruct the landscape precisely does not necessarily preclude the possibility to identify climatic trends. A traditional approach has been to base interpretation on the variations between arboreal and non-arboreal components of pollen diagrams. However, this method cannot provide information for regions or time periods in which few or no trees existed. Moreover, as will be demonstrated later, different assumptions as to the cause of fluctuations between arboreal and non-arboreal elements can lead to completely different conclusions as to what climatic changes were occurring. In particular it seems obvious that the direct and indiscriminate translation of AP-NAP ratios into moisture curves, as has been done by van Zeist and Bottema (1982) is a gross over-simplification except in specific cases where it can be demonstrated that the taxa involved are likely to have been responding to a moisture factor and not to some other cause, climatic or otherwise.

Although species of *Artemisia* and Chenopodiaceae can tolerate long periods of drought, their respective moisture requirements are sufficiently different to allow their relative fluctuations to be used as indicators of moisture conditions. *Artemisia* is not a plant taxon of extreme deserts, as it extends into drier areas only where local edaphic conditions compensate for deficient precipitation (Zohary, 1973). On the other hand it can be found in areas of higher rainfall when some other factor limits the growth of grasses or trees. The spread of *Artemisia* has been attributed to destruction of the natural vegetation by humans (Pennington, 1969; Zohary, 1973) and to conditions too cold for trees (Pennington, 1974; Mack *et al.*, 1979; Davis, 1965). Mack *et al.* (1979) also mention instances of cold, wet conditions in both tundra and alpine environments of the northern United States in which a predominance of *Artemisia* was established. Provided a cold winter and a dry summer occurs, *Artemisia* can probably thrive under a wide range of moisture conditions.

Most Chenopodiaceae species can survive on much less moisture than *Artemisia*, and they are among the most characteristic of desert plants. Many species are halophytic which enables them to occupy the saline soils caused by increased aridity, particularly in inland basins. In addition, various non-halophytic genera are adapted to xeric conditions. The genera *Anabasis* and *Hammada* which interdigitate with and replace *Artemisia* as moisture decreases are examples of such Chenopodiaceae in the Middle East (Thalen, 1979; Zohary, 1973) (Fig. 23).

Since these two groups produce abundant and widely-distributed pollen, occur together, and differ in their moisture requirements, the fluctuations in the two pollen types relative to one another should be indicative of changes in moisture conditions. In at least one surface study of a community which included both Chenopodiaceae and *Artemisia*, variations in surface pollen assemblages were shown to reflect the relative abundance of each group (Martin, 1963).

Furthermore, curves of the Chenopodiaceae-*Artemisia* (C/A) ratios should represent moisture changes more accurately than any individual pollen curve, because the influence of all the other pollen types, inherent in percentage pollen diagrams, is eliminated. This is particularly important at the critical times during which tree pollen was increasing. Moreover, because both Chenopodiaceae and *Artemisia* reproduce and spread rapidly and because they are continually present in the area, the response of the C/A ratio is more rapid than the response of arboreal pollen which may lag behind the climatic change due to the longer life cycles of trees and to the time which may be taken by immigration if they were not previously present.

The validity of the C/A ratio as a moisture indicator was examined by comparing values along moisture gradients. This was done for three regions in which extensive surface sampling had been carried out. In each case a relationship can be seen between moisture and the C/A ratio even in regions where the total Chenopodiaceae and Artemisia pollen count was low, as in coastal Lebanon and Mediterranean Turkey (Fig. 24).

The first group of sites was in western Iran. The sixty samples included assemblages from the relatively moist region of the oak forest climax, through the intermediate Pistacia-Amygdalus steppe, and into the lower-rainfall Mesopotamian piedmont (dry-steppe) zone (Wright et al., 1967). In the oak forest regions the combined C/A ratio was 1, it doubled to 2 in the intermediate zone and increased to 4.5 in the driest zone. The transect was extended into the desert region in the surface studies reported in Chapter II where Chenopodiaceae pollen was high and no Artemisia pollen occurred.

The second group of samples was from sites in Lebanon and Syria (Bottema and Barkoudah, 1979). The same trend was exhibited here. There was a total of 85 samples through all the vegetation zones of Syria and Lebanon with the exception of the alpine and sub-alpine regions. The average values for the five groups ranged from 1.6 in the steppe to 0.8 in the forest steppe, 0.54 in both the lower and upper Mediterranean and 0.37 in the oro-Mediterranean

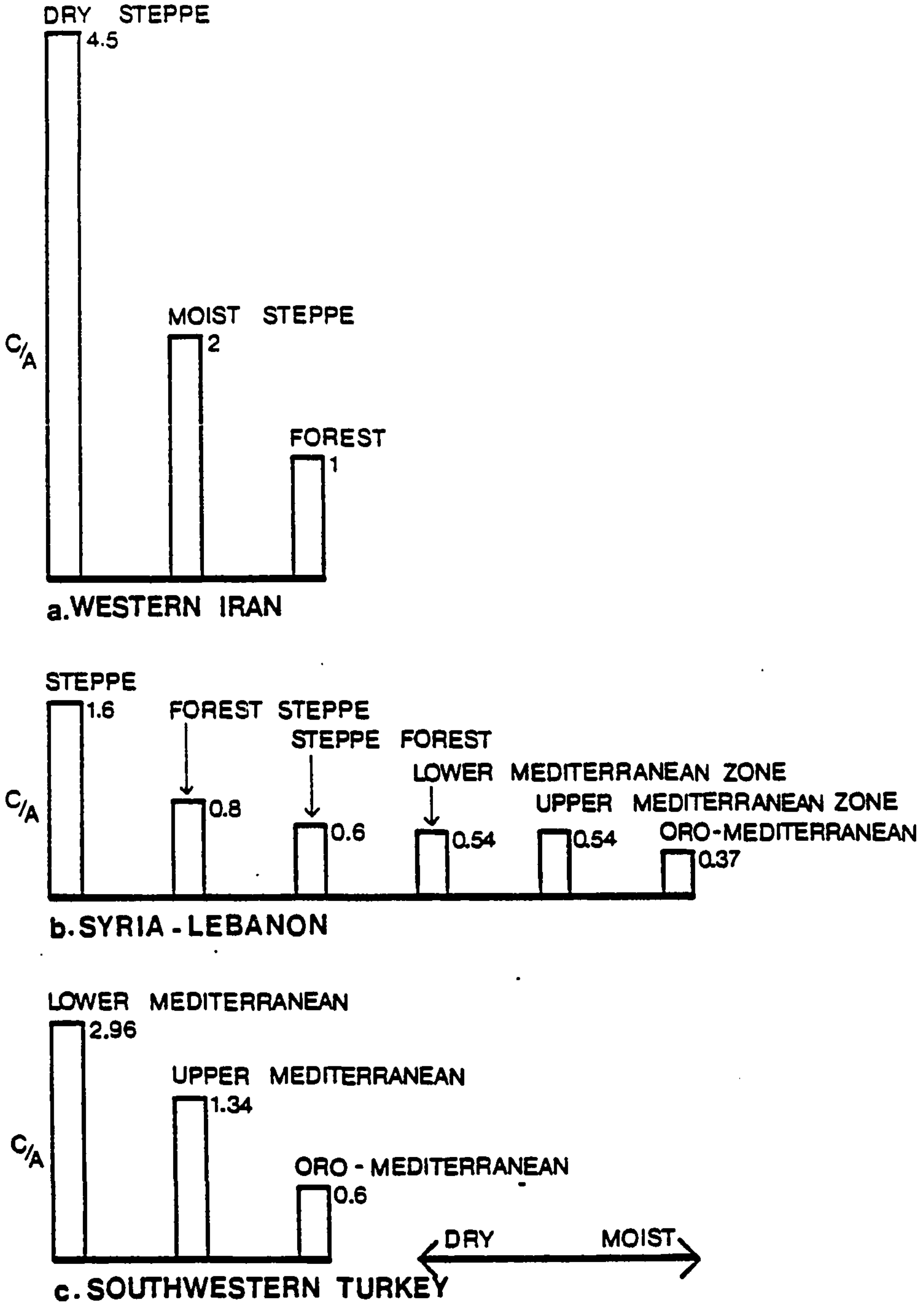


Fig. 24. Average C/A Ratios of surface pollen assemblages for three regions of the Middle East grouped and arranged according to moisture. Data from Wright *et al.* (1967), Bottema and Barkoudah (1979) and van Zeist *et al.* (1975).

(mountain) zone. Fifty-four samples in the Mediterranean zones of Turkey (van Zeist *et al.*, 1975) showed the same trend, ranging from 2.96 in the lower Mediterranean (0-300 m) to 1.34 in the upper Mediterranean (300-1000 m) and 0.6 in the oro-Mediterranean zone (1000-1500 m) (Fig. 21).

These comparisons indicate that this ratio is apparently a valid indicator of moisture and can be a useful tool in determining past environments from pollen assemblages. Like other botanical indicators of climate the C/A does not reflect absolute rainfall but rather is indicative of the effective precipitation. Regions with some summer rainfall, for instance, have much lower ratios than regions with equivalent precipitation but with summer drought, and those with marine influence have lower ratios than those from more continental sites. The southwestern Turkey samples, in addition to those shown here, included four samples from the xero-euxinian zone, a region of low, but year-round precipitation. It did not seem appropriate to include them because they were from a different rainfall regime and also perhaps included too few pollen grains of *Artemisia* and Chenopodiaceae to be reliable. The C/A ratio for these samples is only 0.36, or 0.13 if a sample which seems anomalously high in *Artemisia* is included.

Moisture trends determined from C/A ratios are of course subject to various sources of error. Under certain conditions local overrepresentation can be expected to occur. Van Zeist *et* al. (1975) have noted conditions under which local Chenopodiaceae plants in dried, saline lake bottoms have caused excessive pollen from that family to appear in the sediments. However, they have been able to identify these conditions by the poor pollen preservation and by the large number of accompanying Compositae. Under most circumstances, drying lakes would occur under conditions of low moisture so that the phenomenon would only exaggerate an already high ratio. It is also conceivable that when Artemisia is dominant, deceptively low ratios could occur, indicating moister conditions than actually existed. However, in the Iranian plateau, where Artemisia is dominant the C/A ratio is 1.8 - not much lower than the ratio on the steppe west of the mountains where Artemisia is much less common.

Moisture Trends of Eastern Mediterranean-Middle East Pollen Diagrams

To obtain pollen indices of moisture, the percentages of Artemisia and Chenopodiaceae pollen were obtained by measuring published pollen diagrams. This is obviously not the most satisfactory method of obtaining ratios, but the original pollen counts were not available. Other factors which would detract from the accuracy of the curve are infrequent sampling of the original core or low sedimentation rates which would have the same effect as lengthening the time period between samples. In this case, fluctuations could be truncated or missed altogether.

In Figure 25 a series of pollen diagrams from the eastern Mediterranean and Middle East are shown. They include all but one of the diagrams which extend into the Pleistocene in which Artemisia and Chenopodiaceae are separated from other herbaceous pollen types and for which radiocarbon dates can identify the time period between 20,000 and 10,000 B.P. The diagram of Ioannina displays little variation between Chenopodiaceae and Artemisia. It seems apparent that the proximity to the sea supplied sufficient moisture, so that changes which occurred had little effect on the two pollen types. It is not shown here, but will be discussed later.

Only two diagrams have sufficient dates to closely compare the C/A curves, Tenaghi Philippon (Wijmstra, 1969) and Zeribar (van Zeist and Bottema, 1977). The similarity between the two is so striking that it leaves little doubt that moisture trends were similar region-wide, at least until 10,000 B.P. All five of the diagrams show a moist pleniglacial (i.e. low C/A ratio). The first dry period apparently occurred about 16,000 years ago. Beginning at about 13,500 B.P. a very strong drying trend occurred that, after a moister phase, was followed by several other strong fluctuations. The similarity between these fluctuations and late glacial temperature changes is notable, with moist periods corresponding to cold periods. This is not surprising considering

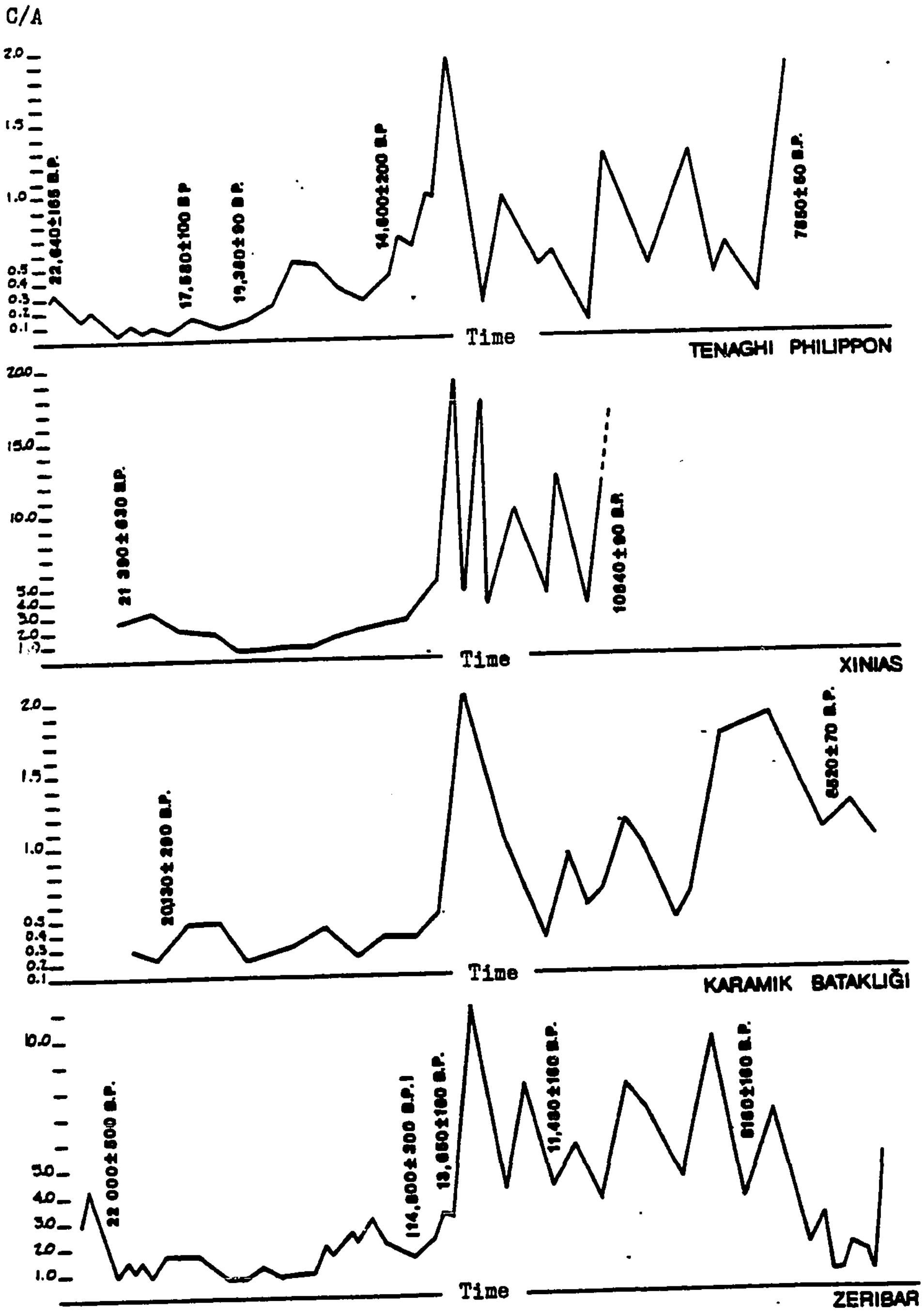


Fig. 25. Comparison of C/A curves from Greek and Middle Eastern pollen diagrams.

the important effect that temperature has on available moisture, and in the Middle East, perhaps on actual precipitation (Striem, 1979). Peter Mehringer (personal communication) has utilized this same ratio to identify temperature trends in the southwestern United States. On the other hand, it will be shown that in the Holocene, a combination of high temperatures and higher precipitation also result in low C/A values.

The C/A moisture curves give results in accordance with other kinds of evidence (Chapter I) as well as climatological models which suggest an intensification and southerly depression of the westerlies into the Mediterranean latitudes during the glacial periods (Rognon and Williams, 1977; Lamb, 1977). The results also show that trends were approximately regional. This is closer to what is to be expected in a region under the control of a single precipitation regime modified primarily by orographic influences.

Thus a sequence of trends occurred throughout most of the region. This included (1) colder and perhaps moister Pleistocene winters, accompanied by hot dry summers, (2) aridity in late glacial times and (3) summer precipitation increasing or beginning about 9000 B.P. Although each change was registered by the vegetation in one way or another the effects differed according to the preadaptations of the plant life.

CHAPTER IV

CLIMATIC CHANGE IN THE EASTERN MEDITERRANEAN AND MIDDLE EAST BASED ON C/A CURVES AND ECOLOGY

Modern Vegetation

C/A ratios and "moisture curves" in which increases and decreases in arboreal pollen have been tied to increases and decreases in moisture (van Zeist and Bottema, 1982) show little agreement with one another. Obviously, the very low arboreal pollen which was recorded in glacial-period pollen diagrams throughout the region must be significant. If not caused by aridity, what then was the cause? Since the effects of the glacial period changes can be considered only in light of the present-day relationships between climate and vegetation, it is useful to review the ecological requirements of the vegetation of the various subregions.

Although the entire area is to some extent under the influence of the Mediterranean Sea and is characterized by winter rainfall and summer drought, a great variety of climates and vegetation types occur. Climate ranges from wet to arid, oceanic to highly continental, and from absolutely rainless summers to summers in which up to one-third of the precipitation falls in that season.

In the northernmost of the Mediterranean lands where summer rain occurs, the forests are similar to those of central Europe. Trees are adapted to cold winters as well as to relatively moist summers and are either deciduous angiosperms or evergreen conifers.

Towards the south in the true Mediterranean climate, summer rainfall decreases and is finally eliminated completely. In this region, the tree species are limited mainly by the extended period of summer drought. The most common adaptation for surviving the dry period and for taking advantage of the moist but relatively mild winter, is the development of sclerophyllous, persistent leaves. The hard, leathery leaves are protected from summer desiccation while the evergreen habit allows photosynthesis to continue throughout the year, reaching maximum efficiency during the moist months. In the coastal mountains, where the drought is less severe, deciduous trees and evergreen conifers persist.

Inland from the Mediterranean region, the climate becomes even harsher. The moderating influence of the sea disappears so that summer drought and heat are intensified while winters become much colder. The adaptive advantages of the sclerophyllous evergreen habit no longer apply and so even the Mediterranean species are eliminated. Trees are confined to river banks and to the mountains. They are almost always deciduous as the severity of the winter requires dormancy. Since summer drought also restricts growth, it is only during the spring, or perhaps the autumn that reliable activity can occur. This is the region characterized by the Artemisia-Chenopodiaceae steppe described in Chapter III.

In semiarid to arid regions with warm winters, due to their more southerly location or to their proximity to the sea, various perennials that can tolerate summer drought, but not cold winters, replace *Artemisia* and Chenopodiaceae. Annual vegetation that can take advantage of the mild winters also thrives. These include both ephemerals and longer-living annuals which develop vegetatively all winter and bloom in spring or early summer (Chapter II).

The Pleniglacial

25,000 - 16,000 B.P.

Throughout the entire eastern Mediterranean and Middle East the C/A ratios indicate that during the Pleistocene a moist climate occurred, while the high percentages of *Artemisia*- and Chenopodiaceae pollen indicate that summers were dry and winters cold with temperatures regularly falling below 0°C (Walter, 1971). However, because of the pre-adaptation of the arboreal vegetation the same glacial climatic trends can be expected to have had a somewhat different effect in each of the regions.

Fig. 26 shows the C/A curves for Zeribar and Tenaghi Philippon. Both sets of curves indicate that the period from about 25,000 to 17,000 B.P. was moist with the exception of a dry phase which occurred around 22,000 B.P. This dry period may be equivalent to the world-wide interstadial which occurred at this

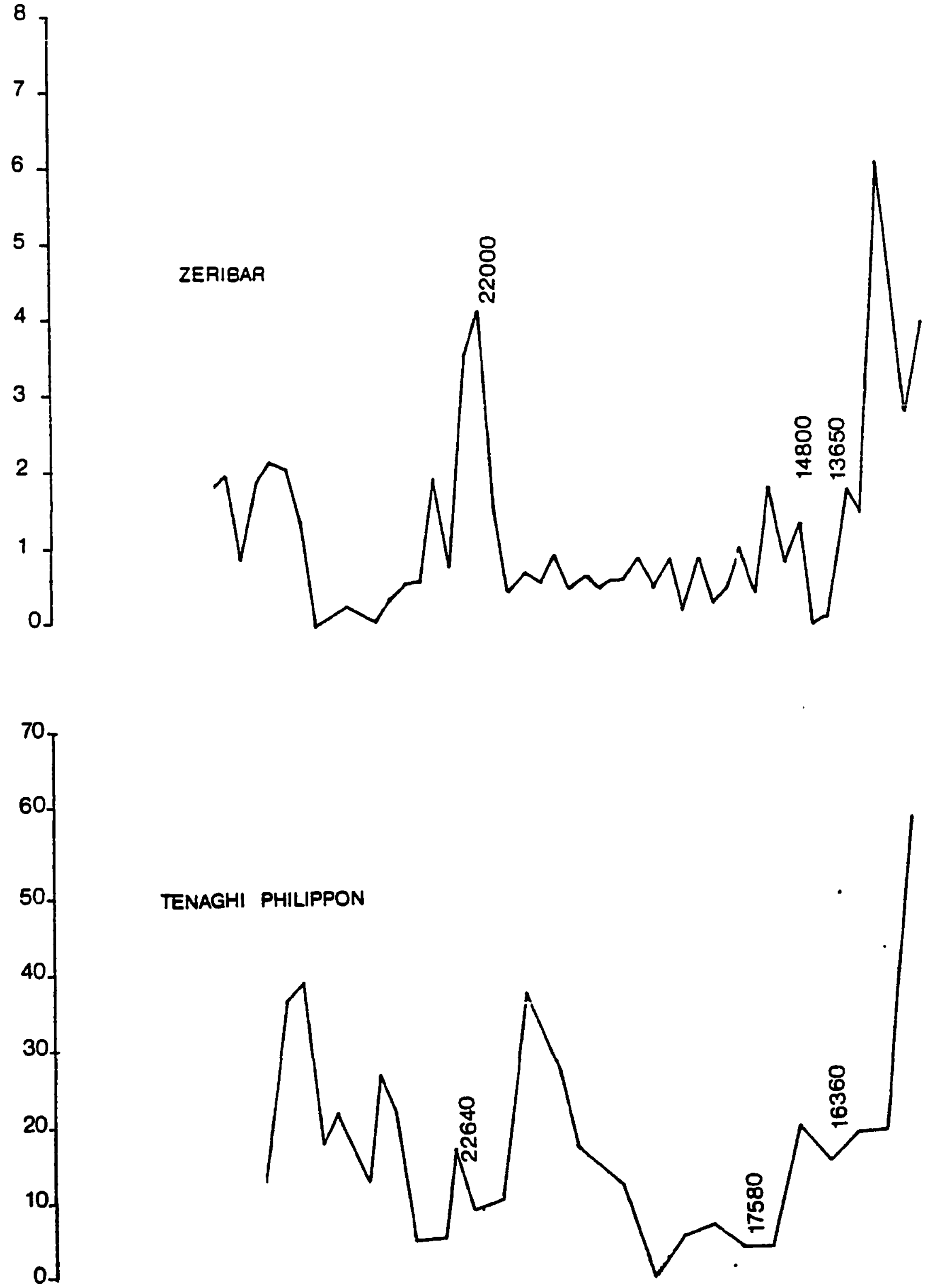


Fig. 26. C/A curves for Zeribar and Tenaghi Philippon 25,000 B.P. to 15,000 (13,000) B.P.

time (Mörner, 1973). At Lake Zeribar the earlier period (before 22,000 B.P.) appears to have been moister while at Tenaghi the maximum moisture may have occurred between 20,000 and 17,000 B.P.

In the region in which some summer rainfall occurs, there are four pollen diagrams long enough to include the pleniglacial. They are the Greek diagrams of Tenaghi Philippon, Xinias, and Ioannina, and the Turkish diagram of Karamik-Batakliği (Figs. 7, 8, 9, 14). In all of these diagrams the pollen of Artemisia and Chenopodeaceae steppe largely replaced that of the forest trees. At Xinias, Tenaghi, and Karamik-Batakliği arboreal pollen was very low. It was slightly higher at Ioannina. The pollen that occurred was primarily of trees that can survive both low temperatures and summer drought, such as Abies, Cedrus, Pinus, Betulacae, Salix and Juniperus, all of which grow at the higher elevations in Lebanon and Syria. The small pollen percentages present in these Greek and Turkish diagrams could quite easily have been due to long-distance transport or redeposition, and do not necessarily imply that the trees were growing in the vicinity. Pollen of trees requiring summer precipitation such as Carpinus, Tilia, Corylus, and deciduous oak was very low or absent.

By far the most important effect of the glacial climate in this region seems to have been a reduction or elimination of summer rainfall. Obviously the drastic decrease in trees could not have been due solely to the low temperatures as many of these trees survived in refuges farther to the north where it must have been even colder. It was not possible for the summer-drought-resistent Mediterranean species to fill the vacated niches as most of them are quite sensitive to frost, and are not even able to survive in these habitats today (Larcher, 1981). Instead Artemisia and Chenopodiaceae replaced the excluded trees. Deciduous Quercus pollen, which sustained low but continuous percentages during the pleniglacial at Karamik-Batakliği (Fig. 14) may have been due to the location of this site near a zone of modern continental climate and therefore near a source of trees adapted to both cold winters and dry summers. The relationship between the C/A curve and variations in any of the three kinds of tree pollen, Pinus, Quercus and Cedrus is not apparent.

Towards the end of the glacial period Pinus pollen percentages fluctuated in the sediments of Ioannina, Xinias and Tenaghi Philippon. Bottema (1978) has attributed the initial increases at Xinias and Ioannina to the period of time equivalent to the "Lateglacial" of northwest Europe. Howver, at Tenaghi Philippon, the first increase, which is well-dated, obviously occurred during the pleniglacial. Assuming the correlation of the Xinias and Tenaghi Philippon diagrams suggested by the C/A curves is correct (Chapter III), Pinus pollen also initially increased at Xinias during the pleniglacial and decreased during warming periods. At both sites Pinus remained clearly in phase with moisture (Fig. 27, Fig. 28).

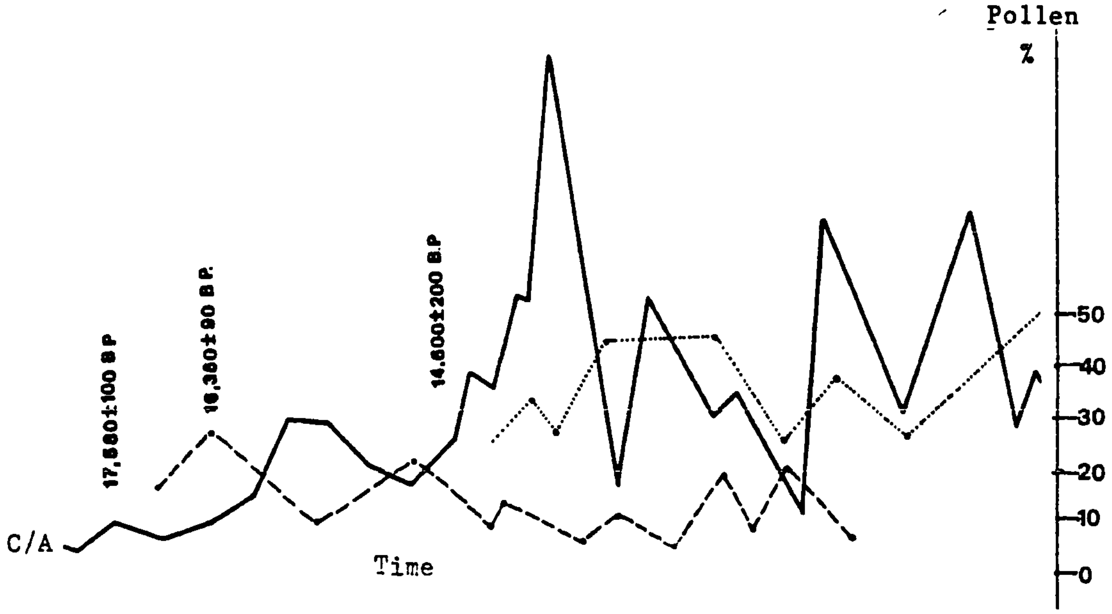


Fig. 27. Tenaghi Philippon. Pollen of Pinus (dashed line) and of Quercus (dotted line) with C/A curve.

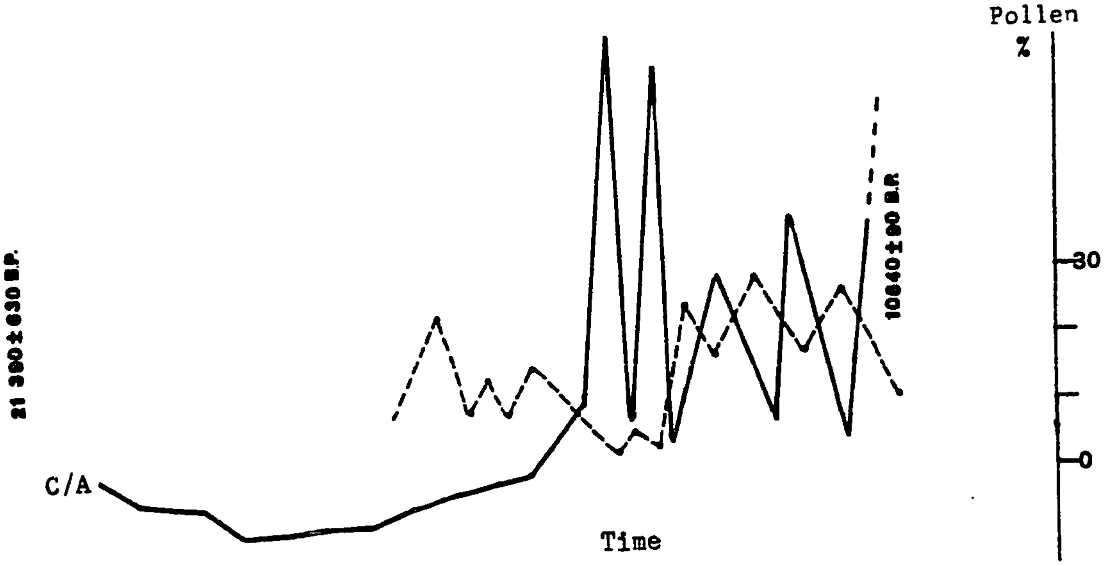


Fig. 28. Xinias. Pollen of Pinus (dashed line) with C/A curve.

I suggest that at Ioannina as well the increases in Pinus were in response to the improved moisture conditions which occurred during cold phases (Fig. 29).

On the other hand, Quercus pollen increased during the drier phases at Tenaghi Philippon. Clearly it was not limited by aridity. The establishment of the Quercus forest occurred earlier at Tenaghi than at either Ioannina or Xinias. Migration lag does not seem to have been a factor at Ioannina, as low percentages of Quercus pollen occurred throughout the glacial period there but were absent at Tenaghi. Apparently conditions favorable for the spread of oak occurred earlier at Tenaghi than at Ioannina.

To the south in the Levant where summer drought is absolute today, a reduction in summer rainfall is obviously impossible while relative humidity may have actually increased due to the lower summer temperature. Thus a similar change in climate to that which had a negative effect on the trees of the zone in which summer rainfall occurs today would have had a positive effect where trees were accustomed to summer drought. Moreover the varied topography and the north-south trend of the Levantine mountains would have provided the vegetation with easy access to lower altitudes and/or latitudes.

Unfortunately there are no pollen diagrams from the coastal Levant though some cores from the interior have been studied. Published diagrams of Birkit Ram from the Golan Heights (Weinstein,

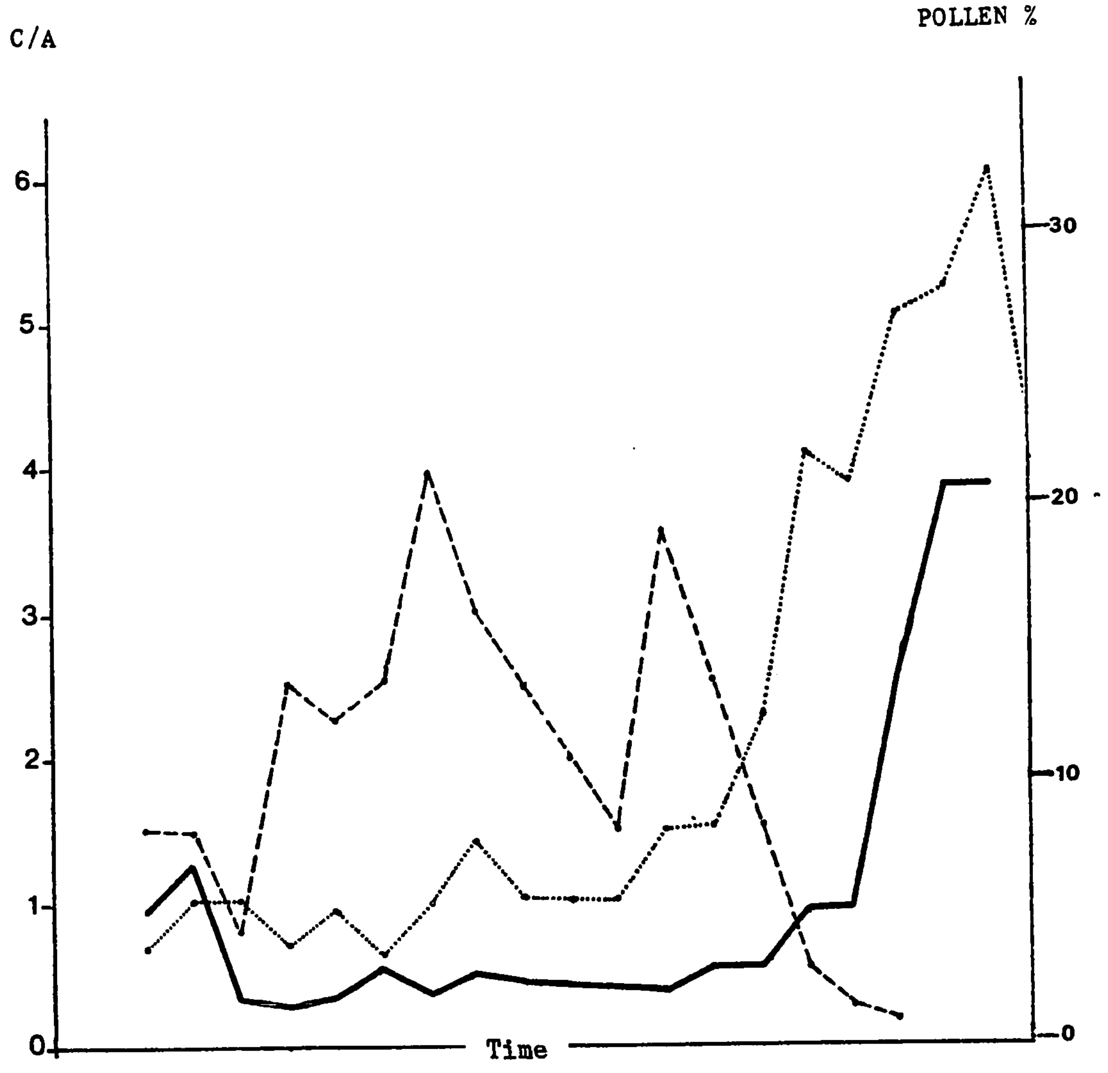


Fig. 29. Ioannina. Pollen of <u>Pinus</u> (dashed line) and of <u>Quercus</u> (dotted line) with C/A curve.

1976) and from the Huleh Swamps (Horowitz, 1971) are too general and too poorly dated to be of much help. The Huleh diagram of Tsukada (1974) is well-dated but only a very generalized diagram has so far appeared in print. Here tree pollen was generally higher before 20,000 B.P. If the tree-pollen curve is indicative of moisture at this site it may be that the Jordan Valley was under the influence of the southerly regime which experienced its moistest period before 22-20,000 B.P. (McClure, 1976, 1978; Street and Grove, 1979). This is not entirely unexpected as Huleh lies at at a latitude of 34° degrees, considerably farther south than the location from which any of the other diagrams were obtained.

The diagram from the Ghab Valley (Fig. 15) was not included in Figure 25 because it is actually composed of parts of three diagrams from cores of sites that must have differed somewhat from one another. Moreover the connections between diagrams cannot help but be somewhat subjective and could result in either repetition or elimination of intervals. Although there is only a single date for this part of the Ghab diagram it is apparent that tree pollen in general was high during the glacial period. Most important is the fact that the relatively warmth-demanding vegetation such as *Olea*, *Phillyrea*, and *Carpinus* were replaced by the mesic, deciduous *Quercus cerris*. *Q. cerris* only occurs today above 800 m and it seems reasonable to assume higher moisture to account for its increase during the glacial period. (Fig. 15). *Quercus* calliprinos, the evergreen oak occupies the lower slopes today, but since it sometimes extends to 1500 m where Q. Cerris forests have been destroyed (Zohary, 1973) it is unlikely that the species was directly limited by the reduction in temperature, but that the lower temperature and the increased moisture gave the competitive advantage to Q. cerris.

Van Zeist and Woldring (1980) have correlated Zone I of Ghab with the "Lateglacial" of northwestern Europe. The oscillating moisture conditions apparently caused a general reduction in arboreal pollen. Probably the rapid change from cool, moist to hot, dry conditions affected Quercus cerris while the sudden cold intervals of 12,000-11,800 and 11,000-10,000 B.P. delayed the spread of the more thermophilic trees (Fig. 15).

The period 11,000-10,000 B.P. which corresponds to the cold Younger Dryas and the Loch Lomand Stadial of northern Europe is difficult to identify from the C/A curves. It appears that at Zeribar and Tenaghi this period was moist, but the lack of dates makes it impossible to be certain. At Xinias by 10,680 B.P. the C/A is very low but the total amount of Chenopodiaceae and Artemisia pollen is so low that the significance of the ratio is doubtful. Between 10,000 and 9,000 B.P. summer precipitation must have resumed in the regions where it occurs today, allowing trees to spread rapidly (Figs. 7, 8, 9, 14). At Ioannina (Fig. 29) as well as at Xinias the combination of higher temperatures and summer rainfall finally may have allowed deciduous _Quercus_ to replace _Pinus_.

CHAPTER V

VEGETATIONAL AND CLIMATIC CHANGE IN KURDISTAN: A REAPPRAISAL OF PALYNOLOGICAL EVIDENCE

According to the original interpretation of the pollen diagrams of Lake Zeribar, Lake Mirabad, and Lake Van, a very long period of aridity lasting from at least 40,000 B.P. to 5,500 B.P. occurred in the Zagros-Taurus Mountains of Kurdistan. The elapse of thousands of years between the initial warming phases (13,500 - 10,000 B.P.) and the establishment of the *Quercus-Pistacia* forest (5,500 - 3,400 B.P.) seemed to the palynologists studying these sites to eliminate low temperature as a factor. Perhaps it was also difficult for northern Europeans to attribute high percentages of *Artemisia* and Chenopodiaceae pollen to anything other than low precipitation.

Tree pollen began to increase gradually about 10,000 B.P., thus a gradual increase in precipitation was also assumed. Modern moisture levels are thought not to have been attained until 5,500 B.P. at Lake Zeribar (van Zeist and Bottema, 1982) and 3,400 B.P. at Lake Van (van Zeist and Woldring, 1978) when the forest was reestablished at each site.

This interpretation raises a number of questions quite apart from the conflicting evidence of the C/A curve. A dry glacial period is contrary to a variety of evidence from the same vicinity, including a large reduction in glacial period snow line (Wright, 1961), greatly expanded lakes -including Lake Zeribar and Lake Van - (Roberts, 1982), and evidence of increased fluvial activity on the floor of the present Gulf (Kassler, 1973). Moreover trees seem to have become established first at the driest site, Lake Mirabad, before spreading to the higher altitudes and latitudes of Lake Zeribar and to Lake Van. This is opposite to the pattern which would be expected if the trees had been migrating from moister refuges in the north, or from higher altitudes. At the same time the forest was expanding at Zeribar, aridity indicators such as *Plantago* and Compositae were increasing along with the C/A ratio, a situation which surely calls into question the assumption that the tree curve is representative of moisture.

The alternate history presented here is based largely on the modern vegetation. The high percentages of *Artemisia* and Chenopodiaceae pollen are shown to be compatible with the vegetation that occurs today above the tree line in the Zagros mountains. The elimination of trees during the glacial period is attributed not to a decrease but to an increase in precipitation which when combined with the lowered temperature of the Pleistocene would have produced excessive snow, shortening the growing season to the extent that the trees could no longer survive. Finally it is shown that a sustained period of low precipitation is not necessary to account for the relatively recent reestablishment of the forest and that its late return can be explained by an extremely slow migration, due to normal summer conditions of drought and heat.

The Pollen Assemblages of Pleistocene Zeribar

The pollen spectra of the pleniglacial sediments are similar to what would remain if the tree pollen were subtracted from the modern pollen assemblages of the Kurdistan region. The flora of these mountains is largely composed of herbaceous annuals including grasses which complete their life-cycles during the short period when suitable temperature and moisture conditions coincide. Since most species are insect-pollinated and bloom only briefly during the spring, their contribution to the pollen rain is negligible. The annual Chenopodiaceae are an exception, both in that they bloom in the late summer after almost all other annuals are dead and in that they produce copious amounts of anemophilous pollen.

Among the few shrubs and trees only *Quercus*, *Artemisia herba-alba* and some perennial Chenopodiaceae produce much pollen. *Pistacia* is underrepresented while the presence of *Acer* and several rosaceous trees and shrubs may go virtually unregistered (Wright *et al.*, 1967).

In most mountainous regions conifers form the upper tree line. In the Zagros range, however, they have apparently been practically excluded by the hot, dry summer and *Pistacia* and *Quercus* occupy the highest forested zones. The timberline thus is 1600 m lower than at equivalent latitudes in the southwestern U.S. where summer rainfall occurs (Odum, 1971).

The vegetation above the timberline is an often narrow zone of shrubs dominated by *Cotoneaster racemiflora*, *Lonicera arborea*, and *Daphne acuminata* (Guest and Al-Rawi, 1966). Above this zone is the thorn cushion or tragacanthic vegetation named for the subgenus of *Astragalus* which dominates the region. The compact cushions of dwarf shrubs and low spiney herbs are protected by their growth habits from the harsh climate of extreme winter cold and intense summer insolation. In addition to *Astragalus*, characteristic plants are *Acantholimon*, *Cousinia*, *Onobrychis cornuta*, *Cirsium* and *Prangos*.

The true alpine vegetation does not occur until nearly 1000 meters above the timberline. Here are found primarily various herbaceous species of Compositae, Labiatae, Cruciferae, and Caryophyllaccae. In addition *Prunus*, *Asperula*, *Galium*, *Achillea*, *Stachys*, *Vicia*, *Ranunculus*, and *Primula* have been mentioned (Guest and Al-Rawi, 1966).

Only *Quercus aegilops* subsp. *brantii*, *Pistacia atlantica* and *P. khinjuk* are well enough adapted to the extreme continental conditions to form forests in this region. Therefore, when, during the glacial period, these species had been eliminated from the region for whatever the reason, the plants available to fill the vacant niches would have been those not eliminated along with the trees. Since among these plants only Artemisia, Chenopodiaceae and Gramineae produce appreciable amounts of pollen, it is their pollen that would have replaced that of the trees.

It is in fact questionable that Chenopodiaceae and Artemisia were present to any appreciable extent in the immediate area around Lake Zeribar during the glacial period. The landscape may have been similar to that of the subalpine tragacanthic or alpine herbaceous vegetation, both of which produce little pollen. Faegri and Iversen (1975) have pointed out that thermal up-drafts along mountains cause vertical transport of pollen from lowland to subalpine regions. The strongly prevailing northwesterly winds may have further enhanced the movement of Chenopodiaceae and Artemisia pollen from the lowland desert and steppe to the mountain regions where it would have been washed down with the precipitation. Surface studies along altitudinal gradients substantiate that these factors result in the relative increase of long-distance transport types beyond the tree line(Wright, 1967).

Markgraf (1980) has strongly cautioned against applying lowland pollen data to the interpretation of fossil pollen profiles from mountain regions. She found "...with increasing elevation, independent of the density of the forest, relative percentages of long-distance dispersal increase and finally surpass the local pollen production...with increasing elevation the pollen representation of the given vegetation type becomes more and more distorted."

Maher (1963) demonstrated how phenology may affect the incorporation of pollen into lake sediments at high altitudes, further distorting the pollen record. The early-blooming plants release their pollen while the lake is still frozen in the spring. As the melt-water from the surrounding snow flows over the surface of the frozen lake it washes away any pollen which may have fallen onto it. In this way, only the pollen of those plants which flower in the summer or early autumn are able to be incorporated into the sediments in significant amounts. In this region Chenopodiaceae and _Artemisia_ are among the few late-flowering plants. The only summer-flowering plants mentioned by Guest (1966) for the subalpine region are _Cirsium_, _Cousinia_, and _Prangos_, a giant herb in the Umbelliferae. It may be of significance that both Umbelliferae pollen and _Cousinia_ pollen were more prevalent in the Zeribar core during the glacial period than later on.

If indeed Maher's phenomenon was in effect during the glacial period, evidence of its elimination may be detected in the diagrams of Lake Zeribar, Zer. Ib 89-90 and 96-98; (Fig. 11) Zer. II 8-9 and 14-15 (Fig. 7, van Zeist and Bottema, 1977). The two sharp drops which occur in the total Chenopodiaceae-_Artemisia_ percentages coincide closely with the sudden warming trends reported from other areas (Coope, 1975; Mangerud _et al._, 1974). On the other hand, a period of warmth coinciding with moisture is required for most

Gramineae to thrive and the pollen diagram may simply reflect the actual change in pollen production due to warmth occurring earlier in the spring when conditions are still moist.

Ecology of Zagrosian Trees and Suggested Limiting Factors During the Pleistocene

Although other species of trees occur in the Zagros mountains, *Quercus aegilops* subsp. *brantii* L. (*Q. brantii* Lindley), *Pistacia khinjuk* Stocks, and *Pistacia atlantica* var. *kurdica*, (*P. mutica*) are the most important species and the only ones which would have contributed significant pollen to the sediments of Lake Mirabad and Lake Zeribar. They occur together throughout most of the Kurdo-Zagrosian oak forest, which extends along the Taurus-Zagros arc from southeastern Turkey to northeastern Iraq continuing south and east into the Iranian Zagros mountains (Fig. 30). A wide variety of ecological conditions occurs over the extensive range of this forest offering excellent opportunities for studying the relationships between the trees and their environments.

Although *Quercus* species can easily be distinguished in the southern region discussed here, to the north is an important center of distribution with many species clusters that cannot be easily separated. The nomenclature used here follows that of Flora of Iraq Vol. IV (Guest *et al*., 1981). Guest *et al*. (1981), Zohary (1973) and Rechinger (1971) have all included *Q. persica*, *Q. vesca*

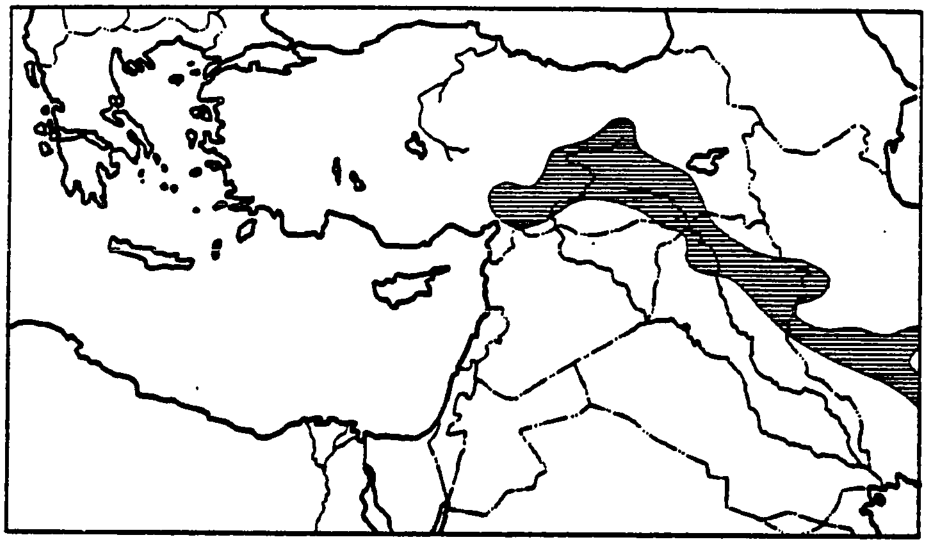


Fig. 30. The modern distribution of <u>Quercus aegilops</u> subsp. <u>brantii</u> (Zohary, 1977).

and Q. oophora within the same species except that Zohary and Rechinger, as well as the authors of the earlier palynological studies, including the present author (El-Moslimany, 1982) have used the synonym Q. brantii rather than Q. aegilops. The species Quercus boissieri Reut. of Zohary, which is an important element to the north, is here included within the Q. infectoria complex. While maintaining these as separate species, Zohary (1973) has nevertheless remarked that they "are not readily distinguishable from one another."

A very important characteristic of the dominant trees of the Zeribar region, Quercus aegilops, Pistacia atlantica and P. Khinjuk, is their ability to tolerate conditions of low rainfall. In this region, as well as in the drier lower altitudes and latitudes, Q. aegilops is the only oak which occurs. Zohary (1973) has reported its presence in locations with rainfall as low as 330 mm. Pistacia has even less demanding moisture requirements.

In northern Iraq where more rainfall occurs, two other Quercus species are found. Chapman (1957) and Guest and Al-Rawi (1966) have given general descriptions of the Quercus forest in this region, dividing it into a lower, a middle and an upper zone. In the lowest and driest zone Q. aegilops is again the exclusive oak. It occurs with various species of Crataegus and with Pistacia khinjuk. The middle forest zone (1000-1500 m) may be dominated by Q. aegilops and/or Q. infectoria depending on the moisture conditions. Where one dominates the other is also abundant.

By 1200 m *Quercus libani* becomes important usually occurring as a co-dominant with *Q. infectoria*. In this zone according to Zohary (1973), *Q. aegilops* dominates the mountain tops, as well as the southern and eastern slopes. On western slopes *Q. infectoria* dominates while *Q. aegilops* is stunted. *Q. infectoria* and *Q. libani* share the dominance of northern and northwestern slopes. According to Chapman (1957), *Q. aegilops* is rare above 1650 m. and never occurs above 1800 m. In this highest part of the forest *Q. libani* often forms pure stands.

The only in depth study of the Iraqi forest (the trees and shrubs of Gara Mountain, Mosul, Liwa) has been published by Agnew (1962). The objective analysis of a specific area differs somewhat from the more subjective but more general observations of Chapman (1957), Guest and Al-Rawi (1966) and Zohary (1973).

Agnew sampled along transects from the valley floor (1000-1300 m) to the summit plateau (over 1700 m). He found the zonation to be determined more by site differences than by altitude (Fig. 31). The study was confined to the northern slopes but observations of the southern slopes of the mountain confirmed that the zonation was similar except that the *Q. libani* forests were "very attenuated".

The lowest and driest forest where *Quercus aegilops* occurs alone was not included in this study, the lowest slopes and valleys of Gara Mountain being typical of the "Middle Forest" zone. This

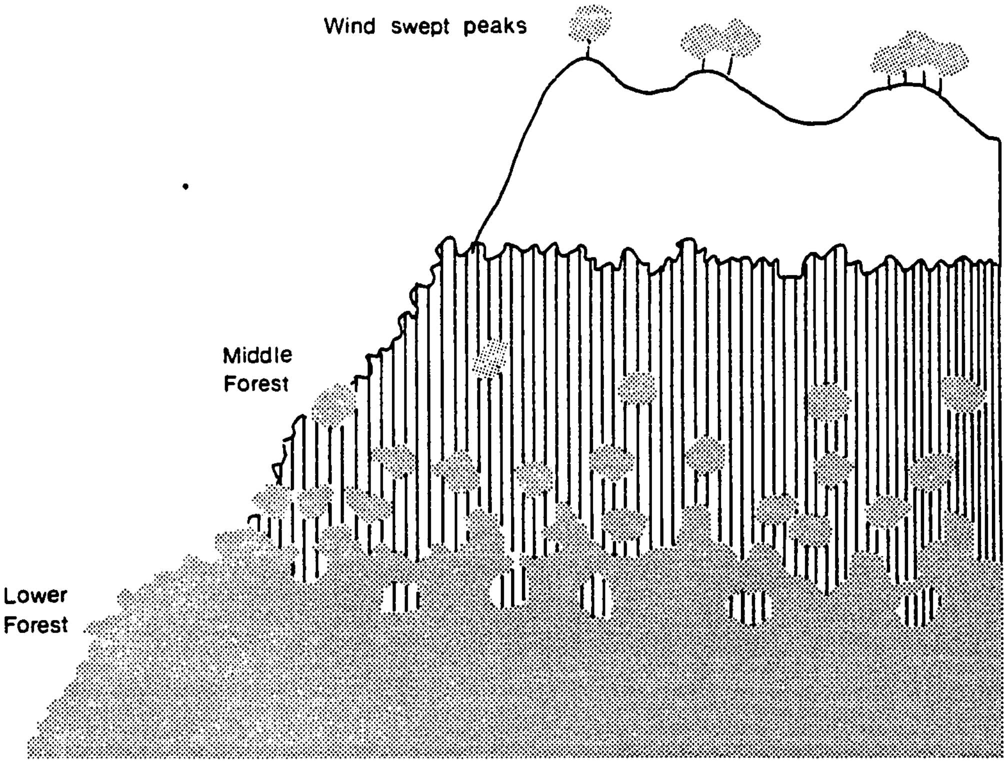


Fig. 31. The three habitats of Quercus aegilops subsp. brantii in northeastern Iraq.

area is dominated by Q. infectoria and Q. aegilops and in general is more disturbed than other sites. Traces of original vegetation in mesic habitats at these altitudes suggest that a closed canopy of Platanus orientalis with Hedera helix and Vitex vinifera may have existed under undisturbed conditions with oak occupying the drier sites.

Above 1300 m Acer cinerascens is a constant in the understory, but the dominants and other shrub species differ. On the rocky and shallow-soil ridges of the slopes, Quercus aegilops dominates with Pistacia khinjuk as an important subdominant. Q. libani dominates the more mesic sites, ravines and ravine sides.

On the summit plateau Quercus aegilops again dominates, but Pistacia atlantica replaces P. khinjuk as a subdominant. Agnew found difficulty in explaining the dominance of these xerophytic trees at the high altitude in a region of precipitation greater than 1000 mm, but apparently the short period after the snow melts and before the soil completely dries out in June or July renders the region too xeric for Quercus libani.

The exposed nature of the plateau summit, the mountain tops and other topographically specialized environments of Q. aegilops must be emphasized. Mountain tops are almost constantly subjected to highly desiccating winds which reduce the effectiveness of increased precipitation. Only highly xerophytic vegetation can be expected to survive in such an environment. The absence of Quercus *aegilops* and *Pistacia atlantica* from most regions above 1500-1800 m is obviously not due to any sensitivity to low temperature, otherwise they would not be able to thrive at these specialized high-altitude sites. The trees are obviously highly tolerant not only of low moisture but of low temperature. The trees of the summit plateau are confined to high ground between shallow drainage gullies which dissect the plateau. Since the soil appears uniform, the only explanation for the absence of trees in the hollows is the tendency for snow to accumulate in these environments (Barry, 1981). The vegetation in the hollows is similar to that above the treeline.

Zohary's (1973) observation that in the high forest zone *Q aegilops* thrives on southern and eastern slopes, is absent on north slopes and stunted on westerly ones also implies that this tree is limited by snow. The excessive build-up and later melt of snow on north slopes would prevent the occurrence of the trees there in contrast to the southern slopes, and while western slopes may be warmer than eastern slopes, leeward slopes tend to be considerably drier than windward slopes even on a microclimatic scale (Geiger, 1969). This would account for the stunted nature of the trees which face the westerly storms that bring winter snow to the Zagros mountains. The preference of *Q. aegilops* for drier sites also explains why in the Middle Forest Zone it is confined to ridges. (Fig. 31).

The role of competition must be given serious consideration in any instance of a preference for what is generally considered to be a poor site. The question remains as to whether *Q. aegilops* being unable to compete with other trees for the moist habitats is therefore relegated to the drier (less favorable) sites. However, the relationships of the same three *Quercus* species in southeastern Turkey clearly demonstrates that *Q. aegilops* competes very successfully with the other species on mesic sites where heavy snowfall does not occur. Southeastern Turkey is similar to northeastern Iraq in temperature but differs in the amount and distribution of precipitation. For example, Rowanduz, Iraq (elev. 1006 m) receives 940 mm of precipitation, all of it in the winter. Elazig, Turkey (elev. 1090 m), however, receives only 400 mm of precipitation, a small amount of which falls in the summer. This summer precipitation apparently more than compensates for the lower annual amount as *Q. libani* is found between 800 and 1000 m in altitude, much lower than it occurs in northeastern Iraq. Other relatively mesic species are also able to penetrate favorable sites in this region (Zohary, 1973). Under these conditions, *Q. aegilops* remains dominant in the presence of *Q. infectoria* and *Q. libani*, even occurring alongside the other two species on north-facing slopes. Moreover it reaches an altitude of 2000 m. Apparently the preference of *Q. aegilops* for dry sites in northeastern Iraq is due to the heavy snow which is likely to accumulate in moister regions and not to either a requirement for low moisture or to an inability to compete with the other species.

There has been little agreement on the reported upper limit of _Quercus aegilops_. The altitudinal limit has been reported to be as low as 1600 m and as high as 2500 m. This cannot be attributed primarily to latitude, which would account only for about one-third of the difference (Fig. 32). Moreover, the altitudinal limit for both _Quercus aegilops_ and _Pistacia atlantica_ increases not only to the south but also to the east and even to the north of the northeastern Iraqi forest. Significantly the maximum winter precipitation occurs in northeastern Iraq and decreases in every direction just as the tree line increases. Fig. 32 shows the different reported upper limit of _Q. aegilops_ from southeast to northwest compared to the difference attributable to latitudinal (temperature) change.

The forest ecology of Kurdistan results in important conclusions, which can be related to the Pleistocene vegetational history and its causes:

1. _Quercus aegilops_ and _Pistacia atlantica_ can tolerate both low temperatures and low moisture.
2. _Quercus aegilops_ and _Pistacia atlantica_ and probably _P. khinjuk_ cannot tolerate heavy snowfall.
3. Growth of _Q. aegilops_ is improved by increased moisture provided snowfall remains low.

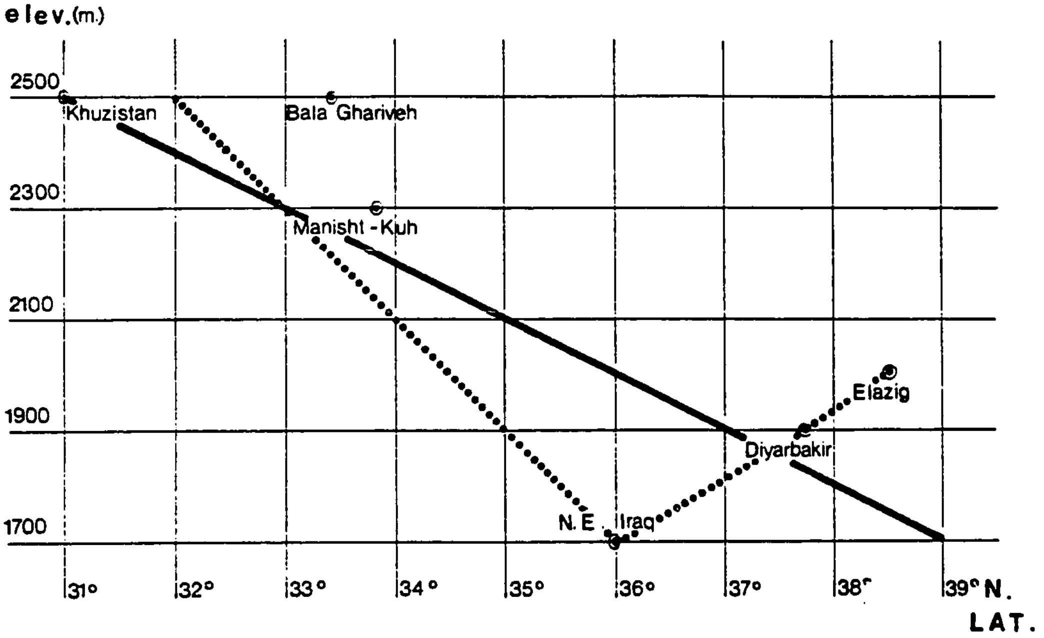


Fig. 32. Expected north to south variation in upper tree line due to latitude (solid line) and reported tree line of <u>Quercus aegilops</u> (dotted line) in the Zagros-Taurus Mountains (Khuzistan, Pabot, 1960; Bala Ghariveh and Manisht-Kuh, Bobek, 1951; N.E. Iraq, Guest and Al-Rawi, 1966; Zohary, 1973; Diyarbakin and Elazig (Zohary, 1973).

A moderate increase in precipitation combined with the general decrease in temperature could have caused enough of an increase in snowfall to have eliminated *Quercus aegilops* and *Pistacia* from the mountains of Kurdistan during the glacial period. Based on the limiting effect of various factors on these trees this is a more plausible explanation than either decreased temperature alone, decreased precipitation or a combination of the two.

Van Zeist and Bottema (1977) have attributed the elimination of *Quercus aegilops* and *Pistacia* from the Zeribar region to lowered precipitation while acknowledging that lowered temperature would have been a factor at high altitudes. Freitag (1977), accepting their explanation, placed the Pleistocene precipitation for the Zagros mountains at one fourth to one half of its present-day amount. This seems astoundingly low but would be a necessary assumption if the absence of trees is considered to have been caused solely by low moisture.

It should be noted that Wright's (1960) report of snow line lowering during the glacial period probably requires higher precipitation as well as lower temperature. A lowering of the tree line equivalent to the lowering of the snow line can be expected to have occurred during the full glacial, virtually eliminating most of the trees from northeastern Iraq. The more southerly latitudes and lower precipitation would have allowed trees to reach higher elevations in the regions of Zeribar and Mirabad, but even here the lowered snow line would almost certainly have been sufficient to account for their absence in the surroundings of both of these lakes. It is almost inconceivable that precipitation could have increased dramatically in northeastern Iraq while at the same time Lake Zeribar and Lake Mirabad 200 and 500 km to the southwest, respectively, and under control of the same climatic influences, could have experienced drastically reduced precipitation.

Neither the lowered snow line nor the lack of trees need imply that the last glacial period was uniformly moist and cold. The moraines described by Wright (1960) could have been formed at any time during the glacial period. As for the forest, the pollen diagram offers no suggestion as to when it was eliminated, while extremely long periods of time may elapse before a destroyed forest can be reestablished and the equilibrium between vegetation and climate restored. However, according the the C/A curve, the moistest periods of the past 40,000 years occurred 25,000 to 16,000 B.P. with a brief dry phase around 22,000 years ago.

The downward displacement of trees by snow would not necessarily have resulted in extensive lowland forests of oak and pistachio, for the lower the altitude the more the trees would become subject to the limiting factor of summer drought. The effect of drought may have been almost as important during the Pleistocene as today, even assuming an increase in winter precipitation. Thus the forest may have been confined to a very narrow band squeezed between the climatic pressures of two extreme seasons, or confined to the southern Zagros mountains.

Oates (unpublished) has reported on two pollen samples from an archeological site in southern Mesopotamia. The youngest sample is of Ubaid age (6190-5650 B.P.) and does not differ much from pollen accumulating in this region today. The second sample is not dated but is from a level with no archeological deposits. It is considerably older than the Ubaid occupation and may be of Pleistocene age. This sample has high percentages of arboreal pollen including _Quercus_, _Alnus_ and _Pinus_. Unfortunately at the present time, this is the only palynological evidence for an earlier depression of the Zagros forest.

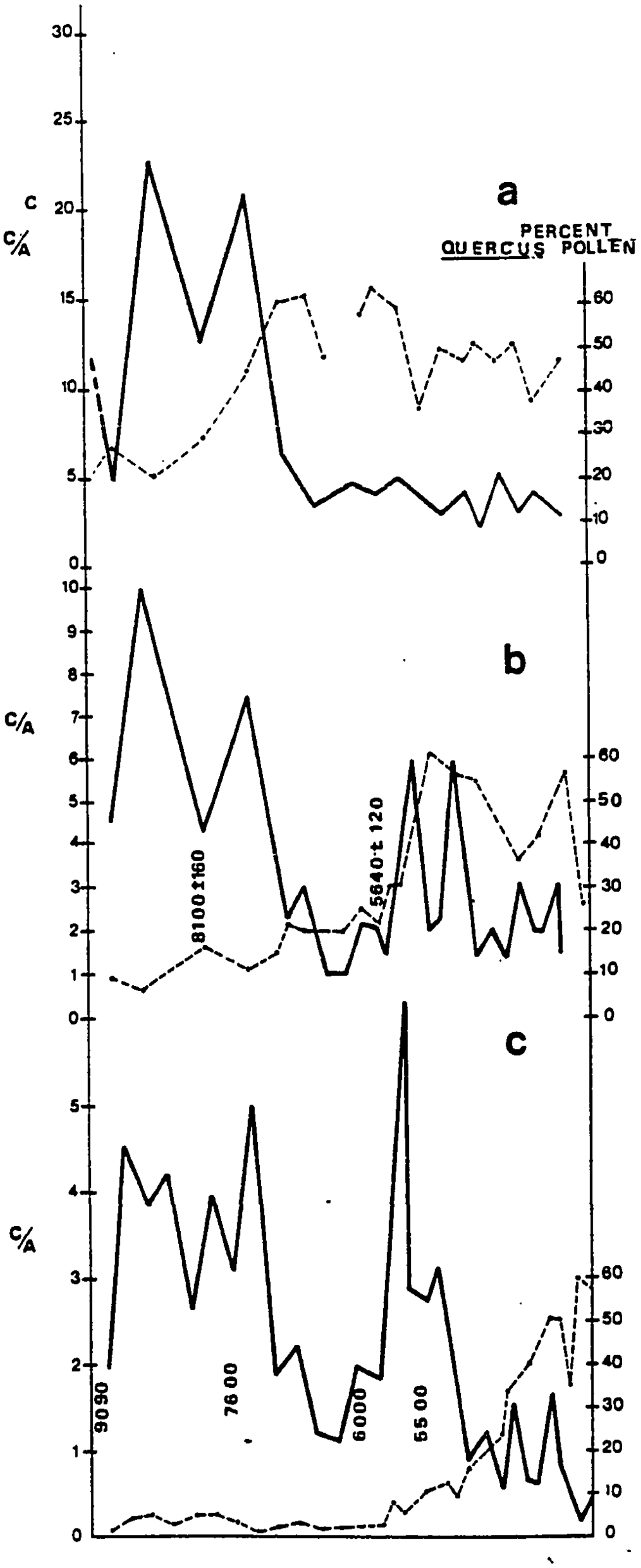
The Reestablishment of the Zagros Forest

The first strong increase in the C/A ratio is assumed to have been coincident with the widespread warming trend which is now well-established for the period between 12,700 to 12,400 B.P. Although this would have eliminated the problem of excessive snow, tree pollen remained low. If the refuges were at lower elevation the immediate effect of a rapid warming and drying trend must have been negative by restoring aridity to regions which had been only marginally mesic enough for the growth of _Pistacia_ and _Quercus aegilops_. The intensification of summer heat and drought would have severely limited the ability of trees to migrate from these lowland refuges even though habitats in the higher elevation had opened up for them. It is likely that this period was the most devastating of the past 40,000 years for the forest trees.

The negative effect of drought on the _Quercus_ forest can be clearly seen in the correlation between high frequency-variations of the moisture curve and the _Quercus_ pollen curve (Fig. 33). However, it is notable that this correlation occurs only during the period of intense fluctuations in moisture. Since this was before the forest had become fully established at the lake sites the changes in oak pollen probably reflect the expansion and contraction of the forest at lower elevations where moisture would have been more critical. It should further be noted that in spite of the periods of intense aridity which occurred between 13,000 and 8,000 B.P. the overall trend of oak was to slowly increase and spread into the mountains.

Even without the period of intense aridity the expansion of the forest would have occurred only very slowly, for even under the considerably more mesic conditions of today _Quercus_ and _Pistacia_ are established only with great difficulty (Zohary, 1962). New seedlings are apparently able to survive only in the shelter of the existing forest. Chapman (1957) has spoken of the scorching winds and high soil temperatures which occur during the summer months in this climate. In a personal communication he told of a reforestation effort which was made on the Gwaizha Dagh Mountain

Fig. 33. Suggested correlation of pollen diagrams for Mirabad, Zeribar and Van. Zeribar and Mirabad are radio carbon dated. Van dates are reverse calibrated varve dates (Stuiver, 1971) to coincide with radiocarbon dates. Broken line represents percentage of *Quercus* pollen.


a
C/A
PERCENT QUERCUS POLLEN
30
25
20
15
10
5
0
60
50
40
30
20
10
0
b
C/A
10
9
8
7
6
5
4
3
2
1
0
60
50
40
30
20
10
0
8100±160
5640±120
c
C/A
5
4
3
2
1
0
60
50
40
30
20
10
0
9090
7800
6000
5500

near the town of Sulaymaniyah in northern Iraq.

> There was no question of the ability of *Quercus aegelops* to grow there as the last remnant of the forest had disappeared only during the preceding generation. *Q. aegilops* as well as *Pinus brutia* was sowed along contour ditches on south and easterly limestone slopes. Both germinated freely but were unable to survive the following summer. Curiously enough I do happen to remember a sack of acorns which had been accidentally dumped in the shade of a wall of the foresters' hut at the foot of the mountain. These sprouted like corn and a considerable number of seedlings survived the summer and seemed to be growing vigorously. I presumed that the clump of close-growing seedlings together with the mass of decaying acorns on the soil had managed to produce a sufficiently favorable microclimate to withstand the Rashidiya wind.

In addition the effect of man and his animals may have played a role in the slow migration of the oak. Not only are goats notorious for the destruction of young seedlings but it is the custom even today to cut the branches and gather the acorns for fodder (Tabatabai and Javanshir, 1966). During times of famine the acorns are also used to make a kind of bread for human consumption (Guest *et al*., 1981). Dispersal ability is also an important factor. The earlier arrival of *Pistacia* may be explained by its lighter seeds which may allow it to spread faster than *Quercus*.

The sequence in which a tree migrates into the various sites of a region can often give clues concerning the location of refuges and the factor(s) which restricted the trees to those refuges. If the *Quercus*-*Pistacia* forest had been spreading from higher to lower elevations as van Zeist and Bottema (1977) have suggested, it should have been established first at the higher altitudes and latitudes of Lake Van, then Lake Zeribar and finally warmer but drier Mirabad.

Actually, however, the opposite seems to have occurred. A general comparison of the Mirabad and Zeribar diagrams gives the impression that _Quercus_ reached its maximum earlier at Mirabad. Van Zeist and Bottema (1977) have however chosen to correlate the diagrams on the basis of the _Quercus_ pollen curves assuming that they reached their maximum at the two lakes during the same time period (Fig. 9,10).

It could perhaps be argued that a change in sedimentation rate at Lake Mirabad would explain the apparent earlier arrival of _Quercus_ at that lake except for one salient feature of the pollen diagram. Shortly after 10,370 B.P. _Quercus_ pollen reached 10% at Mirabad. During the same time period at Zeribar, oak did not register more than 1% and it was not until after 8100 B.P. that it attained 10%. Assuming that the radiocarbon date for the base of Mirabad is correct, the establishment of the forest at Mirabad may have preceded the establishment at Zeribar by at least 2000 years. Figure 33 demonstrates the correlation suggested here.

Plant and animal remains at archeological sites provide independent evidence of forests moving back into the mountains after temperatures had risen and snowfall decreased. Although _Quercus_ pollen was practically non-existent at Zeribar until 10,000

B.P., oak charcoal was found at Pelegawra (elev. 990 m) at about 14,000 B.P. (Braidwood and Howe, 1960). Remains of Red Deer dating from this same time period also indicate that forest was certainly nearby (Bokonyi, 1982). At Shanidar (elev. 765 m) oak pollen registered 6% at 12,000 B.P. (Oates, 1982), and remains of animals which are strictly forest dwellers were found between 11,100 and 9,300 B.P. though they were accompanied by some steppe animals (Bokonyi, 1982). The presence of patches of oak forest at protected low-altitude sites may not have affected the pollen assemblages at Zeribar, which was separated from Pelegawra and Shanidar by 300-600 m of elevation as well as by a series of mountain ridges.

The section on Bubiyan will discuss pollen evidence for a northerly extension of summer rains into the Shatt-al-Arab Basin centered around 8000 B.P. A moist interlude shows up very clearly during this time period in the Zeribar C/A curve. Mirabad being considerably more to the south can be expected to have benefited for a longer time period. The extension of this period of summer rainfall could explain why the two subsequent dry periods, which can be seen in both the Zeribar and Van diagrams seem not to have occurred at Mirabad and why they were apparently more intense at Lake Van than they were at Lake Zeribar (Fig. 33). The expansion of the oak forest into Mirabad may have coincided with this moist period and it is likely that summer rainfall promoted the spread of the trees. Certainly summer rainfall would have eliminated the problems associated with the spread of the oak forest today (Chapman, 1957). Zohary (1973), noting the existence of trees in regions from which they seem incapable of spreading has questioned if tree migration might not be limited to occasional favorable periods of time during which unusually moist conditions occur.

At Lake Van the _Quercus_ forest did not reach its maximum until 3600 P.B. (varve date). If the varve dates are calibrated to coincide with radiocarbon dates this amounts to a 2600 year lag between Lake Zeribar and Lake Van. However, although the _Quercus_ pollen reached its maximum much earlier at Lake Zeribar than at Lake Van, the arrival time at the two lakes did not differ much. A population can be considered to have arrived at a site just prior to the logrithmic increase in population size - (Watts, 1973; Tsukada, 1982). It is evident that _Quercus_ migrated into the regions around both lakes during the moist interval 8000 to 6000 B.P., as at about 6000 B.P. each population began its exponential increase. During the subsequent dry period oak quickly expanded to its maximum at Lake Zeribar. However at Lake Van the dry period was much more intense and the population grew at a much slower rate until moisture increased after 5000 B.P.

CHAPTER VI

THE NORTHERN ARABO-PERSIAN GULF

An obvious way to test the hypothesis presented in Chapter V would be to examine pollen preserved in sediments from lowland Iraq. The Iraq Geological Survey has obtained cores from the southern marshlands and it is likely that some of these contain Pleistocene sections which could be of use in determining the existence of lowland forest during this period as well as sections which could confirm or refute the existence of summer precipitation 9,000 - 7,000 years ago. Unfortunately, due to the political situation in Iraq, it is unlikely that these cores will be available for study in the near future. An alternative was to obtain sediments of datable material somewhat farther south from the deltaic deposits of the Shatt-al-Arab within Kuwait.

Geology and Geomorphology

Bubiyan Island, neighboring Warba Island and the northern shores of Kuwait are composed of fine deltaic sediments deposited by the Shatt-al-Arab as it enters the Gulf. Excessive evaporation causes a current of water to enter through the Straits of Hormuz. This current moves north along the deeper waters off the coast of Iran. As it is deflected around the head of the Gulf it sweeps the fine river sediments with it depositing them southwest of the river mouth (Kassler, 1973). These fine, rapidly-accumulating, deltaic deposits of the Tigris-Euphrates-Karun river system provide an ideal environment for the preservation of pollen that records the past history and climate of the Shatt-al-Arab basin (Fig. 34). Desolate, uninhabited Bubiyan-Warba is actually little more than a mud-flat which barely extends above the level of the surrounding sea. It is often flooded by tides and is largely devoid of vegetation except for Halocnemon strobilaceum on the ridges and Seidlitzia rosmarinus on the somewhat higher and sandier southern part of the island (Halwagy and Halwagy 1974).

The loads of the Shatt-al-Arab and its tributaries are discharged into the remnant of an old subsiding basin, the Northern Arabian Gulf Basin. The underlying Precambrian basement complex may still be unstable and undergoing periodic subsidence. The ingress of the Shatt-al-Arab over ancient waterworks and its failure to build a true delta, the persistence of the marshy lowlands of southern Iraq, the great thickness of the sedimentary column and the presence of marine or estuary sediments far to the north have all been attributed to periodic subsidence.

However, eustatically higher sea level and other environmental factors must also have played a role in the history of the delta area (Larsen and Evans, 1978). There are indications that the Gulf itself has not undergone any significant subsidence during the Holocene. Deltaic sediments in Kuwait have been deposited on a level surface 35m below sea level at the same depth as a submarine

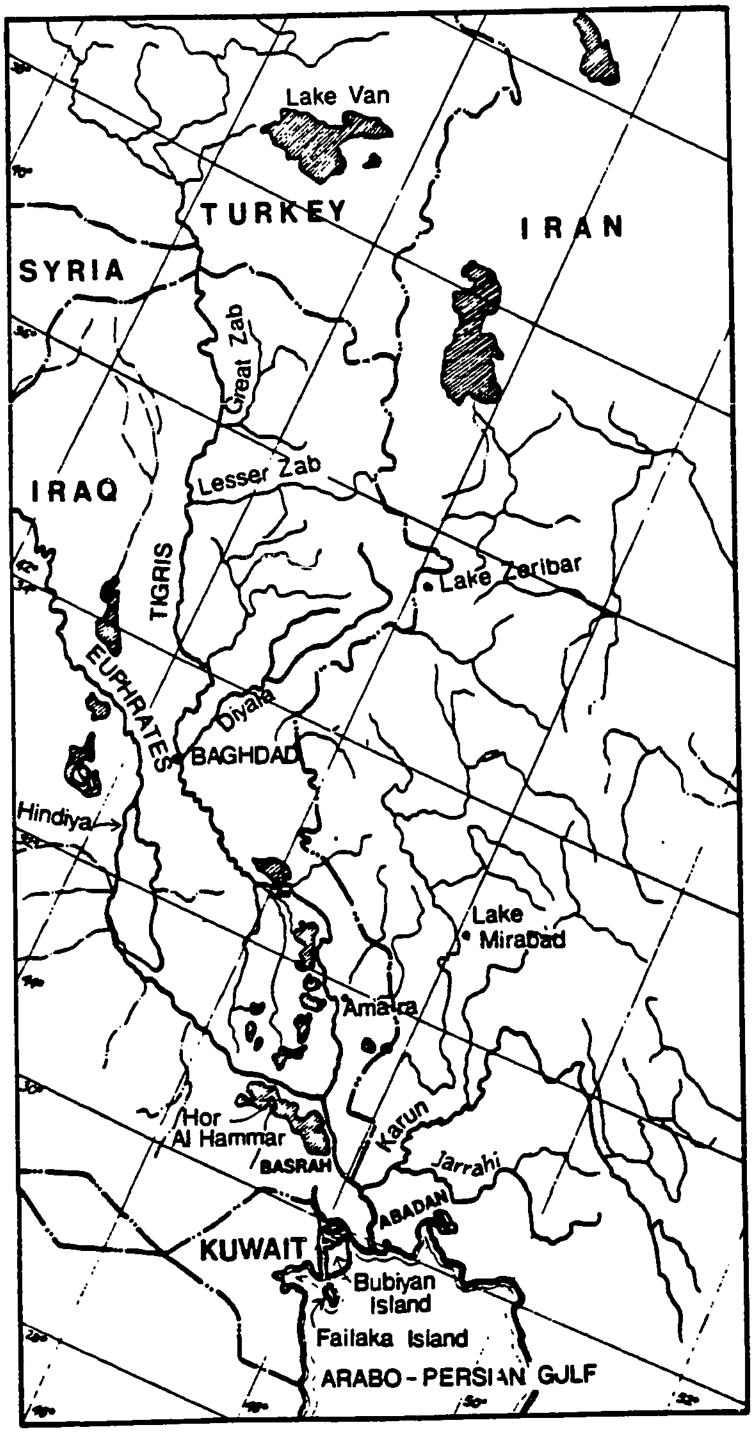


Fig. 34. The Shatt-al-Arab Basin.

platform which can be traced from Abu-Dhabi to Kuwait, dated tentatively to between 11,000 and 9000 B.P. (Larsen and Evans, 1978). A second submarine platform at -5m (probably <7000 B.P.) can also be traced between Abu-Dhabi and Kuwait (Larsen and Evans, 1978).

The Tigris and Euphrates together drain a vast watershed of 193,000 square kilometers, of which two thirds is in the Iraqi and Syrian deserts and one third in the mountains of Turkey, Iran, and Iraq. The headwaters of both rivers are in the Taurus Mountains of Armenia, originating primarily from melting snow.

The Tigris flows east from the mountains, and then follows an almost straight path southeast, parallel to the Zagros range. The Euphrates reaches Iraq by a much more leisurely route flowing westward towards the Mediterranean before looping back towards the south and southeast to arrive in the Iraqi northern desert. In northern Iraq each river has formed its own distinct valley which has limited the shifting of the river courses. An indication of their stability is the location of ancient cities near the present-day river banks (Roux, 1964).

In the south, however, the rivers have changed courses many times. In fact archeological evidence suggests that in the early days of Mesopotamian civilization the two rivers did not join to form the Shatt-al-Arab as they do today but rather entered the Gulf separately (Roux, 1964). Below Hit and Samarra the gradient drops so low that the rivers meander across a single large valley or alluvial plain. There are many side branches, and because meandering rivers tend to raise their own beds they sometimes flow above the plains. When they overflow their natural levees swampy lakes are formed.

Within Iraq, the Tigris forms the boundary between the Jazira and the Foothill province until it joins with its tributary, the Lesser Zab, at which point it flows south through the Mesopotamian Plain. The Lesser Zab, as well as the Greater Zab and the Diyala drain the Zagros Mountain and foothills. A fourth tributary, the Adhain, drains only the foothills.

The Euphrates flows across the northern desert of Iraq and approaches the Tigris near Baghdad, but then turns abruptly southward before again flowing east to join the Tigris at Qurna. The Euphrates has only two tributaries in Syria and none in Iraq, other than ephemeral desert streams. The occasional torrential rainfalls, however, have caused these streams to form many large wadis which dissect the western desert between the plateau-land and the Euphrates. At one point the Euphrates divides to form two branches, the Hindiya and the Hilla (Fig. 34).

The two rivers lose a tremendous amount of water during their long journey from the mountains to the head of the Gulf. According to Berry et al., (1970) the discharge of the Tigris is reduced from 1236 cubic meters per second to 231 cubic meters per second between

Baghdad and Amara through irrigation, evaporation and seepage into the marshland. This reduction in discharge is dramatically illustrated by noting that at the time of the spring floods the river commonly rises six to seven meters in Baghdad whereas below Amara there is almost no noticeable variation. The Euphrates' reduction in discharge is even greater than that of the Tigris, amounting to more than 90% the total. About half of the reduction occurs as the river crosses the desert and half when it spreads out over the extensive Hor-al-Hammar, the swampy wasteland of Southern Iraq (Berry _et al_., 1970).

Above Qurna, a decrease in the gradient of the Tigris to 3.4 centimeters per kilometer causes it to deposit all of its load but the clay-sized particles. The gradient of the Euphrates falls even lower before it reaches Qurna, to only 1.3 centimeters per kilometer. Thus when the two rivers join to form the Shatt-al-Arab the Euphrates is extremely clear and virtually the only materials in suspension are the clay-sized particles contributed by the Tigris. Since the gradient remains low to the sea these sediments are also soon deposited (Berry _et al_., 1970).

The lack of an appreciable elevation gradient allows the effect of the tides from the Gulf to extend all the way to the confluence of the two rivers, a phenomenon which is exploited in irrigating the extensive date-palm plantations along the Shatt-al-Arab. The salinity of the water is not much affected. At

Basrah and Abadan the water remains quite fresh, and even at Fao it is only slightly brackish (Fisher, 1968). Midway between Basrah and Fao the swift Karun River, laden with mud from the Iranian Zagros, enters the Shatt-al-Arab. It is this river which supplies the alluvial sediments to the Gulf (Berry et al., 1970).

Early attempts to explain the extensive marshes of southern Iraq resulted in the idea that the head of the Gulf had originally been far to the north and that the huge amounts of sediments deposited by the river had gradually filled in the northern part of the sea by the process of normal delta building. The swamp lands were thought to represent regions which were still in the process of being converted into land (Beke, 1835; De Morgan, 1900).

The Hammar Formation, marine deposits of clay and sand, extends as far north as Amara and underlies the recent alluvium of southern Iraq. Since it contains remains of recent marine organisms it seems to indicate that the Gulf extended much farther during the Holocene. Lees and Falcon (1952), however, noted that the situation is more complex than previously believed and has involved tectonic movement, alluviation and eustatic sea level changes. They accounted for the swampy conditions and local marine inundations by a prevalent subsidence in those regions.

MacFadyen and Vita-Finzi (1978) found that the marine fauna is represented by Foraminifera and small molluscs, which are easily transported up a tidal river, and include species characteristic of fresh and brackish water condition. The larger molluscs of the Gulf are lacking. They emphasize that even today tidal waters penetrate 150 kilometers up the Shatt-al-Arab and conclude that the Hammar Formation can be accounted for by estuarine conditions, which at the maximum of the Holocene transgression extended somewhat farther north than they do today.

Extending westward from the Shatt al-Arab and southward from Hor al-Hammar is the extensive sand and gravel covered Dibdibba Plain. In the region of the Iraq-Kuwait border it is dissected by wide, shallow Wadi al-Batin. Dibdibba is considered to be one of the deltaic fans of a great river system that at one time crossed the Arabian peninsula. It is much larger than that which appears on the surface, as it underlies much of the surface alluvium and Hammar Formation (Larsen and Evans, 1978).

The existence of Dibdibba has often been presented as evidence of Pleistocene pluvial periods (Holm, 1960; Fuchs et al., 1968) but its age is now estimated at between 3.5 and 1 million years (Hötzl et al., 1978). It must be emphasized, however, that it is not the rainfall factor alone that has kept these rivers from being rejuvenated. During the period of their formation the base level of erosion was drastically lowered. Additionally, the extensive arid phases that followed resulted in enormous accumulations of aeolian materials which clogged the old river channels. When subsequent moister periods occurred, local fluviatile sediments accumulated in the obstructed valleys. Erosion since that time has been almost entirely dependent on local relief and primarily involves shifting of sediments from within the wadis (Hötzl *et al*., 1978).

The sediments of the channels have only been studied to a limited extent. The lowest levels consist of non-local gravels and represent the great Pliocene-Pleistocene humid period. These are covered by fine clastic materials with occasional thin layers of local gravels. The local gravels are assigned to the moister phases of the Pleistocene (Hötzl *et al*., 1978).

Climate

The lands of lower Mesopotamia, the western shores of the Arabo-Persian Gulf and the surrounding deserts and mountains are characterized by extremely hot summers with no rainfall at all and by relatively cold winters with rainfall dependent upon the arrival of depressions from the Mediterranean. As the depressions enter Iraq, they move through the relatively low-pressure Mesopotamian lowland which forms a corridor to the Arabo-Persian Gulf. At these times the northwesterly winds which prevail throughout the year are weakened and southeasterly winds bearing warm, moist air from the Gulf dominate. These air masses which originate in the Indian Ocean penetrate as far north as Mosul, causing rains which may continue for several days. The passing depressions, however, intensify the movement of cold air from the higher-pressure plateaus to the lowlands and the weather again becomes crisp and cold (Al-Shalash, 1966).

During the spring the depressions from the Mediterranean become less frequent and weaken to the extent that they are no longer able to penetrate into southern Iraq. The increasingly intense heating of the land, however, causes convectional thunderstorms which bring some precipitation to the regions in the vicinity of the Gulf.

By summer the entire region is dominated by the low pressure belt which extends from northwest India to the Sahara. The continental tropical mass which descends over the area brings dry, hot weather. The northwesterly winds, no longer moderated by the Mediterranean cyclones, are intensified. These winds, called Al-Shamal locally, bring relief from the high temperatures and also help clear away the oppressive humidity which may occur in the vicinity of the Gulf. They often raise great dust storms as they cross the dry, barren desert.

The summer southeast monsoon which brings welcome moisture to India, Sudan, and southwest Arabia brings no precipitation to this region. By the time the Indian monsoon reaches Iran it is almost devoid of moisture and yields no more than an occasional shower on uplift over the Zagros mountains. As it descends on the western side of the Zagros range it is dry and stable. Along the southern margins of the Sahara and the southwest Asian deserts the north-eastward flow of moist tropical maritime air is met by hot, dry, southflowing, continental air which overrides it and prevents precipitation. Cumulus clouds may form and showers may fall, but they do not reach the ground due to the dry atmosphere at lower elevations (Al-Shalash, 1966).

The climate of this region is highly continental and this is reflected in the large annual and diurnal range of temperatures. Large diurnal and annual contrasts occur in the Zagros mountains also. The coldest month of the year is January. Frost sometimes occurs even as far south as Kuwait. The hottest month is July when temperatures in some places occasionally reach as high as 50°C. The contrast between day and night is greatest in the summer when outgoing radiation is greatest; the difference is as much as 20°C. In regions within the influence of the Gulf, both diurnal and yearly ranges of temperature are somewhat less (Al-Shalash, 1966).

The desert regions of the south have an extremely low rainfall averaging less than 100 mm per year but increasing to 150 mm in regions influenced by moisture from the Gulf. The extreme variability of the rainfall is of even more significance than the low average. Halwagy and Halwagy (1974a) remarked on both spatial and temporal variability, noting that in Kuwait rainfall during the winter of 1963-64 was only 23 mm while during 1953-54 it was 206 mm. In April 1968 the Kuwait International Airport received 19.8 mm while the experimental farm 6 km away received only 3.6 mm. During the same month Ahmadi, only 25 miles from the airport, received 36.9 mm. In addition to being localized, rainfall may also be very intense. On March 16, 1962, 65 mm of precipitation fell during a single 2-hour period in Kuwait (Halwagy and Halwagy, 1974a). Rumney (1968) noted that a single rainfall may in some instances provide more precipitation than the yearly average.

Procedure

Earlier attempts by myself and others (Whyte, 1961) to study the pollen in sediments of this region were not successful because the standard methods of carbonate and silicate digestion, heavy liquid separation, or a combination of the two did not concentrate the pollen sufficiently. However, the use of Calgon and of 7μ sieves, similar to the methods of Cwynar et al., (1979) (Chapter II) in most cases resulted in significant amounts of pollen. The procedure, however, was extremely time consuming and sieving usually needed to be repeated several times.

Abdulla Al-Zamel of Sheffield University provided the samples and the radiocarbon dates. The sediments studied were from short cores taken from Bubiyan Island and from off-shore locations near the island. Some of the samples were very rich in pollen, while in others the entire residue was examined without finding more than a few pollen grains. Deltaic samples are noted for their high pollen content and it has generally been presumed that this is due to the transport of pollen by rivers (Müller, 1959; Stanley, 1967; Balsum and Heuser, 1976). In addition pollen in the sea would be deposited when the density of the sea water is suddenly reduced by the influx of fresh river water. A third factor is the ability of pollen to be preserved in rapidly accumulating fine sediments and its tendency to behave as do other particles of similar specific gravity and sizes and thus to be transported and deposited with the fine terrestrial sediments (Koreneva, 1966; Stanley, 1966, 1967; Traverse and Ginsberg, 1966).

Pollen and Other Microfossils

The pollen content of the samples from the Bubiyan region are shown in Table D.1 . Colonies of Pediastrum as well as pollen of freshwater aquatic plants are included in the table. Also are included Histrichospheres and Foraminifera. Pediastrum are indicators of freshwater bodies and Histrichospheres and Foraminifera of brackish or marine conditions.

The material studied palynologically came from three environments, from Bubiyan itself, from off-shore sediments in submarine channels and from off-shore, organic-rich deposits (Fig. 35). Some of the organic-rich deposits were consolidated peat formed in situ in freshwater ponds north of the Gulf at a time of lower sea level and over which the sea eventually transgressed.

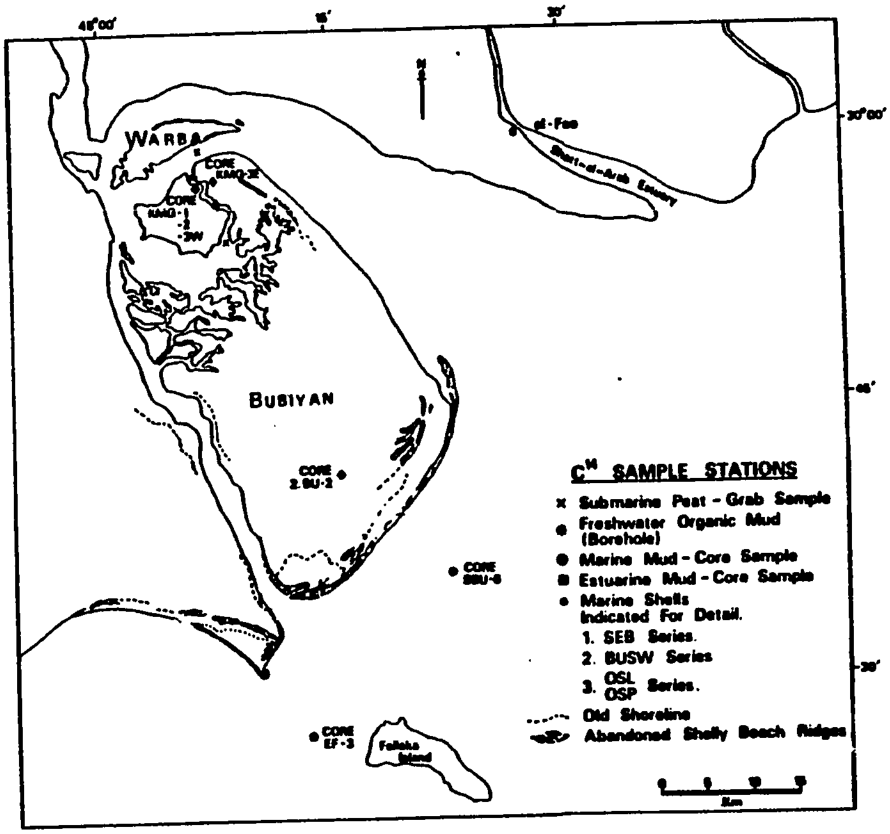


Figure 35. Bubiyan and Warba Islands showing locations of cores and grab samples.

These sediments were buried in alluvium and later exposed when the mouth of the river shifted. The pollen content of each group of sediments is shown in Figure 36 and Table C1 .

The marine samples, other than the submerged peat are relatively high in Pinus. This is assumed to indicate water-borne pollen and is characteristic of modern marine and alluvial sediments. Low Pinus may indicate sediments are not alluvial and/or that they were deposited during a time of weakened northwesterly winds. The relatively high percentages of Chenopodiaceae, more than 40%, is similar to the pollen accumulating today in this region.

The two cores from Bubiyan itself show little variation from top to bottom, and also differ little from the strictly marine samples. Pollen content in both sets of samples included a mixture of well-preserved grains which stained bright red with safranin and others which were degraded and hardly accepted the stain at all. This was an indication that pollen within a single sample was deposited under different environmental conditions and/or at different times. Detailed study of the sediments have shown that marine and delta deposits were mixed and reworked, and the original radiocarbon dates obtained are not meaningful (Al-Zamel, personal communication, 1982).

Much more information is available from the organic sediments. The samples of the KML series have several characteristics in

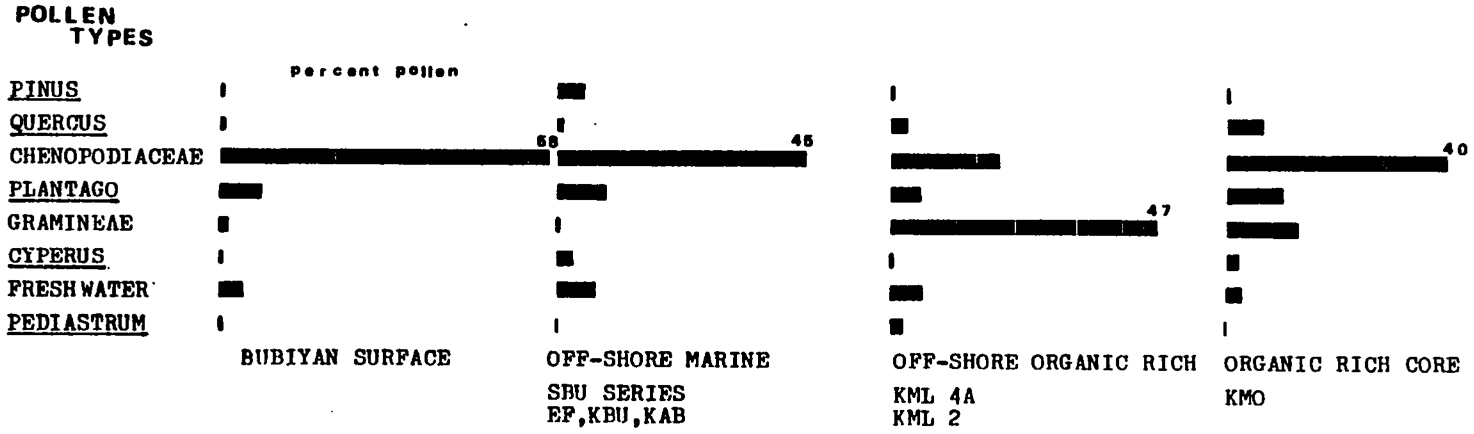


Fig. 36. Important pollen types in samples from various environments in the region of Bubiyan Island.

common including high Gramineae and lower Chenopodiaceae pollen, a lack or low percentage of Pinus and the presence of Pediastrum. The climatic implications of these sediments must be considered in the general ecological context in which they were formed. Since they occurred somewhat above the contemporary sea level it is logical to consider that they were sediments of a salt-marsh environment. However this does not seem to be the case. Although freshwater pollen is sometimes found in marine deposits, Pediastrum seems to be generally deposited in situ. It may be that these colonies are not buoyant and therefore tend not to be transported very far or perhaps that the colonies are fragile and break up when agitated. It was not seen in any of the modern samples known to have been sedimented in a marine or brackish environment and is apparently a reliable indicator of freshwater deposition.

Increased precipitation may have filled small depressions causing lakes to form, or they may have resulted when sluggish streams became dammed by alluvial or deltaic sediments. However, the peat formation does not compare well with the modern marsh sediments. Two samples taken from the marshland environments (Hor-al-Hammar) north of Basrah are sticky grey clay which accumulates as the finest sediments settle out of the slowly moving water. Nor do the modern pollen assemblages bear any resemblance to those of the peat. The combined assemblages of the two modern samples are presented with the two series of peat samples in Fig. 37.

The period of time 9000-7000 B.P. may have been characterized by weaker northwesterly winds and stronger monsoon-type systems and perhaps the lack of pine pollen was in part due to a change in the direction of the prevailing winds. Alternatively, the low values of pine pollen in the peat sample may suggest that the lakes were not connected to the rivers. Alluvial and marine sediments are usually higher in pine pollen than aeolian deposits are and a separate rain-filled pond or lake would explain the low pine pollen. Other explanations are also possible. Pine forests occur near Zawita in the province of Mosul in northern Iraq, and farther north in Turkey. If the lakes had been fed by a river originating in the southern Zagros mountains, such as the Karun or the Jarrahi rather than the Tigris-Euphrates system (Fig. 34) water-borne pine pollen would not have occurred.

Whatever the cause of the formation of the lakes or ponds the high Gramineae- and low Chenopodiaceae-pollen percentages clearly indicate that they formed under conditions of higher rainfall. The fact that the series included almost no Hammada-type pollen also indicates that the climate was not arid. Increasing rainfall under the continental conditions of today would have resulted in increasing the Artemisia pollen but more evenly distributed precipitation would have allowed perennial and annual grasses to

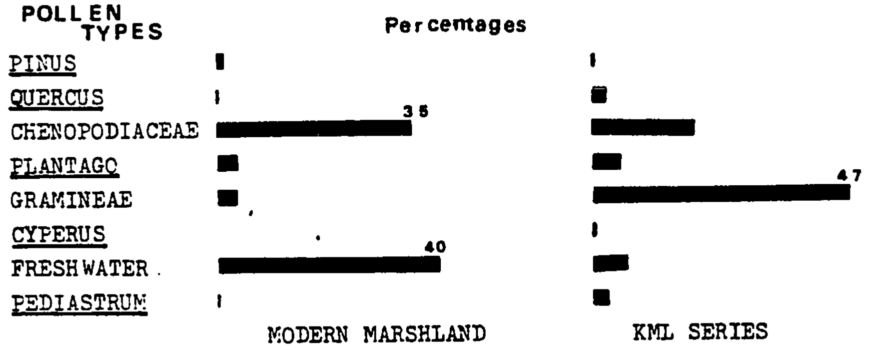


Fig. 37. A comparison of some important pollen types in modern marshland sediments (Hor-al-Hammar) and the Holocene peat sediments, north of Bubiyan Island.

spread at the expense of the present-day desert shrubland. If temperature had been somewhat higher Acacia flava may have become more prevalent. Zizyphus also must have spread. Unfortunately no direct evidence of these poor pollen-producers is evident.

As an additional check on the environment of the peat formation, Dr. Matti Eronin identified the diatoms of KML2. The diatoms identified by him and their ecology are given in Table 5. The diatoms clearly indicate a small lake or pond. The very few marine or brackish diatoms probably blew in from the nearby sea (Eronin, personal communication). There was an unusually large number of sponge spicules in the sample. In addition, phytoliths associated with Panicoid grasses were common. Other Gramineae phytoliths, not associated with a particular subfamily, Gramineae cuticle and various unidentified palynomorphs were also observed (Fig. 38).

The short KMO series (Fig. 39) appears to have been sedimented under climatic conditions much closer to those of today. The changes that occur may represent increasing precipitation, may simply represent a changing environment of deposition, or may indicate that sediments are not a continuous series. The relatively high percentages of Hammada in the lower levels and a proportion of Cyperus conglomeratus equivalent to the modern pollen assemblage suggests that at least at the beginning of this period an environment like that of today existed, with communities of

TABLE 5

DIATOMS FROM PEAT SAMPLE NORTHERN ARABO-PERSIAN GULF 7800 B.P.

Diatoms	Habitat
Eunotia formica	Freshwater, small lake, pH independent
Eunotia pectinalis	Freshwater, small ponds pH about 6.5
Eunotia pracripta	Freshwater, small lakes
Nitzschia sp.	Freshwater, small lakes
Cocconeis placcntule	Freshwater
Coscinodiscus sp. (nodulifer?)	Saline water
Pinnularia microstarron	Freshwater
Hyalodiscus scoticus	Saline water
Navicula cuspidata	Brackish
Amphora ovalis	Freshwater
Caloneis silicula var. truncatula	Freshwater
Cyclotella meneghiniana	Brackish water
Cymbella amphicephala	Freshwater
Navicula oblonga	Freshwater
Pinnularia gibba	Freshwater
Pinnularia sp.	Freshwater
Synedra ulna	Freshwater
Gomphonema sp.	Freshwater
Mastogloia braunii	Brackish water
Stauroneis acuta	Freshwater

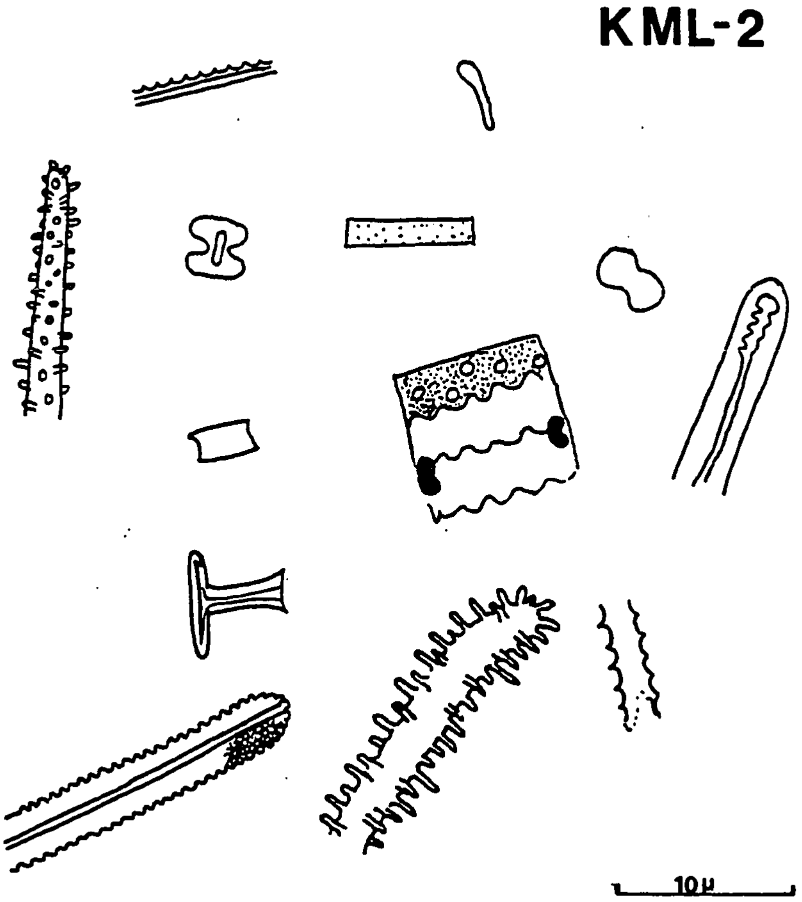


Fig. 38. Microfossils from submerged peat deposit, including Panicoid phytoliths, sponge spicules, monocot epidermis and unidentified palynomorphs.

Cyperus conglomeratus and Hammada nearby as well as other modern communities which are less likely to have shown up in the pollen record. The fact that Chenopodiaceae pollen is mostly of the Hammada type and that the sample is low in Pinus implies a water source other than the Mesopotamian Rivers, although the relatively high level of Hystrichospheres may imply brackish conditions.

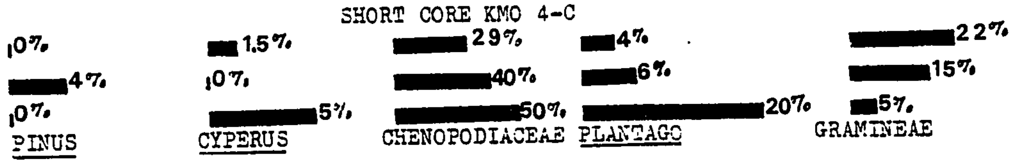


Fig. 39. Changes in important pollen types in core KMO-4C.

Between the 15 and 20 cm levels, the surroundings may have been moister but the pond itself must have dried up, for the pollen content is low and it is poorly preserved. The high Pinus-pollen percentage suggests an incursion of marine or river water. In the uppermost sample Gramineae are considerably higher than they are in surface assemblages of today but they are nonetheless still relatively low. Chenopodiaceae- and Plantago pollen is also low, while the percentages of other herbaceous pollen are high, suggesting that winters were warmer and annual flowering occurred over a longer period of time; an extended period of warmth plus moisture would have allowed increased pollen of Graminae as opposed to the increased growth of ephemeral types. The lack of *Pinus* pollen in this sample was striking; several additional slides, the equivalent of about 800 grains, were scanned without any occurring. This may partly be due to the freshwater environment of this sample; however, some wind-deposited grains of *Pinus* should have occurred unless the predominantly northwesterly wind system of today was weakened.

The two peat samples were taken from deposits dated from between about 7900 and 8500 B.P., the same period which climatic modeling has suggested experienced increased summer precipitation (Kutzbach, 1981; Kutzbach and Otto-Bliesner, 1982). Apparently the monsoonal systems extended at least as far north as the northern Gulf region. However, Al Zamel (personal communication) has found that during the specific time periods of peat deposition 7900, 8500 and 9900 B.P. (Godwin and Willis, 1958, 1959) the rates of sea level rise in the Gulf slowed or halted temporarily, implying that they were deposited during cold trends. If indeed cold trends occurred during peat formation the summer precipitation or shortened summer drought may be interpreted as having been due to interaction between Mediterranean depressions and monsoonal systems during transitional seasons.

Other evidence that this region experienced increased precipitation during this time period comes from archeological studies. Butzer (1971) suggested that dry farming spread during this time. Oates (1982) has reported a number of sites that appear to be farming villages in the region of Hatra which today has precipitation well below the level of reliable agriclulture. There several sites of the Hassuna culture 8400-7900 B.P. have been identified. Similar evidence comes from the Bouqras region of Syria, but this evidence is not as absolute since it is possible that irrigation could have been employed (Oates, 1982). In Hamrin Basin, marshy conditions prevent the use of certain areas. The complete lack of settlements prior to 6846±182 B.P. (BM-483) may have been due to the spread of the marshy land under conditions of increased precipitation (Oates, 1982).

It appears that the influence of this summer precipitation may have been felt as far north as the Ghab valley in Syria. There is a general consensus that pollen evidence indicates increased moisture for this time period (leRoi-Gourhan, 1974; van Zeist and Woldring, 1980). The increase in Carpinus, in particular, indicates summer precipitation. Although Carpinus extends today into northern Syria, it is an important component of the forest only in regions with some summer precipitation (Zohary, 1973).

CHAPTER VII

THE RUB'AL-KHALI

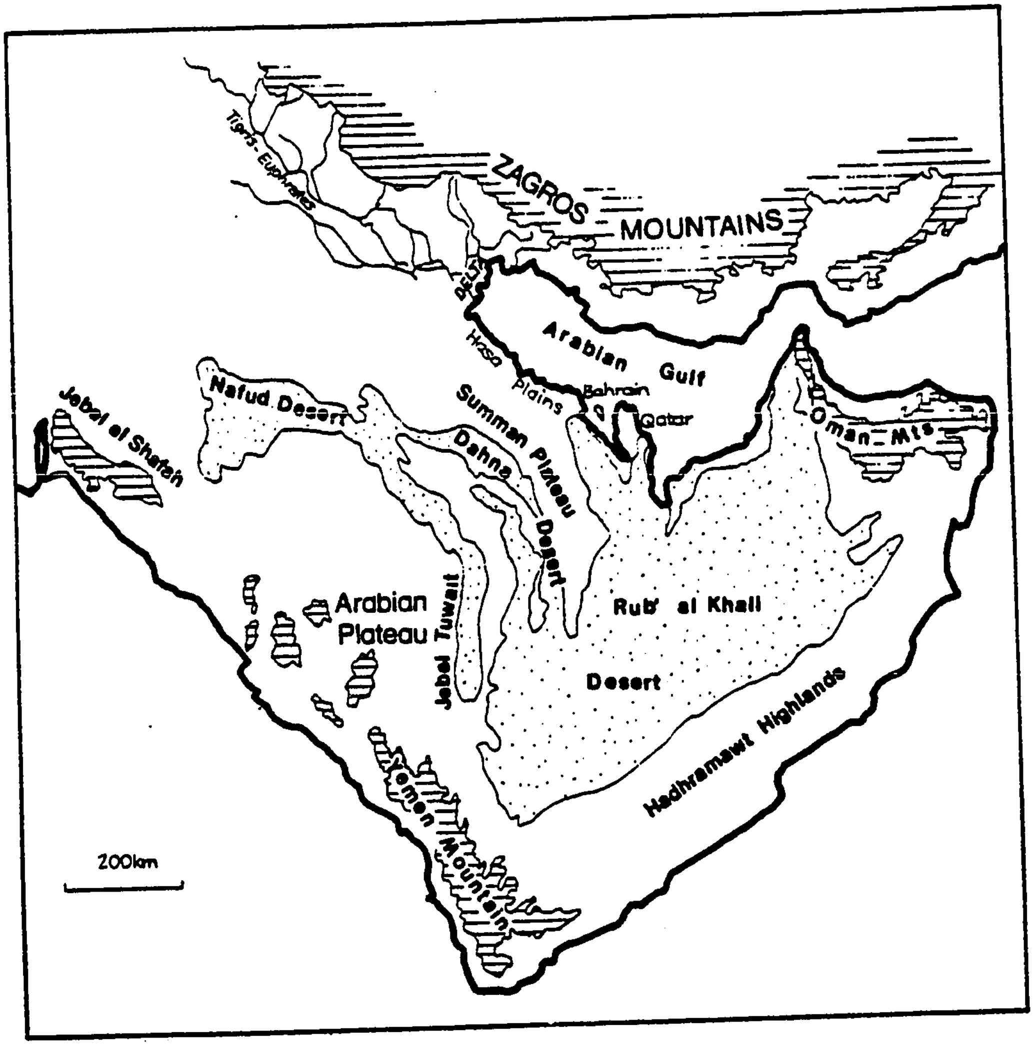
Description of the Area

Geology and Geomorphology

The powerful orogeny which resulted in the Taurus-Zagros Mountain arc, and in the mountains of Oman, had little effect on the Arabian Peninsula. Volcanism along the Red Sea Rift and a slight tilting toward the Gulf occurred, but the crystalline shield itself and the massive sediments of the shelf were hardly disturbed.

In the southern part of the Peninsula is the Rub'al-Khali (The Empty Quarter) also known as the Great Arabian Desert (Fig. 40). This is the largest sand desert in the world, occupying about 600,000 km^2 (Chapman, 1978). It is surrounded by mountains, high scarps or plateaus, all of which contributed alluvial sediments to the basin prior to the onset of Pleistocene aridity. The basin had been essentially leveled by that time and the surface distribution of today is unrelated to the structural form of the original basement. It is these alluvia which have provided the material for the extensive system of aeolian dunes as well as for the formation of reg plains (McClure, 1978).

The Rub'al-Khali is so desolate and forbidding that even the nomadic Arab Beduin generally restrict themselves to the outer fringing areas. A tremendous variety of dune classes and shapes have been identified from the Rub'al-Khali. In the north are



Fi.. 40. The Rub'al-Khali and its surroundings.

primarily transverse or barchan dunes oriented at right angles to the prevailing wind in regions of mobile sand, and longitudinal somewhat stabilized dunes oriented parallel to the prevailing wind. In the central and western portions of the desert '<u>urug</u> dunes predominate. '<u>Urug</u> dunes also are long parallel dunes. They have sharp crests and are the result of two dominant wind systems. The dunes are separated by broad valleys which themselves are sand-filled and contain dunes of the transverse type. The eastern part of the Rub'al-Khali is known for the giant complexes of red sand mountains some of which reach as high as 200 to 300 meters. The sand mountains are separated by long salt-encrusted sabkhas. These inland sabkhas are the result of interaction between a high water table, aeolian sedimentation and deflation. Evaporation through the surface causes the precipitation of various evaporites (Johnson et al., 1978).

The reports of lake beds (McClure, 1976, 1978) in this region of such extreme aridity quieted forever the notion that pluvial periods were only due to reduced evaporation. Obviously precipitation must have increased dramatically. Numerous radiocarbon dates have placed the Pleistocene series of lakes between 36,000 and 17,000 B.P. All of these lakes rest on an alluvium of white to grey sand. The Holocene lake series (9000-6000 B.P.) occurs between aeolian units of red sand. McClure (1978) has attributed these red-sand formations to periods of hyperaridity and has therefore assumed that the extremely arid climate did not exist until the end of the Pleistocene wet phase (around 17,000 B.P.). The beds on which the Holocene lakes are preserved appear to have been an old longitudinal dune system similar to that which exists today. Apparently the wind system as well as the precipitation 17,000 - 9000 B.P., was similar to that of the present time.

Study of the Pleistocene lacustrine sediments has determined that the lakes were relatively shallow and lasted for short periods. Freshwater molluscs, *Melanoides tuberculata*, *Planorbis*, *Lymnaea*, *Unio* and *Corbicula* occurred in the freshwater phase; Ostracods, *Chara*, and gastropods in the marl (intermediate) phase and marine Foraminifera during desiccation. (McClure and Swain, 1974). *Bos primigenus*, *Bubalus* and *Hippopotamus* remains have also been identified. Although these lakes were first fully investigated and dated by McClure (1976) Philby (1933) had gathered the shells of freshwater molluscs and calcareous deposits from various parts of the Rub'al-Khali, and thus it was recognized that lakes had existed, though they were not dated.

The Holocene lakes have been described as mostly of the playa type (McClure, 1978), although the presence of well-preserved pollen in some of the lakes suggests that they were not seasonally dry. The lithology, like that of the Pleistocene lakes, is mostly fine silty mud which originated from sand-slope flooding and resulted in the settling out of the finest sediments, forming more or less impervious linings of the small sand hollows in which the lakes were formed. Some of the lakes contain fossils similar to those of the Pleistocene series but others are barren. Diatoms, sponge spicules, algae, and phytoliths have been observed. Originally, the spore-pollen content of the Rub'al-Khali lakes was reported as being meager, and indeed until the development of fine sieves by which pollen could be concentrated (Cwynar, *et al*., 1979) it was not feasible to extract pollen from sediments such as these.

Climate

The Arabian Peninsula is situated in the middle of the band of mid-latitude desert which stretches from the west coast of Africa to northwest India. In addition to having low precipitation, it is characterized by the erratic and poorly-distributed rainfall typical of such regions. Summers are extremely hot, yet winters can be very cold, often falling below freezing in the central and northern parts of the peninsula. The Rub'al-Khali is the most arid part of the entire Arabian Peninsula. Weather data are extremely limited and yearly averages quite meaningless in any case in a region where rainfall is so highly localized and sporadic. Years may pass with no rainfall at all while the equivalent of several years average precipitation may be dumped in a single downpour.

Rain is confined to the winter months when cyclonic depressions make their way from the Atlantic or the Mediterranean. Summer precipitation is generally intercepted by the coastal mountains, but does reach the Rub'al-Khali on very rare occasions (Thesiger, 1959).

Vegetation

The vegetation of the Rub'al-Khali and its surroundings is not well known. Most of the information which is available comes from reports of adventurers such as Thomas (1932), Philby (1933), Thesiger (1947, 1959) as well as others who have not penetrated the Rub'al-Khali itself but have studied the ecology of regional deserts (Zohary, 1973, Vesey-Fitzgerald 1957; Popov and Zeller, 1963; Guest and Al-Rawi, 1966, Halwagy and Halwagy 1974a; 1974b; Halwagy _et_ _al_., 1982. J. Mandaville has kindly provided a list of species (unpublished), many of which have been named since the days of the earlier collectors (Table 6). It must be made clear that the following description of the vegetation is not based on personal observation but on scattered reports and knowledge of the ecology of the same species outside of the Rub'al-Khali.

Only a few species of plants are able to survive such extreme conditions but the landscape offers a variety of environments which are occupied by different communities. Thesiger (1959) has mentioned traveling for miles through the dunes without seeing any

TABLE 6

FLORA OF THE RUB'AL-KHALI SANDS (CORE AREA)

(after J. Mandaville, unpublished)

AIZOACEAE

Limeum arabicum Friedr. - locally frequent but rarely dominant.

CHENOPODIACEAE

Cornulaca arabica Botsch. - dominant of a widespread community.
Haloxylon persicum Bge. - locally dominant in parts of the north and northwest.

POLYGONACEAE

Calligonum crinitum subsp. *arabicum* (Sosk.) Sosk. - a widespread community dominant.

TAMARICACEAE

Tamarix aucheriana (Decne.) Baum - only 1 record (at an artificial water hold).

CAPPARACEAE

Dipterygium glaucum Decne. - widespread

CRUCIFERAE

Eremobium aegyptiacum (Spreng.) Asch. in Boiss. - an annual of the N and NW sands

ROSACEAE

Neurada procumbens L. - Occasional in the north.

CYNOMORIACEAE

Cynomorium coccineum L. - a root parasite; rare

ZYGOPHYLLACEAE

Tribulus arabicus Hosni - frequent, particularly in the northeast.
Zygophyllum mandavillei Hadidi - a community dominant in the north and northeast.

BORAGINACEAE

Moltkiopsis ciliata (Forssk.) Johnst. - locally common, particularly in the fringe areas

OROBANCHACEAE

Cistanche philypaea (l.) Cout. - a root parasite on Chenopodiaceae

GRAMINEAE

Astenatherum forsskalii (Vahl) Nevski - occasional
Stipagrostis drarii (Tackh.) De Winter - frequent

CYPERACEAE

Cyperus conglomeratus Rottb. - a very common constituent of several communities.

ADDITIONAL SPECIES OF THE FRINGING SANDS

CHENOPODIACEAE

Hammada salicornica (Moq.) Iljin
Seidlitzia rosmarianus (Ehrenb.) Solms-Laub.

CARYOPHYLLACEAE

Polycarpaea repens (Forssk.) Aschers. et Schweinf.

ZYGOPHYLLACEAE

Fagonia indica Burm. f.

GERANIACEAE

Monsonia nivea (Decne.) Webb

BORAGINACEAE

Heliotropium digynum (Forssk.) Asch. ex C. Christens.

PLANTAGINACEAE

Plantago boissieri Hausskn. et Bornm.

GRAMINEAE

Stipagrostis plumosa (l.) Munro ex T. Anders.

vegetation at all. The presence of plant life may be completely dependent on the recency and the amount of rainfall. Calligonum is well adapted to growth in loose sand, and can continue to survive even when practically buried by unstable dunes. Dipterygium glaucum, Limeum arabicum, and Cyperus conglomeratus also grow on the dunes as does Cornulaca arabica which is perhaps confined to the northern regions. Most of the vegetation of the sands grows on the less steep slopes or in the hard bottoms of the hollows. Tribulus arabicus generally grows on the hard sand under a steep slope, is often widespread, and is particularly valued for grazing. These hollows are also a favored habitat of Dipterygium, Cornulaca, Limeum, Cyperus conglomeratus and Heliotropium persicum. Thesiger (1947) noted that while Heliotropium and Tribulus were both widespread and preferred similar habitats.they did not often occur together.

The salt flats contain Zygophyllum, Seidlitzia, and Cornulaca; where too saline, this vegetation is confined to the edges of the basins. Thesiger (1949) mentions Hammada salicornicum as dominating the gravel surface of an interdune valley. J. Mandaville (unpublished) names Haloxylon persicum as an important dominant in the north and northeast. This is surprising, for Thesiger (1949) remarked that he crossed the entire sands without seeing Ghadah (H. persicum) until coming out of the sands at Al Arid in the Northeast.

Only a few species of grasses have been reported for the Rub'al-Khali. Migahid (1978) has listed this desert as a location of the perennial _Panicum turgidum_ but others have not mentioned its presence. Surely it must grow in the fringe areas which have slightly higher rainfall.

The Study of Lacustrine Sediments

Pollen

Twenty-two samples from lacustrine sediments of the Rub'al-Khali were processed (Tables 7, 8). Like the samples from Bubiyan, there was an abundance of fine silt and clay which required repeated washing, centrifuging and/or sieving. Only a few samples had abundant pollen. The Pleistocene samples in particular had a very low pollen content. Often the entire residue was examined without seeing more than ten pollen grains, and some samples were completely lacking in pollen. Much of the pollen that was present was so corroded that identification was impossible.

Many of the lakes were of the playa type (McClure, 1978) and under conditions of periodic drying and exposure, pollen is unable to be preserved. The Pleistocene lakes were in general, however, more extensive than those of the Holocene, and in these lakes it is likely that pollen was destroyed later on. Considering the extreme environment of this region over most of the past 18,000 years, it is surprising that even a few samples yielded relatively

TABLE 7

LOCATIONS OF SITES STUDIED PALYNOLOGICALLY IN THE RUB-AL-KHALI

SITE	LOCATION E. LONG./N.LAT.	SITE	LOCATION E. LONG./N. LAT.
MUNDAFAN COMPLEX	45°23'/18°32	III	46°41.5/19°25.5'
B-3		RAK-4-1	46°13'/17°31'
C			
C-2		XX-B-5	46°18'/17°35.5'
C-4			
II-A-1		XX-C-2	46°01.5'/17°30'
II-A-2			
II-A		XX-A:2	46°17.5'/17°33.5'
II-3			
3(d)		AS-3-1	49°43'/21°52.5'
(e)			
I(i)-2		W. GHIRAN	46°44'/20°29'
		JEBEL GHIRAN	46°44'/20°39.5'
HITLAN	46°29/20°16		
		IV	46°42'/20°25'
HIT-1		-7	
HIT-2		-9	
		-MISC.	

TABLE 8

RADIOCARBON DATES OF RUB'AL-KHALI SAMPLES

	Sample Number	Date and Lab Number	Material Dated
Pleistocene Series			
	III	23,075+425 B.P.	A-1209 (Marl)
	IV	21,400+450	I-6987 (Marl)
	3(d)	no date	
	3(e)	no date	
	RAK-4:1	no date	
Intermediate			
	XXB5	12,315+120 B.P.	UGA 1418 (Marl)
Holocene Series			
	B-3	7840+140 B.P.	BETA-5111 (Shells)
	C		
	C-2	9360+130	BETA 5105 (Shells)
	C-4		
	II-A-1	7770+90	UGA-1205 (Marl)
	II-A-2	7400+120	UGA-1208 (Shells)
	II-2		
		7190+85	UZA 1204 (Marl)
	II-3		
		(Actual Date is from slightly above)	
	W. Ghiran		
		6,270+100	Beta-5108 (Shells)
	Jebal Ghiran		
	XXC2	7210+90	UGA 1418 (Shells)
	XXA2	no date	
	I(i)-2	8310+150	Beta-5113 (Shells)
	AS-3-1	7780+90	Beta-5106 (Shells)
	Hitlan-1	No Date	

well-preserved pollen in useful amounts.

It would be hazardous to attempt to draw any conclusions about the vegetation based on the meager and poorly-preserved pollen of any of the Pleistocene samples or of B-3, C, C-2, C-4, XXC2, XXA2, I(i)2, Hitlan 1 and 2, and W. Ghiran. With the exception of the IV-series, the pollen of these sample is mostly from Chenopodiaceae. However, this may be primarily due to the fact that even if badly corroded or damaged, Chenopodiaceae pollen can still be easily identified. This is not true of most other pollen types, and delicate grains such as those of Cyperus or Gramineae could have been totally destroyed. For this reason, conclusions concerning the vegetation will be based only on those samples in which pollen had been well-preserved.

Phytoliths

In a preliminary microscopic study of Rub'al-Khali sediments opaline silica bodies, (phytoliths) were identified along with other microfossils (McClure, 1978). Phytoliths have been identified from many plant taxa, but are particularly common and have been most extensively studied in Gramineae. They occur throughout the plant body, including the epidermis, mesophyll, vascular system and sclerenchyma. However, subfamilies of grasses can be distinguished by the so-called "short cells" of the epidermis, and it is these bodies which have been most useful in the identification of previously existing grassland vegetation from paleosoils (Jones and Beavers, 1963, 1964; Wilding and Drees, 1968; Twiss *et al.*, 1969; Verma and Rust, 1969).

In order to identify the vegetation of the Pleistocene and Holocene Rub'al-Khali more precisely, several samples were examined for phytoliths. Phytoliths were not evident in most samples when the sediment was mounted directly in Permount. In order to concentrate the phytoliths, and to eliminate the very small particles which obscured them and other microfossils, it was necessary to disaggregate the samples in 15% HCl and then to wash in hot Calgon solution, followed by repeated sieving and/or centrifugation as in the treatment for palynological samples. The residue was then dried and mounted in Permount. Modern phytoliths extracted from the same samples that were used for studying modern pollen deposition were used for comparison (Table 9). Line drawings of the fossil phytoliths, as well as of other unidentified palynomorphs, excluding diatoms, are shown in Fig. 40.

The Pleistocene Lacustrine Period

The only Pleistocene samples with more than a few grains of pollen were those of the IV series. The combined pollen content of these samples is seen in Table 10. Although great caution must be used in attributing climatic significance to a pollen assemblage from sediment which has obviously been subjected to processes which

TABLE 9

RELATIVE ABUNDANCE OF PHYTOLITH TYPES IN WIND-BLOWN CHAFF ACCUMULATION, RUB'AL-KHALI

	PHYTOLITH TYPE				
Sample Number	"Cyperus" type	Vascular	Hairs & Needles	Elongate	Gramineae
1	none	e	e	d	none
2	a	d	c	c	none
3	d	d	d	b	none
4	a	d	c	c	none
5	a	c	b	b	none
6	none	none	d	e	none
7	d	d	d	d	none
8	b	d	a	d	none

a very abundant, 5 or more in microscope field (400x)
b abundant, 1-5 in microscope field
c common, more than 10 on slide
d few, 4-10 seen on slide
e rare, 1-3 seen on slide

(see Table 4 for Location of chaff samples)

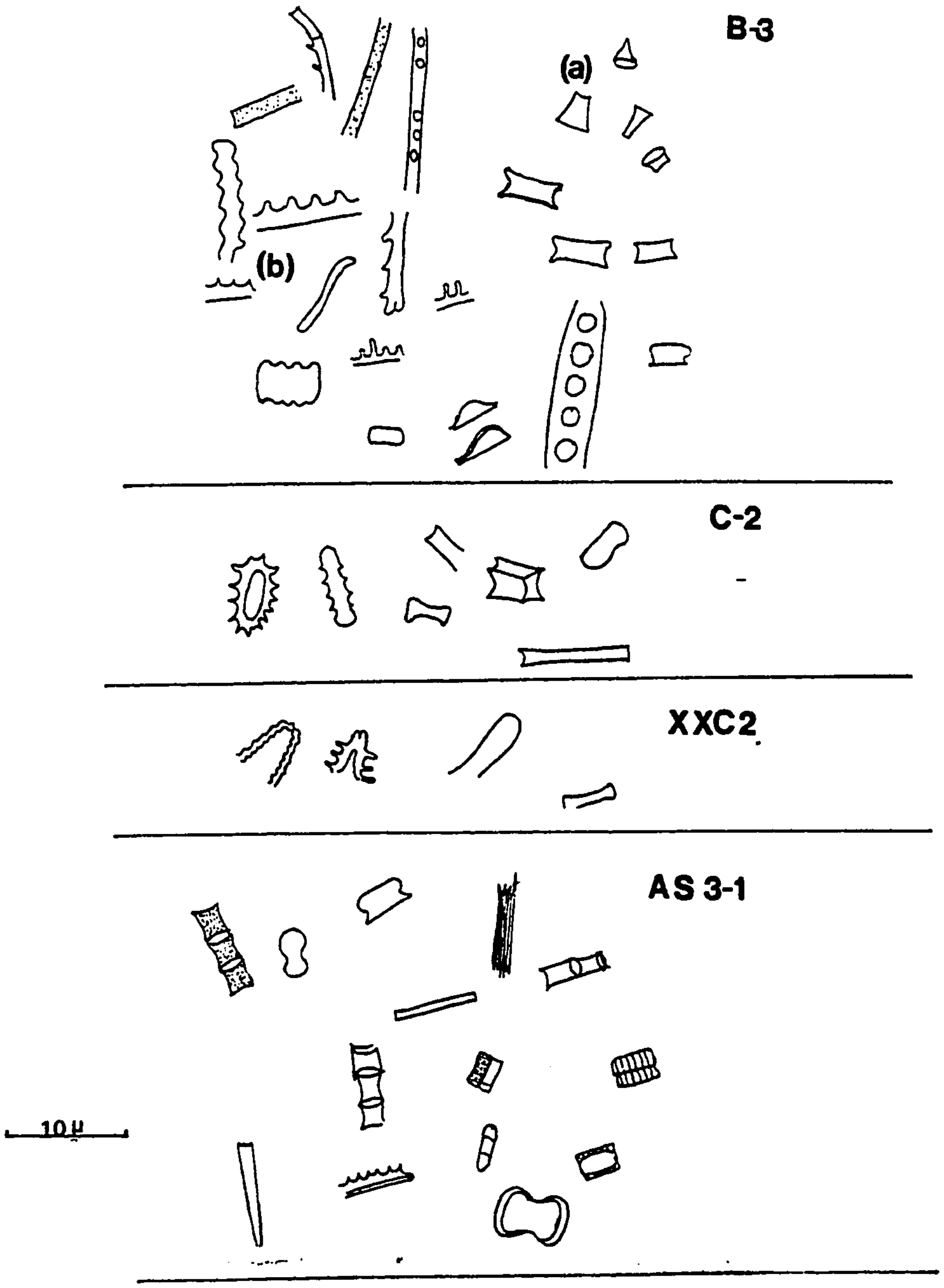


Fig. 41. Phytoliths of the Holocene lacustrine period in the Mundafan region.

TABLE 10

COMBINED POLLEN COUNTS OF RUB'AL-KHALI PLEISTOCENE SAMPLES FROM SITE IV

Pollen Types	Number
Pinus	3
Betula	3
Alnus	1
Zizyphus	1
Chenopodiaceae	15
Campanulaceae	3
Nuphar	1
Other Liliaceae	2
Compositae (Tubuliflorae)	2
Artemisia	1
Convolvulaceae	1
Plantago	2
Malva	1
Cruciferae	1
Caryophyllaceae	3
Leguminosae	1
Gramineae	4
TOTAL	45

have caused most of the pollen to have been destroyed, the number of exotic pollen types which are present, including Betula, Alnus and Pinus, is notable. Contamination is immediately suspected but is unlikely. Each sample was processed and examined at different times. One sample which contained Betula was processed in Kuwait where Betula pollen is never found. Moreover, neither Betula nor Alnus occurred in any of the other samples processed at the same time. All three of these pollen types occur far to the north, implying an intensification of the northwesterly winds and/or an extension of these genera to lower latitudes in North Africa. In either case it is clear that a more southerly displacement of the belt of westerlies should not be discounted as a factor contributing to the increased precipitation of this time period.

The only Pleistocene sample in which any phytoliths were observed was IV-9. They were mostly elongate types which are characteristic of Gramineae, but not diagnostic of a specific tribe or subfamily (Twiss et al., 1969). A very few dumbbell-shaped (Panicoid) phytoliths were observed, as well as circular bodies which can only be tentatively identified as phytoliths, but if so, are characteristic of Festucoid grasses.

Although little information concerning the Pleistocene is available from the pollen, it should be emphasized that the low pollen content should not be attributed to a generally arid landscape. The fact that the Pleistocene lakes were considerably more extensive than the Holocene lakes, implies that increased rainfall would have benefited the vegetation, at least to the extent that it was benefited by the later rainy period in the Holocene.

One Pleistocene sample, XXB5 had an anomalous date of 12,315±120. That is, the date is anomalous with respect to the dates of the other materials. However, since this falls within the earliest reported high-lake levels for Africa, following the late Pleistocene aridity, this date could well be valid. Pollen in this sample is well preserved, and assuming the date is correct, grass was probably not as yet an important plant.

The Holocene Lacustrine Period

Although only about half of the Holocene samples contained ample pollen, certain conclusions concerning the vegetation can be reached. The pollen of the Holocene lacustrine period differs dramatically from the modern pollen with Chenopodiaceae, Gramineae and *Plantago* replacing *Cyperus conglomeratus* and *Calligonium* as the most important pollen types (Table 11).

The richest samples were from within the Lake Mundafan complex. The greater relief in that area probably allowed not only a more substantial accumulation of run-off, but also higher precipitation than elsewhere in the Rub'al-Khali. Evidence of more permanent lakes is also seen in the presence of a relatively large

TABLE 11

PERCENTAGES OF MOST IMPORTANT MODERN AND HOLOCENE-LACUSTRINE PERIOD POLLEN TYPES IN THE RUB'AL-KHALI, BASED ON SUM OF ALL SAMPLES.

Pollen Type	Modern Excluding Sample 1	 Including Sample 1	Lacustrine Period (Holocene)
Chenopodiaceae	3.2	(15.)	70.
Plantago	0.4	(0.4)	11.4
Calligonum	15.	(13.)	1.1
Gramineae	1.1	(0.9)	14.
Cyperus conglomeratus	42.	(37.)	2.4

A pollen type which represents approximately 22% of modern pollen in the Rub'al-Khali has not been positively identified but appears to be from Cistaceae.

amount of pollen of water- and shore plants.

The group of three samples, II-A-1 and 2, II-2 and II-3 is from one site, and similar in pollen content. The most significant feature is the relatively high percentage (about 20%) of grass pollen. It seems probable that this part of the Rub'al-Khali, though populated by the same species as today, must have had a much more luxuriant growth and must have been relatively rich in annual and perennial grasses. The low amount of Cyperus conglomeratus pollen testifies that the dunes which were established between 18,000 and 9,000 years ago had become stabilized by plant growth. This implies a considerable increase in precipitation, which, however, would not have resulted in any more than a semi arid environment.

The low levels of Calligonum is also of significance since this plant commonly grows on semi-mobile dunes. In India Calligonum was negatively associated with summer preciptation, perhaps because precipitation during this season should enhance the growth of various plants which would act to stabilize the dunes.

The sample AS-3-1 contrasts strongly with those from the Mundafan region. The pollen in this sample, although almost exclusively Chenopodiaceous, was remarkably well-preserved and quite abundant. Perhaps the morphology of the lake was such that it remained wet throughout the year, but it was obviously in a much more arid environment than Lake Mundafan. Chenopodiaceae either were the dominant pollen-producers of the region, or else grew on the shore of the lake to such an extent that their pollen overwhelmed that of any grasses that may have been present in the area. This is not surprising, considering its location much farther to the north and east, and therefore farther from both the source of precipitation and the relief required to force the moisture-bearing air to rise sufficiently for the moisture to condense. Significantly, the sites intermediate between AS-3-1 and Mundafan show intermediate amounts of Chenopodiaceae and Gramineae pollen (Fig. 41).

Although the plants which are registered in the sediments imply that grasses increased during this period, it must be stressed that most of the species in the moister fringes of this desert which would be expected to have spread, rarely leave evidence of their existence in the accumulating pollen. Acacia must have been important during this period. However, in surface samples taken from the midst of a flowering Acacia thicket near Wadi Rum in Jordan, not a trace of its presence was found. Similarly pollen of Rhanterium epapposum which dominates vast areas in Kuwait and Iraq not once has been seen in either modern or ancient assemblages of pollen. Lycium, Zizyphus, Prosopis spicera, and Ficus, all likely to have penetrated more deeply into the Rub'al-Khali, are poor pollen-producers (Chapter II).

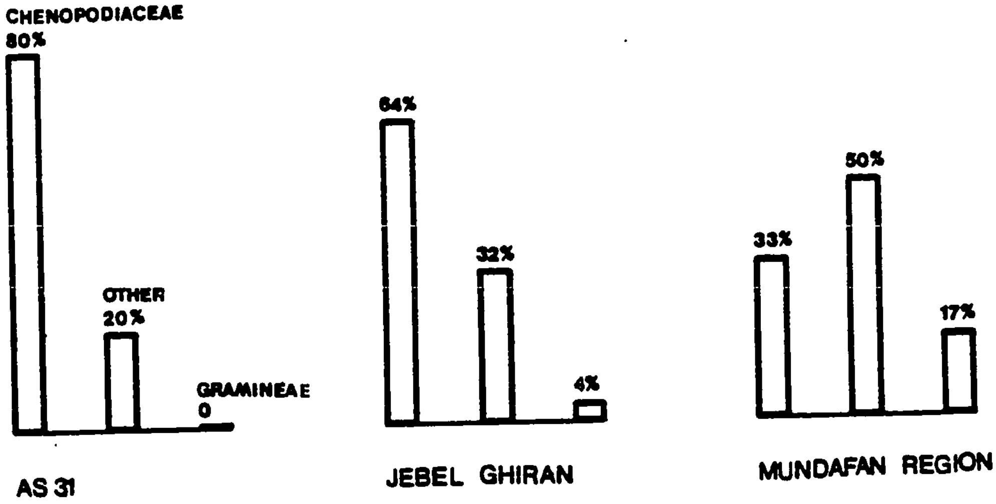


Fig. 41. Change in pollen assemblages of the Holocene lacustrine period from southwest to northeast in the Rub'al-Khali.

Probably the vegetation of this period was rich in the warmth-demanding shrubs and small trees which dominate the moister regions of the Arabian Peninsula today. There is pollen evidence for increased Hammada and Tamarix and they were undoubtedly joined by Prosopis spicigera, Acacia flava, Lycium, and Rhanterium epapposum. In the south and in the Mundafan region, tropical vegetation may have penetrated. The spring, winter and autumn aspect of the spaces among the shrubs may have been similar to that of southern Jordan, but the summer growth must have been lusher than occurs anywhere in this region today, even though rainfall probably remained relatively low. The human populations who inhabited these regions must have been nomadic, and it seems likely that they would have spent their winters to the north where rainfall was more dependable, and migrated south to the summer pastures of the monsoon region following the wild herbivores, or with their own flocks.

Panicum turgidum must have been of great importance during the rainier periods. In fact it may have been largely the presence of this grass which sustained the human populations during this period. Not only is it a prized fodder, but today in the Sahara its grains are collected and eaten like millet, while in the past they may have been used in a similar way by the inhabitants of the Rub'al-Khali.

Phytoliths can be dissolved and also are quite fragile, and their absence in certain of the sediments may imply that they have undergone considerable reworking and not that grasses were not present. It is significant and also unfortunate that many of the sediments which were lacking in pollen were those most lacking in phytoliths and other microfossils.

Modern phytoliths differ greatly from those found in the sediments of the fossil lakes. The modern accumulation of phytoliths includes many more forms which are not specifically characteristic of Gramineae, such as trichomes and silicified vascular elements. A common phytolith in these modern samples was a sheet-like hexagon with a circular impression. This has been described by Metcalfe (1971) as characteristic of some species of the genus _Cyperus_ and indeed they were especially common in samples containing high percentages of _Cyperus_ _conglomeratus_ pollen. No such phytoliths were found in any of the samples of lake sediments, further suggesting that _Cyperus_ _conglomeratus_ was a much less important component of the Rub'al-Khali vegetation during the lacustrine period than it is today.

Four Holocene samples contained phytoliths including Panicoid and Festucoid types, bulliform cells, and, in the case of B-3 Choricoid-type "hats" (Fig. 40). Within the II-series phyloliths occurred but were obscured by the much more numerous diatoms.

The fact that types characteristic of the various sub-groups of grasses occur implies that the grasses were not limited to one particular species. Samples with frequent silicified bulliform cells may indicate that marsh grasses were growing around the lake, as there are indications that these phytoliths only form in grasses which grow in wet habitats (Parry and Smithson, 1964).

It is notable that the samples which included phytoliths were all from the Mundafan region. The lack of phytoliths in other samples is one more indication that grasses were more extensive in the Mundafan region than in other parts of the Rub'al-Khali.

Sample I-i-2 contained many spherical objects with a single pore in the surface or, in some cases, on a raised neck-like structure. They were noted during the pollen counts of this sample and were later seen and photographed on the SEM. They were perhaps algal cysts or rhizopod tests. Loose bundles of needles and short rod-like structures dominated this sediment. These are assumed to have been calcareous, as neither occurred in either sample prepared for pollen analysis or the one prepared for phytolith study, each of which had been treated with HCl.

Sponge spicules have been previously reported from these sediments (McClure, 1978). In II-3, B-3 and C-2 there were numerous pitted rods and in XXC2, B-3 and IV-9 there were other structures which may have been fragments of sponge spicules (Fig. 41). However, they could not be specifically identified as such. Only spicules of silicon would have survived the processing. Calcareous ones would have been destroyed by the HCl.

CHAPTER VIII

CLIMATIC CHANGE IN THE MIDDLE EAST: CONSTRUCTION OF A PRELIMINARY MODEL

The Pleniglacial

Today in the Middle East, the regions producing high Chenopodiaceae- and *Artemisia* pollen are inland regions with highly continental climates - cool winters and dry summers. Apparently the temperate regions of the Middle East were experiencing these more extreme climatic conditions during the glacial period. The dry summers can be explained by the steepened temperature- and pressure gradient between the glaciated lands and the lower latitudes causing cold, dry continental winds which would have prevented the penetration of moist air from the west.

There is no need to invoke great aridity to account for the presence of an *Artemisia*-Chenopodiaceae steppe and, in fact, the relatively low ratio of Chenopodiaceae to *Artemisia* pollen throughout the region indicates that conditions in general were quite moist. At this stage, there is no proof as to whether the moist conditions resulted from increased precipitation or reduced evaporation. However, there is every reason to believe that the factors which control winter precipitation were augmented during the glacial period. The westerlies were apparently more intense (Rognon and Williams, 1977; Bintliff, 1982) and the polar air masses colder. At the same time the Mediterranean-sea-surface temperature decreased a maximum of 3-4°C over most of the eastern basin (Thunell, 1979) while temperature depression on land was apparently much greater. The combination of strengthened westerlies, colder polar air masses and greater land-sea temperature contrast should have resulted in winter storms that more frequently extended south into Mediterranean regions, and in enhanced winter precipitation.

Nevertheless, the most common interpretation for this time-period is that precipitation was minimal but that temperatures were low enough to result in drastically reduced evaporation (van Zeist *et al*., 1975; Lamb, 1977; Butzer, 1978). Bintliff (1982) states that "from around 23,000 to 16,000 B.P. the overall indicators from the eastern Mediterranean are of the most extreme dryness and cold." He later remarks that "the major pluvial lakes of the eastern Mediterranean associate with the aridity climax"!

Although the various factors which control moisture-availability - temperature, humidity, cloud cover, as well as seasonal distribution, intensity and amount of precipitation - will affect various indicators of moisture somewhat differently, there can be no doubt that in one way or another the vegetation will respond to an enhancement of moisture available for life processes just as lake levels do regardless of the cause(s) for the moisture increase. In this region the response is clearly seen in the region-wide low ratios of Chenopodiaciae- to *Artemisia* pollen.

The drastically lowered snow lines reported from Iraq (Wright, 1962) and Iran (Kuhle, 1976; Grunert _et al_, 1978) suggest that precipitation may have increased more to the east of the Mediterranean than it did to the north. While Thunell (1979) and Thiede (1978) have demonstrated a strongly increasing temperature gradient from north to south, Rognon (1979) presented evidence that suggests that a similar gradient occurred from west to east. This should have encouraged frequent occurrences of cyclonic storms to propagate into the southeastern part of the basin providing more precipitation to the Levant, Iraq, Iran and southeastern Turkey than to Greece and western Turkey.

If the moist phase of the Pleistocene north of about 35° was indeed due to increased precipitation it must have been the result of the intensification of cyclonic rainfall. The cause of the precipitation to the south, however, is more controversial, although there is certainly good evidence that the influence of the westerlies extended well into the subtropics (Rognon, 1980; Sarnthein, 1980), perhaps as far south as 20° N. latitude (Diester-Haas, 1976; Sonntag _et al_., (1980).

It is, however, out of the question that cyclonic rainfall could have been responsible for the increased precipitation in equatorial Africa where many lakes reached their highest levels between 30,000 and 20,000 B.P. (Street and Grove, 1979; Gasse _et al_., 1980). Kutzbach (1981) has pointed out that the Northern

Hemisphere experienced a regime of increased summertime radiation during the period 30,000-25,000 B.P. similar to that which may have caused the intensification of the summer monsoons 9,000 years ago, and suggested that increased strength of the monsoons was responsible for the increased rainfall at lower latitudes.

Since increased activity of both the westerly and monsoon systems was probably in effect during this time period, it seems reasonable to attribute much of the increased precipitation to interaction between the two systems, a model which has become increasingly popular and has been particularly well-developed by Flohn and Nicholson (1980) and Maley (1981).

Although he must have been unaware of the theoretical likelihood of strengthened monsoons during this time-period, Huzzayin (1956) anticipated the idea of interacting climatic regimes by a quarter of a century when he suggested the mechanism by which more frequent and more southern westerly depressions would have increased the penetrating ability of the monsoons. Today the efficacy of the monsoons is reduced in the desert regions by the presence of dry, warm tropical air. The moist maritime air may advance far to the north and even form heavy clouds but when it is met and overridden by the dry, warm air masses condensation is prevented. During the Pleistocene as the cool, moist northwesterlies attacked and weakened the continental air masses, the penetrating power of the monsoons would have been increased and precipitation promoted as the warm and cold oceanic air masses met and interacted.

After 25,000-20,000 B.P. the lake levels at the lower latitudes began to fall (Street and Grove, 1979). Probably the intrinsic strength of the monsoon was reduced due to the decrease in summer insolation as well as to the continued cooling of the ocean (Sarnthein *et al*., 1981; Talbot, 1980). At the same time there is evidence that the tradewinds increased (Talbot, 1981; Duplessy, 1982), perhaps due to the withdrawal of the westerlies to more northerly latitudes.

The coldest period in Europe may have preceded the ice-sheet climax by 2,000 to 4,000 years (Mörner, 1973). Ice wedges suggest that this period was also generally dry (Williams, 1975). After 25-22,000 B.P., temperature (Mörner, 1973) and moisture (Williams, 1975; Coope, 1975) apparently increased enabling the ice sheets to advance across the lowlands. This same period, 22,000 to about 17,000, was the moistest period in the Middle East according to the C/A curves. This implies that the latitudes north of 35° including the Middle East, become moist at the same time that the lower latitudes began to become more arid. However, it has been suggested that continued moisture at higher latitudes (after aridity had increased to the south) was more a result of reduced evaporation than of continued higher precipitation (Roberts, 1982).

Although the tropical and subtropical regions became increasingly arid, evidence of lakes at 17,000 B.P. in the Rub'al-Khali, and at 14,000 B.P. on Bahrain demonstrate that occasional periods of rainier conditions still persisted.

Latitudes North of 35°

17,000-9,000 B. P.

From 17,000 B. P. the C/A curves seem to correlate positively with the pattern of temperature changes which has been identified from other regions (Mörner, 1973; Coope and Joachim, 1980), becoming moister during cold phases and drier with increasing temperature.

The first late glacial warming occurred between 17,000 and 15,000 B. P. (Mörner, 1973). This period is well-dated from the Middle East C/A moisture curves as a somewhat drier interval. Indications of the temperature rise are also provided by Japanese pollen diagrams (Tsukada, 1981) and by southwest U.S. lake levels (Spaulding, personal communication) as well as by pollen diagrams from the northwestern U.S. (Tsukada and Sugita, 1982).

The effect of a warming trend would have been to increase the cold meltwater flowing into the Aegean Sea, thus decreasing the sea-surface temperature at the same time that the land temperature was rising. This would cause a decrease in precipitation due to the fact that evaporation from the cold sea was low. On the other hand, as land temperatures again dropped as they did at 14,800 B.P. (Mörner, 1973), meltwater flow would decrease, and land temperatures would fall. Whether this increased the land-sea temperature contrast to the point where precipitation would have increased, or whether reduced evaporation was responsible, it is nevertheless clear that moisture conditions improved again before the late glacial interstadial which reached maximum warmth about 12,700 B. P. (Mörner, 1973; Coope and Joachim, 1980).

The two small C/A decreases which occur in the Tenaghi curve between 14,800 and about 12,700 B.P. - one can be seen at Zeribar - may be artifacts but it is tempting to relate them to one of the set-backs which are reported to have occurred during the overall general increase in temperature (Mörner, 1973).

Although the $\delta^{18}O$ depletion occurred from 20,000 to 11,760 B.P. (Rossignol-Strick et al., 1982), the high influx of meltwater via the Bosporus ended by 13,500 B.P. (Grosswald, 1980). After 12,500 B.P. the source of low-salinity surface water over the eastern Medterranean was flow from the Nile due to increased precipitation in the tropics. This stagnant layer of low-salinity water would itself have had an effect on the climate. When no vertical circulation occurs, the sea surface rapidly heats up in the summer. However, when the weather becomes cold again the stored heat is quickly released to the atmosphere. The effect is to increase the continentality of the climate with hotter summers and colder winters.

Between 11,000 to 10,000 B.P. a cold period corresponding to the Younger Dryas and the Loch Lomand Stadial occurred. This glacial readvance apparently resulted from a feedback mechanism which came into effect between the ocean and the ice sheets. After the initial warming period the sea level began to rise. As it washed over the Arctic sea ice it may have caused huge tabular ice sheets to break off and drift south into the North Atlantic causing drastic cooling of the sea surface and of the winds blowing onto coastal regions (Mercer, 1969; Ruddiman and McIntyre, 1981). A depression of the westerlies to the latitudes of the Middle East may have caused increased precipitation during this time period.

By between 10,000 and 9,000 B.P. the ice sheets had retreated and the surface temperature of the North Atlantic had returned to modern-day levels (Ruddiman and McIntyre, 1981). By 9000 B.P. summer insolation reached its peak (Kutzbach, 1981). This must have resulted in the resumption of summer rainfall throughout Europe enabling the return of approximately modern-day conditions throughout the region under the regime of year-round precipitation.

Lower Latitudes 12,000-6,000 B.P.

Periods of increased precipitation at low latitudes are apparently dependent on periods of high summer insolation (Kutzbach, 1981). Moreover, sapropel formation almost always occurs during high levels of insolation and is apparently caused by flooding of the Mediterranean by water carried from the tropics via the Nile. The stadial which occurred 11,000 to 10,000 B.P. apparently caused the cessation of low-latitude summer precipitation which was initiated in the tropics about 12,000 B.P. Incoming insolation remained high, but apparently the cooling of the ocean, the increase of the albedo due to the readvance of the ice sheets, the lowering of atmospheric temperature or a combination of these factors and perhaps others associated with the cold interval caused an interruption of the rainy period to the south.

At the end of the period, however, precipitation again increased. Lake levels in Africa rose (Street and Grove, 1978) and flooding of the Mediterranean by the Nile resumed (Rossignol-Strick _et al_., 1982). This rainfall gradually spread north, apparently not having its most important effect in the subtropics until about 8,000 B.P. according to the C/A curves of the Zagros pollen diagram, the Rub'al-Khali lakes (McClure, 1976; 1978) and the peat formations of the Bubiyan region.

According to Kutzbach (personal communication) the computer model for the climate of 9000 B.P. indicates that summer precipitation was more extensive than one might expect. He suggested that rain combined with high summer temperatures could have resulted in a rapid return of moisture to the atmosphere due to high levels of evapotranspiration. This self-perpetuating system would have allowed storms to move far beyond their expected limits.

The fact that moisture seems to have increased at the higher latitudes later presents the possibility of renewed interaction between westerly-controlled precipitation and monsoonal systems. Today the erratic precipitation of the Mesopotamian lowlands is still largely dependent upon such interaction when depressions from the Mediterranean are funneled down the valley and are met by moist air coming from the Indian Ocean over the Gulf. The most likely explanation for an increase in precipitation would be increased activity of both of these systems. Today warm air from the Gulf spreads northward throughout the summer resulting in humidity but not in precipitation. If depression from the Mediterranean had continued to reach these latitudes later in spring, or had begun earlier in the fall, precipitation would have increased.

Return to Modern Conditions

6,000 B.P.

By about 6,000 B.P. summer insolation had fallen to a minimum and the southern regions returned to aridity. Winter radiation was high, however, and this would have strengthened the gradient between the polar region and the Mediterranean during winter and may have resulted in the development of stronger and more frequent cyclonic storms. This accounts for the return to modern conditions at Lake Zeribar and other regions of the Middle East which are solely dependent on winter precipitation. The increase of winter precipitation in concert with increased winter insolation does not contradict Striem's (1979) observation of positive correlation between lower winter temperature and precipitation increase, because each storm is associated with an incursion of cold polar air even though surface temperature between storms may be somewhat higher. Thus by 6,000 B.P. with summer precipitation having returned to the regions where it occurs today, winter precipitation close to modern levels and the deserts reestablished, a return to modern conditions came into effect.

Any changes which have occurred since that time are obscured by the effects of human populations and their animals on the vegetation. However, it does not appear that major changes have occurred. In regions where Chenopodiaceae and Artemisia are important the C/A ratios have remained low. Lake levels are high compared to the low levels which occurred during the fluctuations of the late glacial (Street and Grove, 1979; Roberts, 1982). The deserts to the south have remained arid since the weakening of the monsoons about 6000 B.P. (McClure, 1976, 1978).

List of References

Agnew, A. (1962). A study of the oak forests of Gara Mountain, Mosul, Liwa. Proceedings of The Iraqi Scientific Society 5, 31-43.

Al-Sayari, S. and Zötl, J. (Eds.) (1978). Quaternary Sediments of Saudi Arabia. "Quaternary Period in Saudi Arabia." Springer-Verlag, New York.

Al-Shalash, A. (1966). The Climate of Iraq. Amman, Jordan.

Almogi-Labin, A. and Reiss, Z. (1977). Quaternary Pteropods from Israel. *Revista Española de Micropaleontologia* 9, 5-48.

Balsum, W. and Heusser, L., (1976). Direct correlation of sea-surface paleotemperatures, deep circulation, and terrestrial palaeoclimates: Foraminiferal and palynological evidence from two cores off Chesapeake Bay. *Marine Geology* 21, 121-147.

Barry, R. (1981). "Mountain Weather and Climate." Methuen, N.Y.

Beke, C.T. (1835). On the geological evidence of the advance of the land at the head of the Persian Gulf. *Philosophical Magazine* 7, 40-46.

Bender, F. (1975). Geology of the Arabian Peninsula: Jordan. U.S.G.S. Prof. Paper 560-I, Washington D.C.

Berry, R., Brophy, G., Naquash, A. (1970). Mineralogy of the suspended sediment in the Tigris, Euphrates, and Shat-al-Arab Rivers of Iraq and the recent history of the Mesopotamian Plain. *Journal of Sedimentary Petrology* 40, 131-139.

Bigarella, J. and de Andrade, G. (1965). Contribution to the study of the Brazilian Quaternary. Geological Society of America Special Paper 84, 433-451.

Bintliff, J. (1982). Palaeoclimatic modelling of environmental changes in the East Mediterranean region since the last glaciation. *In* "Palaeoclimates, Palaeoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory" (J. Bintliff and W. van Zeist, Eds.). BAR International Series 133 (ii) pp. 485-527, British Archeological Reports, London.

Bintliff, J. and van Zeist, W. (Eds.) (1982). "Archaeological Palaeoclimates, Palaeoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory," BAR International Series 133. British Archaeological Reports, London.

Bobek, H. (1940). Die gegenwärtige und eiszeitliche Vergletscherung im Zentralkurdischen Hochgebirge (Osttaurus, Ostanatolien). Zeitschrift fuer Gletsherkunde und Glazialgeologie 27, 50-88.

Bökönyi, S. (1982). The climatic interpretation of macrofaunal assemblages in the Near East. In "Palaeoclimates, Palaeoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory" (J. Bintliff and W. van Zeist, Eds.). BAR International Series 133 (ii), pp. 149-163, British Archeological Reports, London.

Bottema, S. (1974). Late Quaternary vegetational history of northwestern Greece. Thesis, Groningen, University, The Netherlands.

Bottema, S. (1978). The Late Glacial in the eastern Mediterranean and the Near East. In "The Environmental History of the Near and Middle East since the Last Ice Age" (W.C. Brice, Ed.), pp. 15-28. Academic Press, London.

Bottema, S. (1979). Pollen analytical investigations in Thessaly (Greece). Palaeohistoria 21, 19-40.

Bottema, S. and Barkoudah, Y. (1979). Modern pollen precipitation in Syria and Lebanon and its relation to vegetation. Pollen et Spores 21, 427-480.

Bottema, S. and van Zeist, W. (1980). Palynological evidence for the climatic history of the Near East, 50,000-6000 B.P. In "Préhistoire du Levant: No. 598," pp. 112-132. Centre National de la Recherche Scientifique, Lyon.

Bowler, J., Hope, G., Jennings, J., Singh, G. and Walker, D. (1976). Late Quaternary climates of Australia and New Guinea. Quaternary Research 5, 225-235.

Braidwood, R. and Howe, B. (1960). "Prehistoric Investigations in Iraqi Kurdistan." Studies in Ancient Oriental Civilization #13, Univesity of Chicago Press, Chicago.

Brice, W., (Ed.) (1980). "The Environmental Histoy of the Near and Middle East since the Last Ice Age." Academic Press, London.

Brooks, I. (1982). Geomorphological evidence for climatic change in Iran during the last 20,000 years. In "Palaeoclimates, Palaeoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory" (J. Bintliff and W. van Zeist, Eds.). BAR International Series 133 (ii), pp. 191-228, British Archeological Reports, London.

Butzer, K. (1958). Quaternary stratigraphy and climate in the Near East. Bonner Geographische Abhandlungen 24, 1-157.

Butzer, K. (1961). Climatic change in arid regions since the Pliocene. In "A history of land use in arid regions" (L.D. Stamp, Ed.). Arid Zone Research number 17, UNESCO, 31-56.

Butzer, K. (1971). "Environment and Archeology: an Ecological Approach to Pre-History," 2nd edition. Aldine, N.Y.

Butzer, K. (1975). The Late Glacial and Post Glacial climate of the Levant. In "Problems in Prehistory: North Africa and the Levant" (F. Wendorf and A. Marks, Eds.), pp. 389-410. Southern Methodist University Press, Dallas, Texas.

Butzer, K. (1978). The late prehistoric environmental history of the Near East. In "The Environmental History of the Near and Middle East since the Last Ice Age" (W. Brice, Ed.), pp. 245-254. Academic Press, New York.

Chapman, G. (1957). "Forests and Forestry in Iraq." (Mimeographed report) Ministry of Agriculture, Directorate-General of Forests, Baghdad.

Chapman, R. (1978). Geomorphology p. 19-30 In "Quaternary Period in Saudi Arabia" (S. Al-Sayari and J. Zotl, Eds.), pp. 19-30. Springer-Verlag, New York.

Cita, M., Vergnaud-Grazzini, C., Robert, C., Chamley, H., Ciarenfi, N. and D'Onofrio, S. (1977). Paleoclimatic record of a long deep sea core from the Eastern Mediterranean. Quaternary Research 8, 205-235.

CLIMAP Project Members (1976). The surface of the ice-age earth. Science 191, 1131-1137.

Cline, R. and Hays, J. (Eds.) (1976). Investigation of late Quaternary paleooceanography and paleoclimatology. Geological Society of America Memoir 145.

Coope, G. (1975). Climatic fluctuations in northwest Europe since the last interglacial indicated by fossil assemblages of Coleoptera. In "Ice Ages Ancient and Modern" (A.E. Wright and F. Mosely, Eds.). Seel House Press, Liverpool.

Coope, G. and Joachim, M. (1980). Late glacial environmental changes interpreted from fossil Coleoptera from St. Bees, Cumbria, Northwest England. In "Studies in the Late glacial of Northwest Europe" (J. Lowe, J. Gray, J. Robinson Eds.), pp. 23-30. Pergamon Press, Oxford.

Cwynar, L., Burden, E., McAndrews, J. (1979). An inexpensive sieving method for concentrating pollen and spores from fine-grained sediments. Canadian Journal of Earth Sciences 16, 1115-1120.

Damuth, J. and Fairbridge, R. (1970). Equatorial Atlantic deep-sea arkosic sands and ice-age aridity in tropical South America. Geological Society of America Bulletin 81, 189-206.

Davis, P. (Ed.) (1965). "Flora of Turkey," Vol. 1. University of Edinburgh, Edinburgh.

DeMorgan, J. (1900). Délégation en Perse I, 1-32. As cited in Larsen, C. and Evans, G. (1978). The Tigris-Euphrates-Karun Deltas. In "The Environmental History of the Near and Middle East since the Last Ice Age" (W. Brice, Ed.), pp. 227-244. Academic Press, New York.

Dickson, V. (1955). "The Wild Flowers of Kuwait." Allen and Unwin, London.

Diester-Haas, L. (1976). Late Quaternary climatic variation in northwest Africa deduced from east Atlantic sediment cores. Quaternary Research 6, 299-314.

Doornkamp, J., Brunsden, D. and Jones, D. (1980). "Geology, Geomorphology and Pedology of Bahrain." GeoAbstracts, Norwich, England.

Duplessy, J. (1982). Glacial to interglacial contrasts in the northern Indian Ocean. Nature 295, 494-498.

El-Moslimany, A. (1982). The late Quaternary vegetational history of the Zagros and Taurus Mountains in the regions of Lake Mirabad, Lake Zeribar and Lake Van - a reappraisal. In

"Palaeoclimates, Palaeoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory" (J. Bintliff and W. van Zeist, Eds.). BAR International Series 133 (ii) pp. 343-351, British Archeological Reports, London.

Emiliani, C. (1955). Pleistocene temperature variation in the Mediterranean. Quaternaria 3, 87-98.

Erol, O. (1978). Lake basins of central and southern Anatolia. In "The Environmental History of the Near and Middle East since the Last Ice Age" (W.C. Brice, Ed.), pp. 111-139. Academic Press, New York.

Evans, G., Schmidt, V., Bush, P., Nelson, H.,(1969). Stratigraphy and geologic history of the Sabkha, Abu Dhabi, Persian Gulf. Sedimentology 12, 145-159.

Evans, G., Murray, J., Biggs, H., Bate, R., and Bush, P. (1973). The Oceanography, ecology, sedimentology and geomorphology of parts of the Trucial Coast Barrier Island Complex, Persian Gulf. In "The Persian Gulf: Holocene Carbonate Sedimentation in a Shallow Epicontinental Sea" (B. Purser, Ed.), pp. 81-98. Springer-Verlag, New York.

Faegri, K. and Iversen, J. (1975). Textbook of Pollen Analysis, 3rd edition. Blackwell, Oxford.

Fairbridge, R. (1961). Eustatic changes in sea level. Physics and Chemistry of the Earth 4, 99-185.

Fairbridge, R. (1962). New radiocarbon dates of Nile sediments. Nature 196, 108-110.

Fairbridge, R. (1972). Climatology of a glacial cycle. Quaternary Research 2, 283-302.

Farrand, W. (1971). Late Quaternary paleoclimates of the Eastern Mediterranean area. In "The Late Cenozoic Glacial Ages" (K. Turekian, Ed.), pp. 529-564. Yale University Press, New Haven.

Farrand, W. (1981). Pluvial climates and frost action during the last glacial cycle in the Eastern Mediterranean - evidence from archeological sites. In "Quaternary Paleoclimate" (W. Mahaney, Ed.), pp. 393-410. GeoAbstracts, York, England.

Felber, H., Hötzl, H., Maurin, V., Moser, H. Rauert W., and Zötl,

J. (1978). Sea level fluctuations during the Quaternary Period. In "Quaternary Period in Saudi Arabia," Vol. I (S. Al-Sayari and J. Zötl, Eds.), pp. 50-57. Springer-Verlag, New York.

Felber, H., Hötzl, H., Moser, H., Rauert, W. and Zötl, J. (1978). As Sulb Plateau: Karstification and Geomorphogeny of As Sulb Plateau. In "Quaternary Period in Saudi Arabia" (S. Al-Sayari and J. Zotl, Eds.), pp. 166-173. Springer-Verlag, New York.

Fisher, W. (1968). "The Cambridge History of Iran, The Land of Iran." Cambridge University Press, Cambridge.

Flint, R. (1971). "Glacial and Quaternary Geology". Wiley and Sons Inc., New York.

Flohn, H. and Nicholson, S. (1980). Climatic fluctuations in the arid belt of the "Old World" since the last glacial maximum: possible causes and future implications. Palaeoecology of Africa 12, 3-21.

Freitag, H. (1977). The Pleniglacial, Late-Glacial, and early postglacial vegetations of Zeribar and their present-day counterparts. A supplement to W. van Zeist and S. Bottema, Palynological investigations in western Iran. Palaeohistoria 19, 87-95.

Fuchs, W., Gattinger, T. and Holzer, H. (1968). "Explanatory Text to The Synoptic Geologic Map of Kuwait." Geological Survey of Austria, Vienna.

Garrard, A., Harvey, C. and Switsur, V. (in press). Environment and settlement during the upper Pleistocene and Holocene at Jubbah in the Great Nafud, Northern Arabia. Atlal, Journal of Saudi Arabian Archeology.

Garrard, A. and Stanley Price, N.P., (1975, 1976, 1977). A survey of prehistoric sites in the Azraq Basin, eastern Jordan. Paleorient 3, 110-126.

Gasse, R., Rognon, P., Street, A. (1980). Quaternary history of the Afar and Ethiopian Rift lakes. In "The Sahara and the Nile" (M. Williams and H. Faure, Eds.), pp. 361-400.

Geiger, R. (1969). Topoclimates In "World Survey of Climatology", Vol. 2 (H. Flohn, Ed.). Elsevier, London.

Georgiev, V. and Stoffers, P. (1980). Surface texture of quartz grains from late Pleistocene to Holocene sediments of the Persian Gulf/Gulf of Oman - an application of the scanning electron microscope. *Marine Geology* 36, 85-96.

Gilbert, G. (1890). Lake Bonneville: USGS Monograph I.

Glennie, K. (1970). "Desert Sedimentary Environments," Elsevier, New York.

Godwin, H. and Willis, E. (1958). Radiocarbon dating of the eustatic rise in ocean-level. *Nature* 181, 1518-1519.

Godwin, H. and Willis, E. (1959) Natural radiocarbon measurements I, *Radiocarbon* 1, 13-75.

Goldberg, P. and Bar-Yosef, O. (1982). Environmental and archeological evidence for climatic change in the Southern Levant. *In* "Palaeoclimates, Palaeoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory" (J. Bintliff and W. van Zeist, Eds.). BAR International Series 133(ii), pp. 399-414, British Archeological Reports, London.

Grosswald, M. (1980). Late Welchelian ice sheet of northern Eurasia. *Quarternary Research* 13, 1-32.

Grunert, J., Carls, H., and Preu, C. (1978). Rezente Vergletscherungen in zentral-iranischen Hochgebirgen. *Eiszeit und Gegenwärt* 28, 148-165. As cited by Farrand, W. (1981). Pluvial climates and frost action during the last glacial cycle in the eastern Mediterranean. *In* "Quaternary Paleoclimate" (W. Mahaney, Ed.), pp. 393-409. GeoAbstracts, Norwich, England.

Guest, E. and Al-Rawi, A. (1966). "Flora of Iraq," Vol. I. Ministry of Agriculture, Baghdad.

Guest, E. (Ed.). "Flora of Iraq," Vol. 4. Ministry of Agriculture, Baghdad.

Halwagy, M. (1978). Studies on the airborne pollen and fungal spores of Kuwait. Ph.D. Thesis, University of Reading, England.

Halwagy, R. and Halwagy, M. (1974a). Ecological studies on the desert of Kuwait: I. The physical environment. Journal University of Kuwait (Science) 1, 75-86.

Halwagy, R. and Halwagy, M. (1974b). Ecological studies on the desert of Kuwait: II. The vegetation. Journal University of Kuwait (Science) 1, 87-95.

Halwagy, R. and Halwagy, M. (1977). Ecological studies on the desert of Kuwait: III. The vegetation of the coastal salt marshes. Journal of the University of Kuwait (Science) 4, 33-74.

Halwagy, R., Moustafa, A. and Kamel, S. (1982). On the ecology of the desert vegetation in Kuwait. Journal of Arid Environments 5, 95-107.

Herman, Y. (1972). Quaternary eastern Mediterranean sediments: micropaleontology and climatic record. In "The Mediterranean Sea: A Natural Sedimentation Laboratory" (D. J. Stanley, Ed.), pp. 129-147. Dowden, Hutchinson and Ross, Inc., Stroudsburg, Pa.

Higgs, E. (1978). Environmental changes in northern Greece. In "The Environmental History of the Near and Middle East since the Last Ice Age" (W.C. Brice, Ed.), pp. 41-50. Academic Press, London.

Holm, D. (1960). Desert geomorphology in the Arabian peninsula. Science 132, 1369-1379.

Horowitz, A. (1966). Tropical and northern pollen and spores in recent sediments from the Bay of Elat (Aqaba). Israel Journal of Earth Sciences 15, 125-130.

Horowitz, A. (1969). Recent pollen sedimentation in Lake Kinneret, Israel. Pollen et Spores 11, 353-384.

Horowitz, A. (1971). Climatic and vegetational developments in northeastern Israel during upper Pleistocene-Holocene times. Pollen et Spores 13, 255-278.

Horowitz, A. (1979). "The Quaternary of Israel." Academic Press, N.Y.

Hötzl, H. and Maurin, V. (1978). Wadi Birk In "Quaternary Period in Saudi Arabia" (S. Al-Sayari and J. Zötl, Eds.), pp. 209-215. Springer-Verlag, New York.

Hötzl, H. and Zötl, J. (1978). Climatic changes during the Quaternary period in Saudi Arabia. *In* "Quaternary Period in Saudi Arabia" (S. Al-Sayari and J. Zötl, Eds.), pp. 301-310. Springer-Verlag, New York.

Hötzl, H., Felber, H., and Zötl, J. (1978). Wadi Ar Rimah: the Quarternary development of the upper part of Wadi Ar Rimah *In* "Quaternary Period in Saudi Arabia" (S. Al-Sayari and J. Zötl, Eds.), pp. 173-182. Springer-Verlag, New York.

Hötzl, H., Krämer, F., Maurin, V. (1978). Quarternary sediments, p. 264-301. *In* "Quaternary Period in Saudi Arabia" (S. Al-Sayari and J. Zötl, Eds.) pp. 264-301, Springer-Verlag, New York.

Hötzl, H., Felber, H., Maurin, V. and Zötl, J. (1978). Cuesta region of the Tuway Mountains: accumulation terraces of Wadi Hanifah and Wadi Al Luhy, p. 202-209. *In* "Quaternary Period in Saudi Arabia" (S. Al-Sayari and J. Zötl, Eds.), pp. 202-209. Springer-Verlag, New York.

Huckriede, R. and Wiesemann, G. (1968). Der jungpleistozäne Pluvial-See von El-Jafr und weitere Daten zum Quartär Jordaniens. *Geologica et Palaeontologica* 2, 73-95.

Hutchinson, C. and Cowgill, U. (1963). Chemical examination of a core from Lake Zeribar, Iran. *Science* 140, 67-69.

Huzayyin, S. (1956). Changes in climate, vegetation and human adjustment in the Sahara-Arabian belt, with special reference to Africa. *In* "Man's Role in Changing the Face of the Earth" (W. Thomas, Ed.), pp. 304-324. University of Chicago Press, Chicago.

Imbrie, J. and Kipp, N. (1971). A new micropaleontological method for quantitative paleoclimatology: application to a late Pleistocene Caribbean core. *In* "The Late Cenozoic Glacial Ages" (K. Turekian, Ed.), pp. 71-181. Yale University Press, New Haven, Conn.

Jamieson, T. (1862). On the ice-worn rocks of Scotland. *Geological Society of London Quarterly Journal* 18, 164-184.

Jamieson, T. (1863). On the parallel roads of Glen Roy and their place in the history of the glacial period. Geological Society of London Quarterly Journal 19, 235-259. As cited In Flint, R. (1957). "Glacial and Quaternary Geology," Wiley, N.Y.

Jones, R. and Beavers, A. (1963). Some minerological and chemical properties of plant opal. Soil Science 96, 375-379.

Jones, R., and Beavers, A. (1964). Variation of opal phytolith content among some great soil groups in Illinois. Soil Science of America Proceedings 28, 711-712.

Kaiser, K., Kemph, E., Leroi-Gourhan, A., Schütt, H. (1973). Quartärstratigraphische Untersuchungen aus dem DamaskusBecken und seiner Umgebung. Zeitschrift für Geomorphologie 17 (new series), 263-353.

Kassler, P. (1973). The structural and geomorphic evolution of the Persian Gulf. In "The Persian Gulf" (B.H. Purser, Ed.), pp. 11-32. Springer-Verlag, Amsterdam.

Kendall, R. (1969), An ecological history of the Lake Victoria Basin. Ecological Monographs 39, 121-176.

Koreneva, E. (1966). Marine palynological researches in the U.S.S.R. Marine Geology 4, 565-574.

Kuhle, M. (1976). Beitrag zur Quatärmorphologie S.E.-Iranischer Hochgebirge. Die quartäre Vergletscherung des Kuh-i-Jupar. Göttinger Geographische Abhandlungen, Vol. 67.

Kukla, G. (1977). Pleistocene land-sea correlations. 1. Europe. Earth Science Reviews 13, 307-374.

Kutzbach, J. (1981). Monsoon climate of the early Holocene: climate experiment with the Earth's orbital parameters for 9000 years ago. Science 214, 59-61.

Kutzbach, J. and Otto-Bliesner, B. (1982). The sensitivity of the African-Asian monsoonal climate to orbital parameter changes for 9000 years B.P. in a low-resolution general circulation model. Journal of the Atmospheric Sciences 39, 1177-1188.

Lamb, H. (1977). "Climate: Present, Past, and Future, Vol. 2: Climatic History and the Future." Methuen, London.

Larcher, W. (1981). Low temperature effects on Mediterranean sclerophylls: An unconventional viewpoint. In "Components of Productivity of Mediterranean-climate Regions Basic and Applied" (H.S. Margaris and H.A. Mooney, Eds.) pp. 259-265. Junk, London.

Larsen, C. and Evans, G. (1978). The Holocene geological history of the Tigris-Euphrates-Karun Delta. In "The Environmental History of the Near and Middle East since the Last Ice Age" (W. Brice, Ed.), pp. 227-244. Academic Press, New York.

Lartet, L. (1865). Note sur la formation du bassin de la Mer Monte ou lac Aphaltite et sur les changements survenus dans le niveau de ce Lac. Bulletin Soc. Geol. France, Ser. 2, 22, 420. As cited by Flint, In "Glacial and Quaternary Geology." Wiley and Sons, New York.

Lees, G. and Falcon, N. (1952). The geographical history of the Mesopotamian Plains. Geographic Journal 116, 24-39.

Livingstone, D. A. (1975). Late Quaternary climate change in Africa. Annual Review of Ecology and Systematics 6, 249-280.

Luz, B. (1982). Palaeoclimatic interpretation of the last 20,000 year record of deep-sea cores around the Middle East. In "Palaeoclimates, Palaeoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory" (J. Bintliff and W. van Zeist, Eds.). BAR International Series 133 (ii) pp. 41-46, British Archeological Reports, London.

Luz, B., and Bernstein, M. (1976). Planktonic foraminifera and quantitative paleoclimatology of the eastern Mediterranean. Marine Micropaleontology 1, 307-323.

MacFadyen, W. and Vita-Finzi, C. (1978). Mesopotamia: The Tigris-Euphrates delta and its Holocene Hammar fauna. 115, 287-300. Geological Magazine.

Mack, R., Rutter, N., Bryand, V., and Valastro, S. (1978). Late Quaternary pollen record from Big Meadow, Pend Orielle County, Washington. Ecology 59, 956-966.

Maher, L. (1963). Pollen analysis of surface materials from the southern San Juan Mountains, Colorado. Geological Society of America Bulletin 74, 1485-1503.

Maley, J. (1977). Palaeoclimates of central Sahara during the early Holocene. *Nature* 269, 573-577.

Maley, J. (1981). Etudes palynologiques dans le bassin du Tchad et paleoclimatologie de l'Afrique nord-tropicale de 30,000 ans à l'époque actuelle. *Travaux et Documents de l'Office de l'ORSTOM*, No. 129.

Mangerud, J., Andersen, S., Bergland, B. and Donner, J. (1974) Quaternary stratigraphy of Norden, a proposal for terminology and classification. *Boreas* 3, 109-128.

Markgraf, V. (1980). Pollen dispersal in a mountain area. *Grana* 19, 127-146.

Martin, P. (1963). "The Last 10,000 years: A Fossil Record of The American Southwest." University of Arizona Press, Tucson.

McClure, H. (1976). Radiocarbon chronology of late Quaternary lakes in the Arabian desert. *Nature* 263, 755-756.

McClure, H. (1978). Ar Rub Al Khali. *In* "Quaternary Period in Saudi Arabia" (S. Al-Sayari and J. Zötl Eds.), pp. 252-263. Springer-Verlag, New York.

Megard, R. (1967). Late Quaternary Cladocera of Lake Zeribar. *Ecology* 48, 179-189.

Mercer, J. (1969). The Allerod Oscillation: A European climatic anomaly? *Arctic and Alpine Research* 1, 227-284.

Messerli, B. (1967). Die eiszeitliche und die gegenwärtige Vergletscherung im Mittelmeerraum. *Geographica Helvetica* 22, 105-228.

Metcalfe, C. (1971). "Anatomy of The Monocotyledons, Vol. V: Cyperaceae." Clarendon Press, Oxford.

Migahid, A. (1978). "Flora of Saudi Arabia" 2nd edition. Riyadh Univesity, Riyadh, Saudi Arabia.

Moore, A. (1979) A pre-Neolithic farmers' village on the Euphrates. *Scientific American* 241, 50-58.

Mörner, N. (1973). Climatic changes during the last 35,000 years as indicated by land, sea, and air data. *Boreas* 2, 33-54.

Moser, H., Pak, E., Rauert, W., Stichler, W., and Zötl, J. (1978).

Isotopic composition of waters of Al Qatif and Al Hasa areas 153-163. In "Quaternary Period in Saudi Arabia" (S. Al-Sayari and J. Zötl, Eds.), pp. 153-163. Springer-Verlag, New York.

Müller, Jan (1959). Palynology of recent Orinoco delta and shelf sediments. Micropaleontology 5, 1-32.

Oates, J. (1982). Archaeological evidence for settlement patterns in Mesopotamia and Eastern Arabia in relation to possible environmental conditions. In "Palaeoclimates, Palaeoenvironmants and Human Communities in the Eastern Mediterranean Region in Later Prehistory" (J. Bintliff and W. van Zeist, Eds.), BAR International Series 133 (ii) pp. 359-393. British Archeological Reports, London.

Odum, E. (1971). "Fundamentals of Ecology" 3rd edition. Saunders, Philadelphia.

Neev, D. and Hall, J. (1979). Geophysical investigations in the Dead Sea. Sedimentary Geology, 209-238.

Niklewski, J. and van Zeist, W. (1979). A Late Quaternary pollen diagram from Northwestern Syria. Acta Botanica Neerlandica 19, 737-754.

Owens, R. and Nasr, S. (1958). Stratigraphy of the Kuwait-Basrah area. In "Habitat of Oil. Symposium of American Association of Petroleum Geology," pp. 1252-1278.

Parker, F. (1958). Eastern Mediterranean foraminifera. Report of the Swedish Deep-Sea Expedition, 1947-1948, 8(4), 217-283.

Parry, D. and Smithson, F. (1964). Types of opaline silica deposits in the leaves of British grasses. Annals of Botany 28, 169-184.

Penck, A. (1913). Sitz-Ber. Kgl. Preuss. Akad. Wiss. 1, 77. As cited by Fairbridge (1962). New radiocarbon dates of Nile sediments. Nature 196, 108-110.

Pennington, W. (1974). "The History of British Vegetation," 2nd edition. English Universities Press, London.

Philby, H. (1933). "The Empty Quarter," being a description of the great south desert of Arabia known as Rub'al-Khali. Holt, N.Y.

Picha, F. and Saleh, A. (1977). Quaternary sediments in Kuwait. Journal of the University of Kuwait (Science) 4, 169-185.

Popov, G. and Zeller, W. (1963). Ecological survey: report on the 1962 survey in the Arabian Peninsula. UN Special Fund, Desert Locust Project, Progress Report FAO, Rome.

Rechinger, K. (1971). "Flora Iranica." Akademische Druck-u. Verlagsanstat. Graz, Austria.

Reiss, Z., Merling-Reiss, P., and Moshkovitz, S. (1971). Quaternary planktonic foraminiferida and nannoplankton from the Mediterranean shelf and slope of Israel. Israel Journal of Earth Science 20, 141-177.

Roberts, N. (1982). Lake levels as an indicator of Near Eastern Palaeoclimates: A preliminary appraisal. In "Palaeoclimates, Palaeoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory" (J. Bintliff and W. van Zeist, Eds.). BAR International Series 133 (ii) pp. 235-267, British Archeological Reports, London.

Roberts, N., Erol, O., de Meester, T., and Uerpmann, H. (1979). Radiocarbon chronology of late Pleistocene Konya Lake, Turkey. Nature 281, 662-664.

Rognon, P. (1979). Evolution du relief et paleoclimats depuis 40,000 ans sur la bordure nord du Sahara. Bulletin de l'Association de Géographes Français, 205-214.

Rognon, P. (1980). Une extension des deserts (Sahara et Moyen-Orient) au course du Tardiglaciaire (18,000-10,000 ans B.P.). Revue de Géologie dynamique et de Géographic physique 22, 313-328.

Rognon, P. and Williams, M. (1977). Late Quaternary climatic changes in Australia and North Africa: A preliminary interpretation. Paleogeography, Paleoclimatology, Paleoecology 21, 285-327.

Rossignol, M. (1961). Analyse pollinique de sediments marins en Israël I sediments recents. Pollen et Spores 3, 303-324.

Rossignol, M. (1969). Sedimentation palynologique dans la Mer Morte. Pollen et Spores II, 17-38.

Rossignol-Strick, M. and Duzer, D. (1980). Late Quaternary west

African climate inferred from palynology of Atlantic deep-sea cores. Palaeoecology of Africa 12, 227, 43-46.

Rossignol-Strick, M., Nesteroff, W. Olive, P. and Vergnaud-Grazzini, C. (1982). After the deluge: Mediterranean stagnation and sapropel formation. Nature 295, 105-110.

Roux, Georges (1964). "Ancient Iraq." George Allen and Unwin Ltd, London.

Ruddiman, W. and McIntyre, A. (1981). The North Atlantic during the last deglaciation. Palaeogeography, Palaeoclimatology, Palaeoecology 35, 145-214.

Rumney, G. (1968). "Climatology and the World's Climates." McMillan, New York.

Russell, I. (1889). Quaternary history of Mono Valley, Calif. USGS 8th Annual Report, Part I. As cited In Flint, R. "Glacial and Quaternary Geology." Wiley N.Y.

Sakaguchi, Y. (1978). Palmyra pluvial lake. In "Palaeolithic site of Douara Cave and Paleogeography of Palmyra Basin in Syria." Bull. No. 14, Univ. Museum, Univ. of Tokyo. As cited in: Garrard, A. (in press). Environment and settlement during the upper Pleistocene and Holocene at Jubbah in the Great Nefud, Northern Arabia.

Sarnthein, M. (1972). Sediments and history of the postglacial transgression of the Persian Gulf and northwest Gulf of Oman. Marine Geology 12, 245-266.

Sarnthein, M., Tetzlaff, G., Koopman, B., Wolter, K., Pflaumann, U. (1981). Glacial and interglacial wind regimes over the eastern subtropical Atlantic and North-west Africa. Nature 293, 193-196.

Schoell, M. and Faber, E. (1978). New isotopic evidence for the origin of Red Sea brines. Nature 275, 436-438.

Singh, G., Joshi R., and Singh, A. (1972). Stratigraphic and radiocarbon evidence for the age and development of three salt lake deposits in Rajasthan, India. Quaternary Research 2, 496-505.

Singh, G., Chopra, S., and Singh, A. (1973). Pollen-rain from the vegetation of northwest India. New Phytologist 72, 191-2061.

Sonntag, C., Thorweihe, U., Rudolph, J., Löhnert, E., Junghans, K., Münnich, K., Klitzsch, E., El Shazly, E., Swailem, E. (1980). Isotopic identification of Saharan groundwaters, groundwater formation in the past. "The Sahara and the Nile" (M. Williams and H. Faure, Eds.), 159-175, Balkama, Rotterdam.

Stanley, E. (1966). The Problem of reworked pollen and spores in marine sediments. Marine Geology, 4, 397-408.

Stanley, E.A. (1967). Palynology of 6 ocean-bottom cores from the southwestern Atlantic Ocean. Review Paleobotany and Palynology 2, 195-203.

Stoffers, P. and Ross, D. (1978). Late Pleistocene and Holocene sedimentation in the Persian Gulf-Gulf of Oman. Sedimentary Geology 23, 181-208.

Stuiver, M. (1971). Evidence for the variation of atmospheric C^{14} content in the late Quaternary. In "The Late Cenozoic Glacial Ages" (K. Turekian, Ed.). Yale University Press, New Haven.

Street, F. and Grove, A. (1979). Global maps of lake-level fluctuations since 30,000 years B.P. Quaternary Research 12, 83-118.

Striem, H. (1979). Some aspects of the relationship between monthly temperatures and rainfall and its use in evaluating earlier climates in the Middle East. Climatic Change 2, 69-74.

Swain, A., Kutzbach, J. and Hstenrath, S. (1983). Estimates of Holocene precipitation for Rajasthan, India, based on pollen and lake-level data. Quaternary Research 19, 1-17.

Tabatabai, M. and Javanshir, K. (1966). "Iranian Western Oak Forests I, Kermanshah and Kordistan." Iranian Forest Service, Tehran.

Talbot, M. (1981). Holocene changes in tropical wind intensity and rainfall: Evidence from southeast Ghana. Quaternary Research 16, 201-220.

Thalen, D. (1979). "Ecology and Utilization of Desert Shrub

Rangelands in Iraq." Junk, The Hague.

Thesiger, W. (1948). Across the Empty Quarter. Geographical Journal 111, 1-21.

Thesiger, W. (1949). A further journey across the Empty Quarter. Geographical Journal 113, 21-46.

Thesiger, W. (1959). "Arabian Sands." Dutton, New Yorks.

Thiede, J. (1978). A glacial Mediterranean. Nature 276, 680-683.

Thomas, B. (1932). "Arabia Felix; Across the 'Empty Quarter' of Arabia." Scribner's Sons, New York.

Thunell, Robert C. (1979). Eastern Mediterranean Sea during the last glacial maximum; an 18,000 years B.P. reconstruction. Quaternary Research 11, 353-372.

Thunell, R., Williams, D. and Kennett, H. (1977). Late Quaternary paleoclimatology, stratigraphy and sapropel history in Eastern Mediterranean sediments. Marine Micropaleontology 4, 371-388.

Traverse, A. and Ginsberg, R. (1966). Palynology of the surface sediments of Great Bahama Bank as related to water movement and sedimentation. Marine Geology 4, 417-459.

Tsukada, M. (1974). "Palaeoecology II: Synthesis." Kyoritsu, Tokyo (In Japanese).

Tsukada, M. (1982). Late-Quaternary development of the Fagus forest in the Japanese Archipelago. Japanese Journal of Ecology 32, 113-118.

Tsukada, M. and Sugita, S. (1982). Late-Quaternary dynamics of pollen influx at Mineral Lake, Washington. Botanical Magazine, Tokyo 95, 401-418.

Turner, J. and Greig, J. (1975). Some Holocene pollen diagrams from Greece. Review of Palaeobotany and Palynology 20, 171-204.

Twiss, P., Suess, E., and Smith, R. (1969). Morphological classification of grass opal. Soil Science of America Proceedings 33, 109-115.

van der Hammen, T., Wijmstra, T. and Zagwijn, W. (1971). The floral record of the late Cenozoic of Europe. In "The Late Cenozoic Glacial Ages" (K. Turekian, Ed.), pp. 392-424. Yale University Press, New Haven.

van Zeist, W. and Bottema, S. (1977). Palynological investigations in western Iran. Palaeohistoria 19, 19-85.

van Zeist, W. and Bottema, S. (1982). Vegetational history of the eastern Mediterranean and the Near East during the last 20,000 years. In "Palaeoclimates, Palaeoenvironments and Human Communities in the Eastern Mediterranean Region in Later Prehistory" (J. Bintliff and W. van Zeist, Eds.). BAR International Series 133 (ii) pp. 277-323, British Archeological Reports, Oxford.

van Zeist, W. and Woldring, H. (1978). A postglacial pollen diagram from Lake Van in east Anatolia. Review of Palaeobotany and Palynology 26, 249-276.

van Zeist, W. and Woldring, H. (1980). Holocene vegetation and climate of northwestern Syria. Palaeohistoria 22, 112-125.

van Zeist, W., Timmers, R. and Bottema, S. (1968). Studies of modern and Holocene pollen precipitation in southeastern Turkey. Palaeohistoria 14, 19-39.

van Zeist, W., Woldring. H. and Stapert, D. (1975). Late Quaternary vegetation and climate of southwestern Turkey. Palaeohistoria 17, 55-143.

Verma, S. and Rust, R. (1969). Observations on opal phytoliths in a soil biosequence in southeastern Minnesota. Soil Science of America Proceedings 33, 749-751.

Vesey-Fitzgerald, D. (1957). The vegetation of central and eastern Arabia. Journal of Ecology 45, 779-798.

Vita-Finzi, C. (1978) "Archaeological Sites in their Setting." Thames and Hudson, London.

Walter, H. (1971). "Tropical and Sub-Tropical Vegetation," Oliver and Boyd, Edinburgh.

Wasylikowa, K. (1967). Late Quaternary plant macrofossils from Lake Zeribar, western Iran. Review of Paleobotany and Palynology. 2, 313-318.

Watts, W. (1973). Rates of change and stability in vegetation in the perspective of long periods of time. In "Quaternary Plant Ecology" (H. Birks and R. West, Eds.), pp. 195-206. Wiley and Son, New York.

Weinstein, M. (1976). The Late Quaternary vegetation of the northern Golan. Pollen et Spores 18, 553-562.

Whitney, J.D. (1865). Geological Survey of California. Geology, Vol.I: Sherman and Co., Philadelphia as cited by Flint, R.F. (1971) "Glacial and Quaternary Geology." Wiley and Sons, New York.

Whyte, R. (1961). Evolution of land use in southwestern Asia. In "A History of Land Use in Arid Regions" (L.D. Stamp, Ed.), pp. 57-113. UNESCO, Paris.

Wijmstra, T. (1969). Palynology of the first 30 meters of a 120 m deep section in northern Greece. Acta Botanica Neerlandica 18, 411-527.

Wilding, L. and Drees, L. (1968). Biogenic opal in soils as an index of vegetative history in the prairie peninsula. In "The Quaternary of Illinois" (R.E. Bergstrom, Ed.), pp. 96-103. University of Illinois College of Agriculture Special Publication 14, Urbana, Illinois.

Williams, M. and Faure, H. (Eds.) (1980). "The Sahara and The Nile." Balkema, Rotterdam.

Williams, R. (1975). The British climate during the last glaciation; an interpretation based on periglacial phenomena. In "Ice Ages Ancient and Modern" (A.E. Wright and F. Mosely, Eds.). Seel House Press, Liverpool.

Winstanley, D. 1973. Rainfall patterns and general atmospheric circulation. Nature 232, 549-51.

Woletz, G. (1968). Heavy mineral analysis and stratigraphic significance. In "Explanatory Text to the Synoptic Geologic Map of Kuwait" (W. Fuchs, T. Gattinger and H. Holzer, Eds.). Geological Survey of Austria, Vienna.

Wright, H. (1960). Climate and prehistoric man in the eastern Mediterranean. In "Prehistoric Investigations in Iraqi Kurdistan. Studies in Ancient Oriental Civilizations #31"

(E.J. Braidwood and B. Howe, Eds.). University of Chicago Press, Chicago, Ill.

Wright, H. (1961). Pleistocene glaciation in Kurdistan. Eiszeitalter und Gegenwårt 12, 131-164.

Wright, H. (1967). The use of surface samples in Quaternary pollen analysis. Review of Paleobotany and Palynology 2, 321-330.

Wright, H., McAndrews, J. and van Zeist, W. (1967). Modern pollen rain in western Iran and its relation to plant geography and Quaternary vegetation history. Journal of Ecology 55, 415-443.

Zohary, M. (1962). "Plant life of Palestine." Ronald Press, New York.

Zohary, M. (1973). "Geobotanical Foundations of the Middle East." Gustav Fisher Verlag, Stuttgart.

APPENDIX A

MODERN SURFACE POLLEN PERCENTAGES

TABLE A.1

SURFACE POLLEN PERCENTAGES

KUWAIT - S. IRAQ

Sample Numbers	1	2	3	4	5	7	8	9
Pinus	1.5	2.0	3.0	0	1.0	0	0.5	0
Quercus	0	0	0	0	3.0	0	0	0
Phoenix	0	0	0	2.0	1.3	0	0	0
Chenopodiaceae	37.	41.	10.	34.5	29.	49.	35.	56.
Plantago	3.0	4.0	3.0	0	6.3	5.5	2.5	5.7
Compositae (Liguliflorae)	1.5	2.5	7.0	0	5.3	9.2	14.0	20.0
Compositae (Tubuliflorae)	1.5	3.0	2.0	16.	5.3	7.4	16.6	4.0
Umbelliferae	0	2.0	1.0	0	1.0	10.	5.8	0
Boraginaceae	0	0	0	0	0	0	0.4	0
Cruciferae	0	0	4.0	0	4.6	0	2.4	2.0
Geranaceae	0	0	0	0	0.3	0	0	0
Malvaceae	0	0	0	0	0	0	0	0
Liliaceae	0.5	0	0	0	0.3	1.8	2.5	1.0
Leguminosae	0	2.5	0	4.0	6.6	3.7	7.0	3.0
Tribulus	0	0	0	0	0.3	0	0	0
Nitraria	0	0	0	0	0	0	0	7.0
Zygophyllum	0	0	0	0	0	0	0	0
Gramineae	2.0	1.7	4.0	14.0	16.6	0	2.5	2.0
Cyperus conglomeratus	0	0	0	0.3	1.0	1.8	6.0	0.5
Ephedra	0.7	0	0.3	0	0.3	0	0	0
Nuphar	0	0	0	2.0	0.7	0	0	0
Potamogeton	15.0	11.0	18.	6.0	5.0	0	0	0
Typha-Sparganum	27.	16.	2.	0	0.7	0	0	0
Unknown or unidentifiable	2.5	14.	40.	15.0	6.0	8.0	3.9	0
Hystrichospheres present	Yes	Yes	Yes	No	Yes	No	No	Yes
	200	200	307	100	300	108	206	212

TABLE A.1 (continued)
KUWAIT - S. IRAQ

Sample Numbers	10	11	12	13a	13b	13e	14	15
Pinus	0	3.0	0.8	0	0	0	0	1.0
Quercus	0	1.0	0	0	0	0	0	0
Phoenix	0	0	0	0	0	0.9	0	0
Chenopodiaceae	43.	66.	45.	73.	66.	37.	40.	38.
Plantago	15.	15.	39.	19.	22.	22.	30.	17.
Compositae (Liguliflorae)	29.	5.	2.3	1.	11.0	2.7	3.0	5.0
Compositae (Tubuliflorae)	0	0	4.6	2.4	0	2.0	5.0	3.0
Umbelliferae	3.0	0	0.8	0	0	0	0	2.0
Boraginaceae	0	0	0	0	0	0	0.5	1.5
Cruciferae	0	0	2.3	0	0	0	0.5	1.5
Geranaceae	0	0	0	0	0	0	0	1.5
Malvaceae	0	0	0	0	0	0	0	0
Liliaceae	0	0	0	0	0	2.8	0	0
Leguminosae	0	0	0.8	2.0	0	5.2	0.5	0
Tribulus	0	0	0	0	0	0	0	0
Nitraria	0	0	0	0	0	0	0	0
Zygophyllum	0	0	0	0	0	0	1.5	0
Gramineae	0	0	0	0	0	8.2	0	2.0
Cyperus conglomeratus	4.0	2.0	0	1.0	0	2.8	17.5	13.2
Ephedra	0	0	0	0	0	0	0	0
Nuphar	0	0	0	0	0	1.8	0	0
Potamogeton	0	0	0	0	0	5.7	0	0
Typha-Sparganum	0	0	0	0	0	0.5	0	0
Unknown or unidentifiable	6.0	9.0	4.6	0	0	9.0	2.	10.
Hystrichospheres present	No	Yes	No	No	No	Yes	No	Yes
Total Grains counted	65	201	130	103	9	211	212	125

TABLE A.1(continued)
KUWAIT - S. IRAQ

Sample Numbers	16	17a	17b	17c	18	20	Total Average
Pinus	0.8	0	2.0	0	0	0	
Quercus	0	0	0	0	0	0	
Phoenix	0	0	0	0	0	0	-
Chenopodiaceae	65.0	32.0	60.0	51.	38.0	99.3	45%
Plantago	10.0	21.	6.0	17.	6.7	0	17%
Compositae (Liguliflorae)	0.8	8.0	10.	7.5	22.0	0.09	
Compositae (Tubuliflorae)	4.0	3.0	0	5.6	13.0	0	
Umbelliferae	0.8	1.0	5.3	0	3.3	0	
Boraginaceae	0	1.5	0	0	5.0	0	
Cruciferae	3.2	3.0	0.6	3.7	1.0	0	18%
Geranaceae	0	0	0	0	0	0	
Malvaceae	0	0	0	0	0	0.18	
Liliaceae	0	0	0.3	0	0	0	
Leguminosae	0.8	1.0	1.0	0	1.0	0	
Tribulus	0	0	0	0	0	0	
Nitraria	0	0	0	0	0	0	
Zygophyllum	0	0	0	0	0	0	
Gramineae	5.6	0.5	3.0	1.8	1.6	2.8	
Cyperus conglomeratus	0.8	3.0	5.0	3.7	0	0	
Ephedra	0.8	1.0	1.0	0	0	0	
Nuphar	0	1.5	0	0	0	0	
Potamogeton	1.5	5.0	0	0	0	0	
Typha-Sparganum	0	0	0	0	0	0	
Unknown or unidentifiable	5.6	18.	9.0	2.5	8.3	0	
Hystrichospheres present	No	No	No	No	No	Yes	
Total Grains counted	125	193	282	510	59	1063	

TABLE A.1(continued)
KUWAIT - S. IRAQ.

1 includes 9% algal cysts counted with pollen, .5% *Rumex* and .5% *Amygdalus*.

3 includes 30% unidentified diporate, 2% *Ranunculus*, .3% *Alnus*, .3% *Artemisia*.

4 includes 4% *Convolvulus*, 1% *Tamarix*.

5 includes .3% other Cyperaceae (not *C. comglomeratus*)

6 low pollen

7 includes 1.8% *Tamarix*, .9% *Aizoon*

8 includes .5% Boraginaceae, .5% *Aizoon*, .5% *Eucalyptus*.

9 includes .5% *Frankenia*

#12 includes 2.3% *Tamarix*

#13b - low pollen - 6% Chenopodiaceae, 2% *Plantago*, 1% Compositae.

#13c and 13d - low pollen (mud-skipper zone)

#19 - no pollen (sea-water)

#20 includes .28% *Mesembryanthemum*, .18 *Tamarix*.

TABLE A.2

SURFACE POLLEN PERCENTAGES

JORDAN

	1	2a	2b	3a	4	5	6a	6b
Pinus	0.4	0.8	1.9	0	6.0	6.4	1.4	0
Quercus	3.0	0.6	0	27.	22.	0	0.4	0
Pistacia	0.4	0	0	0	0	0	0.3	0
Fraxinus	62.	0.4	0	0	0	0	0	0
Other Oleaceae	2.8	0	0.6	0	0	0	4.0	1.9
Eucalyptus	0	0	0	0.6	0	0	0	0.5
Salix	0	0	0	0	9.0	0	0	0
Betulaceae	0	0.2	0	0	0	0	0.4	0.5
Juglans	0	0	0.6	0	0	0	0.2	0
Poterium spinosa	0	0	0	0.6	0	0	0	0.5
Other Rosaceae	0.4	0	5.6	0.6	0	0	0.14	1.4
Chenopodiaceae	4.7	2.0	46.	1.3	19.	0	0	4.0
Plantago	2.0	0.2	7.6	7.0	0	0	0	0
Artemisia	0.4	0	0	0.6	0	3.2	0	0
Liguliflorae	1.2	0.4	1.3	16.0	0	6.4	8.0	23.0
Tubuliflorae	3.6	84.	13.0	8.0	38.	9.6	1.9	5.5
Boraginaceae	0	2.0	0	0.6	0	0	0.8	1.9
Umbelliferae	0.8	0.6	2.5	5.7	0	0	1.0	0.9
Cruciferae	0.4	0.6	1.9	5.7	0	0	4.5	3.2
Leguminosae	5.6	0	0.6	1.3	0	0	1.3	0
Liliaceae-Iridaceae	0	0	0	0	0	0	0.3	0
Ephedra	0.4	0	0	0.6	3.0	0	0	0.4
Cereal	1.2	0.2	0	0	3.0	0	65.	0
Other Gramineae	0.2	4.0	8.2	7.6	0	3.2	7.3	7.0
Cyperaceae	0.4	0	0.6	0	0	0	0	1.9
Unknown or Unidentifiable	10.	4.0	9.5	16.0	0	0	2.8	48.
Total Grains Counted	251	506	158	156	521	31	668	215

TABLE A.2 (continued)
SURFACE POLLEN PERCENTAGES, JORDAN

	7	9	10b	11	13	15	16	20
Pinus	45.0	0	0	5.6	1.1	0.3	0	0.3
Quercus	0	2.0	0	1.1	0	5.5	0	0.3
Pistacia	0	0	2.0	0	0.3	0	1.0	0
Fraxinus	0	0	0	0	0	0	0	0
Other Oleaceae	0.8	2.0	0	0	0	3.7	2.0	0
Eucalyptus	0	0.7	0	1.1	0	0	0	0.3
Salix	2.0	3.0	0	6.7	1.9	0	0	0
Betulaceae	0.4	0	0	0	0	0	0	0
Juglans	3.6	0.7	0	0	0	0	0	0
Poterium spinosa	0	0	0	0	0	1.2	0	0
Other Rosaceae	0.4	0	0	1.1	0	0	0	0
Chenopodiaceae	0.8	1.5	76.0	7.9	5.3	4.0	2.0	67.0
Plantago	0	2.0	0	7.9	14.5	1.2	0	2.0
Artemisia	0.8	3.5	0	1.1	0	1.2	3.0	0
Liguliflorae	5.2	2.0	0	10.1	2.2	0.6	0	0
Tubuliflorae	0.8	0	4.2	11.2	36.0	5.6	6.0	6.0
Boraginaceae	0.8	2.0	0	7.9	2.6	3.7	0	9.0
Umbelliferae	0.8	7.0	0	3.4	4.1	14.0	0	0.7
Cruciferae	8.8	0.7	0	12.3	1.5	0.6	0	3.0
Leguminosae	0	6.4	0	5.6	17.0	50.0	1.0	8.5
Liliaceae-Iridaceae	0.4	0.2	2.0	0	0	1.2	0	0
Ephedra	0	0		1.1	0	0.9	0	3.0
Cereal	1.6	4.5	10.8	0	1.9	0.9	0	0
Other Gramineae	16.0	39.0	4.2	0	4.9	1.8	1.0	1.0
Cyperaceae	0	0	0	0	0	0	0	0
Unknown or Unidentifiable	13.	22.	0	14.5	6.4	3.7	84	0
Total Grains Counted	248	139	43	89	262	325	100	291

TABLE A.3

DESCRIPTIONS OF JORDANIAN SURFACE-SAMPLE SITES

Sample Number	Description of Site	Comments
1	Agricultural land, newly plowed, dried ruderal vegetation; ppt. 365	25 "unknowns" include 10 oblate tricolpate grains with little or no sculpture
2a (mud from edge of stream)	(a) Stream in valley, grass along stream edge, *Nerium* nearby, *Quercus* on hills. Dead litter, esp. Compositae; ppt. 100 mm	78% *Echinops* pollen
2b (moss)		46% Chenopodiaceae pollen
3 Soil, litter	*Acacia*, Shrubby Chenopodiaceae, Abundant dried annual vegetation	
4a Soil, litter on hillside near village of Sult	(a) Ruderal vegetation, Rosaceous fruit trees, Carob, Poplar ppt. 200 mm	
4b Bottom of watering trough		Pollen from water trough poorly preserved, and low content
5a litter & soil	Degraded Agricultural Vegetation, Gramineae, Labiatae, dried herbaceous vegetation 1100 m. elev.; ppt. 375 mm	26 Pollen grains only, poorly preserved.
5b litter & soil		
6a soil & litter in wheat-field	Agricultural land, stubble of wheat field, ruderal and herbaceous	65% *Triticum* pollen in (a)

TABLE A.3 (continued)

6b soil & litter 100 m from field	ppt. 350 mm	no *Triticum* pollen in (b) both samples high in in Liguliflorae
7	Near Amman, natural vegetation, Pines on slopes, ppt. 364	45% Pinus Gramineae 16%
8 soil & litter	Near restored reservoir ppt. 225	no pollen
9 soil & litter	Barley cultivated next to Wadi Desert annuals (dried), several Gramineae species	High in Gramineae 4.3% Cereal, 39% Gramineae
10a	Dried natural vegetation scattered perennial vegetation	Low pollen content 76% Chenopodiaceae 10% Cereal
10b		99.5% Cruciferae .5% unknown
11	Run-off vegetation in and around Wadis; ppt. 60 mm	*Pinus*, *Salix* 14% Arboreal pollen
12 Jurf ed-Darweesh	Near old lacustrine sediments *Anabasis*, *Anthemis* in hollows	Low pollen content few grains of Chenopodiaceae pollen
13 soil & litter	Dried annuals: Boraginaceae, Compositae	74% *Centaurea* 38% *Plantago* 45% Leguminosae
14	*Anabis* Community, Stipagrostis *Panicum*, Run-off area, barley cultivation; ppt. 70 mm	Low pollen content
15 soil & litter	Remnants of scrubby oak, severely degraded vegetation ppt. 300 mm	5.5% *Quercus* Leguminosae 50%
16 soil & litter	*Anabasis* community, Stipagrostis *Panicum turgidum*, run-off area barley cultivation; ppt 70 mm	84% unknown grain
17 soil	Barren dessert	Low pollen content

TABLE A.3 (continued)

18 soil	Barren dessert	Low pollen content
19 soil	*Anabasis* community near shore very low cover	No pollen, many fungal spores
20 Wadi Rum soil	Wadi Rum, *Haloxylon* thicket Acacia in wadis	67% Chenopodiaceae
21 soil	*Retama* communitae	Low pollen

TABLE A.4

SURFACE POLLEN PERCENTAGES, RUB'AL-KHALI

	#1	#2	#3	#4	#5	#6	#7	#8
Chenopodiaceae	99.5	1.8	0	0.2	6.4	5.5	11.	0
Limeum	0	6.3	9.0	3.4	0.9	0	4.5	3.8
Calligonum	0	31.	25.	0	0	9.0	0.4	38.
Dipterygium	0	6.0	12.3	7.8	5.8	14.	6.4	5.7
Tribulus	0	0	0	0	0.5	0	0.9	0
Fagonia	0	0	6.8	0	0	0	1.8	0
*Cistaceae (?)	0	9.0	41.	4.4	13.	27.	37.	20.
Plantago	0	0	0	0.2	0	0	0.9	1.9
Gramineae	0	0.9	2.2	1.9	0.6	0	1.9	0
Cyperus	0	50.	0	80.	69.	25.	19.	50.
Unknown	0.7	1.0	2.3	3.0	5.0	22.0	10.	3.8
Pollen Sum	504	222	224	204	341	336	109	104

#1 also contained 0.2% *Ephedra*
#2 also contained 0.9% *Teuchrium*
#4 also contained 0.4% Cruciferae
#7 also contained 0.9% *Zizyphus*, 2.7% Compositae

* This pollen type has not been positively identified but has characteristics of Family Cistaceae. Several *Helianthemum* species occur in deserts of Saudi Arabia but have not been reported from the Rub'al-Khali.

APPENDIX B

SURFACE POLLEN SAMPLES FROM DHAHRAN, RIYADH AND JEDDAH, SAUDI ARABIA

In addition to the sites in the Rub'al-Khali, four additional samples were obtained within Saudi Arabia (Fig. 16). Because these samples came from a few widely-separated sites and because the samples were obtained from such different environments, it is difficult to compare them to each other or to other regions which were sampled. Nevertheless it seems appropriate to include the results here (Table 16).

The first sample was obtained from a saline sink-hole near Dammam. The muddy area around the edge was salt-encrusted and the salinity of the immediate surroundings was such that no vegetation at all occurred. The nearest vegetation was non-halophytic -- several clumps of *Cyperus conglomeratus*. Chenopodiaceae pollen was 32% of the total, Gramineae only 0.9%.

The second sample was obtained only about ten kilometers from the first sample. It came from mud-cracks in a naturally vegetated region watered by the irrigation run-off from a well-landscaped university campus compound. Here Chenopodiaceae was 46%, but Gramineae was 26%, probably due to the native and naturalized grasses growing around the run-off area.

In Riyadh the sample was obtained from wind-blown dust which had accumulated on the balcony and window sills of an unoccupied second story apartment. Its location in the heart of Riyadh explains the relatively high percentages of pollen of planted vegetation, *Eucalyptus*, Rosaceae, and Leguminosae. Onagraceae pollen is probably due to one or more species of *Epilobium* which are characteristic of oasis environments.

The samples from Jeddah were also taken from dust accumulation in the balcony and window sills of an uninhabited apartment, but on the fourth floor and at the edge of the city. The high percentage of Gramineae pollen (25% as compared to 4% at Riyadh) must be due to long distance transport, as there is certainly little in the way of grassland around Jeddah.

TABLE B.1

SURFACE POLLEN PERCENTAGES, DHAHRAN, RIYADH, JEDDAH, SAUDI ARABIA

	A	B	C	D
Pinus	1.3	2.5	0	1.3
Tamarix	2.7	8.3	0	0
Leguminosae	0.9	1.9	4.7	0
Chenopodiaceae	32.0	36.0	24.0	35.0
Plantago	12.0	9.0	22.0	5.5
Cruciferae	1.8	0	1.6	2.0
Umbelliferae	2.2	0.7	0.8	0.6
Boraginaccae	0	1.3	1.6	0
Compositae				
(Tubuliflorae)	2.2	1.9	1.6	2.0
(Liguliflorae)	12.3	3.2	11.0	0.6
Cyperus conglomeratus	16.0	2.5	0	5.5
Gramineae	0.99	26.0	5.5	25.0
Ephedra	0	0	0.8	2.0
Pollen Summary	235	200	126	143

A - Dhahran-Damman saline sinkhole, also includes 0.4% *Nitraria*, 0.4% *Zygophyllum*.

B - Dhahran mudcracks, also includes 1.3% Boraginaceae, 5% unknown.

C - Riyadh wind-blown dust, also includes 0.8% *Zizyphus*, 4.7% *Eucalyptus*, 4.6% Onagraceae, 3.0% Rosaceae, 1.6% Polygonaceae, 2.3% *Cannibis* type, 2.3% *Artemisia herba-alba*, 7.2% unknown.

D - Jeddah wind-blown dust, also includes 0.6% *Acacia*, 1.8% *Emex*, 2.0% *Convolvulus*, 2.8% Polygonaceae, 14% unknown.

APPENDIX C

FOSSIL POLLEN PERCENTAGES, NORTHERN ARABO-PERSIAN GULF

TABLE 17

FOSSIL POLLEN PERCENTAGES, NORTHERN ARABO-PERSIAN GULF

	KMO 4C-2	KMO 4C-2	KMO 4C-2
Pollen Types	0-4 cm	15-20	30-34
Pinus	0	4.0	0
Quercus	7.0	6.0	5.0
Pistacia	2.0	0	1.0
Other AP	0.4	0	0
Chenopodiaceae	29.0	40.0	50.0
Plantago	4.0	6.0	20.0
Artemisia	0.8	0	1
Other Compositae	3.0	6.0	6.0
Cruciferae	0.4	0	0
Umbelliferae	0	0	0
Leguminosae	0.8	0	0
Gramineae	22.0	15.0	5.0
Cyperus Conglomeratus	1.5	0	5.0
Potamogeton-Sparganum-Typha	9.0	0	1.0
Other herbaceous pollen	3.2	0	0
Unknown	4.0	10	0
Other Palynomorphs			
Pediastrum	0.8	0	0
Hystrichospheres	0	6.0	5.0
Coiled Forams			+

TABLE C.1 (continued)

	KAB-3	EF-3	KBU-5W	SBU-6 0-5 cm	SBU-6 45-50 cm
Pollen Types					
Pinus	2.0	2.5	6.0	5.0	4.0
Quercus	1.2	2.0	2.0	0	3.0
Pistacia	0.8	1.0	0	2.0	0
Other AP	0.16	1.2	0.3	0	0
Chenopodiaceae	49.	56.	45.	48.	44.
Plantago	4.5	18.0	2.0	14.0	8.0
Artemisia	0.16	0	0	0.6	0
Other Compositae	1.6	2.5	4.0	8.0	8.0
Cruciferae	0.8	5.0	0	2.5	4.0
Umbelliferae	1.0	0	4.0	1.2	1.4
Leguminosae	2.2	2.5	1.0	0	0
Gramineae	9.0	0	2.0	1.2	1.4
Cyperus Conglomeratus	3.0	1.2	3.0	0	3.0
Potamogeton-Sparganum-Typha	12.0	0	10.0	4.0	4.4
Other herbaceous pollen	2.16	5.0	8.0	7.0	8.0
Unknown	10.0	3.0	10.0	3.0	8.0
Other Palynomorphs					
Pediastrum	0	0	0	0	4.0
Hystrichospheres		0	3.0	2.5	0
Coiled Forams	0	0	0	+	0

TABLE C.1 (continued)

	KML4A	KML2	KMC 25	KMC45
Pollen Types				
Pinus	0	2.0	0	0
Quercus	4.0	2.3	1.2	6.0
Pistacia	0.8	0	7.0	0
Other AP	0.8	0	1.2	1.5
Chenopodiaceae	23.0	15.2	58.0	54.0
Plantago	2.0	10.7	5.0	3.0
Artemisia	0	0.8	0	0
Other Compositae	4.0	1.6	4.0	3.0
Cruciferae		0.8	0	3.0
Umbelliferae	4.0	3.7	1.2	3.0
Leguminosae	1.8	0	0	0
Gramineae	50.0	46.0	6.5	0
Cyperus Conglomeratus	0.8	1.8	0	3
Potamogeton-Sparganum-Typha	0.8	11.5	8.0	4.4
Other herbaceous pollen	3.8	0	4.0	9.4
Unknown	0	4.5	3.0	10.0
Other Palynomorphs				
Pediastrum	3.0	1.2	0	0
Hystrichospheres	+	+	7.0	0
Coiled Forams	0	0	+	0

APPENDIX D

FOSSIL POLLEN PERCENTAGES, RUB'AL-KHALI

TABLE D.1

FOSSIL POLLEN PERCENTAGES, RUB'AL-KHALI

	I2(i)	II-2	II-2-1&2	II-3	III	JG-1	AS31	XXB5
Pinus	0	3.0	1.5	0	0	0	0	6.0
Tamarix	0	6.0	0.6	5.0	0	0	0	6.0
Chenopodiaceae	30.	31.	29.	52.	40.	68.	80.	35.
Plantago	10.0	12.	8.4	10.0	10.0	3.9	0.8	12.
Boraginaceae	0	0	0.3	0	0	0	0	0
Compositae	0	3.0	2.2	1.0	10.0	19.	0.8	0
Umbelliferae	0	0	0.7	2.0	5.0	0	0	0
Cruciferae	10.	0	1.8	2.0	0	0	0	0
Zizyphus	0	0	2.4	1.0	5.0	0	0	0
Geranaceae	0	0	1.1	0	0	0	0	0
Calligonum	0	0	2.8	0	0	0	0	0
Leguminosae	0	0	0	0	0	0	1.6	0
Gramineae	20.	27.	19.1	15.	10.0	3.9	0	6.0
Cyperus conglomeratus	0	6.0	0	0	0	0	0	6.0
Typha	0	0	0	2.5	0	0	0	0
Sparganum-Potamogeton	0	6.0	8.3	0	0	0	0	6.0
Unknown	20.	6.0	21.8	9.5	20.	5.0	16.	23.
Pollen Sum	20	82	274	200	20	102	220	40

Biographical Note

Ann Paxton El-Moslimany

Born: August 2, 1937 in Fullerton, California

Parents: Donald Dorn Paxton
Sarah Frances Paxton (Nee Turman)

Married to: Dr. Mohammad A. El-Moslimany
Children: Samia, Ramsey, Rasheed

Education: Highland High School, Albuquerque, New Mexico.
The Mount, London, England.
New Mexico State University, B. Sc. Biology.
American University of Beirut, M. Sc. Biology (Plant Ecology)
Thesis: A Study of Secondary Succession on a Mountain near Turbol, Bekaa Valley, Lebanon

Publication: The late Quaternary vegetational history of the Zagros and Taurus Mountains in the regions of Lake Mirabad, Lake Zeribar and Lake Van - A Reappraisal (1982). In Palaeoclimates, Palaeoenvironments, and Human Communities in the Eastern Mediterranean Region in Later Prehistory (J. Bintliff and W. van Zeist, Eds.) BAR Series 133(ii), Oxford.