1 Climate changes in the Levant during the Late Quaternary Period

At a rather early stage of the research to be reported in this book, it was decided to use the connections between climate changes, hydrological and socio-economic systems in the Levant in order to establish a basic reference sequence of climate changes during the Holocene. Once this had been accomplished, this sequence would be correlated with other regions over the globe. This decision was based on the following observations.

1. This region is a transition zone between two climate belts: the westerlies system and the sub-tropical or intertropical convergence zone (ITCZ) overlying the Arabian–Sahara desert belt. The rate of movement of these two belts north and south affects the mean annual quantity of rain, as well as its variability from year to year. Consequently, the positions in the past of these belts that affect the Mediterranean region's climatic regime and hydrological cycle may provide information reflecting global climate changes.
2. The Nile, which reflects the easterlies and the tropical climate regime over eastern Africa, reaches the Mediterranean and its sediments reflect the history of the climate changes over its watershed.
3. The relatively moderate size of the Mediterranean region, causing climate changes to be rather synchronous (although not absolute) over most of the area, enables establishment of a regional climate change chronology.
4. The long history of human societies in this region, the abundance of documents and archaeological excavations, all facilitate investigation of the impact of climate changes on past socio-economic systems.

1.1 CONTEMPORARY CLIMATE

The Levant is affected by two climate systems. During winter, the westerlies bring in cyclonic low barometric pressures, causing cold air masses to arrive from the Atlantic and the North Sea. These travel over the relatively warm Mediterranean and become saturated by moisture, which is discharged as rain and snow. The rate of movement of the belts southwestward and, therefore, the number, intensity and duration of the rainstorms reaching the region, varies from year to year. When a belt of high pressure remains over the area, rainstorms are less abundant and the year is dry. Because of the configuration of the coastline of the southeastern edge of the Mediterranean Sea, the deserts of northern Egypt, Sinai, the Negev and southern Jordan lie outside the main path of rainstorms approaching from the west.

As can be seen from the multi-annual precipitation map (Fig. 1.1), precipitation usually declines to the south and the east. Yet the topography also has an influence. For example, the rift valleys are in the shadow of the rain coming from the sea and, therefore, are relatively arid, while the mountains receive more rain and snow in winter. The scarcity of rains and the high variance in rainfall from year to year become increasingly great as one goes farther into the desert. Rains in the desert, therefore, are characterized by scarcity and randomness.

Precipitation takes place during the winter months, from November to March. This is an advantage over other regions where rain falls in the summer. The temperatures during the winter are relatively low, which means that evaporation is also low. Consequently, the relative effect of the winter rains is rather high. The development of high-pressure systems often follows the low-pressure systems and causes clear and cold weather conditions. Many of the rainstorms, affected by a barometric low in the northern and central part of this region, enter the desert areas as smaller eddies on the margins of the bigger cone of low barometric pressure. They form small convective cells, a few to tens of kilometers in diameter. This causes rain to fall on a limited area around the center of the cell – other more peripheral areas may remain dry. Such a rainstorm may be of high intensity and last for only a few minutes, or it may continue for up to a few hours. Sometimes precipitation descends as hail, and it may snow at the higher elevations during a cold winter. Rainstorms may be preceded by a barometric high over the desert area. In this case, a flow of dry, hot air from the desert blows dust, which flows in the direction of the barometric low. In the autumn and spring, when dust storms are most abundant, the hot,

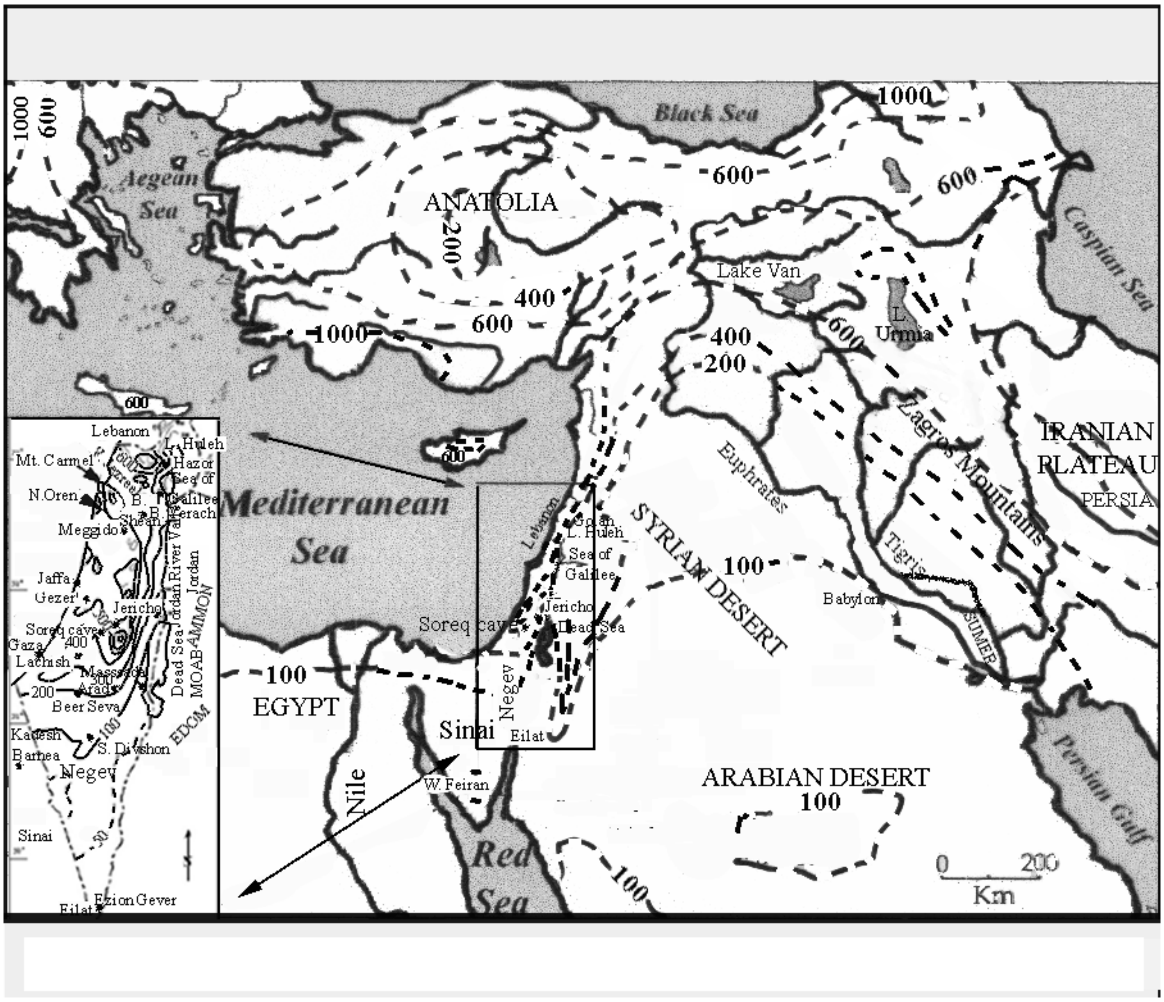

Fig. 1.1. Map of the Middle East showing the multi-annual precipitation (mm per year).

dry periods (known locally as *khamsin*) can come to an abrupt end with a heavy rainstorm. Most dust storms are connected with a barometric high over the continent and lows approaching from the sea.

The Mediterranean Sea acts as a gigantic temperature regulator, because of the high heat capacity of the water. As distance from the sea increases, the regulatory effect decreases. As a result, the temperature differences between day and night, as well as seasonal temperatures, are high. The influence of the Red Sea, the Dead Sea and the Persian Gulf, which are enclosed in narrow depressions, is limited to their very close vicinities. Thus, in the desert areas, the differences between day and night temperatures may reach 15 °C and in some extremes even 20 °C. In summer, the temperature can reach 40 °C during the day, while during the night it drops to about 25 °C. On a winter night, the temperature may fall below 0 °C, while during the day it may reach 20 °C. Ambient air temperature increases in a directional pattern, similar to that of regional precipitation. (In northern Syria, the average temperature is 5 °C in January and 24 °C in August; in Beirut, it is 13 °C in January and 27 °C in August.)

For inhabitants of these areas, the severity of the high and low temperatures is compensated for by the dryness of the weather during most of the year. This relieves heat stress, since perspiration can evaporate. Humans will feel comparatively comfortable if not exposed to direct sun radiation. However, the dryness causes high evaporation rates from the surface of water bodies and high transpiration rates from vegetation.

During the summer, the weather is less variable, being affected by the semi-permanent surface heat trough centered over Iran and Iraq. This surface trough is coupled with an upper air high-pressure system, producing stable, hot and dry weather. During the autumn (mainly October to November), cool and moist air masses occasionally penetrate the region from the north and produce rainfall. Spring (mainly March to April) is characterized by frequent occurrences of *khamsins* and dust storms, although some rainfall may occur.

Overall, six main air masses, originating over the following areas, affect the weather over the Levant:

1. The Arctic Ocean;
2. The Atlantic Ocean, south and west of Iceland;
3. Northern Russia and Siberia;
4. Northern Russia, being modified while passing over the Volga–Ural basins;
5. The Atlantic Ocean south of the Azores;
6. The North African and Syrian–Arabian desert.

Air masses of the first four areas originate at high latitudes and are characterized by low temperatures and dryness. The masses acquire moisture as they pass over the Mediterranean Sea. The last two air masses originate at low latitudes and are characterized by high temperatures, and dryness, which they maintain.

Rainfall in the Middle East, on the whole, has an inverse correlation with temperature, except in areas under the influence of the summer rainfall regime (Crown, 1972). A synoptic analysis of excessive rainfalls in Israel (Amiran and Gilead, 1954) shows that they are the result of an influx of deep, moist and cold polar air into the eastern Mediterranean along meridian trajectories, which makes contact with the warm surface air in a Cyprus low. With the build-up of the Siberian anticyclone as winter progresses, this situation becomes less probable. There is less chance of a strong jet stream forming over central Europe and the Mediterranean that would feed sufficient air into such a rainfall-causing circulation system. Such excessive rains are, therefore, restricted to the beginning of the season, i.e., November or December.

Aridity in the Levant has three general causes (Otterman, 1974):

- separation of the region from oceanic moisture sources owing to distance or topography (rain shadow);
- the existence of dry stable air masses that resist convective currents;
- the absence of a course of events that cause convergence to create unstable air masses and provide the lifting necessary for precipitation.

Zangvil (1979) investigated the temporal fluctuations of seasonal precipitation in Jerusalem during the period 1946/47 to 1953/54. He employed time spectrum analysis and filtering techniques. A prominent peak appeared in the spectrum at a period of 3.0–3.3 years. (Rainfall oscillations in California also show a peak around 3 years.) The most prominent peak in the spectra occurred at 3.3 years at most of the East African stations. A more than average rainfall in east Africa during the main rain period of January to April is probably associated with a more intense Hadley circulation. This circulation causes strong westerlies in the same longitude, resulting in reduced rainfall in the eastern Mediterranean. Zangvil (1979) suggests that there is, perhaps, a connection between the El Niño southern oscillation (ENSO) and the rainfall in Jerusalem. The ENSO is a world-wide phenomenon, having a dominant period of 3 to 6 years, which corresponds to Jerusalem rainfall oscillations, the first peak at 3.0–3.3 years and the secondary one at 5 years. A similar observation for the eastern part of the Iberian peninsula was found by Rodó *et al*. (1997).

Analyses of the multi-annual trends of variation of precipitation (Alpert *et al.,* 2002; Ben-Gai *et al.,* 1998) have shown that, while there is a general decrease in the overall quantities of precipitation over the Mediterranean region, there is a trend for an increase in the number of rainstorms of high intensity and for either rainier or drier years within the average rainstorms and years.

1.2 THE CLIMATE DURING THE LATE PLEISTOCENE

In general, the climates during glacial periods of the Quaternary, evidenced in the Mediterranean region by sea regressions, were cold, while interglacial and post-glacial periods, evidenced by transgressions, were warm and dry (Horowitz, 1989). In the coastal plains this resulted in the accumulation of black and brown clayey soils in the marshy areas and red loamy soils on the sandstone outcrops. In the mountain areas on the limestone rocks, terra rosa type soils developed. During the interglacial periods, the deposits of sands and the formation of coastal dunes along the coastal plain indicate a warmer and drier climate, as well as an increased supply of sands. These were brought from the delta of the Nile by the Mediterranean counter-clockwise currents (Emery and Neev, 1960; Issar, 1968, 1979; Rohrlich and Goldsmith, 1984). However, during a short period at the climax of the glacial periods, it seems that the climate became dry (Bar-Matthews *et al.,* 1997), possibly because it fell under the influence of the continental high-pressure zone of eastern Europe. The climate during the Last Glacial Period was not different, namely generally cold and humid, except during its climax. During this glacial period, the water found under the Negev and Sinai deserts in the Nubian sandstone layers was recharged. This is evidenced by its carbon-14 (^{14}C) age (which ranges between 30,000 and 20,000 (30 ka and 20 ka) while the oxygen-18 (^{18}O) to deuterium ratios show an Atlantic, rather than a Mediterranean, pattern (Gat and Issar, 1974). By comparing these ratios with the isotopic composition of contemporary rains and their relation to the trajectories of the rainstorms (Leguy *et al.,* 1983), Issar and Bruins (1983) have suggested that during the Last Glacial Period, a west to southwest trajectory of cyclonic lows was dominant. These came over the Mediterranean to reach the Sinai and the Negev, after entering and crossing the Libyan desert and Egypt. These lows intensified dust storm activity, to be followed by torrential rains. This caused the deposition of a loess layer some tens of meters thick (Issar, 1990). In the southern Sinai, shallow lakes extended all along the drainage basin of Wadi Feiran; the ^{14}C dates of the sediments were 24 ka BP (Issar and Eckstein, 1969). At the end of the glacial periods, at *c*. 15 ka BP, the deposition of loess became considerably less and, instead, the activity of sand dunes was extended. In the sand layers overlying the loess, epi-Paleolithic type tools were found (Goring-Morris and Goldberg, 1990; Issar and Tsoar, 1987; Issar *et al.,* 1989). Geyh (1994), on the basis of isotopic oxygen and carbon in the paleo-water under the deserts of the eastern Mediterranean, came also to the conclusion that the movement southward of the ITCZ can explain the pronounced climatic variations that characterized the transition from the Late Pleistocene Epoch to the Holocene Epoch. When warmer conditions prevailed, the regions governed by the westerlies became drier while the monsoonal regions became more humid (Geyh, 1994).

A calcareous layer is found in the upper part of the loess section all over the northern Negev (Bruins, 1976; Bruins and Yaalon, 1979). It was deposited *c*. 13 ka BP, according to radiocarbon dating by Goodfriend and Magaritz (1988). Whether this calcareous horizon is synchronous with the deposition of the loess or was formed later needs further investigation. In my opinion, it is epigenetic and the result of flushing of carbonates and sulfates from overlying layers and their deposition at a certain depth during a period of higher summer rains. This is inferred from the composition of the heavy oxygen and carbon isotopes in the stalagmites of Soreq Cave, which rose abruptly from 13.5 ka to *c*. 11.5 ka BP (Bar-Matthews *et al.,* 1997). The higher $^{13}C/^{14}C$ ratio points to the increase of C4 type vegetation, while the higher $^{18}O/^{16}O$ ratio suggests a warmer climate. These two indicators together would indicate a savanna landscape. In such a landscape, the topsoil becomes enriched in salts during the dry period as a result of evapo-transpiration, while during the rain season these salts are partially leached downwards because of the general decrease in precipitation caused by the warmer climate. The fact that the summer rains coming from the Indian Ocean system were abundant during this period is indicated by the freshwater lake deposits in the erosion cirque of Djebel Maghara in northern Sinai (Goldberg, 1977). Abundant arboreal pollen from this period, which was found in the central Negev, is additional evidence for a savanna habitat in a region that at present holds only a few trees along the riverbeds.

During the Last Glacial Period, the paleo Dead Sea, which at that time extended over most of the Jordan Valley and was known as Lake Lisan (Picard, 1943), clearly had a humid period during the Late Pleistocene, resulting in Lisan-type greenish-gray and laminated clay sediments (Neev and Emery, 1967). Lake Lisan proper was first formed *c*. 70 ka BP and after a few fluctuations it reached its maximum level of approximately 164 m below MSL at *c*. 25 ka BP. It stayed at this level for about 2000 years and then the level started to fall until, at *c*. 10 ka it was approximately 325 m below mean sea level (MSL) (Bartov *et al.,* 2002), or even 350 m below MSL (Begin *et al.,* 1985).

Stiller and Hutchinson (1980), investigating the stable isotopic composition of carbonates of a 54 m core in Lake Huleh, northern Israel, found ^{18}O data which suggested that no very drastic climatic changes occurred.

Based on palynological data, Van Zeist (1980) claims that from 24 ka to 14 ka BP it was colder and markedly drier than today and from 14 ka to 10 ka BP, there was an increase in temperatures. Many sites suggest a distinct rise in humidity around 14 ka BP.

Pollen diagrams from Lake Zeribar, Kurdistan, Zagros Mountains (El-Moslimany, 1986) show the absence of trees during the last glacial period and the migration of forest into the region between 10 and 5.5 ka BP. This has been interpreted as indicating aridity during the Pleistocene, with gradually increasing precipitation during its late glacial phase and the Holocene. However, the sensitivity of these species (*Quercus aegitops* and the associated *Pistacia atlantica* var. *mutica* and *Pistacia khinjuk*) to snow and their tolerance of low overall precipitation indicate that higher snowfall, rather than low precipitation, was the reason they did not thrive during the Pleistocene.

Stevens *et al*. (2001) investigated a core from the same lake and argue that low ^{18}O values would suggest a relative increase in winter rains rather than overall changes in effective moisture, and vice versa. Also Griffiths *et al*. (2001) argue for changes in the seasonality of the rains as an important factor in determining the nature of the sediments at Lake Mirabad, which is situated in the same region.

Based on continuous pollen diagrams from boreholes that penetrated the entire Quaternary sequences of the Hula (Huleh) and Dead Sea lakes, Horowitz (1979, 1989) concludes that the Dead Sea served as a continental base level throughout this period. According to Horowitz, the glacial phases in Israel were manifested by periods of somewhat lower temperatures and higher rainfall, some of it in the summer. The interglacials were hot and dry, with Saharan conditions prevailing. The interstadials had the character of a present-day short, rainy winter and a long, dry, hot summer. It is possible that short dry phases might have occurred in Israel at peaks in the glacial phases, but in general, the periods recorded by low sea levels had a wet climate.

Leroi-Gourhan (1974, 1980, 1981), investigating pollen spectra in the Middle East, found that there were fluctuations of wet and dry phases as well as of temperature during the Lower and Middle Würm. The cold–wet maximum seems to be dated around 45 ka BP, while drought conditions characterized the coldest Würmian phase. This probably explains the scarcity of archaeological evidence of occupation between 23 and 19 ka BP. The Late Glacial Period showed some improvements in climate, dated to 17 ka, 13.5 ka and 12 ka BP. Thereafter, a richer and more diversified flora marked the beginning of the Holocene. Leroi-Gourhan maintains that the increase in pastoral and agricultural population densities since 10 ka BP influenced the soils and vegetation. There is enough evidence to allow us to conclude that it became more humid at about 10 ka BP.

Data from the pollen time series from epi-Paleolithic and Neolithic sites in the Jordan valley, including the regions of Fazael and Mallaha, led Darmon (1988) and Leroi-Gourhan (Leroi-Gourhan and Darmon, 1987) to suggest the following climate changes for the transition period from the Pleistocene to the Holocene:

1. Kebaran (*c*. 19 ka–14.5 ka BP): slightly humid;
2. Geometric Kebaran (*c*. 14.5 ka–12.5 ka BP): a humid period;
3. Natufian (*c*. 12.5 ka–10.3 ka BP): a humid period in the Early Natufian, but the climate progressively becoming drier through the end of the Natufian period;
4. Pre-pottery Neolithic ((PPN) A: *c*. 10 ka to 9.5 ka BP): wetter, marked development of trees, *c*. 10 ka BP; relatively forested conditions between 10.25 ka and 7.9 ka BP.

Weinstein (1976) investigated the late Quaternary vegetation of the northern Golan, manifested by the pollen assemblage of samples from borehole P/8, drilled at the center of the lake of Birket Ram. This is a rather small, elliptical volcanic crater lake, 900 m × 600 m, bordered by very steep slopes. The present average annual precipitation is 1000 mm. The fluctuations in pollen samples seen in this section are significant, and a more intensive dating effort should be carried out since dates are rather scarce. A gradual change from a more forested landscape to a Mediterranean one can be seen in the upper part of the section, from 39 to 30 m (at 36 m, ^{14}C age is 28,400 ± 3000 BP). The assemblage is 80% arboreal pollen, of which conifers constitute 88%. From 30 to 22.5 m, the arboreal assemblage is reduced to 33%, consisting of 75–80% *Quercus* sp. and 40% Irano-Turanian types. From 22.5 to 11.5 m, there is an increase in the arboreal assemblage to 60%, of which 89% is *Quercus* sp. and only 20% Irano-Turanian types. One can conclude that towards the upper part of the profile, presumably uppermost Pleistocene, the climate became more humid.

A geomorphological study was carried out by Sakaguchi (1987) in the district of Palmyra in the eastern arid part of Syria (present mean annual precipitation is 125 mm). This survey provided the evidence for the existence of a pluvial lake, which went through periods of high and low levels since at least 100 ka BP. A wet period of the lake ended *c*. 19–18 ka BP; later it became brackish to saline and totally dried up, leaving behind a sabkha. At 10 ka BP, it rejuvenated and existed until 8 ka BP.

A study by Klein *et al.* (1990), of fossil and modern *Porites* corals from reef terraces in the southeastern Sinai along the Red Sea, indicates that the sea level was higher and a wetter climate prevailed in Sinai during the Late Quaternary, possibly with a summer rainfall regime. Most fossil corals showed degrees of fluorescent banding after irradiation with long-wave ultraviolet light, while living *Porites* corals did not exhibit distinct fluorescent banding. The source of fluorescence is humic acid of terrestrial origin, as was found in corals from the Great Barrier Reef of Australia (Isdale and Kotwicki, 1987). The distinct fluorescent banding in the fossil Sinai corals is understood to be a function of periodic terrestrial runoff floods during the lifetime of the corals, irrespective of later events. Modern corals show skeletal banding patterns: low-density bands being deposited in summer and narrow high-density bands in winter. Fossil corals have a similar density-banding pattern. An important finding is that the fluorescent bands related to humic acid from runoff floods are superimposed on the low-density portions of the skeleton bands, which implies summer rainfall (Klein *et al.,* 1990). This is in accord with the conclusion, already mentioned, that during warmer periods the climate of Sinai was influenced by summer rains.

According to Herman (1989), surface water temperatures of the Mediterranean, during glacial temperature minima, were *c*. 3 °C lower than the present in summer and *c*. 3–4 °C lower in winter. Salinities were highest during the peak of the glacial period when climates were more arid than today. The sea level was very low (130–140 m below MSL); the discharge of the Nile was greatly reduced and the connection between the Mediterranean Sea and the Black Sea (Bosphorus sill at 36 m below BSL), which is a major supplier of low-salinity water, was reversed.

Thunell and Williams (1983, 1989) investigated the paleo-temperature and paleo-salinity history of the Eastern Mediterranean during the Late Quaternary. They maintain that the Mediterranean isotopic signal is a complex record of regional temperature and salinity changes superimposed on compositional changes caused by the global ice volume effect. Hydrographic conditions in the Mediterranean at 8 ka BP must have been considerably different from those at 18 ka BP as well as from those of today. The water balance at 8 ka BP became positive as precipitation and runoff exceeded evaporation. Salinities were considerably lower at 8 ka BP and the west–east (increasing) salinity gradient was reversed to an east–west gradient. This is supported by east African climate records, which indicate the onset of very humid conditions at *c*. 12.5 ka BP, with wettest conditions occurring between 10 ka and 8 ka BP. This was also a time of intensified African monsoons and increased Nile discharge.

Larsen and Evans (1978) reported on findings from layers of the Hammar Formation in the subsurface of the present delta of the Shat-el-Arab. These contained recent marine fauna. They consider these findings as evidence for a transgression phase starting *c*. 10 ka BP. The fresh and brackish water deposits with marine lenses overlying the Hammar Formation are interpreted as layers laid down in a deltaic environment, caused by the progradation of the delta to the southeast. This has advanced *c.* 180 km during the last 5000 years

Sanlaville (1992) carried out geomorphological investigations of the paleo-climate of the Arabian Peninsula and found that these four humid phases occurred during the Quaternary. The two earliest stages, between *c.* 128 ka and 105 ka BP (isotopic stage 5e) and between 85 ka and 70 ka BP (isotopic stage 5a), as well as the last one, which took place during the earlier part of the Holocene, could be correlated with northward movement of the monsoon rains. He attributed the wet inbetween phase, which occurred during isotope stage 2, to a southward migration of the westerlies belt.

It can be concluded that the transition period from the Pleistocene to the Holocene was one of general warming up, but with considerable fluctuations. In general, the frequency and intensity of the typical heavy dust and rainstorms, causing the deposition of the loess, decreased and, instead, the supply of sand and mobility of the sand dunes of the Sinai and Negev increased. This increase in the supply of sand resulted from the higher levels of the Nile and the strengthening of the rainstorm system over eastern Africa, The sand supply to the eastern Mediterranean was, probably, reinforced by the erosion of the Nile delta caused by the rise in the sea level. A warm period characterized by summer rains may be distinguished between 13 ka and 11 ka BP. This may have been followed by a cold humid spell, which more accurate dating may correlate with the Younger Dryas. This was followed by a warmer period, which continued until about 10.5 ka BP.

1.3 CLIMATE CHANGES DURING THE HOLOCENE IN THE LEVANT

The initial procedure adopted by the author to establish the sequence of climate changes during the Holocene was based on a chrono-stratigraphical cross section derived mainly from the sequence of ratios of $^{18}O/^{16}O$, with the ratios of $^{13}C/^{12}C$ as auxiliary data (Fig. 1.2). These isotopic data came from a core from the bottom of Lake Van in Turkey (Lemcke and Sturm, 1997), from a core at the bottom of the Sea of Galilee (Stiller *et al.,* 1983–84), from speleothemes of caves in upper Galilee (Issar (1990) based on M. A. Geyh *et al.,* unpublished data) and from the Soreq Cave in the Judean hills in the central part of Israel (Bar-Matthews *et al.,* 1998a,b) and from cores at the bottom of the eastern most part of the Mediterranean Sea (Luz, 1979; Schilman *et al.,* 2002). Needless to say, each time series has its advantages as well as constraints, especially when it comes to the dating of the various layers. Consequently, the time boundaries suggested in this cross section (Fig. 1.2) should be taken as a synthesis and a marker zone, which may fluctuate on the time dimension either because of the natural environment or because of the different methods of sampling and dating.

The reason for choosing sequences of ratios of $\delta^{18}O/^{16}O$ (the relative proportion of ^{18}O to ^{16}O in the sampled water compared with the isotopic composition of standard mean ocean water (SMOW)) as the most significant time series was because these ratios are strongly influenced by the ambient temperatures and climate regimes in general (Ferronsky and Polyakov, 1982; Fritz and Fontes, 1980; Gat, 1981) but are not influenced by anthropogenic activities. It was also assumed that, in the Middle East, the influence of climate changes on the $\delta^{18}O/^{16}O$ ratio could have been rather pronounced, based on the observation that the isotopic composition of contemporary rainwater is influenced by the trajectories of the rainstorms (Leguy *et al.,* 1983). There is no reason to suggest that such changes in the global climate regime would not have equally influenced these trajectories, and thus the $\delta^{18}O/^{16}O$, in the past. Therefore, interpretation of the stable isotope data as climate and humidity indicators follows the basic assumption that the $\delta^{18}O$ values of precipitation are interrelated with temperature (Geyh and Franke, 1970) and with other meteorological factors (such as changes in the storm trajectories, in the seasonal distribution of precipitation and humidity (Gat, 1981; Leguy *et al.,* 1983) and higher or lower rates of evaporation). This assumption was indeed justified by the interrelations that could be shown between the isotope time series and other proxy-data time series, as will be shown below.

As already mentioned, when correlation lines are drawn, small discrepancies caused by the dating and time scales used in the different data sources must be taken into consideration. These apply to the different amplitudes of the $\delta^{18}O$ records of the lake and sea sediments and of the speleothemes. For example, the water balance of the Sea of Galilee is also determined by an inflow of groundwater from the flanks of the rift valley. Spring water collected along the shore yielded ^{14}C dates of more than 10 ka BP. This would “dampen” the corresponding isotope variations. A certain retardation factor should be taken into consideration for the isotopic composition of the sediments of Lake Van, where part of its inflow comes from springs. In contrast, changes in $\delta^{18}O$ values of speleothemes reflect the fluctuations of isotope composition of the meteoric water over decades. The samples of 1 mm thickness analyzed represent age ranges of about 10 years.

In addition to the problems involved in the ^{14}C dates in relation to the isochrones, some other elements must be taken into consideration. First, the curves presented in the cross sections are modified by the running average method, in order to reduce the impact of noise created by short-term but intense fluctuations. Second, there are differences caused by the reservoir effect of the non-saturated and saturated zones in the subsurface of speleothemes, which is similar to the effect of groundwater storage for springs. Yet even with all these uncertainties, an apparent general

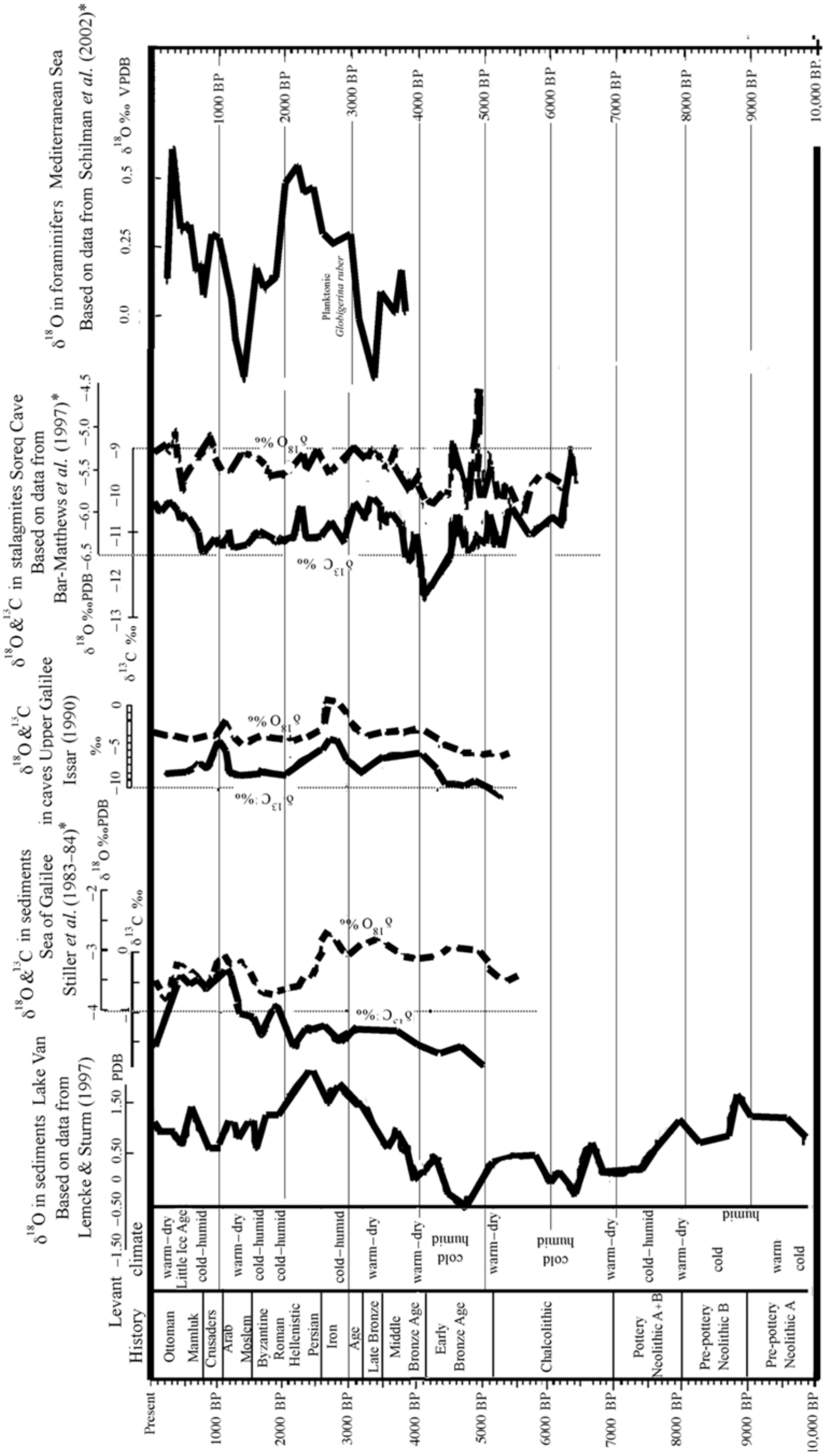

Fig. 1.2. Time series for environmental isotopes in the Middle East. *Adjusted to scale and streamlined (3–5) points by the running average method.

correlation of covariations can be observed. However, because of the problems outlined above, it is suggested that conclusions should also take into consideration other time series of natural proxy-data that are available for this region. These include the paleo-levels of the Mediterranean Sea, the ratios of planktonic foraminifers in the sediments of the eastern Mediterranean, and the Dead Sea lake levels (Fig. 1.3).

As presented in Fig. 1.2, the cross section starts with the $\delta^{18}O$ and $\delta^{13}C$ time series obtained from lacustrine carbonate cores drilled in Lake Van in Eastern Turkey (Lemcke and Sturm, 1997; Schoell, 1978), which is a closed lake at an altitude of 1720 m above MSL. The precipitation on the drainage basin of the lake is influenced by the Mediterranean climate system. The isotopic investigation is part of a general study that has been carried out by a multidisciplinary group (Degens *et al.*, 1984.) The lake has a volume of 607 km^3 and a maximum depth of 451 m and is in a tectonically active zone in eastern Anatolia. The lake level was at its highest at the height of the Last Ice Age, about 18 ka BP when it was 72 m above the present level. According to the pollen analysis, the vegetation was of a steppe type from 10 ka to 6.5 ka BP; from 6.5 ka to 3.4 ka BP, it was forest vegetation and from 3.4 ka BP to the top of the section, the vegetation is contemporary and shows the impact of agriculture. The drop in the level of the lake and the increase in the salinity of the water between 10 and 9 ka BP were interpreted as a change to a warmer and dryer climate. This can be observed in a trend towards a heavier composition of the $^{18}O/^{16}O$ ratios in the isotope curve. Around 7 ka BP, there was a rise in the level of the lake, a decrease in its salinity and a marked increase in the percentage of arboreal pollen. This is interpreted as a change to a more humid climate. One can observe a simultaneous decrease in the $^{18}O/^{16}O$ ratios. At *c.* 3.5 ka BP there is again a sharp decrease in the $^{18}O/^{16}O$ ratio, which reaches its lowest level at 2.7 ka BP and marks another cold period. Because of the increase in agricultural activities since then, the pollen and sedimentological records may present the impact of anthropogenic processes, and the author prefers to rely mainly on the isotope curve, which shows relatively low ratios from 1.8 ka to *c.* 0.8 ka BP, a heavier composition between 0.8 ka and 0.5 ka BP and an increase in the ratio at the top of the column.

Another isotopic composition time series, presented in Fig. 1.2, is that from a core taken from the Sea of Galilee (Stiller *et al.,* 1983–84). This lake is fed by the Jordan River, and by the floods and springs from Galilee and the Golan Heights. Thermal springs also flow into the lake. The base flow of the Jordan is maintained by the outflow of springs emerging from the aquiferous Jurassic limestone rocks of Mount Hermon, in the eastern part of the Anti-Lebanon. These rocks are highly permeable and the water from the rain falling on the mountain and from the melting snow, which covers the higher stretches of the mountain each winter, quickly infiltrates the subsurface to enrich the aquifer from which these springs arise. The average annual precipitation on the mountains may reach 1200 mm. The two main springs feeding the upper Jordan are the Dan and the Banias (comes from Pan, the Greek god patron of springs). Because of high permeability and the high rate of precipitation, the water flow of these two major springs is fairly regular. The difference between summer and winter is regulated by the large underground storage of Mount Hermon. A long spell of dry years and low snowfall on the drainage basin may cause a decrease in the total quantity of water in the springs, leading to a reduction in the flow of the Jordan and a low water level in the Sea of Galilee. This is intensified by a decrease in the volume of the floods and by higher evaporation rates from the lake, causing the levels of the lake to drop. One may assume that the ratio of $^{18}O/^{16}O$ in the carbonate sediments will be higher in such years. While the precipitation on the catchment area of the springs emerging from the southern tip of Mount Hermon is high, the precipitation on eastern Galilee and the Golan Heights, which form the catchment area of the floods and springs, is less abundant, and the rates of flow are strongly influenced by the average annual rainfall.

The reinterpretation, carried out by the present author, of the $\delta^{18}O/^{16}O$ sequence from this core was correlated with the $\delta^{13}C/^{12}C$, data, assuming that depleted ratios signify more humid conditions, and thus abundant C3 types of vegetation, while a heavier composition indicates a drier climate and abundance of C4 type of vegetation.

Only four ^{14}C dates (at 5240 ± 520, 2955 ± 220, 2170 ± 125, 1020 ± 115 BP) were taken, the oldest one of which was near the bottom of the core hole at *c.* 5.0 m. Nevertheless, the spread of the dated samples along the column, and the body of other proxy-data available, in addition to $\delta^{18}O/^{16}O$, $^{13}C/^{12}C$ ratios (i.e., percentage of $CaCO_3$) and the detailed pollen analysis (Baruch, 1986; Stiller *et al.,* 1983–84), enable this time series to be used to interpret climate changes in the region during the upper half of the Holocene.

These data have been used by the author in his argument against the prevailing paradigm which claims that no significant climate changes occurred during the upper part of the Holocene and attributes all environmental changes to human activity (Issar, 1990). This is also the case with the data from the Sea of Galilee (Stiller *et al.,* 1983–84), which were initially interpreted as reflections of anthropogenic factors rather than climate changes.

The examination of this core (Fig. 1.2) enables us to distinguish various zones. Zones of high $\delta^{18}O/^{16}O$ and $\delta^{13}C/^{12}C$ ratios are from *c.* 5.0 ka to 4.5 ka, from 2.8 ka to 2.3 ka, from *c.* 1.5 ka to *c.* 1.2 ka and, finally, at 0.4 ka BP. Zones with only high $\delta^{13}C/^{12}C$ ratios are from 4.2 ka to 3.5 ka and at 1.8 ka BP. Toward the uppermost part of the $\delta^{18}O/^{16}O$ curve, starting at *c.* 0.3 ka BP, there is a trend to heavier ratios.

The other $\delta^{18}O$ and $\delta^{13}C$ time series presented in Fig. 1.2 average the results of 41 stalagmites taken in 10 caves in Galilee,

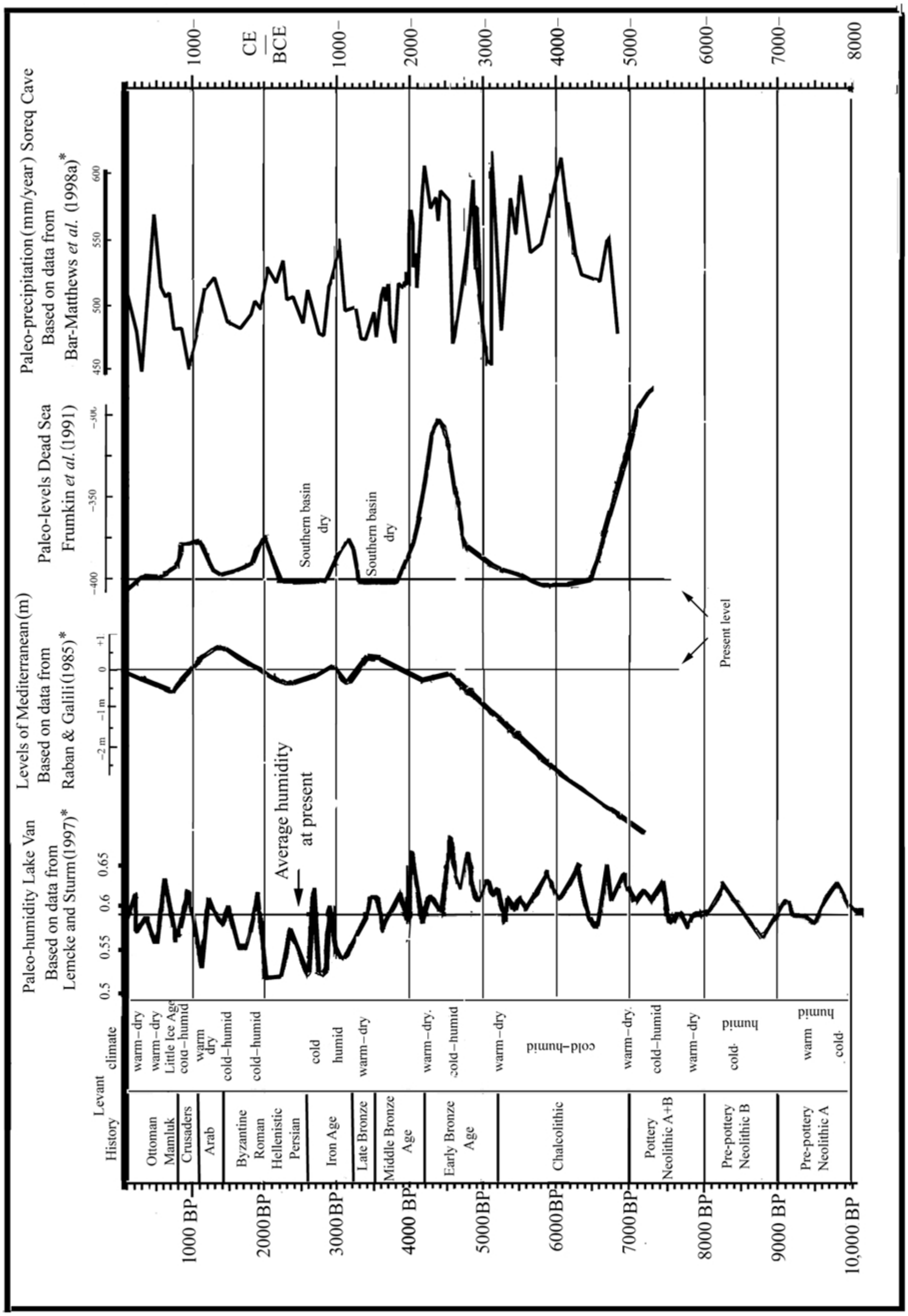

Fig. 1.3. Paleo-hydrology time series in the Middle East. *Adjusted to scale and streamlined (3–5) points by the running average method.

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northern Israel. The age determination for all the sequence was from calibration of ^{14}C and uranium/thorium ($^{234}U/^{230}Th$) dates. Precisions of *c.* 300 years have been obtained, taking a reservoir effect of 900 years into account (Geyh *et al.,* unpublished data). Therefore, speleotheme ages are considered to be calibrated dates with a $\pm$ 300 years margin of error. That these dates, within this margin of error, are reliable can be deduced from the close similarity between this speleotheme curve and the one from the Sea of Galilee. Periods of heavy isotopic composition occurred *c.* 4 ka, 3.8 ka and 1.2 ka BP, while periods of light compositions occurred *c.* 4.8 ka, 3.3 ka, 2.0 ka and 1.0 ka BP.

Another sequence of $\delta^{18}O/^{16}O$, forming a time series of paleoclimatic significance, is of a speleotheme from a cave in the vicinity of Jerusalem, in the mountainous part of central Israel (Fig. 1.2; Ayalon *et al.,* 1998; Bar-Matthews *et al.,* 1991, 1993, 1996, 1997, 1998a,b). The age determinations were made by the $^{230}Th/^{234}U$ method (Kaufman *et al.,* 1998). The isotopic record, which is traceable for the last 58 ka, shows a pronounced difference between the values characterizing the speleothemes that were formed before 6.5 ka BP and those formed later, including the contemporary deposits. This, according to Bar-Matthews *et al.* (1998a,b), is probably because of altogether different climatic regimes.

This is an important observation with regard to the exact time dimension that is suitable to provide proxy-data for simulations using general circulation model (GCM) scenarios. Climate scenarios of the Pleistocene (glacials and interglacials) are not suitable whereas that starting *c.* 6 ka BP is. With regard to the climate changes during the last 6.5 ka, the team working on the speleothemes of Soreq Cave (Ayalon *et al.,* 1998; Bar Matthews *et al.,* 1998a,b) have calculated the paleo-rainfall values by correlating the paleo-$\delta^{18}O$ records with the contemporary ratios of $\delta^{18}O$/rainfall. Based on the $\delta^{18}O$ and $\delta^{13}C$ values and calculated paleo-rainfall, they divide the record into four stages. Stage 1 lasted from 6.5 ka to 5.4 ka BP and was very wet. During the period extending from 5.6 ka to *c.* 3.0 ka BP (stage 2), the climate was, in general, humid, interrupted by four short dry spells. One was between 5.2 ka and 5.0 ka and another was at *c.* 4.0 ka BP. Stage 3, lasting from *c.* 3.0 ka to *c.* 1.0 ka BP, was transitional to drier and more stable conditions. Stage 4, from *c.* 1.0 ka BP to the present, was characterized by fluctuations in rainfall. The high values between 0.4 ka and 0.5 ka BP may be connected with the Little Ice Age, while the increase in $\delta^{13}C$ values, which started *c.* 0.7 ka BP, may indicate a process of deforestation and increased grazing during the Turkish period.

The curve of $\delta^{18}O$ composition of pelagic and planktonic foraminifers (Luz, 1991) is not too conclusive. In general, changes in the $\delta^{18}O/^{16}O$ values reflect changes in oceanic temperatures and the water in which the animals lived. Such ratios in foraminifers' shells in deep-sea sediments enabled the establishment of the sequence of climate changes during the Quaternary (Emiliani, 1955). This, however, is mainly seen in planktonic assemblages. The isotopic record for the benthonic forms shows low fluctuation because of the relatively stable temperature of the water at the bottom of the sea. Shackleton and Opdyke (1973) have demonstrated that the changes in isotopic values reflect the changes in the continental volume of ice as melted glacier water causes the water of the oceans to become isotopically lighter. It is certain that the fluctuations in the isotopic composition between glacial and interglacial periods resulted from the glacial effects (Bowen, 1991). However, it seems that the isotopic composition of the Mediterranean Sea is more complicated as the isotopic record from cores taken from the Mediterranean Sea also seems to reflect local changes. Consequently the isotopic composition of the Mediterranean Sea reflects not only climatic parameters such as precipitation, evaporation and residence time of water mass within the basin but also the hydrological regimes of the Black Sea, the Nile and the Atlantic Ocean.

From the ratio of $\delta^{18}O/^{16}O$ of the epi-pelagic foraminifer *Globigerinoides rubes*, Rossignol-Strick *et al.* (1982) found that the oxygen isotopic composition ratio decreased through several large shifts to minimal values between 8 and 6 ka BP (see also Luz and Perelis-Grossowicz, 1980). The sharp depletion in $^{18}O/^{16}O$ ratio and the lowering in salinity from 8 ka to 7 ka BP may represent the heavy Nile floods during a mainly rainy period in Africa (Nicholson, 1980; Nicholson and Flohn, 1980), and it seems likely that the Nile was the major source of fresh water responsible for the low salinities in the Mediterranean Sea. However, the Nile water, coming from areas of low latitude, should be isotopically heavy. In a recent work, Luz (1991) suggested an alternative explanation for the isotopic depletion. He claimed that a high influx of low-salinity water entered the Mediterranean Sea from the Black Sea when the rising sea surface reached the level of the Bosphorus. This alternative explanation is not in agreement with the findings of Erinc (1978), who concluded that, even though the sea level rise in the Black Sea and in the Mediterranean Sea started simultaneously after the peak of the last glacial period, the Black Sea basin was disconnected from the Mediterranean. Moreover, the rise in sea levels caused the intrusion of the Mediterranean into the Black Sea. Cores obtained in the Black Sea (Degens, 1971; cited in Erinc, 1978) indicate, "that the main intrusion of saline water into the Black Sea started 7140 $\pm$ 180 years ago". In conclusion, it is clear that the reasons for the changes in oxygen isotope composition of the foraminifers of the Mediterranean have yet to be elucidated. In their book *Noah's Flood: The New Scientific Discoveries about the Event that Changed History*, the marine geologists William Ryan and Walter Pitman (1998) argue that this intrusion (around 7500 years ago) was caused by the breaching of the barrier at the Bosphorus, at the northeastern part of the Sea of Marmara, which filled up an ancient lake, the predecessor of the Black Sea, the level of which was 150 m lower than the present sea