

0277–3791(95)00070–4

# SEA–LAND CORRELATION OF POLLEN RECORDS IN THE EASTERN MEDITERRANEAN FOR THE GLACIAL–INTERGLACIAL TRANSITION: BIOSTRATIGRAPHY VERSUS RADIOMETRIC TIME-SCALE

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**Abstract** — Pollen diagrams based on marine cores from the Eastern Mediterranean and Arabian Seas and land cores from Greece, Turkey, the Levant and western Iran during the last deglaciation reveal a similar succession of conspicuous pollen abundance maxima: an early phase with Chenopodiaceae signaling the highest aridity, a late phase with *Pistacia* and Gramineae in the Mediterranean domain, and tropical humid taxa in the Arabian sea domain, indicating conditions of mildest winter and wettest summer. Between these two phases, the record for deciduous oak in the Mediterranean and Near East shows a continuous increase that points to rising moisture.

The chronology of this succession and its exact relationship with the marine isotopic record of global climate are established using marine cores. The marine records dated by the AMS  $^{14}\text{C}$  method show that the Chenopodiaceae phase correlates with the Younger Dryas chronozone, globally dated 11,000 to 10,000 BP, during which the climate reversed to quasi-glacial conditions at least in the northern hemisphere. They also show that the *Pistacia* phase, during which the Mediterranean climate reached its seasonal optimum, occurred from 9000 to 6000  $^{14}\text{C}$  years BP (Boreal and early Atlantic chronozones defined in NW Europe) in the first half of the Holocene. The oak pollen abundance increases rapidly from 10,000 to 9000 BP (Preboreal chronozone).

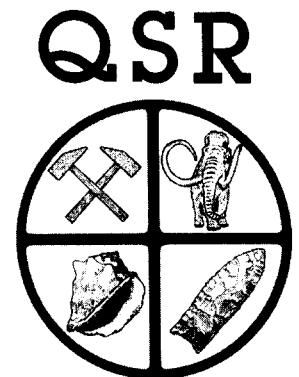
Thus, in terms of climate, the Younger Dryas chronozone is regionally expressed by wide-spread desert conditions, as a cold and arid period. During the *Pistacia* phase, the climate was most favourable both for plants that require frost-free winters, such as the Mediterranean *Pistacia*, and those that need spring/summer moisture, such as Gramineae at low annual moisture level (seasonally ~300 mm), and deciduous oak at higher levels (~600 mm all year, without summer drought). During the brief intermediary phase, the climate changed drastically through an increase of winter temperature and of spring/summer moisture.

The chronologies of the land cores, however, based on few  $^{14}\text{C}$  dates, show significant discrepancies with the marine-based time-frame. These discrepancies imply a lack of coherence in the climate history of this mediterranean-irano-turanian region. We propose using the chronology derived from the marine records for the entire region. The local  $^{14}\text{C}$  dates generally appear too old, perhaps because of geological contamination of the material by older carbon.

## INTRODUCTION

The fossil records show that the Late Quaternary went through a rapid succession of extreme climate conditions from the Last Glacial Maximum to the present Interglacial. Linked to the general climatic amelioration, the deglaciation, initiated ~15,000  $^{14}\text{C}$  year BP (Bard *et al.*, 1990), did not proceed smoothly, in puzzling discrepancy with the continuous insolation increase during the northern hemisphere summers that runs from 24,000 to its peak at 11,000 astronomical year before present (1950) (Berger, 1978). It was interrupted by the Younger Dryas, originally defined as a chronozone in NW Europe, which occurs between the Bølling–Allerød interstadial and the Preboreal chronozone of the Holocene (Mangerud *et al.*, 1974). The Younger Dryas is now seen as an abrupt and possibly global climatic accident of reversal to quasi-glacial conditions (Denton and Hendy, 1994). Several methods have been employed to date it precisely. Conventional  $^{14}\text{C}$  dates are 11,000 to 10,000 BP in series from land (Mangerud *et al.*, 1974) and

the sea (Fairbanks, 1989; Kennett, 1990; Bard and Broecker, 1992; 11.2–10.5 ka BP, Lehman and Keigwin, 1992). Calibration by the U/Th method applied on corals yields 13,200 to 11,500 BP (Bard *et al.*, 1990). The cold event may actually have lasted 1700 years. The shorter duration indicated by the  $^{14}\text{C}$  method may be due to a plateau in  $^{14}\text{C}$  ages. In two Greenland ice cores, stratigraphic and visual methods yield calendar years 12,700 to 11,550 (Johnsen *et al.*, 1992), 12,900 to 11,650 (Taylor *et al.*, 1993; Alley *et al.*, 1993). The Younger Dryas according to the  $^{14}\text{C}$  dates in Europe ended at 10,000–10,200 BP. The average calendar age is 11,500  $\pm$ 200 BP, according to ice-cores annual layers, calibration of  $^{14}\text{C}$  ages by U/Th and varves in Lake Gosciarz (Alley *et al.*, 1993). In that lake, varve count suggests that the Younger Dryas lasted 1600+85–80 years and ended at 11200+500–200 calendar years BP (Ralska-Jasiewiczowa *et al.*, 1992). It is in terms of calendar years that the comparison can be made with the astronomical variation of insolation according to the Milankovitch theory.



Here we attempt to establish the bio-chrono-stratigraphy of the mid-part of the deglaciation using pollen records from the Eastern Mediterranean domain. Their location is seen in Fig. 1. We identify two marker zones in pollen records of marine cores, for which the oxygen isotope stratigraphy has been dated by AMS  $^{14}\text{C}$  dates. These zones span the period 11,000 to 6000 BP. They are defined by peak abundances of *Chenopodiaceae* for the Younger Dryas period and of *Pistacia*, accompanied by *Quercus*, for the early Holocene. The same time interval in a marine core from the north-western Arabian sea helps to set the frame for the paleoclimate history of the Africa–Asia land-bridge. Next, we establish the presence of these two marker zones in Late Quaternary land pollen records from the Eastern Mediterranean and Near East Region, and calculate their ages according to accumulation rates derived from the  $^{14}\text{C}$  dates, though only a few dates are available. The result of this obviously risky procedure is then compared with the chronology obtained from the marine cores. The regional character of the Mediterranean climate constraints leads us to envision that major climate changes have been synchronous through the area. Consequently we assume that the biological marker zones are synchronous, and propose to uphold the marine chronology as valid for the land records.

#### PRESENT CLIMATE OF THE EASTERN MEDITERRANEAN

The subtropical anticyclone belt, at  $30^\circ$  latitude in both hemispheres, is generated by the subsidence of the poleward flow of the upper tropical atmosphere as it is cooled by its approach to the high latitudes. According to the strength of the meridional hemispheric temperature gradient, the anticyclone core seasonally shifts in latitude, poleward in summer, and equatorward in winter (Newell *et al.*, 1972). This shift explains why the climate of the Mediterranean Region, dominated by the dynamics of the eastern North Atlantic subtropical anticyclone, participates in two different regimes. In winter, the Mediterranean regime is that of the extratropical belt of low pressure where the dominant winds are the cyclonic rain-bearing Westerlies. In that wet season, the limiting bioclimatic factor is not moisture, but temperature, as in the mid latitudes zone. The regular occurrence of winter frost in the mid latitudes led to selection of deciduous trees that can withstand or even require it. But in the Mediterranean Region, harsh winters cannot be tolerated by the arboreal vegetation that has overcome the stress factor of the other season, drought in summer. In summer, the Mediterranean regime is dominated by the subsidence of subtropical air, and is subject mainly to dry northerly winds generated by that anticyclone. Summer drought has led to the selection of an arboreal vegetation capable of sufficiently lowering its evapotranspiration. Such conditions are inimical to the trees that have successfully adapted to the other limiting factor, harsh winter. Topography modulates this climatic pattern, by favouring convective precipitation in summer from onshore winds, as in the Amanus mountain range of SE

Turkey, and decreasing temperature, most sensitively in winter. Local conditions generate many variants of this climate, which includes increasing continentality eastward into the Irano-Turanian territory, beyond the littoral fringe of Eu-Mediterranean climate.

This seasonal balance is important for the palaeoclimatic interpretation of the fossil pollen records. The temperature minimum in winter, and extent of the summer drought are the bioclimatic factors that have shaped the plant cover of the Mediterranean Region through the Quaternary. Evergreen and also deciduous species of *Pistacia* can withstand summer drought in the Mediterranean and Irano–Turanian territories, but come to dominate the vegetation only where the winters are mild, the season when the middle latitudes bioclimate regime provides adequate moisture. Temperate deciduous trees, of which *Quercus* is the most conspicuous in the pollen records, are absent under an Eu-Mediterranean climate because of the summer drought, even though their thermal requirement of a sufficiently long summer would be fully satisfied by that regime. Mild winters, wet summers are a potential mode of climate optimum for the Mediterranean region, that is presently extant on part of the east coasts of Asia and America: evergreen and deciduous trees could co-exist, notwithstanding actual competition. It is interesting that this combination is observed today in south-eastern Europe and the Near East only in places where topography forces the air of on-shore winds to uplift. In northern Iran, the northern slopes of the Elbourz mountain facing the Caspian sea, and in Georgia, the Colchica on the Caucasus coast of the Black sea, harbour lush deciduous Hyrcanian and Colchican forests where some arboreal species are Tertiary relics. In contrast cold winters, even if they are wet, and dry summers, even if they are warm, are the most severe, stressing conditions for an arboreal climax in the lowlands. The grass steppe belt of the Ukraine north of the Black Sea between the deciduous forest-steppe to the north, and the Mediterranean vegetation of the south coast of Crimea to the south, illustrates the origin of treeless expanse between these two seasonal constraints. The deciduous trees of the forest-steppe are arrested in their southward progression by the summer drought, and the evergreen trees of the Eu-Mediterranean Crimean forest cannot expand northward because of harsh winters.

#### CLIMATE IMPLICATION OF THE SELECTED PLANTS

This paper presents an argument that relies on the pollen abundance of a few plant taxa in the records that can be seen as indicative of the climatic constraints of the Mediterranean Region. We discuss the climatic connotation of these plants in the present and the fossil records. The most significant taxa are *Chenopodiaceae* and *Pistacia*, with *Gramineae*, *Artemisia* and deciduous oak secondary.

##### *Chenopodiaceae*

Plants of the *Chenopodiaceae* family are associated with the most arid conditions, being widespread in saline

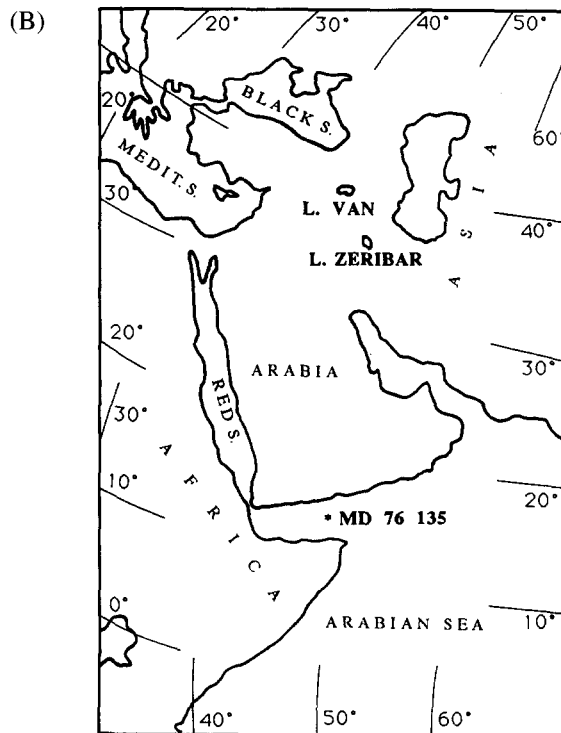
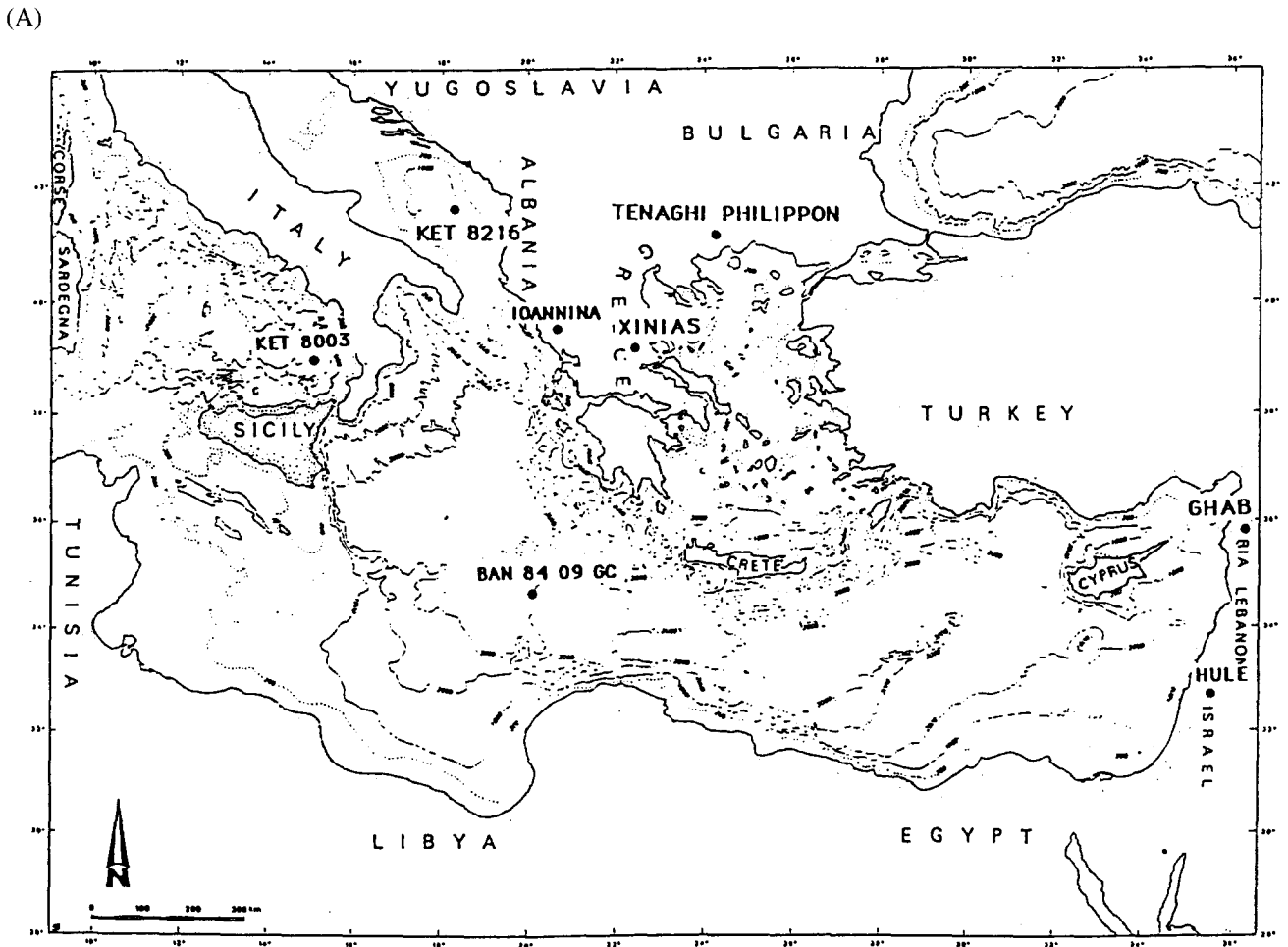


FIG. 1. Location of land and marine sites: A—In the Eastern Mediterranean domain. B—In the Arabian sea, Eastern Turkey and Western Iran.

soils of Mediterranean and NW African coasts as well as interior desert expanses of less than 100 mm annual precipitation. In the present-day pollen rain, the Chenopodiaceae pollen abundance is high in and near the areas where they dominate the land cover, reaching 50 to 90% of total pollen in coastal salt flats in NE Greece (Bottema, 1974), 75% in the maritime atmosphere off West Africa at the latitude of coastal salt-marshes along the northern Saharan desert (Calleja *et al.*, 1993), and 48% in the northern Saharan ground-dust (Cour and Duzer, 1980). In the fossil records from Greece and the Near East, the highest abundance of Chenopodiaceae pollen therefore signals the most arid climate phase of each record: 15% in lake Ioannina (Bottema, 1974), 90% in lake Xiniias (Bottema, 1979), 35% in the Tenaghi Philippon marsh (Wijmstra, 1969), 50% in the Ghab Valley marsh (Niklewski and Van Zeist, 1970), 17% in lake Hula (Baruch and Bottema, 1991), 55% in lake Van (Van Zeist and Woldring, 1978), 83% in lake Zeribar (Van Zeist and Bottema, 1977). A strong moisture deficit leads to lower lake levels, with salt flats at their periphery and to regionally expanded desert conditions. There is no direct temperature inference inherent in this aridity signal. However, the record in the Tyrrhenian sea of isotopic oxygen and pollen, discussed below, leaves no doubt that marine surface temperatures decreased at 11,000 BP as aridity on land, signalled by peak Chenopodiaceae pollen abundance, increased (Rossignol-Strick and Planchais, 1989). That sea-surface temperature decrease is dated between 11,010 and 10,390 BP in the Atlantic off Portugal (Bard *et al.*, 1987). This indicates that the arid conditions occurred in the Mediterranean region when temperature was low. The moisture deficit that is expressed by the Chenopodiaceae value is due to low precipitation at a time of low temperature. Evaporation of the Atlantic and Mediterranean sea-surface controls the moisture load of the air masses that flow eastward over Greece and the Near East. This today is the unique source of moisture for Greece and the Near East. At 11,000 BP, the sea-surface temperature decrease may have reduced the evaporation at the sea-surface. Thus, at that time, a lower moisture load would have been contributing to the westerly air flow. This observation leads us to the hypothesis that the steps of the climate evolution for the different parts of this topographically varied area ought to be in phase with each other.

### *Pistacia*

The second major stratigraphic marker identified in this paper is a *Pistacia* phase. *Pistacia* trees are leading plants in the vegetation of the Irano-Turanian and Mediterranean territories (Zohary, 1973). In the circum-Mediterranean maquis and garrigue, under an Eu-Mediterranean climate with very mild winters, the evergreen *Pistacia lentiscus* is a thermophilous shrub, very widely but rather scatteredly distributed in the lower mountain zone up to 300 m (Turrill, 1929; Rikli, 1943–1948). It is characteristic of the maquis, but does not dominate it. In the more continental Irano-Turanian territory, the deciduous species *P. atlantica* dominates,

with almond trees (*Amygdalus*), in a savanna or low sparse woodland (steppe-forest). Figure 2 shows the area of greatest density for this formation in Western Iran on the southwestern foothills of the Zagros mountain range (up to 700–800 m elevation) between 32 and 18°N, in the transition zone between the lowland *Artemisia* steppe (semi-desert) and the upland degraded xerophilous deciduous oak (*Q. brandtii*) forest-steppe. In this area, annual precipitation is around 350 mm (300–500 mm, Van Zeist and Bottema, 1977; 200–400 mm, Freitag, 1977). According to Bobek (1963), the *Pistacia*–*Amygdalus* steppe-forest requires at least 300 mm precipitation, and above 500 mm, is replaced by the oak forest-steppe. In two stations close by but at higher elevation, and therefore colder than the savanna zone, Khorramabad at 1310 m and Shiraz at 1500 m, (Fig. 14) the mean annual temperature is 16.2°C, the winter temperature is 6–7°C and the long summer drought signals a Mediterranean regime of seasonal precipitation (Zohary, 1963, 1973). In terms of temperature, the pistachio-almond savanna lies in the subtropical part of the continental Irano-Turanian territory, contiguous at its southern limit with the tropical, Sudanian elements of the Gulf region.

On this basis, it is concluded that mild winters are a characteristic climatic requirement for the dominance of the deciduous, Irano-Turanian *Pistacia*. The distribution area of *P. atlantica* extends from Western Pakistan to Iran, Turkey, the Aegean islands, along the southern shores of the Mediterranean sea (Sinai, Lybia, North Africa) and westward to the Canary Islands. Among the other deciduous species (*P. khinjuk*, *P. vera*, *P. terebinthus*, *P. palaestina*), *P. vera* is recorded eastward to Central Asia, under very continental conditions, but is not a leading plant in the vegetation (Zohary, 1973). Thus, *Pistacia* is the dominant tree in the vegetation by its deciduous species (mainly *P. atlantica*) in the mildest, subtropical variety of climate in the continental Irano-Turanian territory, presently at moderate altitude. Its evergreen species (mainly *P. lentiscus*) signals the very mild Eu-Mediterranean climate in the lowlands.

This dominance is expressed in the pollen rain by only a few percent of total pollen, which reveal that *Pistacia* is therefore much underrepresented. The pollen types of the different species are not distinguishable. In southeastern Turkey, below Lake Van (1646 m a.s.l.), near Siirt at less than 1000 m a.s.l., which has a mean January temperature of 2–3 °C (Van Zeist and Woldring, 1978), *Pistacia khinjuk* is a common tree in the oak woodland vegetation. The ratio of pistachio to oak trees is 1/2 to 1/3, whereas in the pollen rain, the values are 20 times lower for *Pistacia* (3.9%) than for oaks (77.1%) (Van Zeist *et al.*, 1968). Within the pistachio / almond savanna (*P. khinjuk*, *P. atlantica*) of the Zagros foothills, the *Pistacia* abundance in the pollen rain is only a few percent (3.5%) (Wright *et al.*, 1967). In one site, *Pistacia* trees represent 52% of the vegetation, but only 9.4% in pollen abundance, whereas the same values for oak are 32 and 87.7%. In NW Greece (Epirus) in the Eu-Mediterranean evergreen lowland forest (macchia) below 400 m, the pollen rain shows only a few percent of *Pistacia* (1 to 3%

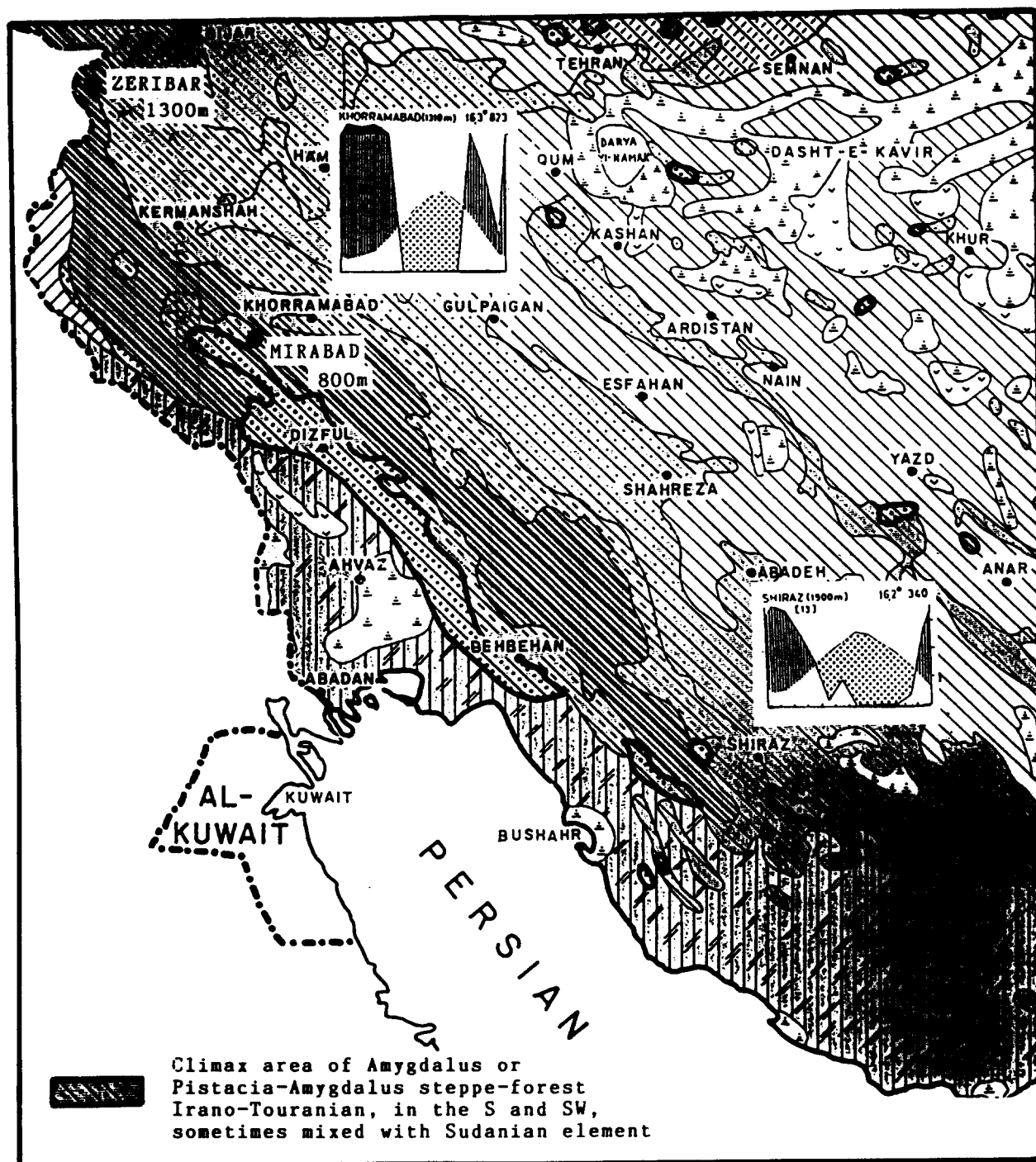


FIG. 2. Map of vegetation in Western Iran: area of maximum density of the deciduous *Pistacia atlantica* in the Irano-Turanian territory on the southwestern flank of the Zagros mountain range (after Zohary, 1963).

in three samples, 10% in one) in areas where the tree, *Pistacia lentiscus*, is common (Bottema, 1974). In the deciduous forest zone with evergreen elements from ca. 400 to 700 m elevation on the eastern side of the Pindus mountain range, one high *Pistacia* percentage (7.9%) is attributed to the deciduous *Pistacia terebinthus* (Sample 27). In the coastal Eu-Mediterranean forest zone, the average January temperature is 10°C. There, the frost-free winters represent a climate optimum, with precipitation ca. 400 mm/year.

In all the fossil pollen records that will be discussed below, there is a biozone in which *Pistacia* pollen abun-

dance is consistently higher than most values in the present pollen rain, up to 7–8%. This suggests that pistachio was probably more abundant than oak and the dominant tree in an almost closed forest vegetation. In the Ioannina I and II records, NW Greece (Epirus) (470 m a.s.l.), the species in this biozone is believed to be the deciduous *P. terebinthus*, rather than *P. lentiscus*, because of scarcity of pollen of other Eu-Mediterranean plants (Bottema, 1974). However *P. lentiscus* is also possible, as it may have been a pioneer able to withstand less moisture than *P. terebinthus*, and expanded from the lowland in the reconquest of previously very arid land. This view is sup-

ported by the evidence from this area, since only *P. lentiscus* is as abundant in the present pollen rain as recorded in fossil samples, and presently the most abundant *Pistacia* near Ioannina is *P. lentiscus* at an elevation of 300 m. In the pollen records where *Pistacia* is undoubtedly deciduous, for instance in those from lake Van (1646 m a.s.l. at latitude 38.5°North) (Van Zeist and Woldring, 1978) and lake Zeribar (1300 m a.s.l. at latitude 35°32'North) (Van Zeist and Bottema, 1977), the biozone where *Pistacia* abundance is similar to those of the present savanna can be interpreted as reflecting a rise of the mild winter temperatures presently confined to below 800 m in the region to at least 1300 m.

The discussion of the pollen diagrams below will show that the biozone of *Pistacia* peak abundance is preceded by a biozone of Chenopodiaceae maximum. The rapid transition between the two biozones is thought to reflect an increase in precipitation (Van Zeist and Woldring, 1978). Moreover, at the beginning of the *Pistacia* biozone (X1 in Ioannina), winter temperatures are believed to have risen to the same level as present (5.1°C in January) (Bottema, 1974). Thus, the precipitation increase was accompanied by a regional temperature increase, particularly in winter. The highest values of *Pistacia* pollen in the middle part of this biozone (X2) suggest higher winter temperature than in zone X1. We therefore assume that winters were warmer than presently in zone X2 when *Pistacia* pollen abundance is greater than in the present pollen rain. Nevertheless we do not underestimate the role of the moisture rise, estimated from ca. 100 to ca. 350 mm, in the expansion of pistachio.

Three other taxa, although of major importance, are secondarily used in the present investigation: Gramineae, oak and *Artemisia*.

### Gramineae

In the two most continental land pollen records (Van and Zeribar), Gramineae (Poaceae) pollen are very abundant at the earliest stage of the Holocene. In the more westerly sites, grass pollen do not reach such abundance and give way at an earlier stage to increasing amount of oak pollen, presumably as the level of precipitation becomes adequate (ca. 400 mm for the maquis in Israel, according to Zohary, 1973). The whole area has been submitted to human pastoralism for so long that presently it is not always possible to discern whether the natural herbaceous ground cover would be grass or sage-brush. Indications derived from soils and precipitation amounts are ambiguous. In the Middle East, chernozem (200–300 mm rainfall) and brown steppe soils (250–350 mm) are widespread, particularly in the Syrian and Anatolian plateaux. However the vegetation on these soils is mainly the sage-brush semi-desert, not the grass steppe which characterises them in the Ukraine (Zohary, 1973). In inland Syria-Palestine, between the western margin occupied by the Mediterranean forest, and the central desert with Chenopodiaceae, precipitation would seem sufficient (150–350 mm) to sustain a grass steppe, instead of the Irano-Turanian *Artemisia herba-alba* semi-desert

(Zohary, 1973). The absence of grass-steppe could be a result of overgrazing since prehistoric times, or of the confinement of rains to the winter months, without snow-cover, associated with severe drought from April to October. Some areas, such as inner Anatolia, southern Arabia and southern Iran, have some rain in summer, and could be better suited to a grass steppe vegetation. The grass steppe of the temperate zone occurs in the Ukraine in a belt where precipitation is 350–450 mm (Walter, 1974, 1979). About a third is snow, so that the short, dense roots of grasses find soil moisture during the growing season from April to the end of June. There is rain from thunderstorms in summer, but most of it evaporates. The drought from July to September prevents the establishment of deciduous trees. Further east in Kazakhstan, the lower precipitation (250–300 mm) imposes a more intense and longer summer drought regime, but the spring snow-melt still supports a grass steppe. It is in terms of moisture availability of up to ca. 300 mm without spring and summer drought, that we will interpret the grass phase in the early Holocene.

### Deciduous Oak

The deciduous oak is a most important feature of the pollen records. However, the oak tends to be overrepresented in the pollen records. This is revealed by its abundance in the present-day pollen rain in western Iran, relative to its presence in the vegetation (Wright *et al.*, 1967). The annual precipitation requirement of the oak forest-steppe of the Zagros is at least 500 mm (Bobek, 1963). The rapid increase of its pollen abundance during the earliest Holocene, toward peak values after 9000 BP, reflects its pioneering role in forest development.

### Artemisia

This dominant plant in the continental semi-deserts of the Middle East and Central Asia (Walter, 1974), corresponds to conditions of aridity less extreme than those accepted by Chenopodiaceae. In the pollen records, maximum values of *Artemisia* occur either with or before those of Chenopodiaceae in the period of very rapid and broad change investigated here. Thus the pollen abundance of Chenopodiaceae is here considered better suited to record the widest range of that change, and little emphasis is placed on that of *Artemisia*.

## STRATEGY

We examine the pollen records of marine cores that are adequately dated by the oxygen isotope stratigraphy and/or AMS <sup>14</sup>C dates on single species foraminifer samples, in the Mediterranean and the northern Arabian seas. We establish the chronology of the Chenopodiaceae and *Pistacia* stages of the pollen succession, according to the previous discussion. We search for the same succession in the land pollen records of Greece and the Near East, and use the <sup>14</sup>C dates of these records to derive their chronology. Assuming we identify this pollen succession, we compare the land-derived and marine chronologies

and discuss their coherence, or lack thereof, with a view on upholding the option that achieves the greatest consistency with the global evidence of climate evolution during the Late-Glacial and Early Holocene.

### *The Pollen succession in Marine Cores*

In this section we will demonstrate that in the records of oxygen isotope and pollen assemblages from cores in the Eastern Mediterranean and northern Arabian seas (Fig. 1B), the two steps of the last deglaciation which experienced the most extreme climate are respectively in phase in the two oceans. These two phases are considered to reflect a severely arid/cold Younger Dryas period and the succeeding regional climate optimum of maximum precipitation (with at least some in summer), and mild winter temperature.

#### *Core KET 8216 in the Southern Adriatic sea (Rossignol-Strick et al., 1992) (Fig. 3)*

This core was recovered at a water depth of 1166 m in the southern Adriatic basin. The sediments are normal marine. They were deposited in oxygenated water, except in the 74–47 cm interval where the colour is greenish-black, indicating the reducing conditions of poorly or non-ventilated bottom water. This is a sapropel, the latest organic-rich layer in the series which intermittently deposited in the Eastern Mediterranean during the Quaternary. In the upper 170 cm, the chronology is established by nine AMS  $^{14}\text{C}$  dates obtained from the planktonic foraminifer *Globigerinoides ruber* (Fontugne et al., 1989). The  $\delta^{18}\text{O}$  abundance curve is based on a 10 cm sampling interval, smaller in the sapropel. The heavy values identify the Last Glacial Maximum from 16.7 to 13.78 ka BP. From 13.05 to 9.99 ka BP, the isotopic curve displays a plateau, then reaches the lightest values within the Holocene sapropel, dated 9 to 6 ka BP. It stabilizes to local post-glacial values at 5 ka BP. The isotopic plateau or reversal at mid-way in the deglaciation is a typical feature observed in cores with high sedimentation rate. In a core from the Bay of Biscaye, it has been associated with the Younger Dryas chronozone and pollen abundances that reveal a colder, dryer vegetation (Duplessy et al., 1981). Because the set of AMS  $^{14}\text{C}$  dates in core KET 8216 is concordant with the isotopic stratigraphy, and although the resolution of its pollen record is not high, this core will be our standard to which we will compare the chronology of the land pollen records of the Eastern Mediterranean region.

Figure 3 shows the pollen diagram of core KET 8216, redrawn from Rossignol-Strick et al. (1992). It is based on a pollen sum which excludes the sums of *Pinus* pollen and Pteridophytic spores. The three pollen sums are displayed in Fig. 3. The motive for this exclusion is differential rates of degradation of the pollen taxa in the marine environment. The pollen record of longer cores from the Eastern Mediterranean, which display the complete series of Quaternary sapropels, consistently shows an abrupt change in the pattern of pollen concentration and relative abundance at the sharp transition from sapro-

pel to normal sediments (Cheddadi, 1988). In normal sediments as in the present core, the total pollen concentration is much lower, and resistant *Pinus* pollen and fern spores has much higher relative abundance than in the reducing conditions of sapropel deposition. Early diagenesis in the water column is much more active in oxidizing than in reducing conditions. In the Eastern Atlantic off saharan West Africa, the relative abundance of *Pinus* pollen is much higher in the sea-floor assemblage than in the atmosphere above (Calleja et al., 1993).

At 100 cm in core KET 8216, the age derived from the AMS  $^{14}\text{C}$  dates is 11 ka BP, the lower boundary of the Younger Dryas chronozone. At this depth, the percentages of *Artemisia* and Chenopodiaceae increase to a peak, and those of deciduous trees decrease to a trough: *Quercus*, *Corylus*, *Ulmus*, *Fagus*. This suggests very dry conditions unfavourable to tree growth in most of its source area, with precipitation in the driest parts as low as 150–300 mm/year, the range acceptable to *Artemisia*. This dry phase at 11 ka BP appears as the local expression of the Younger Dryas cold event. It interrupts the regional expansion of deciduous trees that is synchronous with the deglaciation, as moisture increases in the Mediterranean domain.

From 90 cm at 10 ka BP to 74 cm at 9 ka BP (between 9.38 and 8.61 ka BP), the abundance of *Quercus* pollen and, more irregularly, of other deciduous trees increase. Decreasing isotopic values indicate warming sea-surface temperature. Within the sapropel, 74 to 47 cm, from 9 to 6 ka BP, maximum percents are seen for *Quercus*, *Pistacia*, as well as *Corylus*, *Ulmus*, *Tilia*, *Fagus*. In summary, there is a rapid succession in pollen percentages: (1) peak values for herbs (*Artemisia* and Chenopodiaceae) synchronous with low values for trees that identify the Younger Dryas, the driest period, (2) increase for *Quercus* between 10 ka BP and 9 ka BP, signaling moisture increase, with higher temperature documented by the isotopic data, (3) maximum percentage of *Pistacia* during sapropel deposition from 9 to 6 ka BP, indicating the warmest winters.

#### *Core KET 8003 in the southern Tyrrhenian sea (Rossignol-Strick and Planchais, 1989) (Fig. 4)*

Paterne et al. (1986, 1988) have established the chronology of this core and its isotopic record. They have identified ash-layers by their chemical composition, and correlated them by this composition to lava flows in Italy, where these flows are radiometrically dated by the  $^{14}\text{C}$  and K/Ar methods. Five dates are obtained, the oldest  $55.4 \pm 2.2$  ka BP within isotopic stage 3 to  $12.97 \pm 0.18$  ka BP at the end of isotopic stage 2. The latter date is applied to a rhyolitic ash-layer that was deposited at 130 cm core depth and chemically correlated with the pumices in the explosion crater of Pollara in the Eolian islands, dated by the  $^{14}\text{C}$  method at  $12.97 \pm 0.18$  ka BP. From the pollen record of this core (Rossignol-Strick and Planchais, 1989), we show in Fig. 4 the abundance for *Quercus* and three herbs taxa from 24 to 9 ka BP. *Pistacia* pollen is not found in that core. Its major interest

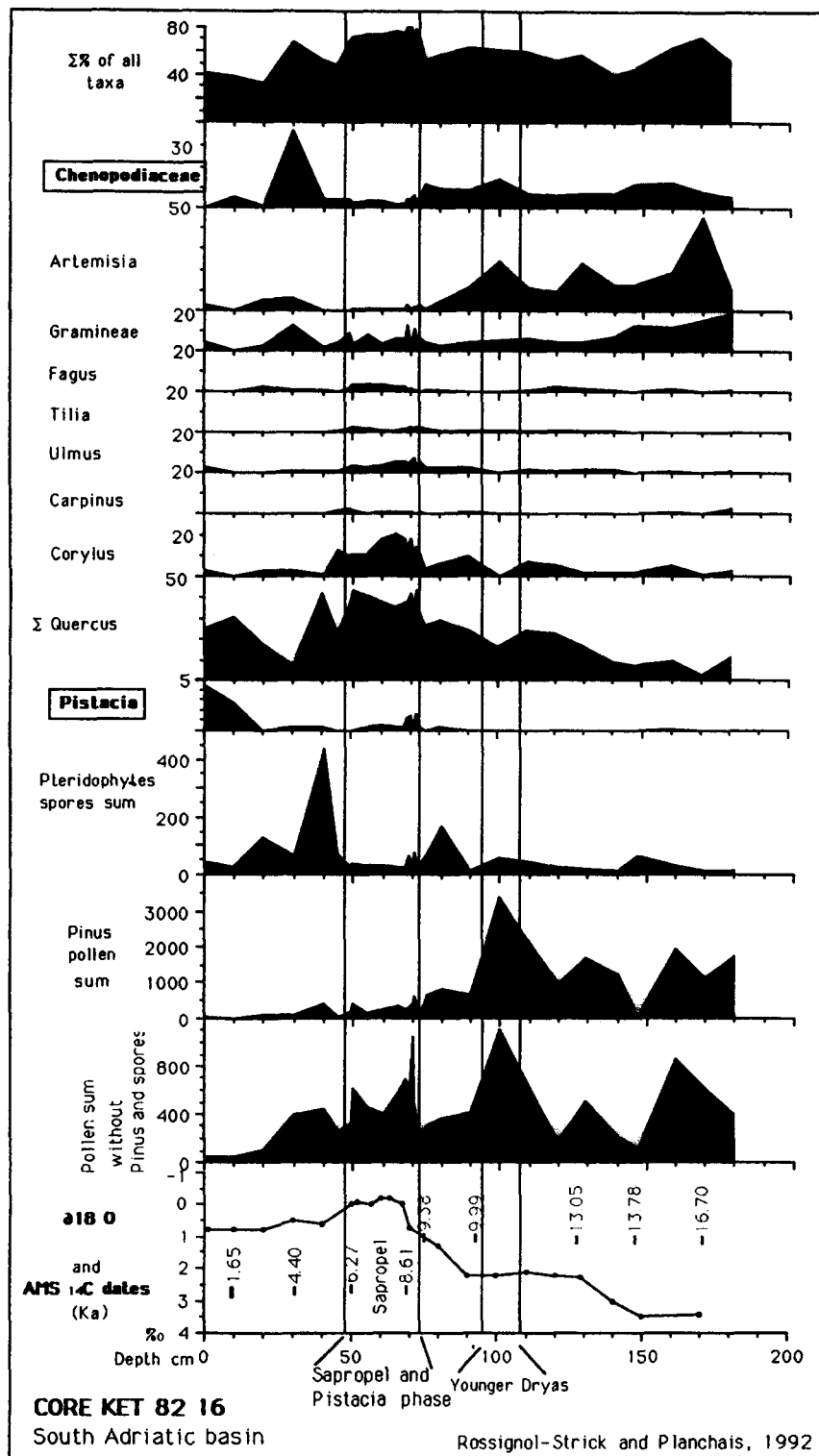


FIG. 3. South Adriatic sea core KET 82 16 (41°31'N, 17°59'E, 1166 m water depth): records of oxygen isotope (Fontugne *et al.*, 1989) and pollen percentage for selected relevant taxa (Rosignol-Strick *et al.*, 1992). Pollen data recalculated and redrawn. AMS <sup>14</sup>C dating performed on monospecific (planktonic *Globigerinoides ruber*) or assemblage of planktonic foraminifers (Fontugne *et al.*, 1989). Three pollen sums are shown: 1—Pteridophytic spores, 2—*Pinus*, and 3—the rest of the pollen assemblage. The percentages of the selected taxa are based on the third pollen sum. Last column on top: sum of these percentages.



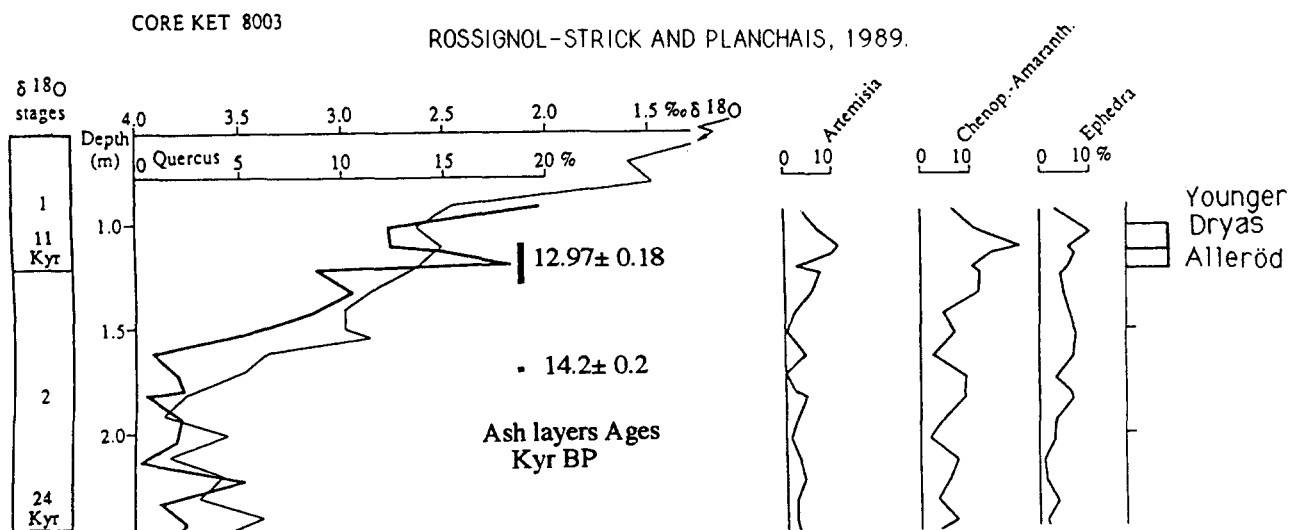


FIG. 4. Tyrrhenian sea core KET 8003 (38°49'N, 14°29'E, 1900 m water depth): records of oxygen isotope (planktonic *Globigerinoides bulloides*) (Paterne *et al.*, 1986) and pollen percentage for selected relevant taxa (Rossignol-Strick and Planchais, 1989). Dates by correlation of ash-layers in the core, based on their chemical composition, with lava flows in Italy that have been dated by  $^{14}\text{C}$  (on wood included in the lava flows) and K/Ar analysis (Paterne *et al.*, 1986).

for the present purpose, is a cold and arid phase at 110–100 cm depth, shortly after 12.97 ka BP, expressed by return to heavy isotopic values, decrease of *Quercus* percentage and peak values for hers. Its proposed identification as the Younger Dryas (Rossignol-Strick and Planchais, 1989) appears to have been widely accepted. The same isotopic reversal is also clearly seen in two other cores of the Tyrrhenian sea (Paterne *et al.*, 1986). The increasing trend for *Artemisia* and Chenopodiaceae percentage from low at 150 cm during the isotopic deglaciation, to maximum at 110 cm in the Younger Dryas, is interrupted at 120 cm by a brief decrease. There, *Quercus* pollen has a peak value for which suggests the interstadial of the Bølling–Allerød chronozone. Thus the most arid phase of the last 24 ka occurs in the Younger Dryas time interval. This is consistent with the pollen record of core KET 8216 and strengthens our identification of an extreme arid and cold episode in the Mediterranean domain as the regional expression of the Younger Dryas event. The reliability of the pollen data, is asserted by the pollen sums: 425 and 139 grains for the interstadial, 921, 153 and 786 grains for the Younger Dryas, excluding those of *Pinus* (respectively 699, 86, 2679, 121 and 1977 grains).

#### Core BAN 84 09 GC in the southern Ionian Sea (Cheddadi *et al.*, 1991) (Fig. 5)

The 475 cm long core, which is entirely black, was raised from the 46 km<sup>2</sup> anoxic Bannock Basin (34°19'N, 20°01'E) in the Ionian sea, at 3405 m water depth, below the oxic-anoxic interface at 3160 m. The isotopic and pollen records have shown that the upper part of the core, from 260 cm to the core-top is redeposited. The records for the *in situ* part of the core, including the pollen count, are shown in Fig. 4.

Two AMS  $^{14}\text{C}$  dates are available, framing the isotopic signal of the deglaciation: 14,670±180 BP at 359 cm, and

8760±1.70 BP at 295–299 cm, after a 400 year correction for the reservoir effect. The similarity of the trend of the Late Quaternary isotopic record in Mediterranean cores with that of cores from the global ocean has led to completely accept their correlation. In core BAN 84 09 GC, the Holocene sapropel is identified by the most depleted isotopic value at 310–275 cm, and the highest pollen concentration at 310–285 cm.

Here the pollen abundance succession for Chenopodiaceae and *Pistacia* is the same as in core KET 8216. At 320 cm, the percentage is maximum for Chenopodiaceae and lowest for *Artemisia*, Gramineae and temperate deciduous trees. This signals the very arid climate of the Younger Dryas. The inferred age is 10.95 ka BP. Isotopic values show no reversal. At 330 cm, an interstadial, dated 11.9 ka BP, is coeval with the end of the first pulse of the deglaciation, Termination Ia (Duplessy *et al.*, 1981), and the Allerød interstadial of NW Europe.

The abundance of *Artemisia* in the BAN core in the Ionian sea varies in contrast with that in the Tyrrhenian and Adriatic seas records. It decreases from maximum in the Last Glacial Maximum at 18 ka BP at 400 cm, to minimum at 11 ka BP in the Younger Dryas, reached after a small increase in the interstadial at 330 cm. We interpret this contrast as due to the trend of increasing continentality and aridity in the pollen source areas from the Tyrrhenian to the Ionian sea, eastward and southward. This trend is obvious in the pattern of abundance for Chenopodiaceae pollen in the Younger Dryas layer. It is higher in the BAN core (40%) than in the two others (respectively 20% and 14%). In the driest, lowland belt of the European shores of the Mediterranean, a decrease of the moisture supply to just below the requirement of *Artemisia* plants (200–250 mm annual precipitation) induces a reduction of this taxon and an expansion of the less demanding Chenopodiaceae (100–150 mm). This trend is expressed by the pollen abundances of the BAN

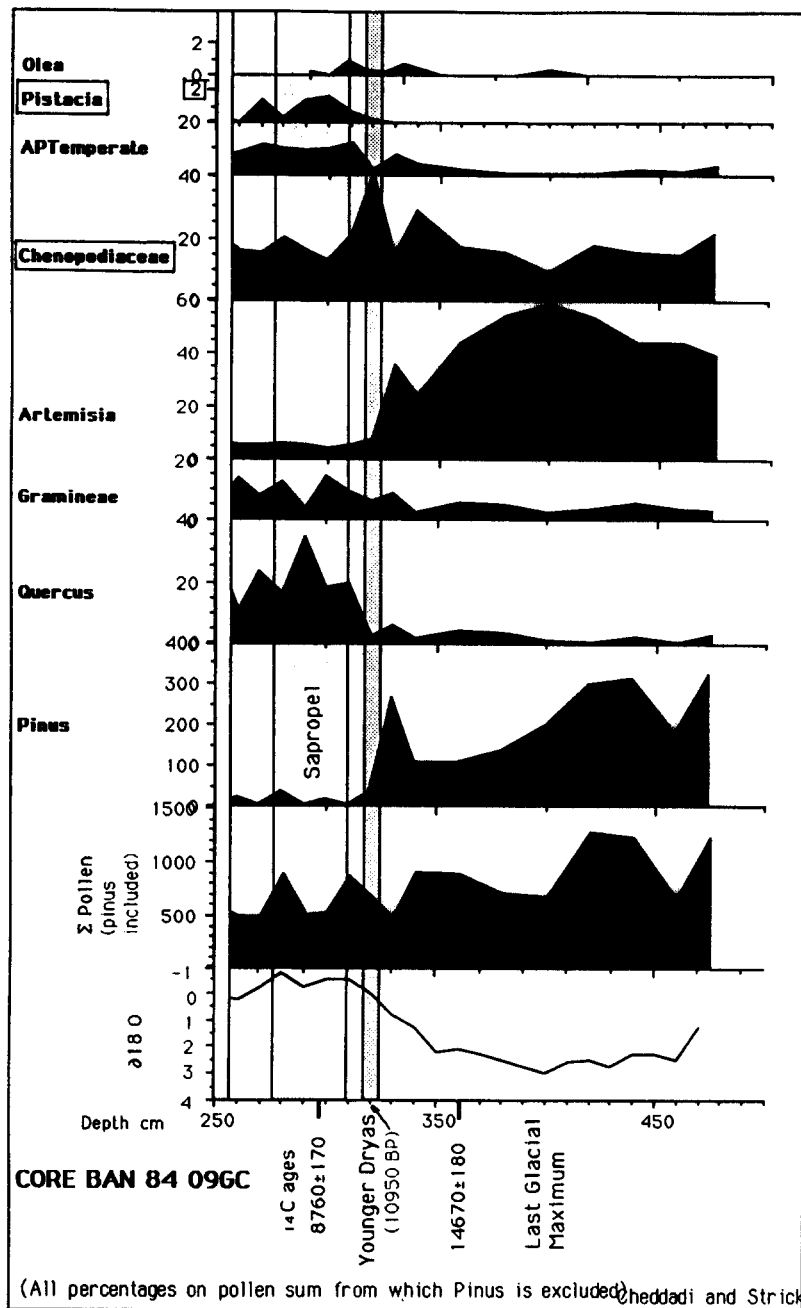


FIG. 5. Ionian sea core BAN 84 09GC (34°19'N, 20°01'E, 3405 m water depth) in the small anoxic Bannock basin (Cheddadi *et al.*, 1991): records of oxygen isotope (*Globigerinoides ruber*) and pollen percentage for selected relevant taxa (redrawn). AMS  $^{14}\text{C}$  dates on assemblage of planktonic foraminifers.

core. But when the moisture supply, though decreasing, still provides 200–250 mm, *Artemisia* and *Chenopodiaceae* plants expand their territory at the expense of the more demanding *Gramineae*. Consequently, the pollen abundance of *Artemisia* and *Chenopodiaceae* in the Tyrrhenian and Adriatic sea records increases, and that of *Gramineae* decreases. Nevertheless, the *Chenopodiaceae* increase is smaller in the Ionian record.

In the BAN core, at 310 cm, the increase of *Quercus* and other deciduous trees and the decrease of the driest herbs signal the beginning of the Holocene at 10 ka BP. The abundance of *Pistacia* reaches its peak (2%) at 300 cm, at 9.05 ka BP, and remains high until 280 cm at 7.14 ka BP, within the virtual sapropel. The pattern is the same

as in the Adriatic core, with maximum for *Chenopodiaceae* at 11 ka BP during the Younger Dryas, increase for *Quercus* at 10 ka BP, appearance and peak of *Pistacia* at 9–7 ka BP as the sapropel is deposited.

*Core MD 76 135 in the Western Arabian sea (Van Campo et al., 1982; Prell and Van Campo, 1986) (Fig. 6).*

This core was drilled off the southern façade of the Africa–Asia land bridge (14°26'N, 50°31'E, 1895 m water depth). The oxygen isotope records of benthic as well as planktonic foraminifera display at 165 cm core depth the reversal and the plateau that are associated with the Younger Dryas chronozone (Duplessy *et al.*, 1981), and have been observed and dated in many cores from the

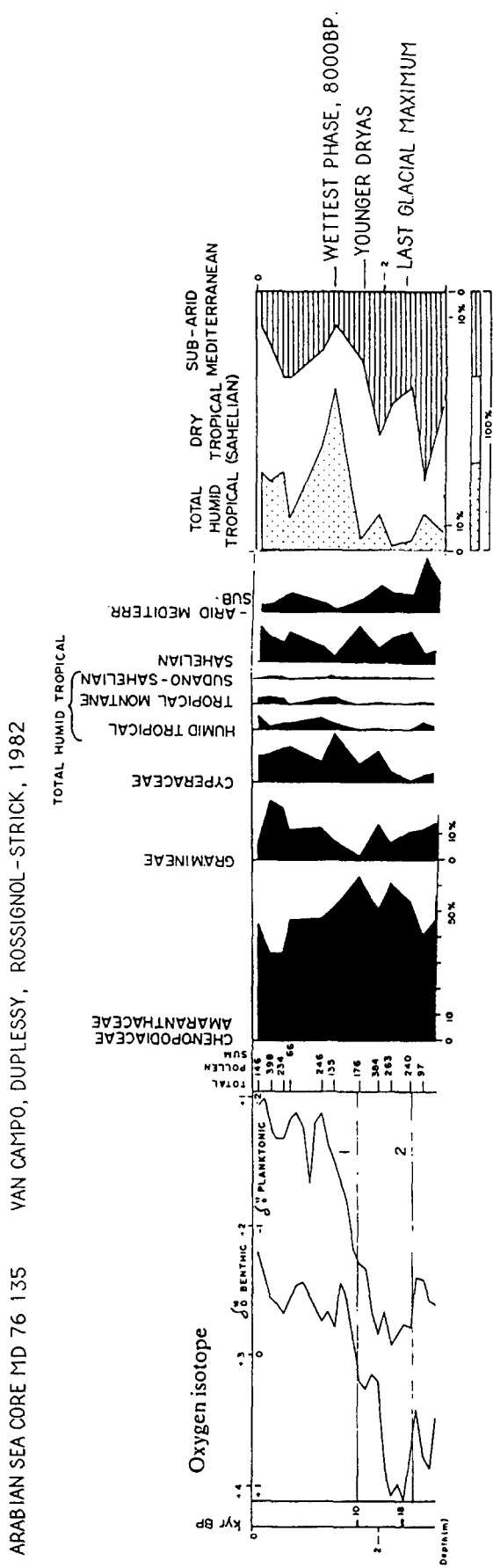


FIG. 6. Northern Arabian sea core MD 76 135 (14°26'N, 50°31'E, 1895 m water depth) (Van Campo *et al.*, 1982): records of oxygen isotope (planktonic and benthic foraminifers) and pollen percentage for selected relevant taxa.

Atlantic (Bard *et al.*, 1987; Lehman and Keigwin, 1992) and the Pacific (Kudrass *et al.*, 1991). At this level, the pollen record shows that Gramineae–Cyperaceae decline and Chenopodiaceae and sahelian taxa rise. Those pollen originate in southern and coastal Arabia. The tropical humid and montane taxa from East Africa, Ethiopia and Yemen also decline. Chenopodiaceae percentage is higher than during the Glacial Maximum at 220 cm. These values indicate the desiccation of peripheral land. At 130 cm, dated 8 ka BP, the abundance of tropical humid and montane taxa is maximum, while Chenopodiaceae and sahelian taxa decrease. This is the wettest period of the Holocene, the optimum of tropical climate. Concurring with these marine data, land records in northern Africa and western Asia have shown that the African–Asian monsoon was strongest between 0–9 and 6 ka BP (Swain *et al.*, 1983; Gasse *et al.*, 1990, 1991; Gasse and Fontes, 1992, Van Campo and Gasse, 1993).

Thus, the isotopic record from the Arabian sea shows the rapid succession of the Younger Dryas and the early Holocene optimum that is matched in the pollen record respectively by the most arid and the most humid phases since the Glacial Maximum. During the Holocene optimum, the source of the heaviest summer precipitation is the Equatorial Westerlies generating the summer monsoon, around the Arabian sea and the extra-tropical Westerlies in the Eastern Mediterranean domain.

### The Pollen Succession in Land Records in Greece and the Middle East

#### Core I in Lake Ioannina (Bottema, 1974) (Fig. 7)

Proceeding from west to east in the Eastern Mediterranean region, we first inspect the pollen record of Lake Ioannina (alt. 470 m), in Epirus, NW Greece,

north of the Ionian sea. The Ioannina core I is dated by one  $^{14}\text{C}$  date,  $10190\pm 90$  BP at 277–265 cm (mean depth 271 cm), mid-slope of the postglacial rise of *Quercus* pollen percent. There is also one date in Ioannina core II (13 km to the SW of core I),  $4535\pm 40$  BP at 220–230 cm. In Ioannina I, the same stage of the pollen succession is recognized at 140 cm. We therefore feel confident in attributing that age to the 140 cm level of Ioannina I. Based on these two dates, the sedimentation rate of Ioannina I is  $10\text{ cm} = 431.68$  years. The chronostratigraphy which is derived for this core will be compared to that of the marine cores.

The relative wetness of this westward facing site, past and present, is evident in the permanence of ~10% *Quercus* pollen during the Würm Glacial. This may well be the reason why the Younger Dryas expressed in the marine cores by maximum Chenopodiaceae is not outstanding here. The lowest arboreal pollen (AP) percentage is seen in subzone V5 (440 to 375 cm). Its derived age of 17,500 to 14,680 BP points to the general period of the Last Glacial Maximum. In subzone W1, most conspicuous among the trees, the *Pinus* and *Abies* percentages increase. They drop in subzone W2 (335–313 cm), then increase in subzone W3 (313–285 cm). In subzone W2, neither Chenopodiaceae nor *Artemisia* display any peak, but Gramineae do, as *Pinus* and *Abies* retreat. This suggests that some territory is lost by these trees and gained by grasses, as moisture and/or temperature declined. Subzone W2 is therefore a discrete phase of less favourable conditions for tree life. The derived age of subzone W2 is 12,953 to 12,003 BP, which is too old for identification with the Younger Dryas chronozone.

The other marker, the *Pistacia* zone, is seen here from 260 to 180 cm. According to the intrinsic chronology of Ioannina, it is dated 9715 to 6260 BP. The AMS dates of

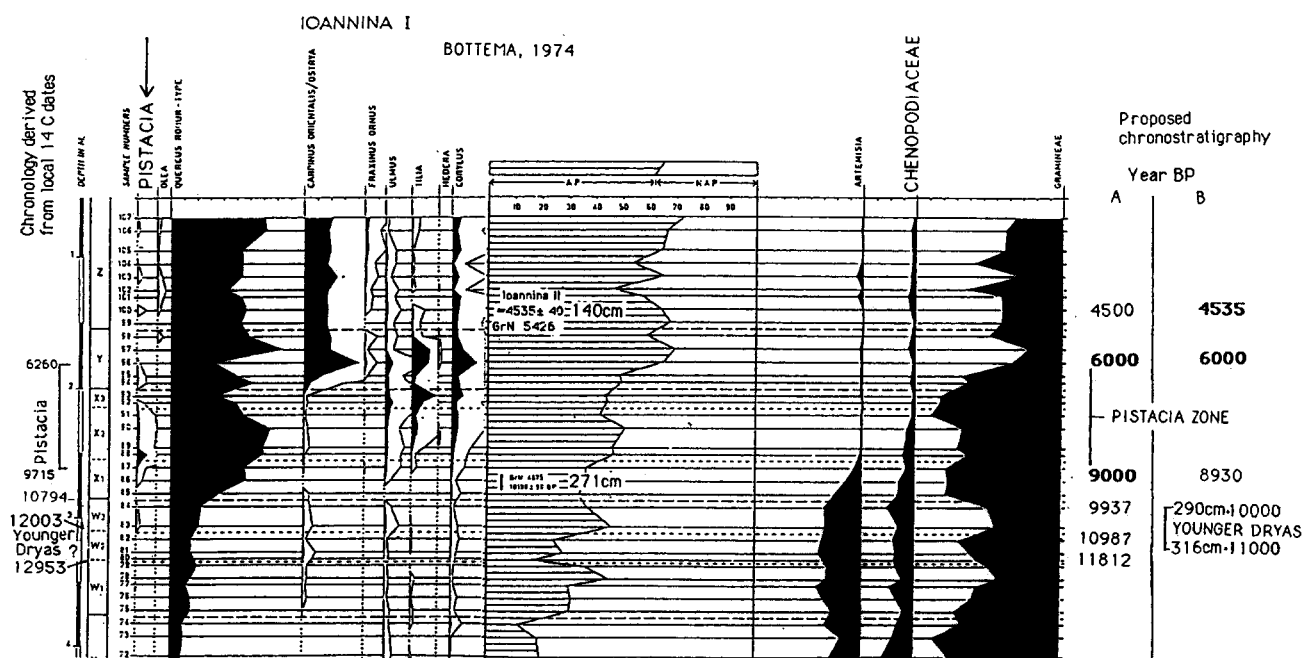


FIG. 7. Diagram Ioannina I (formerly a lake) in Epirus, north-western Greece, 470 m above sea level (a.s.l.) (Bottema, 1974): pollen record of selected relevant taxa. The upper  $^{14}\text{C}$  date is transferred from diagram Ioannina II.

core KET 8216 suggest an age from 9000 to 6000 BP, coeval with sapropel deposition. This would suggest that the 10,190 BP date would only be a few hundred years too old.

Dating the *Pistacia* zone according to the marine AMS dates yields a 10 cm = 375.0 years sedimentation rate in Ioannina I. We now derive the time-scale for Ioannina I from this marker zone. In Fig. 6, the right side column A shows that subzone W3 occurs from 10,987 to 9937 BP, and subzone W2, from 11,812 to 10,987 BP. The age for W3 is consistent with the Younger Dryas chronozone but the zone is less dry than W2. This time-scale confirms the assignment of the 4535 <sup>14</sup>C years BP age to the 140 cm level, which it dates 4500 BP.

A third time-scale can be devised, based on the 4535 BP age at 140 cm, and 6000 BP as the top of the *Pistacia* zone at 180 cm, with a 10 cm = 366.25 years sedimentation rate. It is shown in Fig. 7, column B. The base of the *Pistacia* zone is 8930 BP, in good agreement with the marine record. The Younger Dryas chronozone of 11,000 to 10,000 BP unfolds in Ioannina I from 316 cm to 290 cm. This depth interval includes the upper part of subzone W2 and the lower part of subzone W3, and is consistent with the pollen record. At 271 cm, the mid point of the 265–277 cm interval dated 10190±90 BP by <sup>14</sup>C, the age of 9333 BP is registered. This 857 year younger age corresponds to a vegetational stage where the deciduous oak forest has significantly expanded. This time-

scale yields the best agreement with the global and regional records.

*Core in Lake Xinias (Bottema, 1979) (Fig. 8)*

In south-central Greece, coring has been done in Lake Xinias (alt. 500 m). The pollen record clearly shows the same pollen succession as that observed in the Adriatic and Ionian seas cores. A treeless phase with peak Chenopodiaceae (*Atriplex*-type) abundance (90%), low *Artemisia* and Gramineae (~5% each) is seen from 220 to 170 cm. This suggests an extremely dry, even desert episode, with less than 100 mm precipitation. Subsequently, the *Quercus* pollen abundance begins to increase at 170 cm, and culminates at 90 cm. A zone with peak *Pistacia* abundance is seen from 140 to 40 cm.

This pollen record has been dated by the <sup>14</sup>C method. The two upper dates are 10,680 ±90 BP (organic fraction) at 150 cm, and 21,390±430 BP at 370–380 cm. This defines a 10 cm = 476 years sedimentation rate. Accordingly, the Chenopodiaceae zone was deposited between 14,012 and 11,632 BP, respectively ~3000 and ~1600 years older than the limits of the Younger Dryas chronozone. The boundaries of the *Pistacia* zone are 10,680 BP and 5444 BP, respectively 1700 years older, and 556 years younger than indicated by the marine records.

Based on this marine time-scale, the attribution of the ages of 9000 and 6000 BP to the boundaries of the

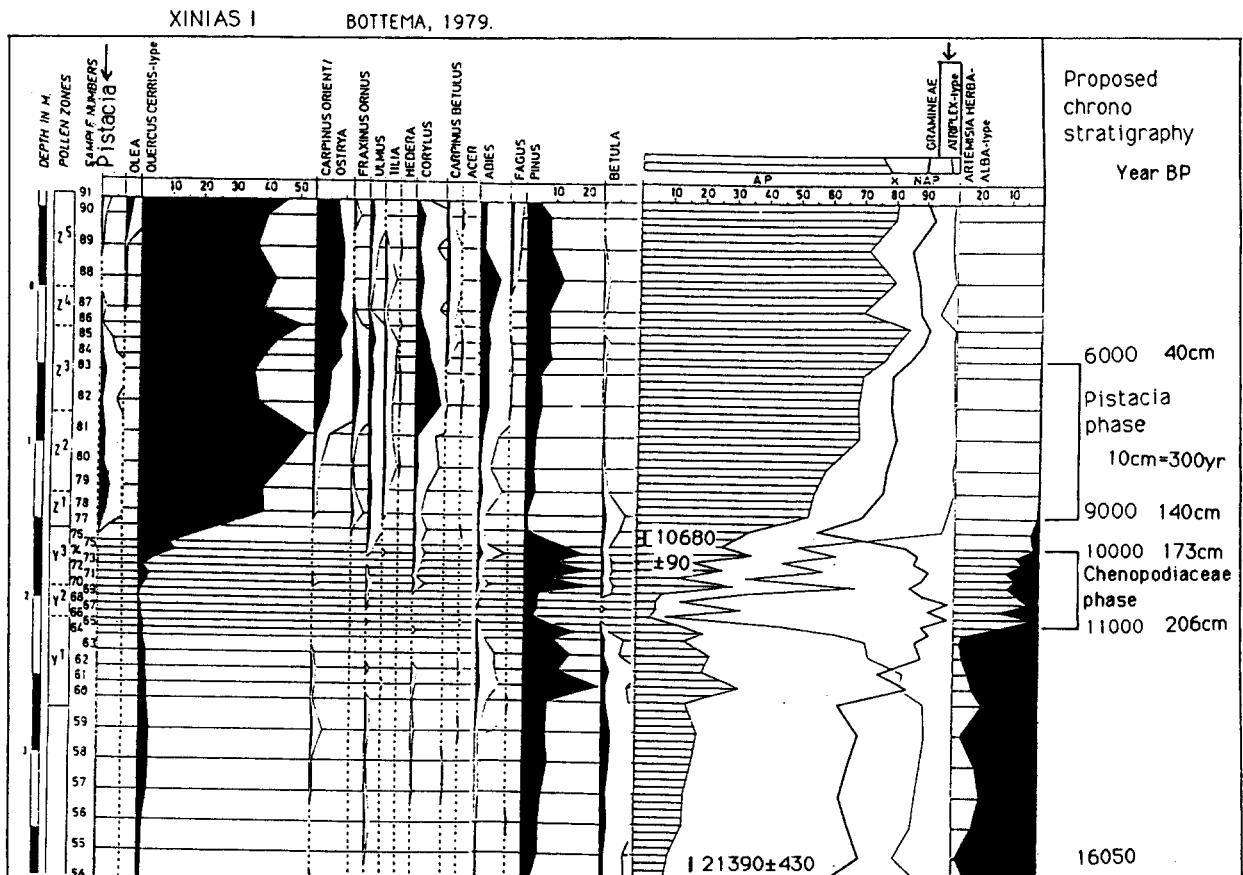


FIG. 8. Diagram Xinias I (formerly a lake) in Thessaly, Greece, 500 m a.s.l. (Bottema, 1979): pollen record of selected relevant taxa. At 1.50–1.60 m, <sup>14</sup>C dates of 10,680±90 BP on organic fraction, 11,150±130 BP on calcareous fraction.

*Pistacia* zone implies (sedimentation rate: 10 cm = 300 years) that the Chenopodiaceae zone 4 spanned from 11,400 to 9900 BP. This time interval comes closer to the Younger Dryas chronozone than that yielded by the local radiometric dates. The marine time-scale yields an age of 16,050 BP for the 375 cm level which has been dated 21,370 BP by the  $^{14}\text{C}$  method, and 9450 BP for 155 cm,  $^{14}\text{C}$  dated 10,680 BP. At 375 cm, the pollen record with 27% *Artemisia*, 30% Gramineae and 10% Chenopodiaceae, indicates at 16,000 (the Last Glacial Maximum), a climate significantly less arid than during the Younger Dryas chronozone. The Xinias basin may have received 250–300 mm annual precipitation. In our view, there is little doubt that the abrupt, very arid, quasi-desert phase that produced the high Chenopodiaceae pollen abundance in the Xinias record is synchronous with the Younger Dryas cold spell.

In the site of lake Khimaditis (alt. 560 m), at ~120 km NE of Ioannina, the pollen record of core Khimaditis I (Bottema, 1974) displays the Chenopodiaceae zone (50%) at 490–445 cm, and the rise of the deciduous oak pollen abundance above 460 cm, but the presence of *Pistacia*, mainly above 430 cm, is discontinuous. One  $^{14}\text{C}$  age of  $9345 \pm 85$  BP at 445–440 cm identifies the transition from the Younger Dryas to the early Holocene optimum. Presently the natural vegetation around the lake is destroyed. In natural conditions, it would have consisted of a deciduous oak forest, under 800–1000 mm precipitation. The absence of *Pistacia* trees from this type of forest may account for the discontinuity of the presence of its pollen in the fossil record.

*Core in Tenaghi Philippon, southern Macedonia, NE Greece (Wijmstra, 1969) (Fig. 9)*

The pollen record of this very long and famous core in the marsh of the faulted Drama basin (alt. 40 m) shows in its upper 11 meters the same succession as described in the previous cores. In pollen subzone X5, from 700 to 610 cm, the percentage for Chenopodiaceae pollen is highest (25%). Above 610 cm, the abundance of Chenopodiaceae decreases, and after a small surge for *Pinus* in zone Y1, that of *Quercus* greatly expands, from 570 to 550 cm, in subzone Y2a. At 540 cm, as *Quercus* persists, *Pistacia* pollen appears. It remains abundant (max 7%) up to 350 cm, in subzones Y2b to Z2. There is a brief disappearance at 480–450 cm, in subzone Y3, which concerns other trees as well (*Quercus*, *Fraxinus*, *Ulmus*, *Tilia*, *Ostrya*). These abrupt declines are accompanied by a strong peak of *Artemisia* pollen abundance. Above 580 cm, Chenopodiaceae remain low. Thus, from 1100 to 350 cm, the pollen record evolves through the same three phases as in western and central Greece and the periphery of the central Mediterranean: maximum of Chenopodiaceae, increase of *Quercus*, and continuous presence of *Pistacia*. The Holocene begins at 350 cm.

The radiometric chronology of this upper part of the record presents a serious problem. Four  $^{14}\text{C}$  dates (conventional, years BP) have been published (Wijmstra, 1969):  $7850 \pm 50$  at 430 cm,  $14,600 \pm 200$  at 625 cm,

$16,360 \pm 90$  at 730 cm, and  $22,640 \pm 165$  at 950–1000 cm. This set of  $^{14}\text{C}$  dates implies that the vegetational succession of the deglaciation in Macedonia is not synchronous with the identical successions of western Greece. The two phases investigated here would have occurred much earlier: the Chenopodiaceae phase from 17,200 to 14,080 BP, the *Pistacia* phase beginning at 11,660 BP. In agreement with Bottema (1974), we find this difficult to accept, particularly since Macedonia has a more continental, drier climate than western Greece. In the mediterranean domain, as seen above, the climate improvement that is linked to the deglaciation is believed to critically affect the vegetation mainly through an increase of moisture in summer, and an increase of temperature in winter. Thus, it is highly improbable that drier Macedonia, where the summer (May to October) rainfall is 209 mm, would have reached the minimum summer moisture level that sustains the growth of deciduous oaks much earlier than wetter Epirus (same period: 420 mm). Although Macedonia is more eastern, i.e. more continental than Epirus, the mean January temperature in both sites is  $5^\circ\text{C}$ , and cannot be a discriminant bio-climatic factor.

We are thus led to propose that the vegetational phases of the deglaciation time occurred synchronously in Epirus and Macedonia. We identify the Chenopodiaceae subzone, X5, as the Younger Dryas, and the *Pistacia* phase, Y2b to Z2, as coeval with sapropel deposition in the Eastern Mediterranean. The chronology of the deglaciation can be derived from the sedimentation rate of 158 year for 10 cm, based on the 9000 to 6000 BP *Pistacia* phase. Subzone X5 lasted from 11,528 BP to 10,106 BP. The ages of the two levels dated by  $^{14}\text{C}$ , 16,360 BP and 14,600 BP become, respectively, 11,528 BP and 10,106 BP. The rise of the *Quercus* pollen abundance begins at 9632 BP, as moisture increases in summer. Within the *Pistacia* phase, the sharp dry/cold event at 480–450 cm is dated 8054–7580 BP. At 430 cm,  $^{14}\text{C}$  dated 7850 BP, the new age is 7260 BP. The *Pistacia* phase responds to a climate optimum of the warmest winters and abundant summer moisture, during the Boreal and the early Atlantic chronozones. After 6000 BP, colder winters may account for the end of the continuous presence of *Pistacia*. The persistence of adequate summer moisture can account for persistence of deciduous trees.

According to that revised chronology, the interstadial of the Bølling–Allerød chronozone is identified by the substantial increase of *Pinus* pollen abundance from 870 to 700 cm in subzone X4, from 14,214 to 11,528 BP. It is synchronous with the first pulse of ice-sheet melt-water in the Atlantic (Fairbanks, 1989), calibrated by U-Th to 16,000–13,000 BP (Bard *et al.*, 1990).

*Core in the Ghab Valley, NW Syria (Niklewski and Van Zeist, 1970; Van Zeist and Woldring, 1980) (Fig. 10)*

In the marshy middle course of the Orontes valley (alt. ~160 m) in northwestern Syria, an 11 m long core, Ghab I, was collected. Its pollen record displays in its upper two metres the vegetational succession previously

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TENAGI PHILIPPON II

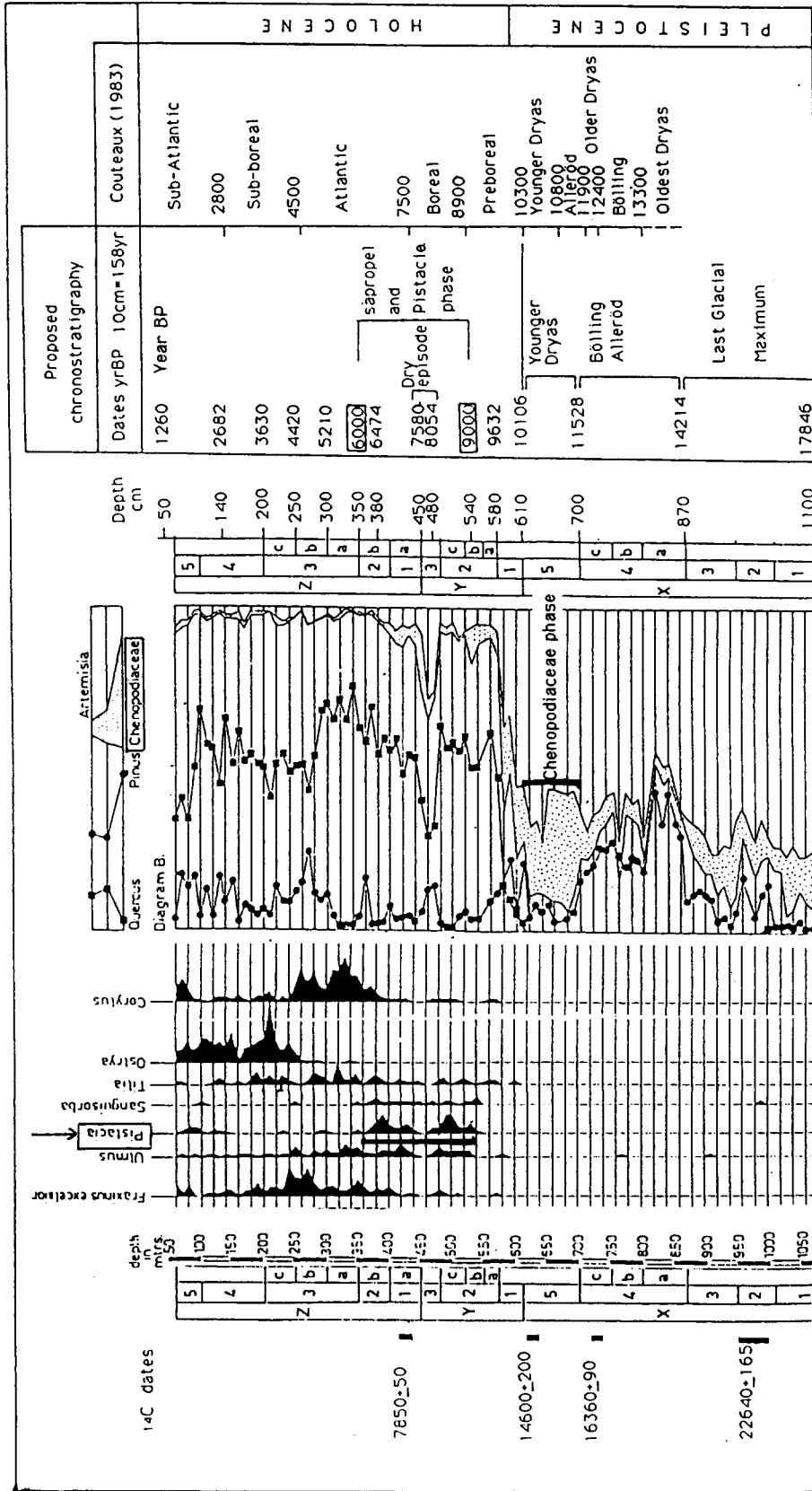


FIG. 9. Diagram Tenaghi Philippon in Macedonia, Greece, 40 m a.s.l. (Wijmstra, 1969): pollen record of selected relevant taxa and <sup>14</sup>C dates.

## GHAB VALLEY, SYRIA NIKLEWSKI AND VAN ZEIST, 1970

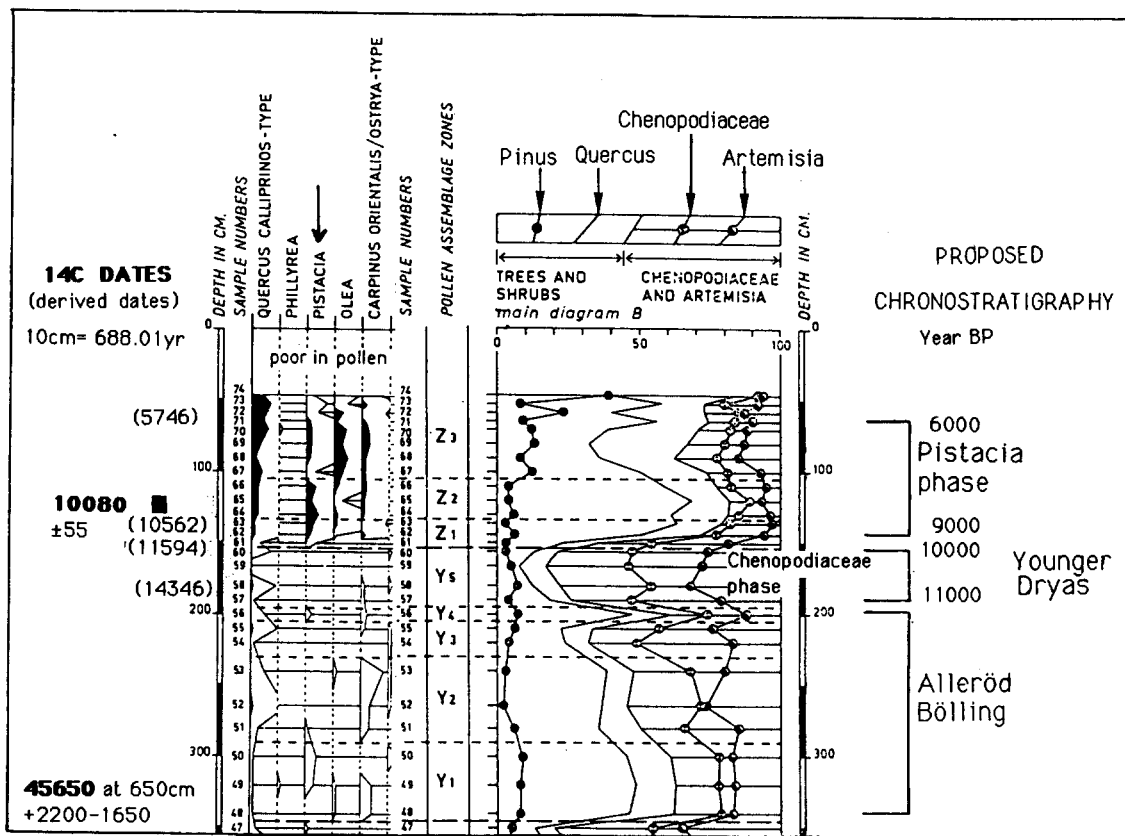


FIG. 10. Diagram Ghab Valley (former lake) in northwestern Syria, (Niklewski and Van Zeist, 1970): pollen record of selected relevant taxa.  $^{14}\text{C}$  dates on shells fragments.

described. A phase with maximum abundance of Chenopodiaceae pollen (50% in the diagram B, from which Gramineae are eliminated), and of *Artemisia* (30%), is seen from 195 to 155 cm in subzone Y5. Immediately after, *Quercus* percent increases, and from 140 to 70 cm, *Pistacia* pollen is continuously present except for a brief interval at 100–90 cm. Three  $^{14}\text{C}$  dates are provided: 10,080±55 BP at 129–137 cm; 45,650(+2200-1650) BP at 645–655 cm; 47,000(+6000-3450) BP at 960–972 cm. According to the two upper dates (sedimentation rate: 10 cm = 688.01 years), subzone Y5 lasted from 14,346 to 11,594 BP, which is older than the Younger Dryas chronozone. We suspect that the older date is not reliable.

Correlation with the Ioannina and Adriatic sea records suggests that deposition of the *Pistacia* zone lasted from 9000 to 6000 BP. Consequently, with sedimentation rate of 10 cm = 428.6 years, the age of 11,000 BP occurs at 187 cm, and 10,000 BP at 163 cm. These levels are very close to the boundaries of subzone Y5 of highest Chenopodiaceae pollen abundance (195–155 cm), which we identified as regionally typical of the Younger Dryas event. Conversely, this reflects on the *Pistacia* zone to support the validity of its proposed age. In this time framework, the age of the level  $^{14}\text{C}$  dated 10080 BP (mean depth 133 cm) would be 9300 BP. It can be safely assumed that the older  $^{14}\text{C}$  dates are actually infinite. Thus, our interpretation of the Ghab Valley pollen record

suggests it is consistent with the regional evolution of climate deduced from the marine records.

*Core in Lake Hula, northern Israel (Baruch and Bottema, 1991) (Fig. 11)*

In the upper valley of the Jordan River, a long core was collected from lake Hula (alt. 70 m). The pollen record of this core was published for the interval from 1630 to 1000 cm. It shows above 1625 cm a high percentage of herbs, mostly grass and *Artemisia* (10%), with a peak for Chenopodiaceae (15%) from 1560 to 1430 cm. From 1475 cm the *Quercus* percentage begins to increase, and *Pistacia* abundance reaches ca. 2% from 1350 to 1250 cm, then 3 to 5% from 1250 to 1030 cm. Four  $^{14}\text{C}$  dates are provided: 17,140±220 BP at 1600–1630 cm, 11,540±100 BP at 1240 cm, 10,440±120 BP at 1120 cm, and 9270±120 BP at 1010 cm. The pollen succession suggests the regional dry phase of the Younger Dryas chronozone from 1560 to 1430 cm, and the optimum *Pistacia* phase of 9000–6000 BP in the 1350–1000 cm interval. However, the  $^{14}\text{C}$  dates do not support this interpretation. According to these dates, the Younger Dryas chronozone should extend from 1230 to 1100 cm. Therefore, the warm, humid *Pistacia* phase would have occurred in most part during the Younger Dryas chronozone. Taking into account the relatively short distance between lake Hula and the Ghab valley,



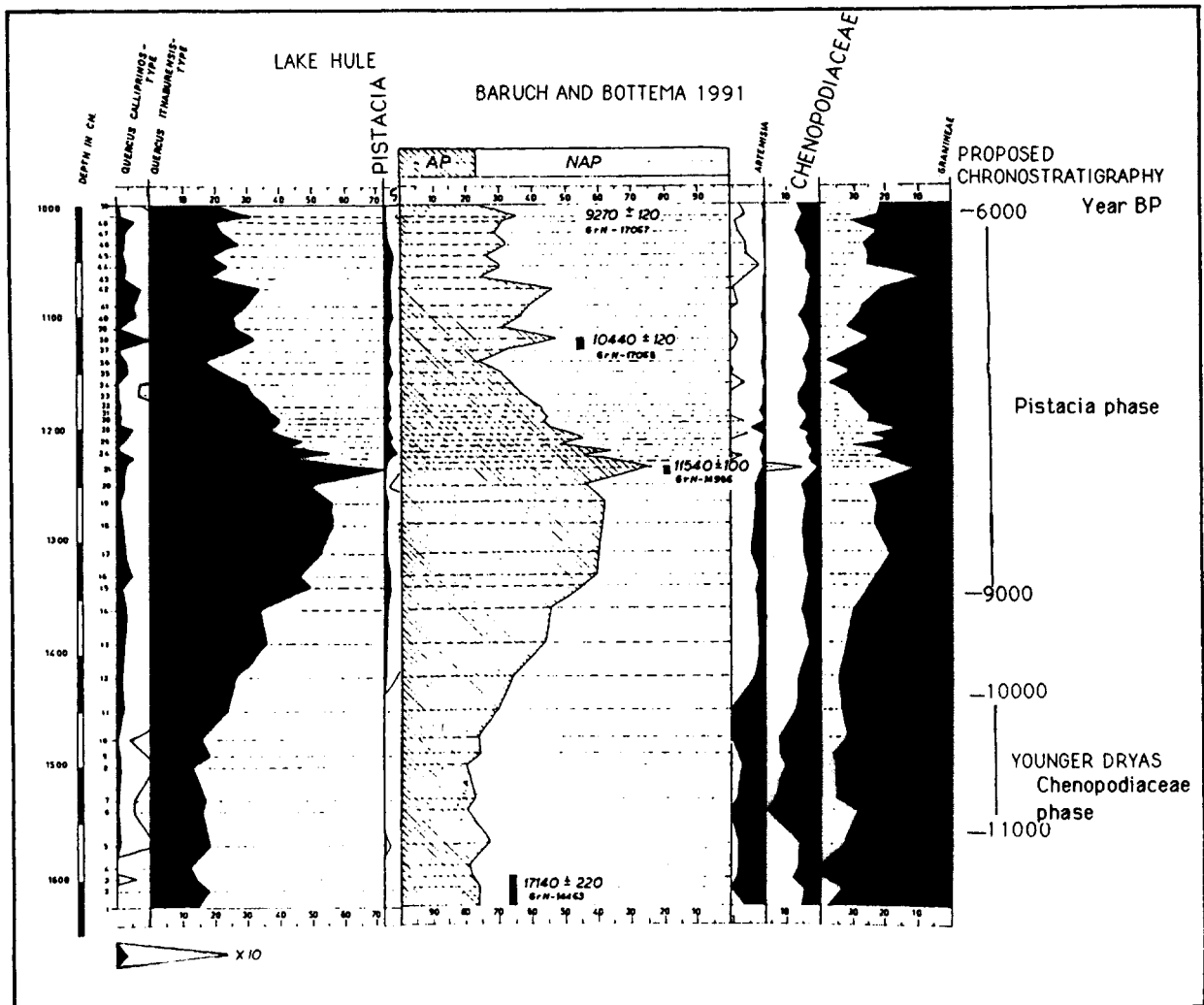


FIG. 11. Diagram Lake Hule, northern Israel (Baruch and Bottema, 1991): pollen record of selected relevant taxa and  $^{14}\text{C}$  dates.

about 300 km, it is difficult to envision that such different climates, severe aridity in the Ghab, and warm winters, moisture at least 500 mm in the Hule, could have coexisted from 11,000 to 10,000 BP. We suggest that the discrepancy of the pattern in the Hule record, previously discussed (Baruch and Bottema, 1991), could be best accounted for by contamination of the material submitted to radiocarbon analysis by hard water effect and old carbonates, which tends to increase the age.

*Core in Lake Van, Eastern Turkey (Van Zeist and Woldring, 1978) (Fig. 12)*

The pollen record of the cores from Lake Van in mountainous eastern Turkey (alt. 1646 m) displays the pollen succession previously described. The chronology of the cores is based on varve counts. The percentages of Chenopodiaceae are maximum in pollen zone 3, dated by the varve count between 7300 and 6400 BP, in samples 16 to 21. At 6400 BP, there is the transition from core 2 to core 13. Immediately above, the *Pistacia* zone with 3–5% extends in samples 24 to 51. The presence of *Pistacia* persists above sample 51 with less than 0.5%. The rise of *Quercus* percentage begins with sample 22. We identify zone 3 as the Younger Dryas chronozone,

from 11,000 to 10,000 BP. We suggest that some layers may be missing at the transition between the two cores. They would represent 1000 years between the end of the Younger Dryas chronozone and the beginning of the *Pistacia* zone at 9000 BP. We propose 6000 BP for the end of the *Pistacia* zone in sample 51. This chronology based on biostratigraphic correlation suggests that the dating by varve count may not be as reliable as expected.

*Cores in Lake Zeribar, western Iran (Van Zeist and Bottema, 1977) (Fig. 13 and Fig. 14)*

Lake Zeribar lies at 1300 m altitude in a valley of the Zagros mountain range of western Iran. Core 1963 J was collected near the lake edge, and its pollen record is the Zeribar Ib diagram (Fig. 14). The first 4 m are coarse, undecomposed peat underlain by water, that has not been sampled. The record displays from 20 m to 16 m the transition from Glacial to Postglacial. Chenopodiaceae pollen abundance is maximum (~50%) from 20.50 m to 16.50 m. The presence of *Pistacia* pollen begins discontinuously at 18.00 m, is continuous from 17.10 m to 8.50 m and discontinuous to core-top. Abundance is higher than ~4% from 14.30 m to 10.65 m. The abundance of *Quercus* pollen begins to rise at 16.00 m. Three  $^{14}\text{C}$  dates were

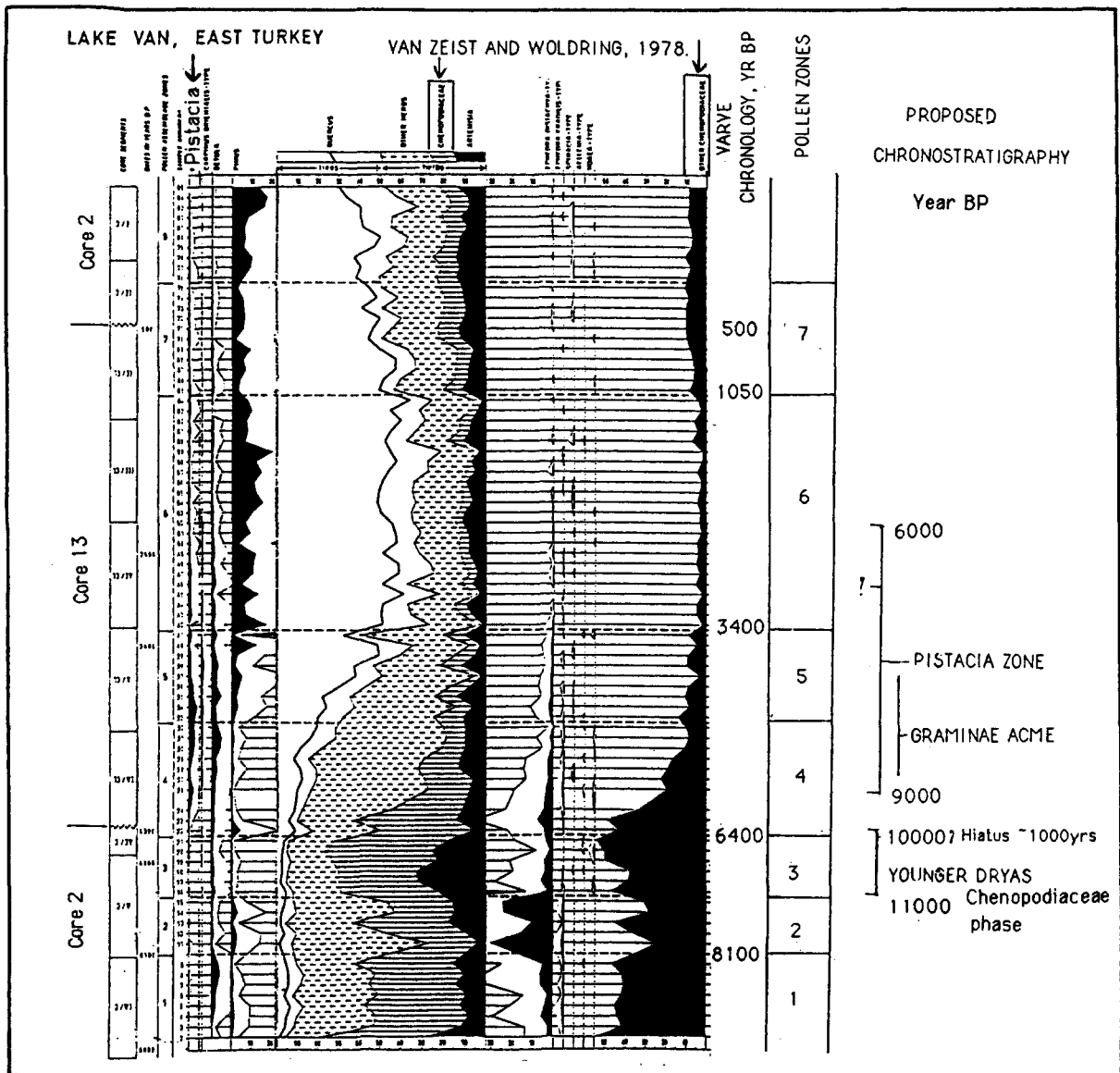


FIG. 12. Diagram Lake Van, eastern Anatolia, Turkey, 1646 m a.s.l. (Van Zeist and Woldring, 1978): pollen record of selected relevant taxa. The original diagram is a composite record from two cores, 20 km apart. Chronology based on varve count.

measured in this interval,  $8100 \pm 160$  BP at 14.10–14.20 m,  $11,480 \pm 160$  BP at 17.10–17.20 m, and  $13,650 \pm 160$  BP at 18.90–19.00 m. A fourth date can be transferred from an other core:  $5460 \pm 120$  BP at 10.50 m.

We propose that the *Chenopodiaceae* phase from 20.50 m to 16.50 m is the Younger Dryas chronozone and that the *Pistacia* phase from 14.70 m to 10.65 m lasted from 9000 to 6000 BP. The sedimentation rates inferred for the two phases would be different. This is supported by the change in lithology at 16.50 m from clay to clay-gyttja, with shells at the transition. In this shallow core site, a hiatus in sedimentation may have intervened. According to the sedimentation rate inferred from the two older dates (10 cm = 120.5 years), the transition at 16.50 m is dated 10,697 BP, and from the two younger dates, (10 cm = 72.33 years), 9895 BP. This potential gap of 802 years suggests that sedimentation at the edge of the lake may have been interrupted by water level lowering during the last 800 years of the Younger Dryas. This is supported by evidence that the water became brackish

(Van Zeist and Bottema, 1977), possibly a consequence of persistent evaporation and declining precipitation. The chronology derived from the younger sedimentation rate assigns the age 9000 BP, the basis of the *Pistacia* period, to level 15.40 cm, and the age 6000 BP, its end, to level 11.25 cm. These levels are consistent with those mentioned above for the *Pistacia* presence and are reported in Fig. 14. The visual limits of the continuous presence of *Pistacia* pollen dated by the same method occurred respectively at 8500 BP and 5570 BP, that is 500 and 430 years younger than the standard ages of this zone. The older sedimentation rate (10 cm = 120.5 years) assigns to the proposed Younger Dryas chronozone (20.50 m to 16.50 m) the respective ages of 15,463 BP and 10,697 BP, which are too old. Actually, comparison with the Zeribar II diagram supports the view that most of the Younger Dryas is missing in core 1963 J, and only its base, spectrum 96 at 16.70 cm, dated 10,938 BP, with 57% *Chenopodiaceae*, is present.

The Zeribar II pollen diagram was built from analysis

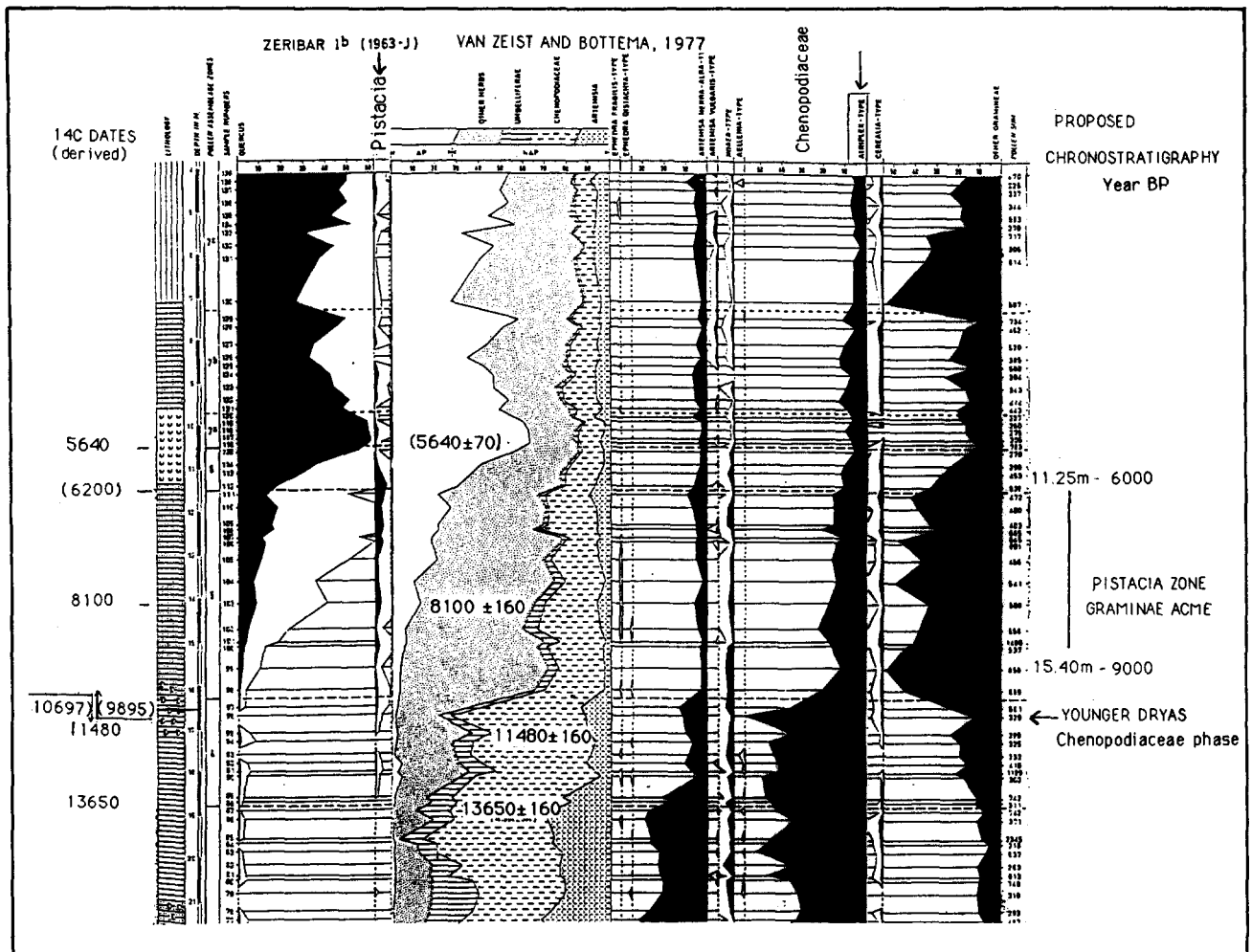


FIG. 13. Diagram Zeribar 1b (core 1963 J) near the western edge of lake, from floating sedge mat, Zagros Mountains, western Iran, 1300 m a.s.l. (Van Zeist and Bottema, 1977): pollen record of selected relevant taxa.

of cores 1963B and 1970B, respectively under 4.30 m and 4.00 m of water in the center of the lake (Fig. 13). There is a phase where the abundance of Chenopodiaceae pollen is high, from 15.40 m to 13.60 m, but that maximum (64 to 83%) is much higher than in Zeribar Ib. It precedes the phase of maximum *Pistacia* abundance, from 13.60 m to 9.60 m. Three <sup>14</sup>C dates are provided in core 1970B: 5640±70 BP at 9.78–9.93 m (mean 9.85 m); 6890±80 BP at 11.00–11.15 m (mean 11.07 m); 10,600±100 BP at 13.60–13.75 m (mean 13.67 m). The sedimentation rates are 10 cm=102.46 years for the upper interval, and 10 cm=142.7 years for the lower one. They assign to the *Pistacia* zone the ages 10,500–5380 BP, and to the Chenopodiaceae zone identified as Younger Dryas, 13,050–10,500 BP.

According to the land-sea correlation, the beginning of the *Pistacia* zone at 13.60 m occurs at 9000 BP, and its end at 9.60 m, at 6000 BP. The Younger Dryas chronozone from 11,000 BP to 10,000 BP begins at 15.40 m and should end at 13.60 m, while the abundance of Chenopodiaceae pollen displays peak value. However, at 13.60 m the end of the Chenopodiaceae phase and the beginning of the *Pistacia* phase coincide, whereas in the other sites, the two events are ~1000 years apart. In core 1970 B, the sedimentation may also have been interrupt-

ed some time at the end of the Younger Dryas and more briefly than in core 1963 J, where the hiatus began at the incipience of the arid period. The hiatus due to extreme aridity probably did not extend beyond 10,000 BP

#### The Zone of Peak Gramineae Pollen Abundance

In the pollen records on land, immediately after the Younger Dryas arid chronozone, the abundance of Gramineae pollen reaches peak value. The interval favourable to Gramineae is seen in Ioannina (zone X1, 2, 3, pollen spectra 85–93, from 280 to 200 cm), before and also after the peak abundance of deciduous *Quercus*, during the *Pistacia* zone; in Xinias (zone Z1, spectrum 77 at 150 cm), before the oak rise, in the lower part of the *Pistacia* phase; in Tenaghi Philippon (zone X5, top, and Y1, from 630 to 570 cm), before the oak rise, just before the *Pistacia* phase and, after a brief decline, also during that phase, with lower abundance; in the Ghab (zones Z1, 2, 3, spectra 61–71, from 155 to 40 cm), rising during the *Pistacia* phase; in Zeribar (zones 5 and 6, respectively in Zeribar Ib, spectra 96–115, from 1630 to 1050 cm, and in Zeribar II, spectra 14–24, from 1350 to 975 cm in core 1970B), during the *Pistacia* phase; in Van (zones 4 and 5, spectra 23–41), during the *Pistacia* phase.

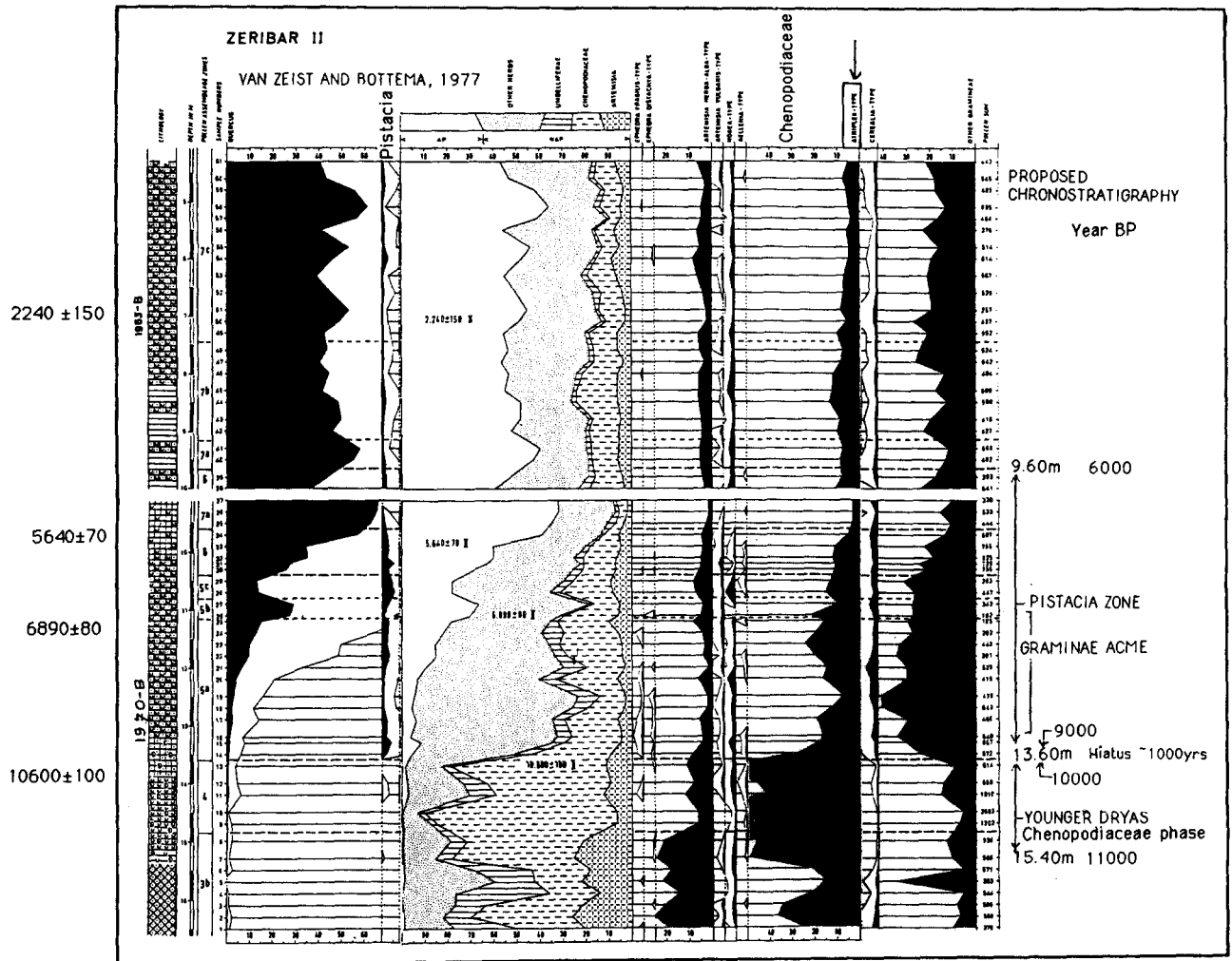


FIG. 14. Diagram Zeribar II (cores 1963 B and 1970 B) near center of lake, 2 km from core 1963 J, Zagros Mountains, Western Iran, 1300 m a.s.l. (Van Zeist and Bottema, 1977): pollen record of selected relevant taxa.

In all sites this peak zone occurs during the *Pistacia* phase. This suggests that grass is part of the regional, vegetation, as well as growing locally around the humid coring sites. Grass do provide a climatic signal. The present grass steppe that runs from eastern Europe to Central Asia around latitude 50°N has two different climate regimes (Walter, 1974). The relatively oceanic regime, where precipitation occurs mainly in winter as snow, with an Atlantic moisture source (annual precipitation 350–450 mm), sustains the grass steppe of eastern Europe, the Ukraine, south-western Siberia and Kazakhstan. In spring the ground is waterlogged from snow-melt. The grass grows with many other ephemerals. From July to September, there is a drought and the steppe desiccates. In the very continental regime of Central Asia, under low pressure in summer and the anticyclone in winter, moisture is supplied in summer (June, July, August) by convective thunderstorms, but not in winter, which is very dry (annual precipitation 280–425 mm). The grass steppe of Mongolia has a short life span in summer. As the spring is dry, the ephemerals are lacking. Thus, the grass steppe of temperate latitudes requires moisture in spring or in summer. Moisture in winter (snow) is of no direct use for the grass steppe. In the sub-mediterranean latitudes (32–36° N), on the high plateau

of Algeria and Morocco in north Africa, where precipitation occurs from October to April, it is winter/spring moisture that sustains the perennial grassland of alfa and esparto, highly resistant to cold, that is abundant between the 200 and 400 mm isohyets, often interspersed with expanses of *Artemisia* (White, 1983).

In the pollen records, the *Pistacia* zone to which is associated the peak of Gramineae reveals that the winters were frost-free, and there was no snow-cover. The moisture required by grass must have been supplied by 200–400 mm of rain in spring, perhaps in part in summer. The co-occurrence of *Pistacia* trees and grass indicates warm winters, and adequate precipitation in spring. The absence of deciduous trees at that stage suggests that annual precipitation, though rising, was still below 450–500 mm.

## DISCUSSION

The timing of the succession of Chenopodiaceae and *Pistacia* phases is established in the marine cores by their correlation with the oxygen isotopic record of global climate. It confirms that the Chenopodiaceae phase identifies the Younger Dryas chronozone, a chronostratigraphic unit of reversal to quasi-glacial conditions, globally

observed from 11,000 to 10,000 BP. The *Pistacia* phase specifies a period of climatic optimum from 9000 to 6000 BP. Regionally, the most arid vegetation of the Late Pleistocene reveals the extreme severity of the Younger Dryas climate. The lowlands at least are very dry (less than 150 mm annual precipitation), and the temperature in winter is well below freezing. At almost all altitudes, the ground-cover is open. In the relatively humid basin of Ioannina, it mostly consists of a grass steppe, and a semi-desert with *Artemisia* closer to sea-level. Around Lake Xinias and in the Drama basin of Macedonia, one would have seen mostly a semi-desert and large expanses of desert. The severity of the winters is documented by the identification in Tenaghi of two Chenopodiaceae taxa that are presently widespread in the extremely continental semi-deserts of Central Asia (Smit and Wijmstra, 1970).

In stark contrast, during the *Pistacia* phase from 9000 to 6000 BP, the climate is most favourable for the diversity of plants that require either some summer moisture, or no-frost winters. Adequate moisture (at least 200–250 mm) in spring or summer is revealed mostly by the peak pollen abundance of Gramineae that is synchronous with that of *Pistacia*, and by the rising pollen abundance of deciduous oak, which cannot withstand a long summer drought. The deciduous oak requires total annual precipitation of at least 500–600 mm. Mediterranean and Irano–Turanian vegetation interpreted from *Pistacia* pollen denotes the highest winter temperature. The mild winter condition in part accounts for the deposition of the most recent sapropel in the Eastern Mediterranean, by preventing the cooling of the sea-surface water in the south Adriatic basin and the deep convection that renews the bottom water in the entire basin.

In the tropics of northern Africa, in southern Arabia and the periphery of the Arabian sea, paleohydrological records suggest that the Early Holocene, generally from 9000 to 6000 BP, was a most humid period (McClure, 1976; Ritchie *et al.*, 1985; Ritchie and Haynes, 1987; Street-Perrott and Perrott, 1990; Gasse and Fontes, 1992). The record for the Younger Dryas chronozone, which is more scarce, indicates that conditions were generally dry (Gasse and Fontes, 1992). The pollen and isotopic records of the Arabian sea sediments reveal that the strongest monsoon in the peripheral lands occurred during the early post-glacial (Van Campo *et al.*, 1982; Prell and Van Campo, 1986). One is led to suspect that, when a set of  $^{14}\text{C}$  dates is the foundation for describing an opposite course of events in some areas of the Near East, this set should be critically reappraised for contamination by old carbon. In the Hule record particularly, the local conditions of the most dense oak forest, that are  $^{14}\text{C}$  dated of the Allerød interstadial and followed by a more sparse forest in the early Holocene, without evidence of severe aridity during the Younger Dryas, would require a marine source for moisture that does not appear generally operating at that time, even in more tropical latitudes.

We propose for the land records a time-scale based on their palynological correlation with the global marine isotopic record. An important consequence is that the chronology based on the  $^{14}\text{C}$  radiometric dates measured

in the land cores is not in phase with the marine chronology. These  $^{14}\text{C}$  dates most often are too old. We suggest that the dated sedimentary material might have been contaminated *in situ* by allochthonous material of older age. The acquisition of material better suited for the radiometric method is desirable.

We now briefly approach the question of the relationship of the terrestrial course of events with the astronomical variation of insolation according to the Milankovitch theory. The end of the cold event of the Younger Dryas coincided with the maximum insolation of the caloric northern summer. This is intuitively coherent. The puzzling question concerns the origin of the interruption around 14,500 cal. years BP (Johnsen *et al.*, 1992; Alley *et al.*, 1993) of the rapid warming of the Bølling–Allerød interstadial, while the insolation of the northern summer was rising. The Younger Dryas is only the very end of the cooling trend after 14,500 BP. Perhaps the interruption of the warming at 14,500 BP may have some link with the slowing of the rate of insolation increase after 16,000 BP for the June insolation at 60°N, after 17,000 BP for the caloric summer half-year at 65°N.

## CONCLUSIONS

The marine records of oxygen isotope and pollen in the Eastern Mediterranean and the Arabian sea, at the periphery of the Afro–Asian land bridge, are dated by the AMS– $^{14}\text{C}$  correlated. These regional isotopic records are readily identified with that of the global ocean. They show the coincidence in the two seas of two successive, contrasted climatic stages of the deglaciation: the cold Younger Dryas chronozone (globally dated 11,000–10,000  $^{14}\text{C}$  years BP), regionally expressed by an extreme arid and cold phase, and the Early Holocene with optimum conditions of warm winters and relatively wet summers.

All the pollen records of the land-bridge display a vegetational succession that reveals the same climate evolution. However, their respective time-scales, based on few  $^{14}\text{C}$  dates, most often differ from that of the marine record. We therefore believe that it is legitimate to bring these time-frames into coherence with the global climate evolution. The regional course of events unravels as follows.

In the Eastern Mediterranean and the Near East, the Younger Dryas quasi-glacial event, identified here by the highest abundance of Chenopodiaceae pollen, is the most arid period of the Last Glacial age, with winter temperature well below freezing point. Very rapidly thereafter, along the next 1000 years of the early Holocene, increasing abundance of deciduous oak pollen reveals that the annual precipitation increases to above 400–500 mm, and the minimum winter temperature rises at least to the no-frost level. From 9000 to 6000 BP, with a brief interruption around 8000 BP, the pollen records indicate that large areas of the lowland and upland are covered by a forest where *Pistacia* is a leading tree. This forest is sustained by the critical factors, high moisture in the lowland and mild winters in the upland, that signal the cli-

matic optimum of the mediterranean domain. In western Iran, the upper limit of the forest is at least 500 m higher than present. In this most continental part of the Near East, at 1300–1600 m a.s.l., the early stage of rising moisture with at least 200 mm of rain in spring/summer allows a lush grass steppe, soon replaced by a forest of deciduous oaks when annual precipitation reaches 500 mm. In the continental regime, convective summer precipitation is not to be assimilated to the intertropical summer monsoon that is generated by the Equatorial Westerlies. The strong and rapid climate improvement that culminates from 9000 to 6000 BP is correlative with the second pulse of the deglaciation. The discrepancies that appear between the proposed timescale and the chronology based on the  $^{14}\text{C}$  dates of the land records require further investigation, particularly the search for uncontaminated material suitable for radiometric dates.

The modeling of Quaternary climate changes that proceeds through reconstructions at certain specific times (Kutzbach and Guetter, 1986; Kutzbach and Gallimore, 1988) requires a reliable chronological basis in order to specify boundary conditions. It is hoped that the present study will be seen as improving that prospect.

#### ACKNOWLEDGEMENTS

Two anonymous reviewers are gratefully thanked for helpful comments and improvement of the English of the manuscript (as well as Joseph Strick for the latter). Discussions with Dr S. Bottema have been very fruitful in prompting me to sharpen the exposition of the theme presented here, and are most pleasantly remembered. This work was initiated in order to gain an overview of the recent climate history of the Eastern Mediterranean and Near East region, in the framework of the investigation supported by Palaeoflux Contract MAST2-CF93-0051 of the EEC.

#### REFERENCES

- Alley, R.B., Meese, D.A., Shuman, C.A., Gow, A.J., Taylor, K.C., Grootes, P.M., White, J.W.C., Ram, M., Waddington, E.D., Mayewski, P.A. and Zielinski, G.A. (1993). Abrupt increase in Greenland snow accumulation at the end of the Younger Dryas event. *Nature*, **362**, 527–529.
- Bard, E., Arnold, M., Duprat, J., Moyes, J., Duplessy, J.C. (1987). Bioturbation effects on abrupt climate changes recorded in deep sea sediments. In: Berger, W.H and Labeyrie, L. (ed.), *Abrupt Climate Change*, pp. 263–278. Reidel.
- Bard, E., Hamelin, B., Fairbanks, R. and Zindler, A. (1990). Calibration of the  $^{14}\text{C}$  timescale over the past 30,000 years using mass spectrometric U-Th ages from Barbados corals. *Nature*, **345**, 405–410.
- Bard, E. and Broecker, W.S. (1992). *The Last Deglaciation: Absolute and Radiocarbon Chronologies*. In: NATO ASI ser. 344 pp. Springer, Berlin.
- Baruch, U. and Bottema, S. (1991). Palynological evidence for climatic changes in the Levant ca. 17,000–9,000 BP. In: Bar-Yosef, O. and Valla, F.R. (ed.), *The Natufian culture in the Levant*. Intern. Monogr. in Prehistory, Archaeology. Ser. 1, Ann Arbor, Michigan, 11–20.
- Berger, A. (1978). Long-term variations of caloric insolation resulting from the Earth's orbital elements. *Quaternary Research*, **9**, 139–167.
- Bobek, H. (1963). Nature and implications of Quaternary climatic changes in Iran. *Changes of Climate*, UNESCO, pp. 403–413.
- Bottema, S. (1974). Late Quaternary vegetation history of Northwestern Greece. Th. Doct. Univ. Groningen, Proefschrift, 190 pp.
- Bottema, S. (1979). Pollen analytical investigations in Thessaly, Greece. *Palaeohistoria*, **21**, 19–40.
- Calleja, M., Rossignol-Strick, M. and Duzer, D. (1993). Atmospheric pollen off West Africa. *Review Palaeobot. Palynol.*, **79**, 335–368.
- Cheddadi, R. (1988). Paléoclimats au nord de la Méditerranée Orientale depuis 250 000 ans. Analyse pollinique et stratigraphie isotopique de quatre carottes marines. Thèse Université Sciences et Techniques Languedoc, Montpellier, France. 118 pp.
- Cheddadi, R., Rossignol-Strick, M. and Fontugne, M. (1991). Eastern Mediterranean paleoclimates from 26 to 5 Kyr BP documented by pollen and isotopic analysis of a core in the anoxic Bannock basin. *Marine Geology*, **100**, 53–66.
- Cour, P. and Duzer, D. (1980). Action actuelle des courants atmosphériques sur la dissémination des pollens au Sahara et dans les régions climatiques avoisinantes le long d'un transect Oran–Abidjan. *Mem. Museum Nat. Hist. Nat., Paris ser.B*, **27**, 66–79.
- Denton, G.H. and Hندی, C.H. (1994). Younger Dryas advance of Franz Josef glacier in the southern Alps of New Zealand. *Science*, **264**, 1434–1437.
- Duplessy, J.C., Delibrias, G., Turon, J.L., Pujol, C. and Duprat, J. (1981). Deglacial warming of the North-eastern Atlantic Ocean. Correlation with the paleoclimatic evolution of the European continent. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **35**, 121–144.
- Fairbanks, R.G. (1989). A 17000 year glacio-eustatic sea-level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature*, **342**, 637–642.
- Fontugne, M., Paterne, M., Calvert, S., Murat, A., Guichard, R. and Arnold, M. (1989). Adriatic deep water formation during the Holocene: Implication for the reoxygenation of the deep Eastern Mediterranean sea. *Paleoceanography*, **4**, 199–206.
- Freitag, H. (1977). The Pleniglacial, Late-Glacial and Early Postglacial vegetations of Zeribar and their present-day counterparts. *Palaeohistoria*, **19**, 87–95.
- Gasse, F., Tehet, R., Durand, A., Gibert, E. and Fontes, J.C. (1990). The arid–humid transition in the Sahara and the Sahel during the last deglaciation. *Nature*, **346**, 141–146.
- Gasse, F., Arnold, M., Fontes, J.C., Fort, M., Gibert, E., Huc, A., Li Bingyan, Li Yuanfang, Liu Qing, Mélières, F., Van Campo, E., Wang Fubao and Zhang Qingsong (1991). A 13000 year climate record from western Tibet. *Nature*, **353**, 742–745.
- Gasse, F. and Fontes, J.C. (1992). Climatic changes in north-west Africa during the Last Deglaciation (16–7 ka BP). In: Bard, E. and Broecker, W.S. (eds), *The Last Deglaciation: Absolute and Radiocarbon Chronologies*. pp. 295–325. Springer, Berlin.
- Johnsen, S.J., Clausen, H.B., Dansgaard, W., Fuhrer, K., Gundestrup, N., Hammer, C.U., Iversen, P., Jouzel, J., Stauffer, B. and Steffensen, J.P. (1992). Irregular glacial interstadials recorded in a new Greenland ice core. *Nature*, **359**, 311–313.
- Kennett, J.P. (1990). The Younger Dryas cooling event: an introduction. *Paleoceanography*, **5**, 891–895.
- Kudrass, H.R., Erlenkeuser, H., Vollbrecht, R. and Weiss, W. (1991). Global nature of the Younger Dryas cooling event inferred from oxygen isotope data from Sulu sea cores. *Nature*, **349**, 406–409.
- Kutzbach, J.E. and Guetter, P.J. (1986). The influence of changing orbital parameters and surface boundary conditions on climate simulations for the past 18000 years. *Journal Atmospheric Science*, **43**, 1726–1759.

- Kutzbach, J.E. and Gallimore, R.G. (1988). Sensitivity of a coupled atmosphere/mixed layer ocean model to changes in orbital forcing at 9000 years BP *Journal of Geophysical Research*, **93**, D1, 803–821.
- Lehman, S.J. and Keigwin, L.D. (1992). Sudden changes in North Atlantic circulation during the last deglaciation. *Nature*, **356**, 757–762.
- Mangerud, J., Andersen, S.T., Berglund, B.E. and Donner, J.J. (1974). Quaternary stratigraphy of Norden, a proposal for terminology and classification. *Boreas*, **3**, 109–127.
- McClure, H.A. (1976). Radiocarbon chronology of Late Quaternary lakes in the Arabian desert. *Nature*, **263**, 755–756.
- Newell, R.E., Kidson, J.W., Vincent, D.G. and Boer, G.J. (1972). The General Circulation of the Tropical Atmosphere and Interactions with Extratropical Latitudes., 2 vols, 258 and 371pp, MIT Press, Cambridge, Mass.
- Niklewski, J. and Van Zeist, W. (1970). A late Quaternary pollen diagram from NW Syria. *Acta Bot. Neerl.*, **9**, 737–754.
- Paterne, M., Guichard, R., Labeyrie, J., Gillot, P.Y. and Duplessy, J.C. (1986). Tyrrhenian sea tephrochronology of the oxygen isotope record for the past 60000 years. *Marine Geology*, **72**, 259–285.
- Paterne, M., Guichard, R. and Labeyrie, J. (1988). Explosive activity of the south Italian volcanoes during the past 80000 years as determined by marine tephrochronology. *J. Volcanol. Geotherm. Res.*, **34**, 153–172.
- Prell, W.L. and Van Campo, E. (1986). Coherent response of Arabian Sea upwelling and pollen transport to late Quaternary monsoonal winds. *Nature*, **323**, 526–528.
- Ralska-Jasiewiczowa, M., Van Geel, B., Goslar, T. and Kuc, T. (1992). The record of the late-glacial / Holocene transition in the varved sediments of lake Gosciadz, central Poland. *Sveriges Geolog. Undersökning, ser. Ca*, **81**, 257–269.
- Rikli, M. (1943–1948). Das Pflanzenkleid der Mittelmeerländer, 3 vol., 1418p, Hans Huber, Bern.
- Ritchie, J.C., Eyles, C.R. and Haynes, C.V. (1985). Sediment and pollen evidence for an early to mid-Holocene humid period in the eastern Sahara. *Nature*, **314**, 352–355.
- Ritchie, J.C. and Haynes, C.V. (1987). Holocene vegetation zonation in the Eastern Sahara. *Nature*, **330**, 645–647.
- Rossignol-Strick, M. and Planchais, N. (1989). Climate patterns revealed by pollen and oxygen isotope records of a Tyrrhenian Sea core. *Nature*, **342**, 413–416.
- Rossignol-Strick, M., Planchais, N. and Paterne, M. (1992). Vegetation dynamics and climate during the deglaciation in the south Adriatic basin from a marine record. *Quaternary Science Reviews*, **11**, 415–423.
- Smit, A. and Wijmstra, T.A. (1970). Application of electron transmission electron microscope analysis to the reconstruction of former vegetation. *Acta Bot. Neerl.*, **19**, 867–876.
- Street-Perrott, F.A. and Perrott, R.A. (1990). Abrupt climatic fluctuations in the tropics. An Atlantic feed-back mechanism. *Nature*, **343**, 1–26.
- Swain, A.M., Kutzbach, J.E. and Hastenrath, S. (1983). Estimates of Holocene precipitation for Rajasthan, India, based on pollen and lake-level data. *Quaternary Research*, **19**, 1–17.
- Taylor, K.C., Lamorey, G.W., Doyle, G.A., Alley, R.B., Grootes, P.M., Mayewski, P.A., White, J.W.C. and Barlow, L.K. (1993). The “flickering switch” of Late Pleistocene climate change. *Nature*, **361**, 432–436.
- Turrill, W.B. (1929). *The Plant Life of the Balkan Peninsula*. Clarendon Press, Oxford. 490 pp.
- Van Campo, E., Duplessy, J.C. and Rossignol-Strick (1982). Climate conditions deduced from a 150 Kyr oxygen isotope-pollen record from the Arabian Sea. *Nature*, **206**, 56–59.
- Van Campo, E. and Gasse, F. (1993). Pollen- and Diatom-inferred climatic and hydrological changes in Sumxi Co basin (Western Tibet) since 13000 BP. *Quaternary Research*, **39**, 300–313.
- Van Zeist, W., Timmers, R.W. and Bottema, S. (1968). Studies of modern and Holocene pollen precipitation in southeastern Turkey. *Palaeohistoria*, **14**, 19–39.
- Van Zeist, W. and Bottema, S. (1977). Palynological investigations in Western Iran. *Palaeohistoria*, **19**, 19–85.
- Van Zeist, W. and Woldring, H. (1978). A postglacial pollen diagram from Lake Van in East Anatolia. *Review Palaeobot. Palynol.*, **26**, 249–276.
- Van Zeist, W. and Woldring, H., (1980). Holocene vegetation and climate of northwestern Syria. *Paleohistoria*, **22**, 111–125.
- Walter, W. (1974). *Die Vegetation Ost-Europas, Nord- und Zentralasiens*. Gustav Fischer Verlag, Stuttgart, 452 pp.
- Walter, W. (1979). *Vegetation of the Earth and ecological systems of the geo-biosphere*. Springer, Berlin, 274 pp.
- White, E. (1983). *The Vegetation of Africa*. UNESCO, 356 pp.
- Wijmstra, T.A. (1969). Palynology of the first 30 meters of a 120 meter deep section in northern Greece. *Acta Bot. Neerl.*, **18**, 511–528.
- Wright, H.E. Jr, McAndrews, J.H. and Van Zeist, W. (1967). Modern pollen rain in Western Iran, and its relation to plant geography and Quaternary vegetational history. *Journal of Ecology*, **55**, 415–443.
- Zohary, M. (1963). On the geobotanical structure of Iran. *Bull. Res. Council Israël*, suppl vol 11 D, 113 pp., 1 map.
- Zohary, M. (1973). *Geobotanical Foundations of the Middle East*, Gustav Fischer Verlag, Stuttgart, 2 vol., 738 pp.