Pollen records and climatic cycles in the North Mediterranean region since 2.7 Ma

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Abstract: This synthesis incorporates the 16 most important pollen records available across the North Mediterranean region *sensu lato* for the last 2.7 Ma. Their location is discussed with respect to the present-day bioclimatic Mediterranean realm. A special effort has been made to redraw, where necessary, the pollen records in terms of modern cyclostratigraphy. The complexity of the evolution of the Mediterranean flora and vegetation as forced by the climatic cycles is evident. The influence of the latitudinal thermic (and xeric) gradient is confirmed, and the superimposition of a longitudinal gradient, forced by the Asian monsoon, is considered. The Mediterranean flora and vegetation were not altered by any important event during the Early–Middle Pleistocene transition between 1.2 and 0.7 Ma.

This paper presents a synthesis of the vegetational and climatic evolution within the bioclimatically defined Mediterranean realm for the crucial time-window of 1.2–0.7 Ma. During this interval, 40 ka obliquity-forced climatic cycles were progressively replaced by *c*. 100 ka glacial–interglacial oscillations paced by multiples of 20 ka precession cycles (Ruddiman 2003; Maslin & Ridgwell 2005). The aim is to document changes that occurred, or did not occur, in this region in response to this global upheaval in climate pattern, known as the mid-Pleistocene revolution. In order to gain a broad insight based on pollen records, it is necessary to widen the spotlight beyond 1.2–0.7 Ma and include pollen data from 2.7 Ma to the present day. This record starts at the beginning of pronounced climatic cycles in the northern hemisphere, and provides a long chronological record from the Praetiglian Stage to the Holocene (Zagwijn 1975) during which time the effects of successive types of climatic cycle have been experienced.

The bioclimatic Mediterranean realm is today defined using the seasonal distribution of temperature and precipitation, summer (the warmest season) being dry (Quézel & Médail 2003). This realm is clearly delimited (Fig. 1), and is subdivided into several belts according to temperature namely the thermo-Mediterranean ($m > 3$°C), meso-Mediterranean (0°C $< m < 3$°C), supra-Mediterranean (-3°C $< m <$ 0°C), mountain-Mediterranean (-7°C $< m <$ 3°C) and oro-Mediterranean ($m < -7$°C) belts, where '*m*' is the mean of the minima of the coldest month (Quézel & Médail 2003). The thermo-Mediterranean belt is characterized by a plant association rich in *Olea europaea*, *Ceratonia siliqua*, *Chamaerops humilis*, *Pinus halepensis*, *P. brutia*, *Juniperus phoenicea*, *Myrtus communis*, *Pistacia lentiscus, P. terebinthus and Lygeum spartium*, while the meso-Mediterranean belt also includes *Olea europaea*, several evergreen species of *Quercus* (e.g. *Q. ilex*, *Q. coccifera*, *Q. suber*), *Pinus halepensis*, *P. brutia*, *Phillyrea and Pistacia*. The supra-Mediterranean belt is rich in deciduous *Quercus* with *Ostrya* and *Carpinus orientalis*; the mountain-Mediterranean belt comprises *Pinus nigra*, *Cedrus*, *Abies*, *Fagus* and *Juniperus*; and the oro-Mediterranean belt consists mainly of *Juniperus* and prickly xerophytes (Quézel & Médail 2003). In addition, types of vegetation depend on the superimposition of the amount of rainfall: desert (perarid bioclimate: mean annual precipitation (MAP) $<$ 100 mm); steppe rich in *Artemisia* and other herbs (arid bioclimate: 100 $<$ MAP $<$ 250 mm); forest-steppe with *Artemisia*, *Pinus halepensis*, *Juniperus* and scarce evergreen *Quercus* (semiarid bioclimate: 250 $<$ MAP $<$ 600 mm); evergreen forest with sclerophilous oaks, *Pinus pinaster* and *P. pinea* (subhumid bioclimate: 600 $<$ MAP $<$ 800 mm); and mixed forest with deciduous oaks, *Fagus* and conifers such as *Cedrus* and *Abies* (humid bioclimate: MAP $>$ 800 mm) (MAP values: if $m = 0$°C; Quézel & Médail 2003). However, *Artemisia* steppes are significant in several contexts: they generally correspond to dry environments (steppes with xeric forcing), but others can develop at high Mediterranean altitude under elevated precipitations (steppes with thermal forcing; Quézel & Barbero 1982).

The modern bioclimatic Mediterranean realm is known to have existed since 3.6 Ma (Suc 1984), i.e. the mid-Pliocene, at a time when the Alpine massifs, such as in the French Southern Alps, Calabria, Peloponnesus and South Anatolia, were less elevated than today. For example, a reconstruction based on pollen data and geomorphology indicates that the

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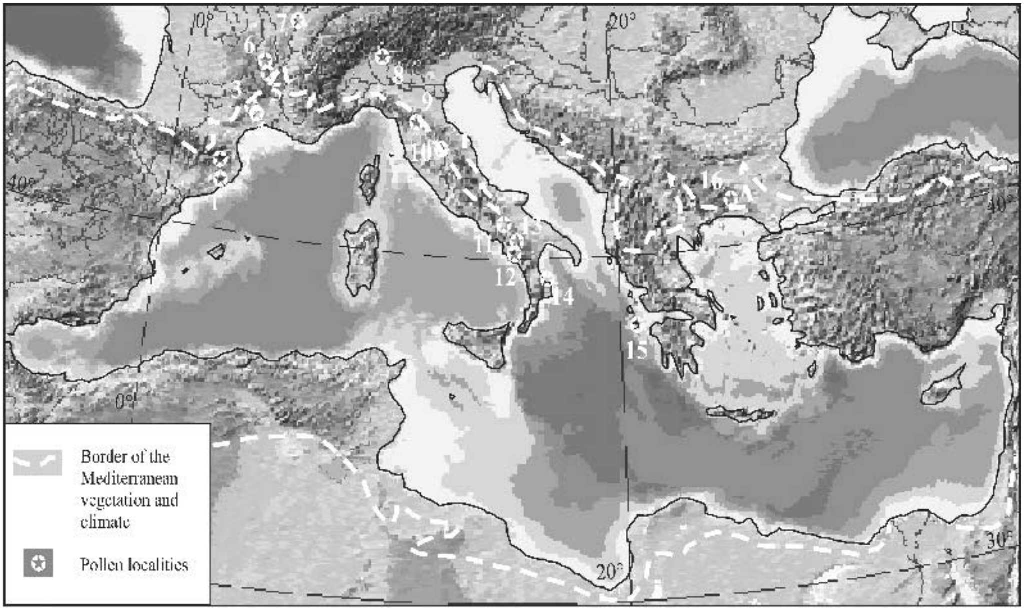


Fig. 1. Map of the Mediterranean region including the pollen localities discussed and the border of the Mediterranean-type vegetation and climate (Quézel & Médail 2003). Localities: 1, Garraf 1; 2, Banyoles; 3, Bernasso; 4, Saint-Macaire; 5, Ceyssac; 6, Senèze; 7, Bresse; 8, Piànico–Sèllere; 9, Upper Valdarno; 10, Colle Curti and Cesi; 11, Acerno; 12, Camerota; 13, Vallo di Diano; 14, Crotone; 15, Zakynthos; 16, Tenaghi Philippon.

Mercantour Massif (French Southern Alps) was 30% less elevated in the Early Pliocene than today (Fauquette *et al*. 1999). Similarly, the Silla Massif (Calabria) is estimated to have been 20% lower during the Early Pleistocene than today (Ciaranfi *et al*. 1983). Nevertheless, despite significant subsequent mountain uplift, the modern bioclimatic subdivision of the Mediterranean realm was already in place at that time (Suc *et al*. 1995*b*) and was merely amplified during the Late Pliocene and Early Pleistocene (Suc *et al*. 1995*a*). Therefore, comparisons will be made in this paper between pollen sites located within the bioclimatic Mediterranean realm and those beyond it (Fig. 1; Quézel & Médail 2003), in order to appreciate fine differences in vegetation irrespective of whether the localities belong to the earliest or most recent glacials and interglacials. In addition, the aforementioned ambivalent significance of modern *Artemisia* steppes was recently emphasized for the Late Pliocene and Early Pleistocene of the north-central Mediterranean region (Subally & Quézel 2002). This also requires comparison between pollen localities of the Mediterranean realm and those beyond.

This synthesis will be used to reinterpret the considered localities in terms of cyclostratigraphy, and to propose a more accurate chronological assignment than was available for most of them when they were published (the exceptions being Senèze, Crotone, Vallo di Diano, Zakynthos and Tenaghi Philippon). The flora, vegetation and climate will be discussed according to the location of the pollen records. Finally, some relevant discrepancies noted between the northwestern and northeastern Mediterranean climatic patterns will be discussed.

Floral and vegetational changes, and climatic cycles in the North Mediterranean realm

The pollen localities at Garraf 1, Zakynthos and Crotone are marine, the last of these being just 30 km from present-day elevations of 1700 m. However, most sites are lacustrine, and some are today located at altitudes below 200 m, i.e. Saint-Macaire, Banyoles, Bresse and Tenaghi Philippon, of which the last three are just 30 km from present high relief of 1000–1500 m. Other localities are now at low altitudes of 200–300 m, i.e. Upper Valdarno, Camerota, and Piànico–Sèllere, but are immediately surrounded by high relief of 1200–2500 m. Some localities are at mid-altitudes of around 500 m, i.e. Bernasso and Senèze, and surrounded by old plateaus of only 700 m, whereas Vallo di Diano is surrounded by still uplifting high massifs of 1000 to 1600 m. Other localities are at rather high altitudes of 700–850 m, i.e. Ceyssac, Cesi, Colle Curti and

Acerno, and are surrounded by high massifs of 1000 to 1600 m; an exception is Ceyssac which belongs to the old French Massif Central, and the present altitude of the surroundings is now probably higher than during the mid-Pleistocene.

Synthetic pollen diagrams have been constructed according to Suc (1984): plants are grouped according to the ecological significance of their modern representative, and/or to their behaviour within the pollen diagrams, e.g. *Cathaya* and the Cupressaceae. The pollen diagrams generally show regular alternations between thermophilous trees and herbs corresponding to successive climatic cycles. These cycles are supported in some cases by oxygen isotope curves obtained from the same sampling, notably at Crotone (Combourieu-Nebout & Vergnaud Grazzini 1991), Vallo di Diano (Russo Ermolli 1994) and Zakynthos (Subally *et al.* 1999) (Figs 2 & 3).

First, the accurate age of each locality will be presented and/or discussed in terms of cyclostratigraphy with respect to the reference oxygen isotope curves of Tiedemann *et al.* (1994) for Ocean Drilling Program (ODP) Site 659 (Central Eastern Atlantic Ocean) and Shackleton *et al.* (1995) for ODP Site 846 (Central Eastern Pacific Ocean) (Figs 2 & 3). Special attention will then be paid to the significance of vegetational changes as documented by pollen data, before examining whether or not the 1.2–0.7 Ma transition from Early to Middle Pleistocene is characterized by change.

Pollen diagrams and cyclostratigraphy since 2.6 Ma (Figs 2 & 3)

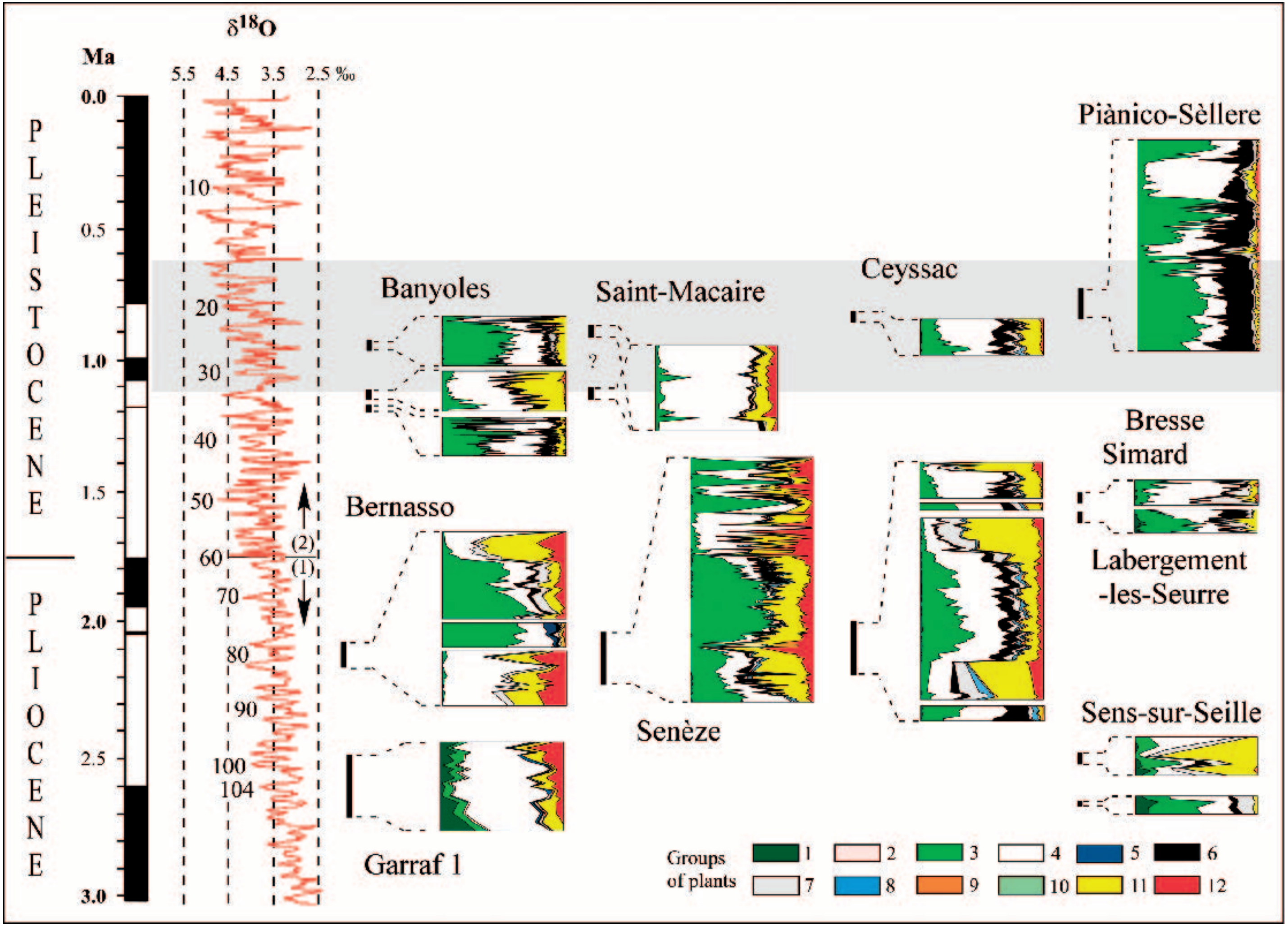
The Garraf 1 pollen diagram records the earliest glacial–interglacial cycles as constrained by its reliable biostratigraphy (Suc & Cravatte 1982). The illustrated part of the section shows successive peaks of steppe plants that probably correspond to even numbers of Marine Isotope Stages (MIS) from 108 to 98.

The Bernasso record (Suc 1978) is earlier than the Olduvai Subchron according to radiometric and magnetostratigraphic dating (Ambert *et al.* 1990). It can be considered as extending from MIS 82 to 78 according to the aspect of the pollen record (two strong glacials separated by an interglacial, itself interrupted by a moderate brief cooling). The Senèze record (Elhai 1969) has recently been more accurately constrained by radiometric ages and palaeomagnetism: it belongs to the interval corresponding to MIS 85 to 76 (Roger *et al.* 2000). The Ceyssac composite section is dated at its top by radiometric ages of several volcanic outflows (Ablin 1991). A re-reading of its pollen record suggests that the lower part of the section, which has been correlated with the Senèze pollen diagram (Ablin 1991), covers a more or less continuous time-span from MIS 83 to 74; its upper part would belong to MIS 21.

The Bresse succession comprises several localities (including Sens-sur-Seille, Labergement-les-Seurre, and Simard) and exhibits a very discontinuous pollen record dated by rodent biostratigraphy (Chaline & Farjanel 1990); it can be considered as representing MIS 107 or 105 and 100 to 98 for Sens-sur-Seille, extending from MIS 55 to 53 for Labergement-les-Seurre, and representing MIS 50 and 49 for Simard. The Banyoles composite section corresponds to three successive nested palaeolakes dated by mammal remains and palaeomagnetism (Julià Bruguès & Suc 1980; Leroy 1990; Løvlie & Leroy 1995). The discontinuous pollen record could cover MIS 35 to 34 and 25 to 24. Sediments of the Saint-Macaire maar are reverse-magnetized and have an age of between 1.4 and 0.7 Ma (i.e. between two well-dated volcanic outflows; Leroy *et al.* 1994); they correspond to a strong glacial which could belong to MIS 34 or 22.

The Piànico–Sèllere section (Moscariello *et al.* 2000) includes the Matuyama–Brunhes reversal (Pinti *et al.* 2001) and consequently should cover MIS 21 to 17. The composite Crotone series (Semaforo and Vrica sections) benefits from a detailed chronology that is based mainly on biostratigraphy and magnetostratigraphy (Spaak 1983; Pasini & Colalongo 1997; Rio *et al.* 1997) and

Fig. 2. ***(overleaf)*** Synthetic pollen diagrams of selected Late Pliocene to Middle Pleistocene localities from the northwestern Mediterranean region *sensu lato* (localities 1 to 8 in Fig. 1) with respect to their time control: Garraf 1 (Suc & Cravatte 1982), Bernasso (Suc 1978; Leroy & Roiron 1996), Senèze (Elhai 1969), Ceyssac (Ablin 1991), Bresse (Chaline & Farjanel 1990), Banyoles (Julià Bruguès & Suc 1980; Leroy 1990; Løvlie & Leroy 1995), Saint-Macaire (Leroy *et al.* 1994), Piànico–Sèllere (Moscariello *et al.* 2000; Pinti *et al.* 2001). The grey area represents the time window 1.2–0.7 Ma. Two successive reference oxygen isotope curves have been plotted: (1) ODP Site 846 from Shackleton *et al.* (1995); (2) ODP Site 659 from Tiedemann *et al.* (1994). Grouping of plants follows Suc (1984): 1, Mega-mesothermic (e.g. subtropical) elements (e.g. Taxodiaceae, *Engelhardia*, *Myrica*, *Microtropis fallax*, *Distylium*); 2, *Cathaya*; 3, mesothermic (i.e. warm-temperate) elements (e.g. *Quercus*, *Carya*, *Pterocarya*, *Liquidambar*, *Carpinus*, *Ulmus*, *Zelkova*, *Tilia*); 4, poorly preserved pollen grains of *Pinus* and Pinaceae; 5, meso-microthermic (i.e. temperate) elements (*Cedrus*, *Tsuga*); 6, microthermic (i.e. cold-temperate) elements (*Abies*, *Picea*); 7, palaeoecologically insignificant elements; 8, aquatic plants (e.g. *Typha*, *Potemogeton*); 9, Mediterranean xerophytes (e.g. *Olea*, *Phillyrea*, *Pistacia*, *Ceratonia*, *Cistus*, *Quercus ilex* type); 10, Cupressaceae; 11, herbs (e.g. Asteraceae, Poaceae including *Lygeum*, Amaranthaceae–Chenopodiaceae, Brassicaceae, Apiaceae); 12, steppe elements (*Artemisia*, *Ephedra*).



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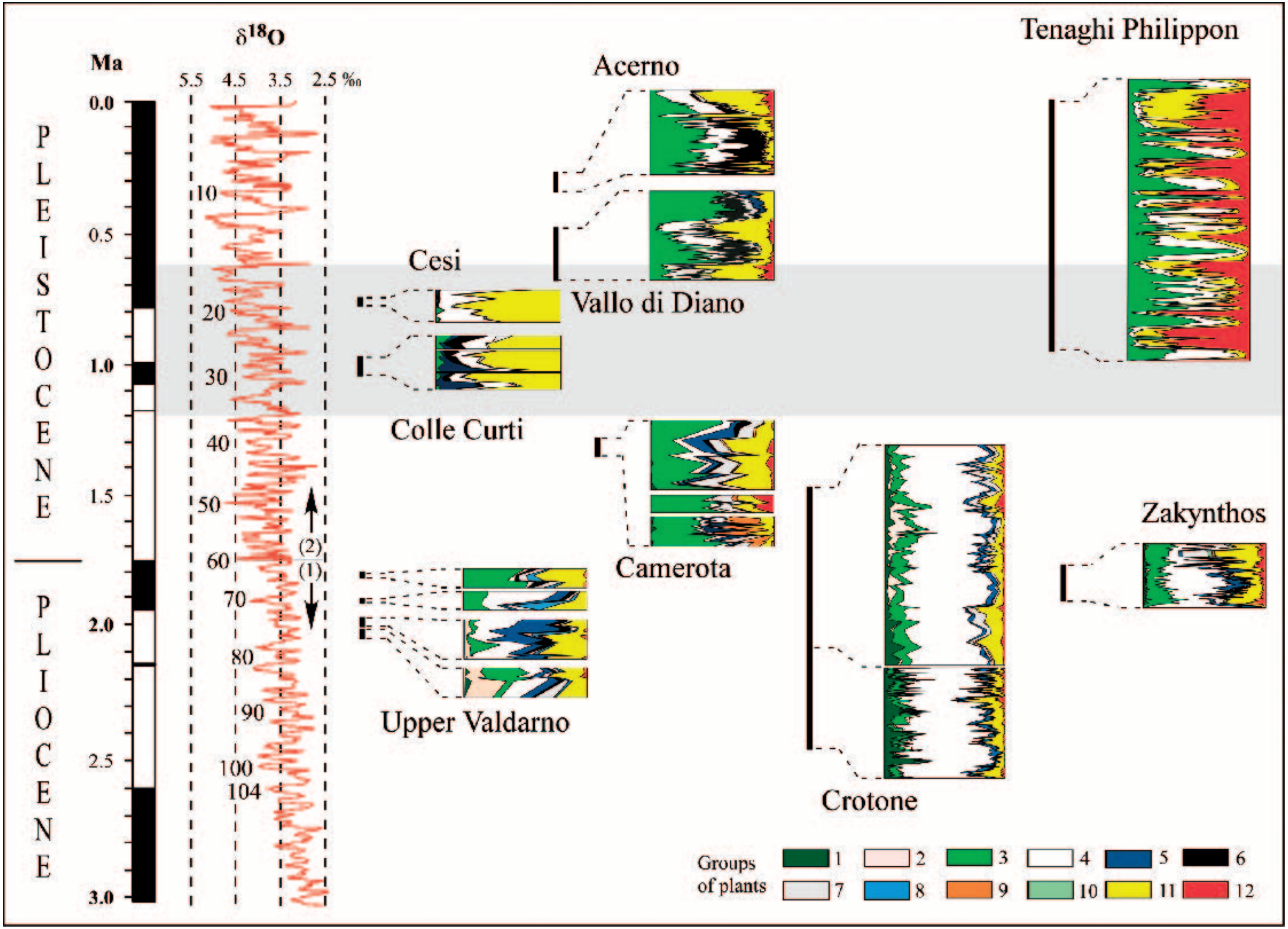
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Cesi
Colle Curti
Upper Valdarno
Acerno
Vallo di Diano
Camerota
Crotone
Tenaghi Philippon
Zakynthos
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refined by an oxygen isotope stratigraphy allowing direct correlation to the marine isotope record (Combourieu-Nebout & Vergnaud Grazzini 1991). The series represents a continuous pollen record which runs from MIS 97 to 46 (Combourieu-Nebout & Vergnaud Grazzini 1991; Combourieu-Nebout 1993).

The lower part of the Citadel section on Zakynthos Island has been studied from biostratigraphic, magnetostratigraphic and oxygen isotope perspectives: it represents a time-span from MIS 70 to 63 (Subally *et al*. 1999). The chronological placement of the Upper Valdarno composite section is given by mammal evidence combined with palaeomagnetism (Albianelli *et al*. 1995). Short, discontinuous pollen records (Albianelli *et al*. 1995) might successively belong to MIS 74, 76, 70 and 65 based on their glacial or interglacial status and vegetational dynamics. The Camerota section has no precise time control and its age is still debated (Russo Ermolli 1999). A composite pollen diagram is available which includes the section of Brenac (1984) probably overlain by borehole S1 of Russo Ermolli (1999). The presence, in very low quantities, of Taxodiaceae, *Engelhardia* and Sapotaceae pollen grains, and the absence of *Cathaya*, supports a younger age for the palaeolake of Camerota than for the Crotone series (located in the same area at low altitude). The importance of mesophilous elements seems in agreement with 'warmer' glacial–interglacial cycles and fits well with MIS 43 to 39.

The mid-altitude Colle Curti and Cesi sections contain mammal faunas and are calibrated by palaeomagnetic reversals (Jaramillo–Matuyama and Matuyama–Brunhes; Coltorti *et al*. 1998). The pollen record indicates successive glacial– interglacial cycles (Bertini 2000) that may respectively correlate with MIS 30 to 26 (Colle Curti) and 18 (Cesi). The Vallo di Diano borehole benefits from good age control (radiometric ages and oxygen isotope record): it extends from MIS 16 to 13 (Russo Ermolli 1994). The Acerno section, which includes a trachytic tuff dated at 297 ka, shows a complete climatic cycle (Munno *et al*. 2001) probably running from MIS 10 to 8. The reference Tenaghi Philippon long pollen record (Wijmstra & Groenhart 1983) represents a time interval that is reliably correlated with marine isotope stratigraphy, i.e. from MIS 25 to 1 (Mommersteeg *et al.* 1995).

Fig. 3. (***previous page***) Synthetic pollen diagrams of selected Late Pliocene to Middle Pleistocene localities from the central and eastern South Mediterranean region (localities 9 to 16 in Fig. 1) with respect to their time control: Upper Valdarno (Albianelli *et al*. 1995), Colle Curti (Bertini 2000), Cesi (Bertini 2000), Camerota (Brenac 1984; Russo Ermolli 1999), Crotone (Combourieu-Nebout & Vergnaud Grazzini 1991; Combourieu-Nebout 1993), Zakynthos (Subally *et al*. 1999), Vallo di Diano (Russo Ermolli 1994), Acerno (Munno *et al*. 2001), Tenaghi Philppon (Wijmstra & Groenhart 1983). The grey area represents the time window 1.2–0.7 Ma. Two successive reference oxygen isotope curves are plotted: (1) ODP Site 846 from Shackleton *et al*. (1995); (2) ODP Site 659 from Tiedemann *et al*. (1994). Plant groups are as listed in Figure 2 caption.

Changes in the North Mediterranean vegetation and flora between 2.6 Ma and today (Figs 2 & 3)

The actual relevance of the Mediterranean steppe vegetation (herb-dominant pollen assemblages rich in *Artemisia*) to glacial phases has been established according to three distinct approaches:

- its record at Tenaghi Philippon immediately preceding the development of Holocene forest (Van der Hammen *et al*. 1971; Wijmstra & Groenhart 1983);
- its record in the Autan 1 and Garraf 1 boreholes as the first steppe development of the Late Pliocene (Cravatte & Suc 1981; Suc & Cravatte 1982);
- its correspondence with the oxygen isotope record from the Crotone series (Combourieu-Nebout & Vergnaud Grazzini 1991).

A transect of pollen records from northwestern Europe to the Mediterranean allowed Suc & Zagwijn (1983) to reconstruct the vegetation of the Last Glacial: in addition to the continuous prevalence of herbs, this transect shows a southward increase in *Artemisia* with a significant threshold when entering the Mediterranean bioclimatic realm. Such a trend is found again here when comparing the Bresse and Piànico–Sèllere glacial pollen floras (located distinctly outside of the Mediterranean bioclimatic realm with respect to latitude; Fig. 1) with others presented on Figure 2, whatever their age (earliest or most recent climatic cycles). Similar latitudinal and mostly palaeoaltitudinal features discriminate the Colle Curti and Cesi pollen diagrams (North Apennines) from others in southern Italy (Camerota and Vallo di Diano) shown on Figure 3. Hence, the development of *Artemisia* steppe, when represented by widespread herbs, depends not only on the latitude but also the altitude and probably the location of the area with respect to the circulation of air masses. The present-day *Artemisia* steppes are linked to arid and subarid bioclimates (Quézel & Médail 2003). For example, *Artemisia* steppe never expanded significantly at the expense of conifer forest in the Po Valley during glacials. This is explained by the high moisture present in the area since the earliest climatic cycles (Fauquette & Bertini 2003; Ravazzi 2003). To the south of the Po Valley (Upper Valdarno, Colle Curti and Cesi), the absence or sparseness of *Artemisia* steppe is probably due to the humidity even during glacials (and still persisting) at mid-altitude localities surrounded by relatively high massifs.

In the Mediterranean realm, glacials are generally characterized by an outstanding increase in herbs, especially *Artemisia*. Nevertheless, the percentage of *Artemisia* varies not only with the geographical features of the pollen site (latitude, palaeoaltitude, palaeoaltitude of the surrounding massifs, etc.) but also with the related time interval. For example, most of the earliest glacials show elevated percentages of *Artemisia* (Garraf 1, Bernasso, Senèze and Ceyssac in Fig. 2; Crotone in Fig. 3) that denote drier conditions corresponding to cooler phases as documented by the oxygen isotope record (MIS 100 and 98, 96, 82 and 78 representing higher values of $\delta^{18}O$). (It should be noted that the high percentages of *Pinus* pollen, which is greatly concentrated by transport to marine sedimentary basins, considerably reduces the percentages of other taxa, including *Artemisia*). The same phenomenon is observed within younger glacials (Saint-Macaire in Fig. 2; Crotone and Camerota in Fig. 3), consecutively relating to MIS 62, 58, 50 and 40, and then 34 or 22.

In contrast, the earliest interglacials are less heterogenous. They generally show a well-developed forest (see Bernasso, Senèze and Ceyssac; Fig. 2), characterized by an enrichment southwards in mega-mesothermic trees such as the Taxodiaceae (Crotone in Fig. 3). The vegetation during younger interglacials was more homogenous (Banyoles and Piànico–Sèllere in Fig. 2) because of the disappearance of mega-mesothermic elements in southern Europe (Camerota, Vallo di Diano, Acerno and Tenaghi Philippon, Fig. 3). Nevertheless, the north–south thermal gradient was not alone in controlling the extinction of thermophilous elements, which may have persisted longer in some protected areas such as the Bresse.

When looking at the long pollen sequences of Crotone and Tenaghi Philippon, which together cover almost all the considered time-span, it is clear that various types of interglacial forests succeeded one another: mixed forests characterized by large amounts of Taxodiaceae (*Sequoia*-type pollen grains), mixed forests where *Cathaya* (an altitudinal conifer living today in subtropical China) prevailed, mixed forests more equitably dominated by Taxodiaceae and deciduous trees, and forests exclusively composed of deciduous trees (Fig. 3). This record respectively concerns: (1) MIS 97 to 75, then (2) 73 to 51, then (3) 49 to 35, and finally (4) 31 to 1. It denotes four long climatic intervals as established by Zagwijn (1975), successively consisting of: (1) long warm interglacials with cool-temperate glacials (Tiglian A–B); (2) temperate long (Tiglian C) and shorter (Eburonian) interglacials with cooler glacials; (3) warm-temperate long interglacials (Waalian) with cool-temperate glacials; and (4) warm-temperate brief interglacials with longer and colder glacials (Menapian to present). This analysis, obvious in the northern Mediterranean region when considering the amount of subtropical and then warm-temperate trees remaining during glacials, supports the validity of Zagwijn's (1975) subdivisions. These so-called megacycles have recently been relaunched on the basis of oxygen isotope records by Kukla & Cilek (1996).

In addition, it has been demonstrated by Combourieu-Nebout (1993) for the Crotone succession that vegetation dynamics during interglacial–glacial transitions 2.4 Ma ago were almost the same as for the recent climatic cycles, based on the reconstruction of Van der Hammen *et al*. (1971): temperature increased prior to precipitation which continued to increase even when temperature started to decrease. Such vegetational dynamics are obvious not only at Crotone (Fig. 3) but also at Senèze, Ceyssac, Vallo di Diano and Camerota, and to a lesser degree at Bernasso (Figs 2 & 3).

However, such a synthetic framework is complicated in the Mediterranean region by the effects of latitudinal (and altitudinal) and longitudinal gradients.

Effects of latitudinal and longitudinal gradients on past Mediterranean vegetation and flora

The influence of a north–south gradient is reflected mainly in the thermophilous trees. Coeval pollen records show an increased quantity of thermophilous elements to the south, a trend that becomes evident when comparing the Senèze (Fig. 2) and Crotone (Fig. 3) pollen records, especially for the Taxodiaceae. Furthermore, the progressive disappearance of these thermophilous elements, which are today absent from the Mediterranean realm, occurred predominantly from north to south (Suc 1996; Popescu 2001; Suc *et al*. 2004) where they persisted until about 1 Ma ago (data from Caltagirone in Sicily: study in progress), i.e. when more severe climatic conditions began in the area.

In parallel, an important influence is also exerted by the Asiatic monsoon which generates a longitudinal gradient that results in the preservation of thermophilous elements in the area, some of these persevering into recent times or even the present day: for example, the Taxodiaceae were still living on the island of Rhodes 500 ka ago (Tsampika section, study in progress), and *Pterocarya*, *Liquidambar*, *Zelkova* and *Parrotia* are still extant in this region.

A problem was raised in the work of Subally *et al*. (1999) for the Citadel section of Zakynthos Island, which suggested that glacials are marked by the development of mid- to high-altitude trees (*Cedrus*, *Tsuga*, *Abies* and *Picea*), whereas interglacials are indicated by herbs (including *Artemisia*). This interpretation will be discussed in detail later.

What happened to the Mediterranean flora and vegetation during 1.2–0.7 Ma?

The cooling at 0.9 Ma has been considered severe (Ruddiman *et al*. 1989). It probably corresponds to MIS 22 which reflects strongly increased $\delta^{18}O$ values. In terms of pollen percentages, and consequently of vegetation changes, this event is not strikingly expressed. For example, in Catalonia and the Po Valley, there is no evidence within the pollen records for a greater expansion of open vegetation during glacials and a reduction of forests during interglacials. It seems that only the composition of the plant ecosystems changed significantly. Because of the low number of pollen data across this interval, only a few regions document what happened at this climatic break: Catalonia, Languedoc and the Po Valley in the northwestern Mediterranean region, and southern Italy.

Suc (1986) has discussed this scenario for the northwestern Mediterranean province. One major step occurred beforehand, at 3.6 Ma, with the establishment of a Mediterranean-like climate (i.e. double seasonality). It caused a severe impoverishment of thermophilous elements requiring humidity all year long (e.g. *Engelhardia*, *Platycarya*, *Rhoiptelea*, Sapotaceae, Menispermaceae, Taxodiaceae, *Symplocos*, *Microtropis fallax*, *Distylium*, *Hamamelis*). However, some elements persisted, such as *Liquidambar*, *Carya*, *Pterocarya*, *Zelkova*, *Parrotia persica*, *Eucommia*, *Cedrus*, *Cathaya* and *Tsuga*. Their disappearance from this area seems to have occurred during the early Middle Pleistocene. Meanwhile, the composition of the *Artemisia* steppes changed considerably: from 2.6 to *c*. 1 Ma, they included some thermophilous herbs and shrubs, such as *Phlomis fruticosa* and Cistaceae. The younger steppes lost these elements but contained more Cupressaceae and, especially, *Hippophae rhamnoides*. This probably corresponds to a lowering in temperature.

In southern Italy, a similar scenario characterized the extinction of thermophilous plants, but here it occurred later. *Engelhardia*, Sapotaceae, and *Distylium* were still present at Camerota (Brenac 1984; Russo Ermolli 1999) and in a slightly younger Sicilian section (Caltagirone: study in progress) during the Early Pleistocene. Their extinction probably occurred at about 1 Ma because they are absent from the Vallo di Diano pollen record (Russo Ermolli 1994). Taxodiaceae, *Liquidambar*, *Carya*, *Pterocarya*, *Zelkova*, *Eucommia*, *Cedrus*, *Cathaya* and *Tsuga* were still present at Vallo di Diano (Russo Ermolli 1994). Some thermophilous plants (*Zelkova*, *Pterocarya*) were to disappear from the Rome region during the last interglacial (Follieri 1979; Follieri *et al*. 1986). *Zelkova* is still living (in very harsh conditions) in Sicily (Di Pasquale *et al*. 1992). In contrast to the northwestern Mediterranean region, herbs and shrubs associated with the *Artemisia* steppes do not show any change at about 1 Ma. They continued to include many Mediterranean thermophilous xerophytes such as *Lygeum* and *Neurada*.

This overview shows just how important latitude is for understanding vegetational and floral changes in southern Europe during the Early–Middle Pleistocene transition.

Possible discrepancy between the northwestern and northeastern Mediterranean regions

Repeated advances of Mediterranean *Artemisia* steppes have been understood as corresponding to glacials, based on the Last Glacial and earliest glacial records (Suc & Zagwijn 1983). For the earliest glacials, this hypothesis was supported by pollen and oxygen isotope analyses on the same samples from the Crotone series (Combourieu-Nebout & Vergnaud Grazzini 1991). However, this reassuring scenario was contradicted by the results of Subally *et al*. (1999) for Zakynthos Island. Here, oxygen isotope and $CaCO_3$ measurements were performed on the same samples as those used for pollen analysis. The curves show, for the Olduvai time interval, close similarity to the reference global oxygen isotope curve (Site ODP 846: Shackleton *et al*. 1995) and the oxygen isotope curve recorded by Combourieu-Nebout & Vergnaud Grazzini (1991) for Crotone. Pollen analyses on Zakynthos Island sediments were performed using the same method as for Crotone, and the sediments corresponded to a similar marine environment (rather deep but relatively coastal terrigenous clays). Pollen grains were transported from nearby lands that included elevated relief (the Silla Massif for the Crotone series, the Peloponnesus Massif for Zakynthos). This means that these pollen results can be directly compared, the reliability of pollen data from marine coastal deposits for vegetational reconstruction being long established (Suc *et al*. 1999). For Zakynthos, Subally *et al*. (1999) concluded that *Artemisia* steppe developed during interglacials and *Cedrus* forest during glacials, indicating that glacials were dry to the west and humid to the east, interglacials humid to the west and dry to the east. The ambiguity in the pollen signal could come from the wide ecological range of the genus *Artemisia sensu lato* which shows the full climatic distribution from perarid and very warm conditions to humid and very cold ones (Subally & Quézel 2002). An intensive investigation is presently underway on the modern pollen of *Artemisia* as well as on fossil specimens from the Late Cenozoic of the Mediterranean area as a means to distinguish 'cool' and 'cold' *Artemisia* species from 'warm' ones using pollen morphology (Suc *et al*. 2004).

Horowitz (1989) suggested that such opposition between eastern and western Mediterranean regions has existed since the earliest climatic cycles, i.e. since 2.6 Ma. His hypothesis was based on the present-day strong climatic difference between the southeastern and the northwestern Mediterranean regions (which may increase further in the context of ongoing global warming: IPCC 2001). He considered that this phenomenon results from variations in the influence of the Asian monsoon that already existed during the Early Pliocene (Zhisheng *et al*. 2001). Bar-Matthews *et al*. (1997) have contested this hypothesis by proposing that the eastern Mediterranean region was characterized by an *increase* in precipitation during interglacials and a *reduction* during glacials on the basis of the last deglaciation and Holocene. But this idea was recently moderated somewhat, with maximum rainfall and low temperature being able to be coeval, and likewise a decrease in rainfall and increase in temperature (Bar-Mathews *et al*. 2003). This means that the matter is not completely resolved because some time lags have been evidenced for the Middle Pleistocene: (1) between *Artemisia* maxima and maxima of other herbs for the Middle Pleistocene in the Peloponnesus (Okuda *et al*. 2002); and (2) between *Artemisia* maxima and the oxygen isotope curve (Capraro *et al*. 2005).

In addition, an example of the early existence (in the Early Pliocene) of some climatic opposition between southeastern and southwestern Europe is provided by pollen records from SW Romania compared to sapropel deposition in the Central Mediterranean Basin with respect to astronomical cycles (Popescu *et al*. in press). In the latter, sapropels (related to precession minima) are better expressed during eccentricity maxima (Hilgen 1991). In contrast, increasing moisture in SW Romania, characterized by expansion of marshes (also in correspondence with precession minima), is better expressed during minima of eccentricity (Popescu *et al*. in press). Accordingly, the intensity of maxima in humidity (occurring during minima of precession) alternated between the western and eastern Mediterranean regions according to fluctuations in eccentricity.

Conclusions

Sixteen pollen localities have been used for this synthesis which provides a good opportunity to recalibrate selected records in terms of modern cyclostratigraphy.

This overview emphasizes the complexity of changes in flora and vegetation related to climatic cycles in the Mediterranean realm between 2.7 Ma and today. Undoubtedly, the latitudinal thermal (and xeric) gradient (and its altitudinal equivalent) controlled most of this evolution. The timing of disappearances of thermophilous plants in a north–south orientation is a clear consequence of this forcing, as well as the persistence of 'warm' steppes to the south after 1 Ma. In addition, a longitudinal Mediterranean gradient is superimposed on the previous one, reflecting the influence of the Asian monsoon. The question of the existence of some (discontinuous?) discrepancy between northeastern and northwestern Mediterranean regions during glacials and interglacials is not completely resolved and requires further research. No important event characterized the 1.2–0.7 Ma Early–Middle Pleistocene transition in the Mediterranean flora and vegetation.

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