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CHAPTER 24

Pollen Paleoclimatology in the Mediterranean since Messinian Time

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A schematic reconstruction of climatic changes in the Mediterranean may be carried out on the basis of pollen. Research on the Messinian series remains incomplete, although some vegetation belts have been identified as related, first, to a subtropical dry climate and then to a cool period, perhaps related in some manner with a glacial front. Upper Pliocene glacial events are known, and indicated by palynological evidence. A point of controversy is the Plio-Pleistocene boundary, usually identified by the migration of "cold" markers in the Mediterranean. According to the most recent hypothesis, their migration was caused not by a synchronous but rather by a previous cooling climate phase. The disappearance of taxa such as *Sciadopitys* and *Taxodium* is of note. The Quaternary glacial and interglacial epochs record different palynological features in the Mediterranean area: Cold front assemblages in the north may correspond to "pluvial" ones in the south (e.g., Greece, Israel, North Africa) with exceptions related to the presence of mountains and distance from the coast. Consequently, an alternation of glacial steppes and cool forests with temperate forests occurs in the north, while to the south glacial-related wood assemblages may occur in succession with xerophytic (dry condition) vegetation. Particular consideration can be given to the last interglacial (R/W), which presents a mild-wet climatic "Pontic" phase; this latter is subdivided into two parts. It is possible to denote palynological changes in relatively recent time related to small climatic variations; oscillations like those of the *Dryas* and others, however, appear less well marked in the Mediterranean area. Pollen diagrams record the appearance of cultivated plants during the postglacial optimum. The present chapter is intended as a synthesis only, with particular attention paid to the Italian region.

Introduction

Palynological research has been used historically for the interpretation of the vegetation record and, consequently, for analysis of paleoclimates. The interpretation of palynological data requires a good knowledge of the present world vegetation, and some caution is needed because of local ecologic factors, human activity influencing recent layers, pollen transported from distant areas, and other such factors that may mask strictly climatic features. For example, the rise of the *Alnus* curve in the Po plain of Italy can be related to changes of the Po River course, with bank and meander hygrophylous (moist) environments. The effects of fire and cultivation by prehistoric man are also recorded in palynological spectra. The nature of curves in pollen diagrams may also be affected by a natural, free-from-climate, evolution of plant associations. Reille (1977), for example, points out that a flattening and a depression of pollen curves may correspond, respectively, to a clearing or a thickening of forest mantle. Rossignol (1961), Rossignol-Strick (1973), Sowunmi (1981), Saad and Sami (1967), Rossignol-Strick and Duzer (1979), and other authors give exam-

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ples of the composition of pollen "rains" related to actual coastal conditions or sediments in coastal cores derived from mountains and plains spread over a wide area. They distinguish the percentage of the allochthonous and autochthonous grains and draw inferences from maps showing the distribution of vegetal taxa and of pollen grains. Obviously, the presence of pollen from a temperate to cool belt may have a climatic and/or an altimetric significance.

We can draw a rather coherent trend, starting from the late Miocene, because at that time vegetation was already "modern," i.e., species were present in the Mediterranean area that today live in other regions. The Messinian salinity crisis influenced biota and evolution more strongly than did the glacial periods, and the subsequent changes may be viewed in general as migrations or local disappearances.

It is not appropriate here to outline the results of palynological investigations in a comprehensive manner because in the Mediterranean we have few references for older epochs (like the Messinian), but many more for the last glacial and postglacial ones. For climatic reconstruction it is important to work on the basis of general features verified by interdisciplinary studies, including palynology and other floral and faunal investigations as presented in the other chapters of Part IV of this volume.

In March 1980, at Erice, Italy, the First Course of the International School of Climatology was held (papers recently published in Berger, 1981). Berger (p. XVI) summarized as follows from the lectures of participating authors: "The temperature of the globe has undergone a progressive reduction during the Tertiary era; during the middle Eocene, the temperature at high latitude was about 15° (Shackleton). On a broad scale, this reduction in temperature may be related to continental displacements by plate tectonics (Ghil). However, there is also evidence for higher frequency of climatic changes, with characteristic periods of the order of 10^5–10^6 years. This could be related to changes in the solar radiation due to astronomical forcing, as is evident from the waxing and waning of the great ice-sheets during the Quaternary. Evidence from oxygen isotopes in deep-sea (Duplessis) and ice cores (Dansgaard), which reflect on both ice volume and sea surface temperatures from transfer functions (Imbrie), and from pollen and soil analysis in land cores (Kukla), converge to show that 17 glacial-interglacial oscillations occurred during the last 1.7×10^6 years. Climatic models using a new astronomical expansion of the orbital elements of the Earth and non-linear feedback have produced curves in phase with geological data for part of this time interval (Berger, Imbrie)".

Extending back the evolution to the late Tertiary, on the one hand, and to historical time on the other, we can bring into evidence the most important features applicable to the Mediterranean area. We have background information on Italy and Greece (published and unpublished data), Turkey, Israel, Egypt, and so on, and data from the Deep-Sea Drilling Project (DSDP) cruises in the Mediterranean Basin. Some of the more important characteristics of climate and vegetation are considered herein: for the Messinian; the Plio-Pleistocene boundary; the different glacial and interglacial oscillations in the northern and southern Mediterranean; and in postglacial time. This chapter is to serve as a synthesis and also as an introduction for the earth scientist who has no palynologial training.

Messinian Time and the Pollen Record

The Messinian comprises the time-span between the Tortonian and the Pliocene. It is characterized by some unusual geological, botanical, and phytogeographic attributes and recently has been the source of much discussion, particularly with regards to a postulated salinity crisis involving partial desertification of the Mediterranean area. Cool or wet and warm climatic conditions remain a source of contention. Palynological research could provide some important information on these topics but, as yet, there are insufficient data. The salinity crisis can perhaps be related to a lowering of sea-level related to glacial periods. The Mediterranean may have been dry (even if not completely), or at least reduced to several basins (*Lago-Mare*). The vegetation inevitably would have responded to such marked climatic and environmental changes. At the International Colloquium on Messinian events in the Mediterranean, held at Utrecht, The Netherlands, in March 1973, a general opinion was voiced that the Messinian (lasting about 1 million years [m.y.]) had a warm climate in the early stages that subsequently deteriorated to a glacial type. The various sedimentary sequences investigated, often lacking absolute dating, have not been proved chronologically comparable in a rigorous manner. This may explain why we find different climatic-vegetational features, some of which are not only dependent on latitude and others which are dependent on their chronological position in the Messinian record. Severe conditions for plants may have been realized under extreme cold, or dry-warm climates. In consequence local vegetation, and not only migrations, should be taken into account.

Bocquet and others (1978) present a new floristic model for the Tyrrhenian Basin during the Messinian and depict migration paths that could have occurred under such paleogeographic conditions (Fig. 24.1). The first palynological data for Messinian floristic events, published by Bertolani-Marchetti (1962, 1968, 1972), concern the "Formazione gessoso-solfifera" of this age in the marginal facies of an evaporitic basin near Bologna (Emilia) and Caltanissetta (Sicily). It is noted that in the Bologna sediments there is a richer plant association, characterized by the *Tsuga–Cedrus* complex, related to a cool climate typical of mountain belts. The finding of fossil wood from mountain forests such as *Picea* in the marly layers confirm the presence of an upper elevation vegetation belt, which lowered during a cool or cold climatic wave. Thermophylous plants prevail in the samples from Sicily suggesting a dry-warm climatic scenario.

A deep pollen level (−113 to 120 m) in a boring collected near Montegrotto (Bertolani-Marchetti, 1961) at the foot of the Euganean Hills (Padua, Italy) is a conch-rich lagoonal marl facies, dated Messinian on a paleontological basis. The vegetation includes hornbeam wood with a probable overlying coniferous belt; the basal environment is brackish, the climate moderately warm.

Pollen and phyllites in Messinian clays have recently been studied at Carbonara Scrivia near Alessandria-Piedmont (Balduzzi et al., 1980). An attempt has been made to reconstruct the climatic belts on the basis of vegetation, following the scheme of Bocquet and others (1978).

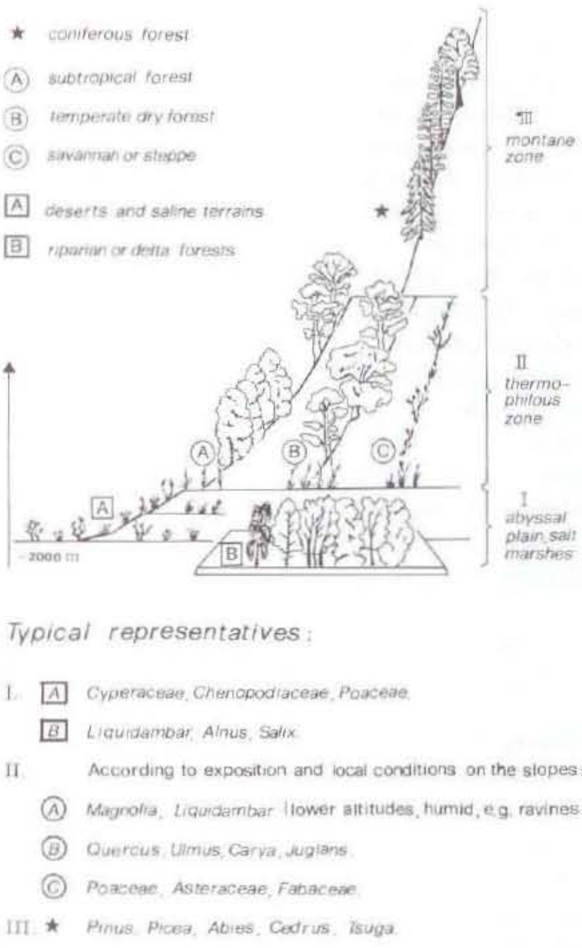


Fig. 24.1. Reconstruction of vegetation belts and their elevation in the Tyrrhenian Basin during the Messinian, according to the data of Bertolani-Marchetti and Cita, 1975 and Bocquet et al., 1978.

These authors, improperly using the term "zone," recognize, from the floristic findings, general temperate-hot climatic conditions, with variations of microclimate and local ecological conditions. The relationship between these findings and the vegetation belts does not coincide exactly; coniferous forests may have reached a lower level during a climatic cooling phase.

Marly beds of Messinian age near Conegliano Veneto (Accorsi and Gamberini, 1976) contain a notable amount (about 28%) of *Taxodiaceae* and 7% mediocrats (*Myrica, Zelkova, Carya*). Thirty percent of the spectrum belongs to *Pinus*. The temperate-cool climate may correspond to a degradation of climate in the late Miocene. Other samples show conditions tending towards warmer (with *Platicarya* and

Zelkowa) or cooler oscillations (with *Pinus, Abies, Picea, Cedrus, Larix*, and a negligible amount of *Taxodiaceae*).

Interdisciplinary micropaleontological investigations, including some summary pollen analyses and studies of stable oxygen and carbon isotopes, were carried out on ten cores from the Lombardy plain in northern Italy (Cita et al., 1978). The sequence includes sediments from upper Oligocene to upper Pliocene. Pollen analysis was carried out on strongly pretreated material and did not permit the proposed hypothesis pertaining to climate and general conditions in the Messinian to be verified. It is likely that, after sample treatment, a preferential selection of the more resistant grains occurred with consequent alteration of vegetation features. For example, the thick-walled grains of *Chenopodiaceae* may not necessarily reflect a true majority related to a steppe climate. The author does not distinguish pines into the two types (*"haploxylon"* and *"diploxylon"*), which are easily differentiated by the bladder insertion. Moreover, the first type need not represent a cool climate. In fact, when it is possible to make percentage counts, the ratio of *"diploxylon"* to *"haploxylon"* increases with an improvement of climate. Although this simple classification was not carried out, it was possible nevertheless to identify genera and species of pollen grains on the basis of formal methodology. Moreover, the presence of grains of different age in the sediments was explained by reworking from older layers.

Berger (1957) and Trevisan (1967) examined the macro- and microflora of Gabbro (Livorno, Tuscany) in a sediment cycle interpreted as Messinian. An average pollen spectrum is drawn by applying the formal method for pollen classification. Affinity with living families or genera is determined. The Gabbro deposits indicate the following: (1) bank woods and scrubs, with *Taxodium* and other marsh taxa; (2) warm and moist subtropical evergreen forest in a damp lowland; (3) temperate-dry oak forest together with some *Pinus* and *Sequoia*, far from a shoreline; and (4) dry light forest, savanna, and shrub steppe, with evergreen oaks, arboreous *Leguminosae*, and so on, probably related to a wide dry hinterland or upland. According to Berger, the data indicate a rather dry subtropical climate, with scarce moist air. The hygrophytes lived in the lower land areas, in brackish water. These conclusions tend to support the arrangement of vegetation belts postulated by Bocquet.

A sampling of Tortonian and Messinian layers was also made in a section near Falconara (southern Sicily). Pollen analysis was useful only for recognition of early and middle Tortonian horizons (unpublished data). The amount of grains transported by wind is indicated on the basis of the *Poaceae* + *Saccatae* curve. An increase of these coincides with an increase of cool forest pollen. This distribution results from an elevation difference rather than from climatic deterioration. The diagram may indicate a subtropical, moderately moist or dry climate, with warmer conditions in the lower and upper parts of the graph. These events precede those affecting overlying sterile Messinian strata. The situation at this locality differs from that of the gypsum section near Bologna.

Some Andalusian upper Tortonian and Messinian sites (southern Spain) have been studied from a stratigraphic viewpoint (Jan Du Chene, 1976) especially with respect to *Dinophyceae*. Large quantities of *disaccatae* pollen were transported by the wind, especially pines (*"haploxylon"* and *"diploxylon"*). The presence of *Tsuga, Oleaceae*, and *Ulmus* type grains in small number is also noted. The pollen flora found was not sufficient for a reliable interpretation of the coastal vegetation soil.

Subbasaltic and interbasaltic fresh-water deposits were investigated at Mirabel (Coirons, Ardèche, France). A radiometric age of 6.4 ± 0.2 m.y. was determined (Naud and Suc, 1975). In the subbasaltic layer are found pollen complexes rich in arboreous plants, indicating a coastal vegetation (*Taxodiaceae, Pterocarya*), hinterland types on drier soil, and, lastly, an upper coniferous belt. The climate probably was temperate—warm and moist. The interbasaltic association suggests an arid environment on the basis of a change of facies and/or by drying of climate. It does not seem possible to establish a correlation with the Mio-Pliocene of the Rhône Valley (Mehon-Vilain, 1970) where a progressively moister climate prevailed in the Tortonian and a drier one in the lower Pliocene.

Within Messinian evaporite sections of the Paghi section (Corfu, Greece; Heimann and Jung, 1976) are marls, arenites, and chemical sediments organized in cycles that may be unrelated to climatic oscillations; the associated floral macrofossils reflect uniform climatic conditions. These findings, in the author's opinion, are much more localized and thus less significant than the pollen data.

Detailed palynological study was carried out in the lower Axios Valley, Central Macedonia, Greece (Sauvage and Mercier, 1966). Discussions still revolve, mostly, about the floristic composition (with scarce Tertiary taxa) rather than about climatic and elevation considerations. It is possible to envision a higher coniferous belt and a lower, smaller belt of oak forest. The abundance of "*saccatae*" and of *Gramineae* pollen indicates a distal origin for a part of the pollen "rain". On the other hand, the presence of small proportions of oak and the prevalence of *Pinus haploxylon* type over the *silvestris* type, suggests a mild climate.

Benda (1971, 1973) investigated the Neogene of Turkey and established six sections, with local names, for the time-span from the Eocene to the youngest Miocene. The "modern" composition of a part of the pollen complexes is noted, however.

Horowitz (1974) provided some data from a boring near Jaffa, Israel, pertaining to the Miocene and Pliocene. Two samples underlying the evaporites, related to a late Miocene regression, record dry climatic conditions as indicated by xeric vegetation components. This paleoclimatic phase preceded the above-mentioned Messinian evaporitic deposition for which palynological information is lacking.

Investigations in the Ukraine by Shchekina (1973, 1975) record a drying of climate and also a lowering of temperature during the late Miocene.

Analyses were carried out on Messinian and pre-Messinian samples from DSDP Leg 42A, Sites 134 (Balearic Basin) and 375 (Levantine Basin) by Bertolani-Marchetti and Accorsi (1978). The results suggest that the climate of the Eastern Mediterranean during the Tortonian, i.e., in pre-Messinian time, was moderately warm (*Pinus diploxylon*, *Quercus*, *Zelkova*, *Eucommia*, *Hamamelis*, etc.) and then became cooler (mediocratic taxa reduced from 15 to 10%) toward the end of this stage.

Cooler climatic conditions are also indicated for the early Pliocene, immediately after the Messinian (mediocratic taxa, 6%). In the Messinian sections of the core, the scarcity of pollen grains may be related to possible mild and cool oscillations that remain poorly defined. .

Four of the five levels examined at DSDP Site 132 (Bertolani-Marchetti and Cita, 1975) revealed a rich and diversified pollen and spore assemblage of Messinian age. This flora shows a succession of vegetal assemblages, with the following configuration: (1) a coniferous belt (*Pinus dipl.*, *Abies*, *Cedrus*, etc.) lowered toward sea-level and a coastal vegetation indicative of brackish and marsh environments; (2) a belt still rich in conifers, including *Podocarpus*, *Dacrydium*, and *Taxus*, probably overlying another belt comprising the uppermost part of the basal level, with hardwoods such as *Quercus*, *Zelkova*, and *Carya*, and an abundant shrub vegetation in plain marshes and moors; (3) still another belt overlying the conifer zone; the thermophylous forest declines while a relatively broad area of coastal forest is probably present; and (4) the expanse of coniferous belt increases, while the mediocrats almost disappear and the *Chenopodiaceae* prevail in the grass vegetation. These aspects seem to coincide with the temperate-cool, temperate-warm, and perhaps dry climatic conditions characterizing the two lower levels, while more severe conditions are recorded by stratigraphically higher samples.

The Messinian, paleontologically, is a poorly understood time-span. As discussed above, the Messinian seems to have undergone two distinct climatic phases: the first, probably a warm and dry spell, in the early part; the second, a cool and perhaps even cold stage, in the latter part. These conclusions are based on very general trends because the lapse of 1 m.y. may in fact have included many oscillations in addition to a prevalently warm phase and subsequent cool climate.

Messinian time seems to incorporate a rather homogeneous set of events throughout the Mediterranean Basin. Thus, much careful documentation is needed to verify whether moist or steppe conditions occurred. For example, the apparent diversity of environmental settings indicated by flora (Berger, 1957) and pollen (Trevisan, 1967) at Gabbro could be a function of more local influences as recorded by phyllites and the more generalized conditions affecting vaster areas (and different vegetation belts) indicated by pollen. In any case we are still unable to establish an accurate and complete climatic reconstruction for this time-span (Bertolani-Marchetti, 1984).

Plio-Pleistocene Events and the Pollen Record

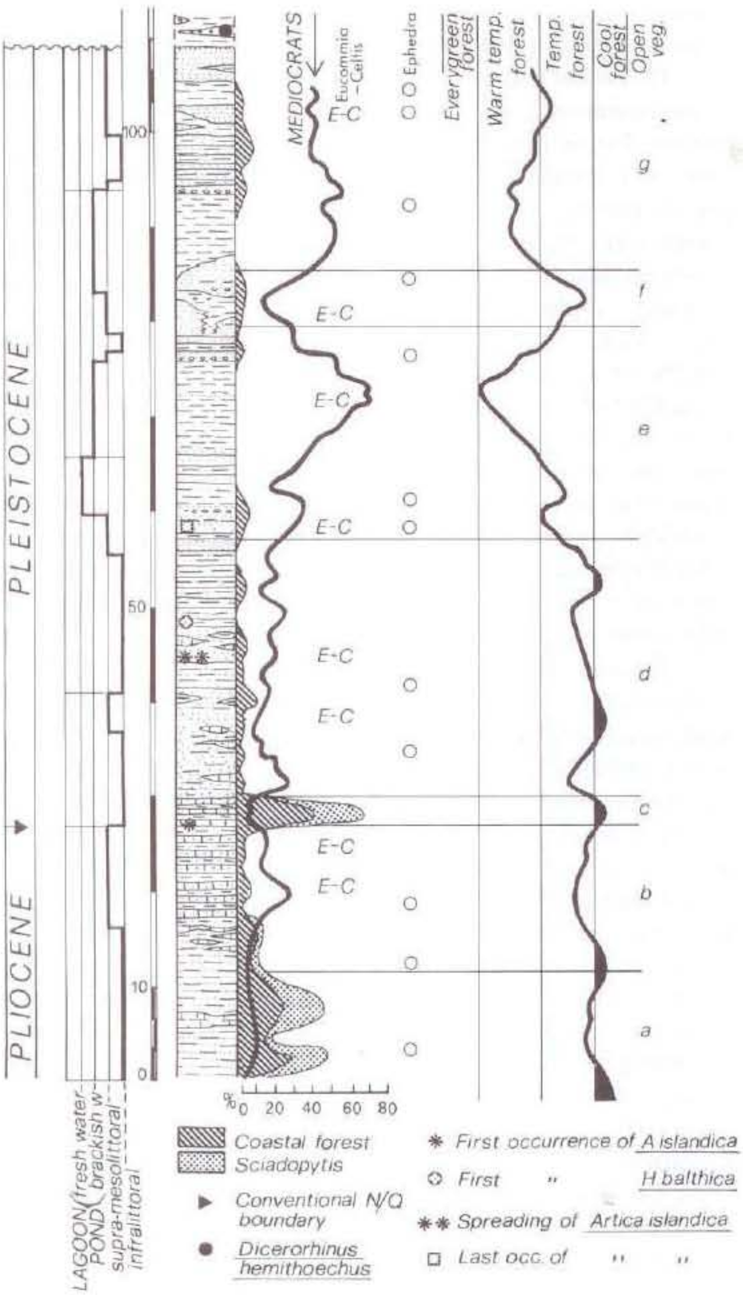
Numerous difficulties are encountered in accurately determining the Plio-Pleistocene boundary and the time-span between the two epochs. It is not always possible to correlate marine sections with continental ones. Interpretations from foraminifera, pollen, and sediment facies are not necessarily reliable. The effects produced by the expansion of polar ice sheets are sometimes different from, or not synchronous with, those of alpine glaciers. With respect to Italy, it should be recalled that the northern continental part was influenced by Alpine glaciation, while the peninsular part (even though a glacial center existed at Gran Sasso, Abruzzo) was influenced by and thus in a stricter sense more an integral part of the Mediterranean area. More "stable" or isolated environments such as those of the Po Valley or the ancient peninsular lakes such as Pietrafitta (Paganelli and Solazzi, 1962) or Valdarno do occur. Admittedly, much information can be obtained from absolute dating methods, paleotemperature determinations, and from paleomagnetic measurements, although magnetic reversal may have a general significance. Paleontological criteria (i.e., extinction of certain mammal or foraminiferal species, or the introduction of new forms) and sedimentological and paleobotanical parameters are commonly used to codify the Plio-Pleistocene boundary. On pollen diagrams this event seems to be identified by the diminution of the *Taxodiaceae* curve. An event of this type is noted on the diagram of the ancient Lago Tiberino, in Central Italy, and called by Lona (1971) the "Tiberian limit." In effect, it records a change of facies and marks the passage from pre-Pleistocenic vegetal types to those in which "Tertiary" components are less evident. The Tiberian limit does not have a specific chronostratigraphic value, but it does seem to indicate climatic and ecologic changes that are not contemporaneous in different regions of Italy, southern France, The Netherlands, and elsewhere. According to Zagwijn (1975, p. 148–149) "it can be hardly doubted that the Tiberian as defined by Lona is time equivalent to the boundary between the Upper Pliocene (Reuverian) and the Pretiglian cold stage of the Netherlands."

The pollen diagrams (Bertolani-Marchetti, 1972; Selli et al., 1977; Bertolani Marchetti et al., 1979) show the position of the conventional Plio-Pleistocene boundary, marked by the migration of "cold guests" into a long cool, but not cold, period (perhaps the "long preglacial" of Selli).

In Italy, clayey layers from lacustrine or lagoonal environments near Villafranca d'Asti, Piedmont (Francavilla et al., 1970), were investigated in order to determine the age and climatic nature of the Villafranchian type section. Pollen analysis revealed a spectra of evident upper Tertiary age, with *Taxodiaceae* (*Sequoia*, *Taxodium*, *Sciadopitys*) in assemblage with other forest plants such as *Pinus haploxylon*, *Cedrus*, and *Tsuga*, which persisted until the lower Pleistocene. The lower spectra showed a gradual impoverishment of the Tertiary flora, in successive wide waves, in accordance with the gradual increase of cold climatic fluctuations.

A Plio-Pleistocene sequence from the Stirone River near Parma, northern Italy, has been studied stratigraphically and palynologically. The pollen diagram (Fig. 24.2) shows two distinct types of *Taxodiaceae* (excluded from the amount of the Mediocrats): The *Sciadopitys* type disappears at the time of the conventional Plio-Pleistocene boundary, probably in connection with a climatic drying. This plant needs 6 m of rain per year. The *Sequoia*/*Taxodium* oscillations are apparently linked to the evolution of the coastline. The climatic curve reveals a cool period in the middle of which appears, for the first time, *Arctica islandica*, followed by a warming up in two successive pulses that mark the dominance of thermophylous flora such as *Quercus*, *Carya*, and *Carpinus*. About 20 m above the base of the fluvio-lacustrine sequence overlying the Plio-Pleistocene lagoonal-infralittoral sequence, Bucha and others (1975) identified the Matuyama-Brunnes boundary (0.69 m.y.). Palynological studies have been made on two similar sequences, the Crostolo River (Reggio Emilia) and Tiepido River section near Mo-

Fig. 24.2 Diagram of the Plio-Pleistocene Stirone River sequence (Parma, Italy). The local paleoenvironmental variations are represented at the left. The mediocrat curve as denoted is related to the vegetation belts (right). The percentage of *Sequoia*/*Taxodium* (coastal damp forest) and of *Sciadopitys* (related to a very rainy mountain climate) are shown. The disappearance of *Sciadopitys* may correspond to the establishment of a Mediterranean climate with dry summers. The reappearance of *Taxodium* forest coincides with changes of the coastline (after Bertolani-Marchetti et al., 1979. Reprinted with permission).



dena (Bertolani-Marchetti and Arobba, 1981; Accorsi et al., 1981).

A particularly significant section is that of the Santerno River, near Bologna (east of the Stirone, Crostolo, and Tiepido). Specialists have examined the sediments, absolute dating results, fauna, and also pollen. The latter warrants a more complete review. The marly nature of the sediments does not, for example, justify the interpretation of Francavilla (1971). Studies of the Pliocene part of this sequence show a climatic trend towards lower temperatures, with comparable oscillations and progressive decrease of the Tertiary taxa. *Sciadopitys*, present all along the diagram, tends to disappear toward the Calabrian boundary. Kukla (1978) revised the age of the Plio-Pleistocene boundary based on existing paleomagnetic dates and on other radiometric methods, and by correlation with Pacific cores. From these studies it is noted that the first appearance of *Arctica islandica* occurred in the Santerno sequence about 2 m.y. ago while faunal changes related to cooling had already occurred at 2.35 m.y. This latter was a period of tectonic activity in the Apennines, and one affected by climatic change. Correlation between the Santerno section and a Pacific core seems, in Kukla's opinion, to reinforce the importance of the above events (see also Becker-Platen et al., 1977).

Palynological studies have been carried out on some samples collected by the late Professor Sergio Venzo in a sequence that seems to contain the conventional Plio-Pleistocene boundary at Le Castella in Calabria (Bertolani-Marchetti, 1976). In the lower levels the flora is impoverished by the previous marked climatic conditions. In each spectrum two vegetation belts are observed. The basal one records changes from a Mediterranean "macchia-gariga" to a steppe vegetation, and then perhaps evolution to a light forest of thermophylous hardwoods (*Quercus, Juglans, Carpinus*, etc.). The upper belt comprised a coniferous forest, with predominant pines, which formed during the drier and warm period. An interbedded turbidite, recognized as a "marker bed" with a typical Pliocene pollen assemblage, was erroneously interpreted as the last Pliocene level. More recent study (Colalongo et al., 1982) has demonstrated that this sequence is entirely Quaternary in age. Consequently, some floral components of this marker bed are derived from older sediments by turbiditic redeposition processes. Moreover, according to investigations of Colalongo and co-workers, the placing of the Plio-Pleistocene boundary at Le Castella leads to incorrect interpretations.

At the INQUA Congress held at Birmingham, England, in 1978, a communication was presented on a marine section at Vrica near Crotone in Calabria (Selli et al., 1977). This section was proposed by Selli as a potential Pliocene–Quaternary boundary stratotype. The sequence here is divided into three units (Fig. 24.3). At the top of the first unit (X) appears *Cyteropteron testudo*, an ostracod typically associated with cold seas. The Y unit above it records the appearance of *Hyalinaea baltica*. In the third, uppermost unit (Z), conditions of thermic deterioration appear to have taken place. Volcanic glass from a depth of about 200 m shows a K/Ar age of 2.2 ± 0.2 m.y. A large, well-preserved pumice block was found in the section immediately above a sand level containing volcanic ash; the K/Ar age of the pumice is 2.0 ± 0.1 m.y. The conventional Plio-Pleistocene boundary would, therefore, fall within the Y unit. At the base of the pollen diagram a cool climate is indicated (*Tsuga, Cedrus, Pinus*, etc.). In the upper part of the X unit, milder climatic conditions are indicated by two rises of the mediocrats curve. The climatic improvement in Y takes place shortly before deposition of the layer containing the pumice block. Subsequently, the mediocrats occur in lower proportions, while the terminocrats increase with some oscillations. The appearance of cold forms seems to follow the climatic deterioration, but with a certain delay. The conventional Plio-Pleistocene boundary, as at the Stirone sequence, occurs during a period characterized by overall cooling (maximum mediocrat context is 23%). A coastal forest developed at intervals characterized by low percentages of *Taxodiaceae*.

Interesting studies, the results of which can be applied to Italy, have been conducted in France (see papers of Suc, 1973, 1974, 1976a, 1976b, 1978a, 1978b, 1979). There it has been found that the extinction of Taxodiaceae at its southern part had a climatic cause and is older than the one in Italy and The Netherlands (see also Bertolani-Marchetti, 1978).

The above-cited vegetal characteristics, with a progressive reduction of taxa during the course of several climatic and ecologic events, signal the beginning and development of the Quaternary sensu stricto. Conditions including a rich Tertiary vegetation are cited in the studies by Van Campo (1979) of the Pliocene sequence at Ichkeul in Tunisia. During the Pliocene, at 3.5 + 0.5 m.y., a large part of northern Tunisia was covered by fresh-water or brackish lakes into which rivers flowed. It is of note that, on the basis of vegetal microfossils, present southwest China is the only region that has a floristic affinity with the Tunisian site. The recent Chinese climate could well be similar to that at the Lake Ichkeul region in Pliocene time. It seems that the immense zone of Tertiary forest, which at that time covered part of the Old World, surrounded the Mediterranean. Among the flora recorded at Lake Ichkeul are those of

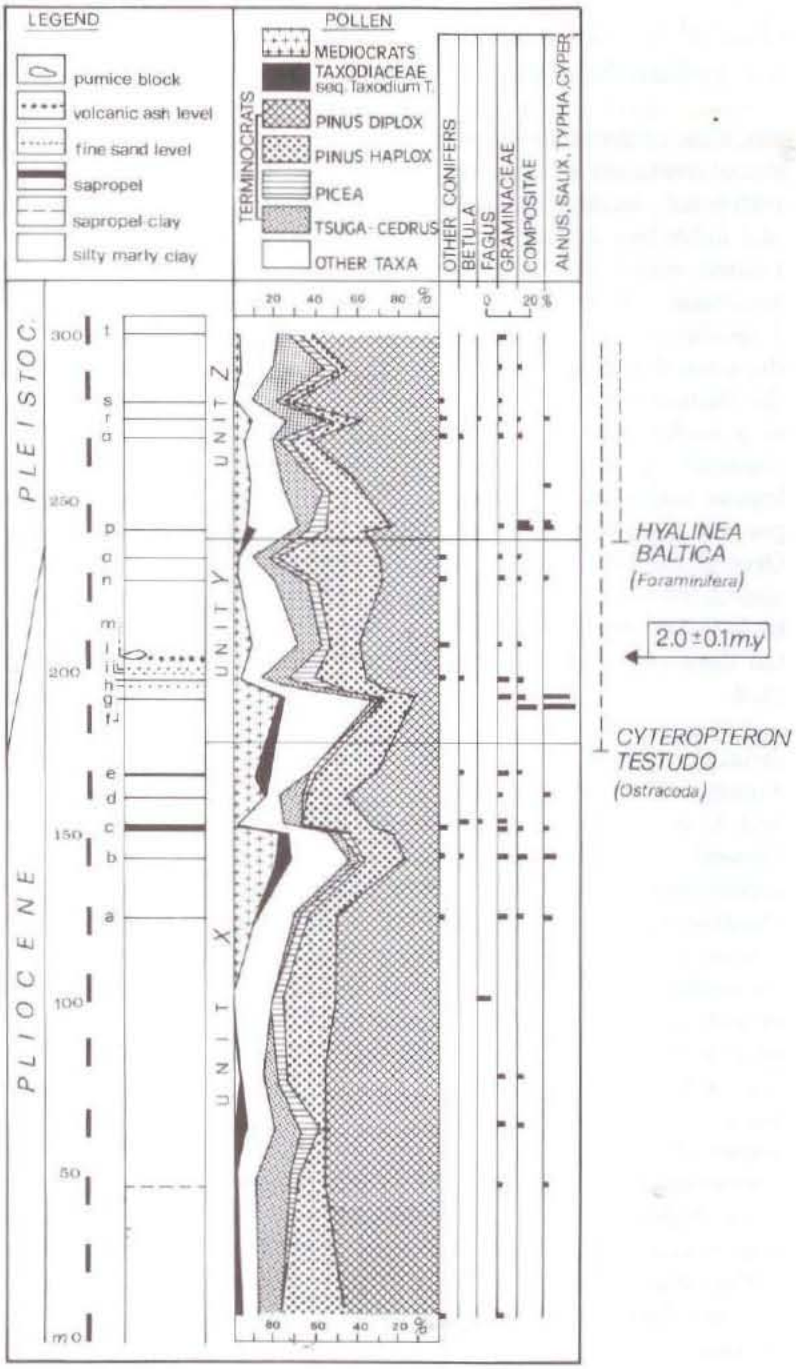


Fig. 24.3. Pollen diagram of the Vrica section (Calabria, Italy), which includes the Plio-Pleistocene boundary. The radiometric age is based on dating of a pumice block. The distribution of cold ostracoda and foraminifera is indicated (after Selli et al., 1977. Reprinted with permission).

an evergreen broad-leaved forest and temperate deciduous broad-leaved forest. The formation of the polar ice caps induced a cooling and drying at the midlatitudes, together with the establishment of the Mediterranean climate rhythm. The evolution of the Mediterranean climate, which with its summer dryness resulted in the disappearance of the taxa linked to climatic conditions of constant humidity. This change is well defined on many of the above-cited stratigraphic diagrams which show the Plio-Pleistocene boundary.

Glacial and Interglacial Events and the Pollen Record

The topic of the Mediterranean glacial and postglacial evolution is a vast one and will be dealt with briefly in this synthesis. There are numerous published studies pertaining to Italy and France, especially for the late Pleistocene and Holocene. Many papers also discuss the Yugoslavian area and of these, the ones treating the coastal area are particularly useful. As for the Quaternary in Israel, the reader is directed to a useful paper by Horowitz (1979), which illustrates the topic from a geological, palynological, and paleoclimatological viewpoint. Important diagrams also have been drawn for Greece, the Near East, and Spain. Attention is also called to a study of the Sahara and the Nile by Williams and Faure (1980) in which substantial data on Mediterranean Africa are assembled.

Authors often disagree on the chronology and division of the Pleistocene. Discussions on the penultimate interglacial (Mindel-Riss) are limited. In the Po plain only a few drill sites (Marchesoni, 1959; Bertolani-Marchetti, 1961; and unpublished data) have penetrated sediments of Mindel-Riss interglacial age. The data are scarce, and thus it is not realistic to interpret the evolution for this entire period on the basis of pollen alone. The last floristic impoverishment in the area occurred during the Würm glacial; in Mindel-Riss time there was the persistence of Tertiary taxa in the Po plain. In the earlier cited discontinuous sequence near the Euganean Hills (Bertolani-Marchetti, 1961), some layers overlaying the Messinian may belong to glacial and interglacial stages until Riss (Milazziano II) time. An impoverishment of Tertiary elements resulted as a consequence of climatic deterioration, but the singular microclimatic conditions related to salty hot-water springs mask other more general factors such as rain and temperature.

The Mindel-Riss in central Italy remains rich in Tertiary taxa as *Pterocarya* and show the spread of *Abies* and *Carpinus*. In northern Italy *Carya*, *Tsuga*, and *Keteleeria* are also found; survival was probably related to unusual microenvironmental conditions. Beech is found in the pollen spectra of this interglacial period in northern and in central Italy. The climate, as interpreted from the vegetation, should be of a colchic type, that is, trending to warm and then moist conditions (Follieri, 1965, 1967).

Marine, dark organic-rich sapropels from deep-sea cores south and southwest of Greece and north of Egypt (Rossignol, 1962) are dated from the early Pleistocene to the Mindel-Riss interglacial on the basis of the floristic composition, including "ancient" taxa such as *Cedrus*, *Pterocarya*, *Carya*, *Liquidambar*, *Zelkowa*, and *Pinus diploxylon*. Plants of strictly Pliocene age, including *Sciadopitys* and *Nyssa*, are lacking. There are spectra of two different categories: A group from the northern Mediterranean includes pollen of trees and shrubs (*Pistacia*, *Olea*, *Pinus halepensis*, etc.), indicating a Mediterranean environment with a two-season year, with cool humid winters and summers that were not really dry. Interpretations of the pollen transport are as follows: by wind for a short distance, then in the sea as pelagic components, with a distribution in marine sediments related to the distance from the shores and to the nature of currents and winds for the north-Mediterranean pollen. The pollen of Nilotic origin are transported as benthic grains by the deep-water currents and form mineral-rich Nilotic masses with sedimentation dependent in part on bottom topography (Rossignol, 1961).

Sapropels serve as good stratigraphic horizons for palynological long-distance correlations.

The last interglacial, the Riss-Würm (the Eemian of the Dutch authors), which started about 130,000 years B.P. (125,000 B.P. according to Kukla), was the last period having an interglacial and not interstadial character.

Szafer, as early as 1925 (in Chiarugi, 1950), developed a pollen reconstruction for Poland, in a scheme that can still be used today. That author distinguished: (1) an arctic phase, with tundra and arctic climate; (2) a subarctic phase with tundra and forests and subarctic climate; (3) a boreal phase with pines and oaks and continental-cool to warm climate; (4) a first subatlantic phase with *Abies alba*, *Taxus baccata*, etc., and suboceanic climate; (5) a pontic-meridional phase with *Tilia*, *Acer tataricum*, *Carpinus*, etc., lacking conifers, with a colchic thermic Mediterranean optimum; (6) a second subatlantic phase with *Fagus*, *Carpinus*, and

Tsuga forests and suboceanic climate; (7) a presubarctic phase with pine and spruce forest and cold climate; and (8) an arctic tundra phase and arctic climate near the Scandinavian ice sheet.

In a radiometrically dated sequence of diatomites at Monte Amiata (Tuscany, Italy), the above phases are sequential with the exception that phases (1) and (8) are only lightly modified (Bertolani-Marchetti and Soletti, 1972).

It is pointed out that the Pontic optimum is divided into a Pontic I and a Pontic II phase, separated by an event, I, called the Interpontic phase. The climatic trend for the whole interglacial is not symmetrical but in effect records three oscillations of progressively shorter mild climate intervals, alternating with three progressively longer cool climatic pulses.

The dominant characters of the Riss-Würm diagrams are the above-cited warm moist climate phase and the late peaks of *Carpinus*. The southern Alpine valley associations (e.g., in Val Vigezzo and in Val Borlezza) include *Rhododendron ponticum*, with *Buxus*, *Castanea latifolia*, and *Pinus peuce* (Bertolani-Marchetti, 1955). The pollen analysis reveals fewer thermophylous plants such as pine, spruce, birch, and others belonging to the *Quercus–Tilia–Acer* belt, with *Carpinus* becoming more predominant in the upper layers. Val Vigezzo and other similar Alpine deposits originated in large lakes filled by marly-sandy sediments. The basin water resulted in widespread microclimatic conditions more humid and mild than those on land, and/or accentuated climatic conditions of the region. In this way, preexisting colchic taxa from older interglacial periods were favored and persisted in different environments. Even today, actual Alpine lakes locally generate a more humid and mild microclimate called "clima insubrico," which results in a vegetation different from that of the surrounding area.

Continental sediments of the alluvial area of Padua (Marchesoni and Paganelli, 1960) belong partly to the Riss-Würm interglacial period. During this time a flora persisted with Tertiary components such as *Castanea* and *Zelkova*, together with *Pinus*, *Abies*, *Carpinus*, *Quercus*, and *Tilia*. At a higher peat level we find that the forest of the glacial Würm was comprised almost exclusively of pines.

In the Fontespilli diatomites diagram, the climate and vegetation highlights of the last interglacial are depicted (absolute dating: 130,000 to 140,000 years B.P.). Pollen analysis has shown a rich wood mantle with *Pinus* (perhaps *P. laricio*), *Picea*, *Betula*, *Fagus*, *Quercus*, *Castanea*, and *Carpinus*. The diagram begins with a cold subarctic climatic phase (Fig. 24.4) and, at the top, ends with a new cool presubarctic phase, with at least two cool-dry intermediate pulses. The first divides two Pontic phases (Pontic I and Pontic II) with a mild moist climate. Be-

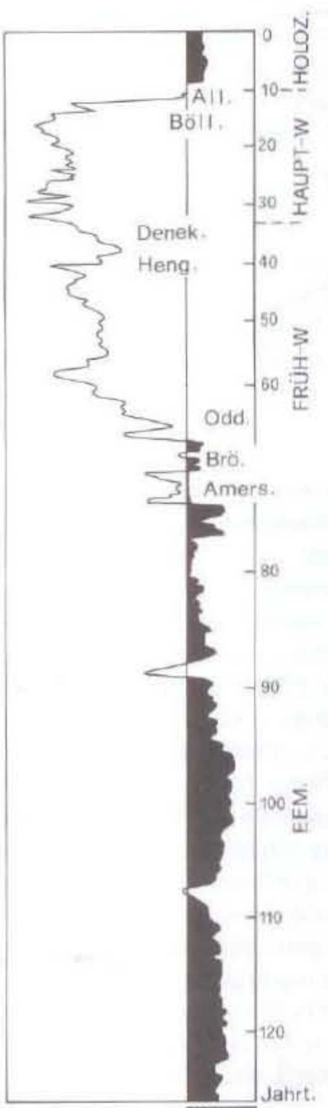
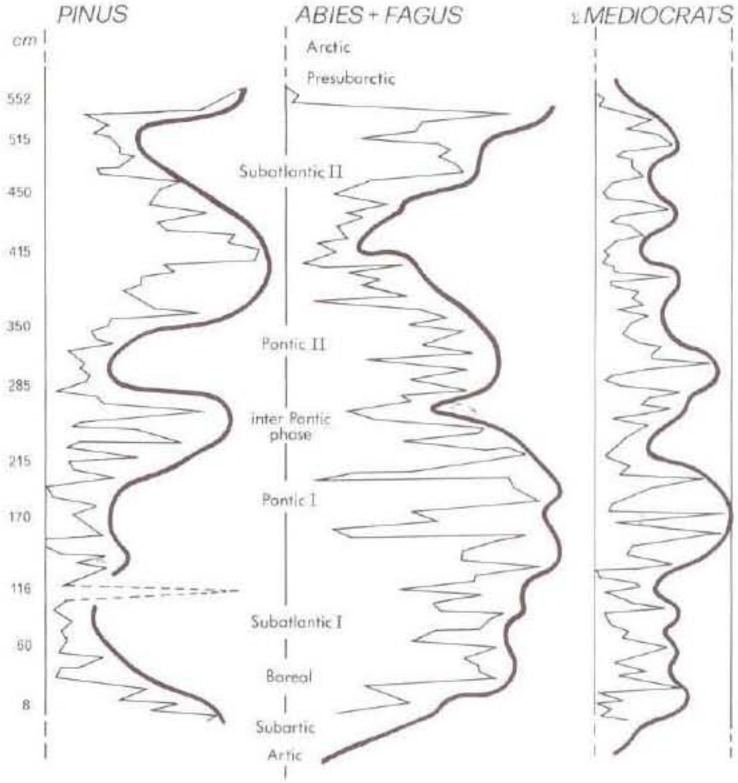


Fig. 24.4. Paleotemperature curve from deep drilling of inland ice at Camp Century, Greenland, pertains to the late Pleistocene and Holocene. At 90,000 years B.P. a marked cooling may correspond to the "interpontic phase" of Monte Amiata (after Thenius, 1977. Reprinted with permission).



(Bertolani Marchetti, 1972)

Fig. 24.5. Curves applicable to diatomites of Fontespilli (Monte Amiata, Tuscany). *Pinus*, *Abies* + *Fagus*, and mediocrat curves, and tentative correlations with Szafer's curve, are shown (after Bertolani-Marchetti and Soletti, 1972. Reprinted with permission).

tween the second cool phase and presubarctic one, an oceanic front occured with (as in almost all preglacial series) a sudden rise of *Carpinus* toward the end. The Fontespilli paleovegetation is almost like the present one and does not include Tertiary taxa. This is probably related to the fact that Monte Amiata is geologically very young and does not include plants of preexisting Tertiary vegetation (see also Fig. 24.5; Thenius, 1977).

In central Italy, north of Rome, the last interglacial is recorded as a long warm period, with persistance of Tertiary taxa such as *Zelkova* in a mixed oak wood assemblage, between two rises of *Fagus*, and with an expansion of *Carpinus* at the top (Follieri, 1965, 1967).

Würm and the Pollen Record

The last glacial epoch (the Würm according to Alpine nomenclature) involves a complex evolution whose oscillations are becoming better understood as a result of recent studies and dating. Overall, the climate follows the general scheme as in all glacial periods, with an oceanic-type introduction and a trend towards dry cold conditions in the final stages. This trend is altered in the Mediterranean area, differing especially with respect to the lower belts of vegetation. The mountain chains have a belt that is more thermoxerophylous than that typically associated with the general climate. It is the hill belt in the Po valley, for example, which today still conserves Mediterranean relicts in its vegetation and which was the refuge of thermophylous types (for example, mixed oak forests) during the glacial epochs. In contrast, the mountains at the same elevation but near the sea show oceanic characeristics, including a marked increase in humidity. An example of this climatic situation can be seen in Italy in the area of the Gargano promontory. Here at 100 to 200 m above a very warm and arid belt near the sea (which is strictly Mediterranean from a thermal point of view), we find the cool and wet "Foresta Umbra" in which beech occurs. The strong marine influence of humidity is also recorded by pollen analysis in the Apuan Alps (Tuscany, Italy) where the red fir is absent from slopes exposed to the sea as a consequence of the lesser influence of continental conditions

(Braggio-Morucchio et al., 1980). Much uncertainty in the interpretations derives from an insufficient evaluation of local conditions. For example, in comparing the diagram of Tenagi Philippon with those of Johannina, in Greece, it should be realized that the latter is located at the foot of a slope of rather high mountains facing the sea, on which beech is found, but which does not grow on the opposite slope. In Poland, the water-table is another contributing factor. It is close to the surface in topographically depressed areas and is deeper at higher elevations (100 to 200 m), so that by walking only a few kilometers, one can progress from an "interglacial" to a "glacial" setting and, thus, from vegetation with marshes and oak woods to forests with *Abies* and *Fagus*.

Events related to the last glacial period seem to have occurred at least since 80,000 years B.P., but the true beginning seems to be around 60,000 years B.P. The beginning of the Würm is dated in Israel (Horowitz, 1971) at about 65,000 to 70,000 years B.P. on the basis of extrapolations from rates of deposition and by potassium-argon dating. At 60,000 years B.P. a cold, humid episode following the Dutch Amersfoort and preceeding the Brorup (interstadial?) introduces the subsequent very dry, cold lower pleniglacial period. Around 38,000 to 35,000 years B.P. the interstadial, or inter-pleniglacial, of Hengelo took place, separated by a cool and very dry climatic deterioration from the interstadial of Denekamp (32,000 to 29,000 years B.P.). Some correlations can be attempted with Greece and France. The first cold oscillations could perhaps correspond to the Drama/Eleuteropolis, while the Hengelo would correspond to the interstadial period of Kalabaki; the Denekamp of northwest Europe would correspond to the Krinides I and II, in turn related to the Arcy phase in France.

The middle Würm evolves with oscillations which constitute, overall, the interstadial period of Paudorf-Arcy, until the upper Würm of Woldstet (upper Pleniglacial) from 25,000 years B.P. until 10,000 to 11,000 years B.P.

Thermal improvement seems to have taken place as early as 18,000 years B.P., but the beginning of the postglacial period is placed by many workers at 10,000 years B.P.

A diagram of Canolo Nuovo (Calabria, Southern Italy; Grüger, 1977) is divided into three parts. The oldest, at the top, has an absolute date of about 36,900 years B.P. and is characterized by an abundant wood cover with predominant beech and the presence of a mixed oak forest. A rather humid Atlantic climate is indicated. The intermediate zone, separated from the preceding by a hiatus, has, at the top, an absolute date of about 12,000 years B.P.; this is related to the Dryas II period. The predominant vegetal cover is a tundra or steppe, with *Gramineae* and lower percentages of *Artemisia*.

This cold wave coincides with one situated at the bottom of the Apennine diagram, at Chiarugi, and has a similar pattern except for a delay in the appearance of *Fagus* and *Abies*. Calabria lies in a strictly Mediterranean area, but steppe interglacials and woody glacials apparently do not occur. Therefore, this region would be more closely related to the Apennines and not to peri-Mediterranean events. Ascending the diagram, we progress across another hiatus toward the upper part, when the woods develop and where there is a widespread diffusion of *Alnus* (*A. cordata*). Grüger attributes this section of the diagram to the postglacial, with a duration of about 6000 years.

The results of palynological investigations of a 120 m deep borehole at Tenaghi Philippon in the Drama Basin of Greece (Wijmstra, 1969) record the entire history of the Riss-Würm, the Weichselian (Würm), and some features of the late glacial. During the Würmian climatic extremes, an open vegetation with *Artemisia* and *Chenopodiaceae* existed. During the early interstadials, a forest with *Quercus*, *Carpinus*, *Ostrya*, and *Fagus* prospered, whereas in the interstadials *Pinus* cf. *nigra* and *P. silvestria* predominated. During late glacial upper levels the *Quercus* curve rises in response to the climatic improvement.

The Johannina (northwestern Greece) diagram documents in its lower and upper sections (the intermediate absolute age is 40,000 ± 1000 years B.P.) an Atlantic climate, as in the Calabria sequence. Bottema (1967) indicates that the *Abies* belt occurred at about 500 m. *Abies alba* lives in Italy, while in Greece *Abies cephalonica* is present. Because this species is more tolerant to high temperature, it descends mountain slopes until it reaches the thermoxerophylous *Quercus calliprinos*/*coccifera* belt with which it mixes. Therefore, the lowering of the

Abies belt in different regions, as related to climatic changes, must be evaluated carefully, taking into account the different species of the genus *Abies*. In the upper part of the Tenaghi Philippon sequence, the interstadial of Kalabachi is included, dated from 39,000 to 35,000 years B.P. In the author's opinion, this corresponds to a part of the Calabria sequence, where the arboreous cover comprises large proportions of *Pinus* and *Quercus*. It is not realistic that locations in Greece, in central-south Italy, or in Syria, are considered truly Mediterranean in terms of flora, while Venice would be classed as being in a different setting. However, it is noted that Venice is influenced by cold air streams from the northeast and for this reason (and perhaps paleogeographic ones related to the ancestral Po Gulf) is included in an area in which Mediterranean vegetation is not present, i.e., the so-called Adriatic *lacuna* (not lagoon). Horowitz (1979) presents pollen diagrams for the Hula (Tiberias) and Kinneret Basin in the northern Jordan Valley. The diagrams involve the last 80,000 years, representing the upper Pleistocene from the last interglacial to the Holocene. It is suggested that the European nomenclature be retained for the climatic stages of the upper Pleistocene and Holocene, using "pluvial" instead of "glacial." Pluvial phases thus can be correlated with European glacial phases, and the same applies for the interstadials and interpluvials.

The climatic evolution observed in the Hula and Kinneret sequences is in general agreement with those described by Neev and Emery in the southern part of the Dead Sea (the latter interpretations are based on geochemical data). Wright and others (in Horowitz, 1979), who examined palynological data in Iran, record a similar upper Pleistocene–Holocene sequence of climatic events. In Syria, Van Liere (in Horowitz, 1979) reports pluvial and interpluvial events, noting relationships between oak and pine pollen contents.

Pollen analysis of upper Pleistocene Hamarmar lacustrine marly sediments in the Dead Sea graben (Rossignol-Strick, 1969) reveals three climatic zones: a median one, more arid than today, preceeded and followed by humid phases. The basal and the upper part of the diagram shows an important proportion of arboreal plants with prevailing pines (*Pinus halepensis*). In the middle part *Chenopodiaceae* evolve in a very dry halophylous environment. The diagram also shows a typical interpluvial phase.

It is well known that the climate since the end of the last glacial period is characterized by progressive thermic improvement until reaching a maximum about 7000 to 5000 years B.P. This "Optimum" has not been repeated to such an extent since that time; there has been a subsequent climatic decline characterized by different events to the present. To define this trend the terms *anathermic*, *ipsothermic*, and *catathermic*, and *anathermic* or *catathermic* only, were coined (cf. Chiarugi, 1937). Much of this nomenclature was formulated for north-central Europe; some also for the northern part of the Alpine belt; and still another for the southern slope.

Various authors recognize the subsequent cool periods, from about 15,000 years B.P., as Dryas I, Dryas II, and Dryas III, divided by two milder climatic oscillations: Bölling and Alleröd (cf. Bertolani-Marchetti, 1982). The postglacial stage begins here with five periods that have the following absolute dating: preboreal (8300 to 6800 B.C.) and boreal (6800 to 5500 B.C.), or Eoholocene; Atlantic (5500 to 2500 B.C.) and subboreal (2500 to 800 B.C.), or Mesoholocene; and subatlantic (from 800 B.C. to the present), or Neoholocene.

A pollen diagram of peat layers near Abetone plotted by Chiarugi in 1950, but still valid today, highlights the forest postglacial cycles of the Tuscan-Emilia Apennines (Fig. 24.6). Following a steppe phase with *Artemisia* and *Salix* (*Dryas III*), a thermal rise appears as recorded by the diffusion of pine and birch and successively by the presence of a mixed oak forest (boreal periods). Paralleling the climatic deterioration (subatlantic), beech, which had been in competition with *Abies*, predominates completely.

Pollen diagrams that are currently available for the Emilian Apennines (peat layers, lakes, and soils) begin from the end of the late glacial stage; those that most closely pertain to the northern slope are relatively recent. Studies on the Parma Apennines (Bertoldi, 1980) and those of our group on the Modena Apennines (unpublished data) also appear to include a younger part of the Würm.

The transition from glacial to postglacial time

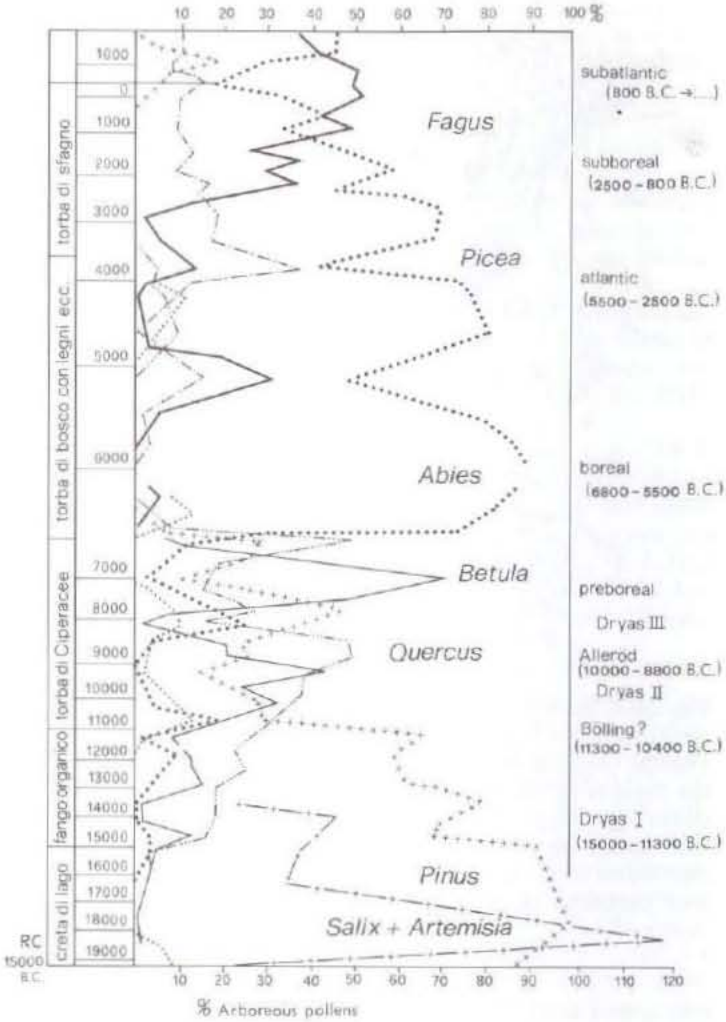


Fig. 24.6. Simplified pollen diagram of the late glacial and postglacial forest cycles of Tuscan Appennines peat layers, near the Abetone Pass. The dating is based on correlation of the summer caloric radiation maximum (11,000 years B.P.) with the oak forest maximum (modified after Chiarugi, 1950. Reprinted with permission). Radiocarbon dates establish the lower level at 14,000 years B.P. and confirm the ages calculated for the upper part of the diagram (Prof. E. Tontiorgi, verbal communication).

is preserved in the sediments of a fossil sink hole in the hills near Bologna (Bertolani-Marchetti et al., 1980). This event, for which radiocarbon dating is available, appears as a change of forest vegetation, from pine and birch wood to a mixed oak assemblage. In a deep layer at this site there are traces of fire (Fig. 24.7).

Many diagrams applicable for the entire Apennines are available, and include those of Chiarugi (1936, 1937), Marchetti (1936), Bonatti (1961, 1963, 1966), Franck (1969), Fancelli-Galletti (1972, 1979), Bertolani-Marchetti (1979, 1980), and Braggio-Morucchio and others (1980). Postglacial palynological diagrams are recently available for the Madonie Mountains, in eastern Sicily (Bertolani-Marchetti and others, 1984). The interpretation of Tyrrhenian Sea diagrams by Francavilla (1973) lacks a correct vegetal basis. The important proportion of conifers, with the prevalence of *Pinus* at the bottom of diagram, suggests a late- or postglacial age. Subsequently, the development of a mixed oak forest occurs.

Two diagrams for the Venice Lagoon (Bertolani-Marchetti, 1966–1967; Bottema and van Straaten, 1966) record the climatic-vegetation events for the late glacial in this area. The passage from glacial pine forest to climactic oak forest in the plain is evident. This is called *Querco-carpinetum boreo-italicum* and denotes the climax of the Po plain for 5000 or 6000 years. Also evident from the diagrams are the steppe climatic phase of the neo-Würm and evidence of alophyle vegetation that indicates the proximity of coastal areas.

In the northern Anatolian mountains, pollen diagrams for the Yenicago and Abant lakes show the persistance of *Pinus* (Beug, 1967) in a

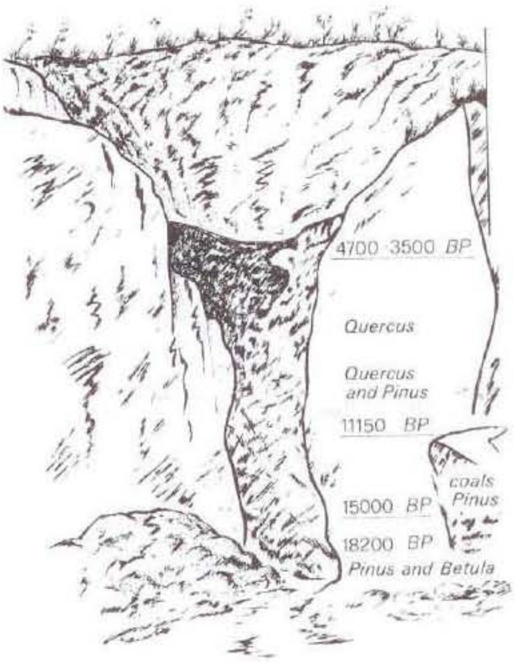


Fig. 24.7. Sketch of a fossil sink hole in gypsum hills near Bologna, Italy. The history of the postglacial vegetal cover is reconstructed by using pollen. On the basis of radiocarbon dating, the Pleistocene-Holocene boundary (11,150 years B.P.) can be defined as well as change of vegetation recorded, i.e., from pine-birch forest to oak-mixed forest. (After Bertolani-Marchetti et al., 1980. Reprinted with permission.)

moist and cool climate, with *Fagus* and *Abies*. At about 2400 years B.P. the climate became drier and warmer; human settlement is indicated by the presence of *Cerealia* pollen and is probably related to a forest degradation, with arrival of *Juglans* and *Castanea* and an increase of *Erica* in the spectra.

Palynological investigations in eastern Anatolia, dated by varve counts, were performed in the postglacial sediments of Lake Van. The bottom of the sequence records a cold (and salty?) steppe. From about 6400 to 3400 years B.P. humidity increased and the steppe was gradually replaced by mixed oak forest. This latter then declined because of human activity. Selective cutting of the mixed oak forest contributed to the disappearance of *Pistacia* and *Pinus*. From the above-cited and other examples, it is evident that in the Near East, regional factors influenced the general climatic trends as revealed by the floral record.

Summary

On the basis of pollen studies it is clear that the Mediterranean has experienced a complex series of vegetation changes owing to a highly variable set of conditions. The Miocene to Recent geologic and geomorphologic evolution involved floral migrations, disappearances, and localized zones of specific plant and vegetal formation. The northern areas have vegetation attributes that differ from the southern ones, and coastal belts can be differentiated from mountainous ones. It is still not possible to reconstruct a continuous and reliable Neogene pollen-climate history. The pollen diagrams used in other studies can supplement our data, but both sets require cautious interpretation. This latter should take into account, in some integrated fashion, all factors, including human ones, that may have influenced the distribution of taxa and vegetal assemblages. Pollen analyses, coupled with other paleontological studies including those presented in other chapters of this volume, can contribute to the refinement of Mediterranean paleoclimatic, paleogeographic, and paleomorphologic problems.

Acknowledgments

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