Acta zool. cracov., 38(1): 3-16, Kraków, 31 May 1995

Structure of West Mediterranean vegetation and climate since 5.3 ma

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Accepted for publication: 20 Oct. 1994

SUC J.-P., BERTINI A., COMBOURIEU-NEBOUT N., DINIZ F., LEROY S., RUSSO-ERMOLLI E., ZHENG Z., BESSAIS E., FERRIER J. 1995. Structure of West Mediterranean vegetation and climate since 5.3 ma. Acta zool. cracov., 38(1): 3-16.

Abstract. Pollen analyses of 31 selected localities from the West Mediterranean region, spanning from the Early Pliocene to the present, are discussed on the basis of latitude, altitude and physiography. Northwestern and southwestern vegetation provinces are identified and their evolution is presented in relation to the climatic changes of the northern hemisphere. The most drastic changes in vegetation affected the northwest Mediterranean province. The Mediterranean open xeric vegetation, widely distributed during glacial phases, has an old origin, predating the earliest Pliocene.

Key words: Pollen, vegetation, climate, West Mediterranean, Pliocene, Pleistocene.

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I. INTRODUCTION

The present-day vegetation pattern around the West Mediterranean region (OZENDA 1975; QUÉZEL 1976) is affected by several local peculiarities, such as:

– the Iberian and Italian peninsulas, which permit an intense southward penetration of "boreal" assemblages thanks to their mountainous skeleton;

– the summer drought increasing southward in parallel with increasing temperatures;

– the only source for humidity is the Atlantic air mass, which is regenerated above the Mediterranean Sea.

During the Lower Pliocene (5.3-3.6 ma), all these factors already played an important role in the organization of the vegetation (SUC 1989). Among other characteristics, the presence before this period of widespread steppes (including subdesertic elements) in southern Spain, southern Italy and North Africa is evidence of the ancient influence of the Sahara desert (BESSAIS unpublished; SUC & BESSAIS 1990; CHIKHI 1992). The floral composition of the Lower Pliocene vegetation was very different from the modern one. Many genera (*Rhoiptelea*, *Engelhardtia*, *Symplocos*, *Microtropis*, *Cathaya*, *Tsuga*, *Pterocarya*, *Carya*, etc.) and even families represented by several taxa (Taxodiaceae, Hamamelidaceae, Sapindaceae, etc.) progressively disappeared from the area without returning because of several west-east oriented barriers [Pyrenees, western Alps, Mediterranean Sea, Sahara desert (SUC 1986)]. This represents a significant difference from North America. This dismantling of the Pliocene Mediterranean flora was induced by the earliest Arctic glaciations (SUC 1984). In this paper, we intend to specify more precisely the structure of the past vegetation and its changes due to climatic fluctuations, as it is documented by pollen records.

Only a few representative and well-dated localities will be considered in this synthesis (Fig. 1). Some areas possess numerous additional pollen sites that allow very precise reconstructions of the local vegetation, such as, for the Lower Pliocene, in Catalonia (SUC & CRAVATTE 1982; BESSAIS & CRAVATTE 1988), Roussillon (SUC 1976; CRAVATTE et al. 1984), in Languedoc (PONS 1964; MICHAUX & SUC 1980-81; SUC 1981; SUC & DRIVALIARI 1991), in the Nice area (ZHENG & CRAVATTE 1986; ZHENG 1990), in north-central Italy (BERTINI 1992, 1994), in southern Italy (BERTOLDI et al. 1989; SUC & BESSAIS 1990).

Three periods are examined:

– 5.3 to 2.6 ma;

– 2.6 to 1 ma;

– 1 ma to Present.

In the Mediterranean area, the two first periods are characterized by very important changes in vegetation structure in relation to the earliest northern hemisphere glaciations. The last period corresponds to the widest amplitude cycles and also to the most severe decrease in minimum and maximum temperatures. The modern physiography of the West Mediterranean region can be considered as established since the earliest Pliocene. The chronological framework followed in this paper (Fig. 1) is that proposed by CITA et al. (in press) which is in agreement with the astronomic cyclostratigraphy (HILGEN 1991).

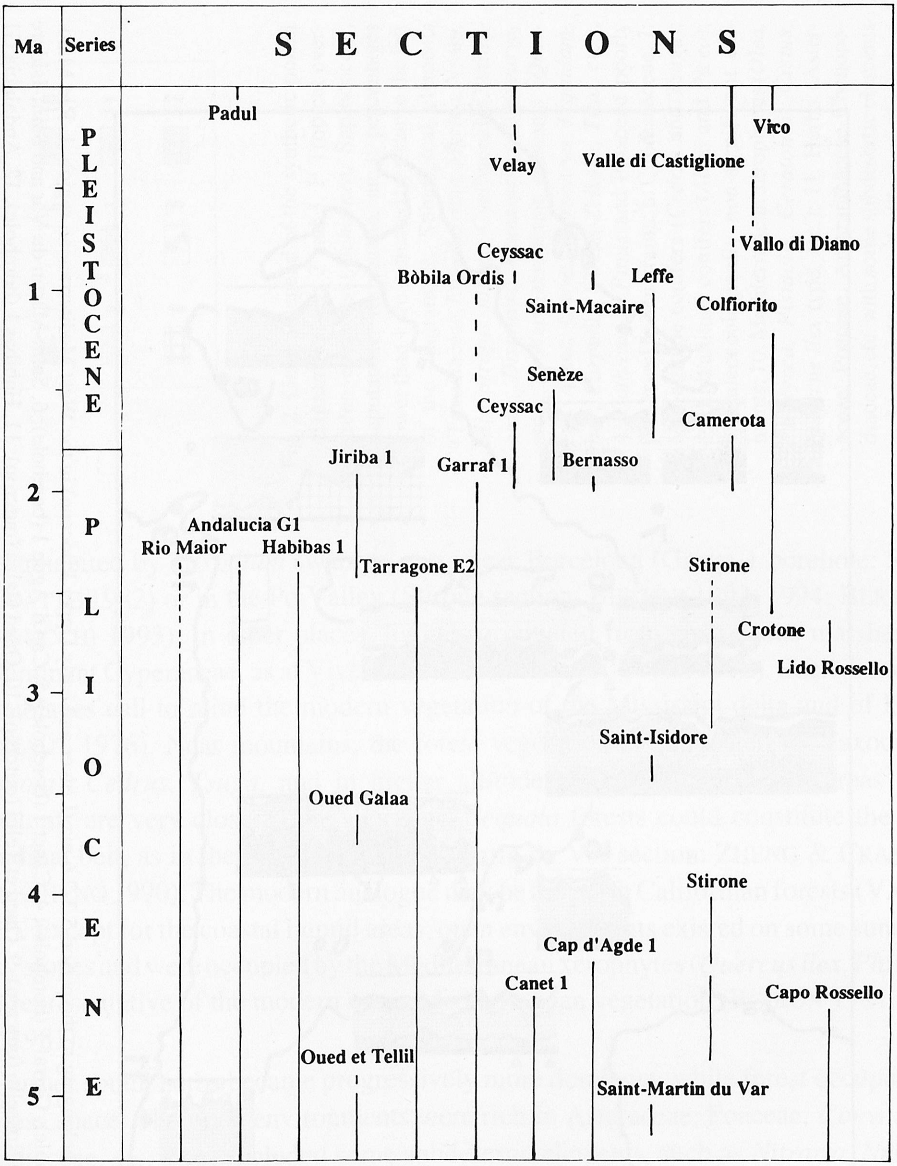

Fig. 1. Chronologic position of the West Mediterranean Pliocene and Pleistocene sections discussed in the text.

II. THE LOWER AND UPPER PLIOCENE: 5.3 TO 2.6 MA

Pollen assemblages allow us to specify a distinct geographical limit between two kinds of vegetation. The transition has been precisely determined along the Spanish coastline near Barcelona (41°25' N latitude), but not as precisely on the Italian coastline, perhaps because of an insufficient number of pollen localities (Fig. 2).

In the north, the predominance of arboreal pollen grains illustrates the great importance of forest cover. The vegetation was closely linked to relief (SUC et al. 1992). Coastal plains

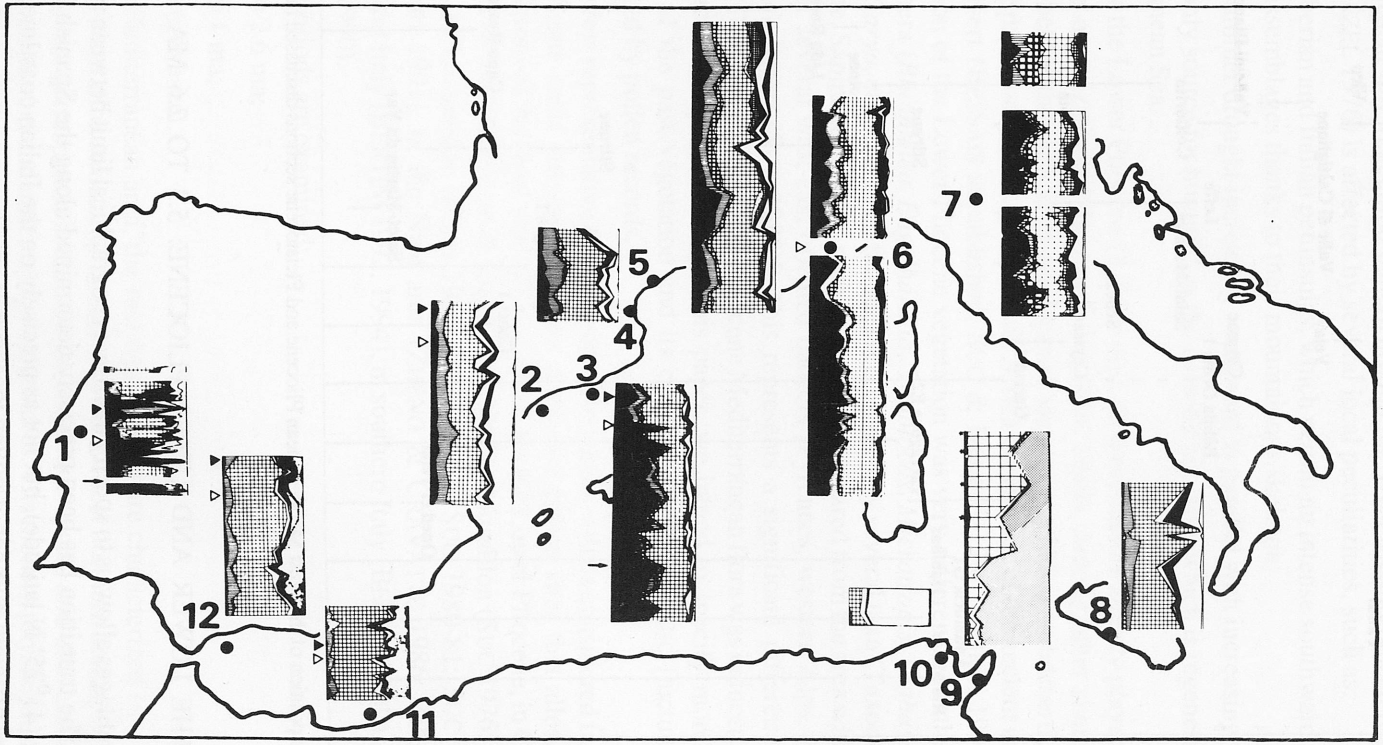

Fig. 2. Selected synthetic pollen diagrams belonging to the period 5.3-2.6 ma (Lower and early Upper Pliocene) in the West Mediterranean region. 1, Rio Maior (F 58 borehole); 2, Tarragona E2 (borehole); Garraf 1 (borehole); 4, Canet 1 (borehole); 5, Cap d'Agde 1 (borehole); 6, Saint-Martin du Var and Saint-Isidore (outcrops); 7, Stirone (outcrop); 8, Capo Rossello (outcrop); 9, Oued et Tellil (outcrop); 10, Oued Galaa (outcrop); 11, Habibas 1 (borehole); 12, Andalucia G1 (borehole). To the left of some diagrams: an arrow indicates the climatic event at 4.5 ma (cooling); a white triangle indicates the climatic event at 3.5 ma (cooling); a black triangle indicates the climatic event at 3.1-3.0 ma (warming). Pollen assemblages: see the general pollen legend.

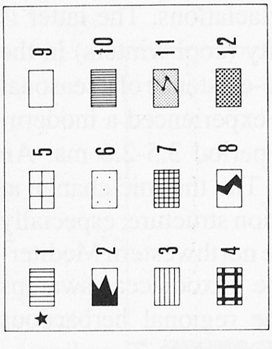

Fig. 2. General legend of the synthetic pollen diagrams on figs 2 and 3. 1: Tropical evergreen elements (*Alchornea*, Sapindaceae, Sapotaceae, Rubiaceae, etc.); percentages lower than 1 are indicated by a star to the left of the diagram; 2: Subtropical elements (Taxodiaceae, *Engelhardtia*, *Myrica*, *Nyssa*, *Microtropis fallax*, Cyrillaceae-Clethraceae, *Distylium*, *Hamamelis*, *Platycarya*, etc.); 3: Warm-temperate elements (*Quercus*, *Alnus*, *Carya*, *Pterocarya*, *Liquidambar*, *Carpinus*, *Ulmus-Zelkova*, *Tilia*, etc.); 4: *Cathaya*; 5: *Pinus* and Pinaceae poorly preserved pollen grains; 6: Cupressaceae; 7: Mid-altitude conifers (*Cedrus* and *Tsuga*); 8: High altitude conifers (*Abies* and *Picea*); 9: Paleoecologically non-significant elements; 10: Mediterranean xerophytes (*Olea*, *Phillyrea*, *Pistacia*, *Ceratonia*, *Cistus*, *Quercus ilex* type, etc.); 11: Herbs (Asteraceae, Poaceae, Amaranthaceae-Chenopodiaceae, etc. with some subdesertic elements as *Lygeum*, *Nitraria*, *Calligonum*) including the steppe elements (*Artemisia* and *Ephedra*); 12: Ericaceae.

were inhabited by *Taxodium* swamps, e. g., near Barcelona (Garraf 1 borehole: SUC & CRAVATTE 1982) or in the Po Valley (Stirone section: BERTINI 1992, 1994; BERTINI & VANNUCCHI 1993). In other places, lignites originated from herbaceous marshes with predominant Cyperaceae, as at Vivès in the Roussillon (SUC et al. 1992). Such juxtaposed assemblages call to mind the modern vegetation of the Mississipi delta and of Florida (MUNAUT 1976). Near mountains, the forest vegetation is dominated by Taxodiaceae (*Sequoia*), *Cedrus*, *Tsuga*, and in higher altitudes *Abies* and *Picea*. In areas where mountains are very close to the shoreline, *Sequoia* forests could constitute the lower altitudinal belt, as in the Nice area (Saint-Martin du Var section: ZHENG & CRAVATTE 1986; ZHENG 1990). The modern analogue may be the north Californian forests (VANKAT 1979). Except for the coastal humid areas, open environments existed on some sunny and rocky slopes and were occupied by the Mediterranean xerophytes (*Quercus ilex*, *Phillyrea*, etc.) representative of the modern meso-Mediterranean vegetation (ROIRON 1981, 1992; SUC 1981).

Further south, herbs became progressively more dominant, while forest occupied less and less space. The open environments were rich in Asteraceae, Poaceae, *Convolvulus*, Geraniaceae, etc. They included some subdesertic elements, such as *Nitraria*, *Neurada*, *Calligonum* and *Lygeum* (BESSAIS & CRAVATTE 1988; SUC et al. in press). *Lygeum* can be abundant in the North African pollen spectra. Such assemblages presage the pollen spectra of the modern steppes of southern Spain and northern Africa. Mediterranean xerophytes are only well represented in the Tarragona area and in Sicily; their assemblage resembles the modern thermo-Mediterranean formation (*Olea*, *Pistacia*, *Ceratonia*, *Ziziphus*, etc.) (BESSAIS & CRAVATTE 1988; SUC & BESSAIS 1990; SUC et al. in press).

At low latitude at Rio Maior on the Atlantic side of the Iberian peninsula (DINIZ 1984a,b), a forest environment (including swamps) predominated. It was mainly composed of *Cathaya*, *Engelhardtia*, *Quercus*, *Sequoia* and *Myrica*, Cyrillaceae-Clethraceae, *Nyssa*, *Symplocos* and *Taxodium*. Mediterranean xerophytes were represented and the oceanic character of the region is indicated by high percentages of Ericaceae.

During the period 5.3-2.6 ma, the climate fluctuated and two coolings occurred at 4.5 and 3.5 ma, indicating the forthcoming onset of the Pliocene glaciations. The latter is considered to correspond to the emergence of thermic seasonality (cool winters) in the northwestern Mediterranean region (SUC 1989). Because of the pre-existence of a seasonal rhythm in precipitation, the northwestern Mediterranean region experienced a modern-appearing double seasonality (thermic and hydric) during the period 3.5-2.6 ma. An important increase in temperature occurred at about 3.1-3.0 ma. The thermic change at 3.5 Ma, together with a decrease in moisture, modified the vegetation structure, especially in the humid areas (swamps and humid slopes of mountains) of the northwestern Mediterranean region (SUC et al. 1992). For instance, the extension of the Taxodiaceae swamps decreased in the Barcelona coastal plain to the benefit of the regional herbaceous associations (SUC & CRAVATTE 1982). A similar reduction concerned the Taxodiaceae swamps of the Po Valley, where the altitudinal coniferous trees (*Tsuga*, *Cedrus*, *Abies* and *Picea*) were expanding (BERTINI 1992, 1994; BERTINI & VANNUCCHI 1993). In exactly the same way, the *Sequoia* forest evolved at the foot of the Alps (Nice area), progressively replaced by open environments at low altitude and by coniferous forests (*Cathaya*, *Cedrus*, *Abies* and *Picea*) at mid and high altitude (ZHENG & CRAVATTE 1986; ZHENG 1990).

No significant change marked the southern European (BERTOLDI et al. 1989; SUC et al. in press) and northern African vegetations (SUC 1989; SUC et al. in press).

On the Atlantic face (Rio Maior), these climatic fluctuations caused variations in the extent of swamp forests relative to open vegetation (mainly Ericaceae moor and sometimes Mediterranean xerophytic association) (DINIZ 1984a,b).

III. THE LATE PLIOCENE AND LOWER PLEISTOCENE: 2.6 TO 1 MA

At low and mid altitudes of the northwest Mediterranean region, this period was characterized by rapid steppe-forest alternations (ELHAI 1969; BERTOLDI 1977; SUC 1978, 1984; JULIÁ BRUGUÈS & SUC 1980; LEROY 1990; ABLIN 1991; LEROY & SERET 1992; LÖVLIE & LEROY in prep.) linked to with glacial-interglacial fluctuations (SUC & ZAGWIJN 1983). The steppic assemblages contain, among other non arboreal pollen, a large amount of *Artemisia.* They sometimes include thermophilous elements, such as *Cistus* and *Phlomis fruticosa* at Bernasso (SUC 1978). They reflect the modern steppes of the low Mediterranean latitudes that do not have to endure very low winter temperatures (QUÉZEL et al. 1980). The interglacial forest assemblages are mainly constituted by deciduous elements such as *Quercus*, *Carya*, *Carpinus*, *Pterocarya*, *Parrotia persica*, *Ulmus*, *Zelkova*, etc. (ELHAI 1969; BERTOLDI 1977; SUC 1978, 1984; JULIÁ BRUGUÈS & SUC 1980; ROIRON 1983, 1992; LEROY 1990; ABLIN 1991; LEROY & SERET 1992). Similar forests are still present in the eastern part of the Mediterranean region (Anatolia, Colchida, meridional Caspian region) (EMBERGER & SABÉTI 1962; ZOHARY 1973; QUÉZEL et al. 1980; QUÉZEL & BARBERO 1985) where they can be closely juxtaposed with *Artemisia* steppes (Central Anatolia) even though the modern development of the latter was partly influenced by human actions (Fig. 3).

Similar *Artemisia* steppe – deciduous forest alternations have been demonstrated in the preglacial Pliocene at Villaroya (northwestern Spain) by REMY (1958). The early record

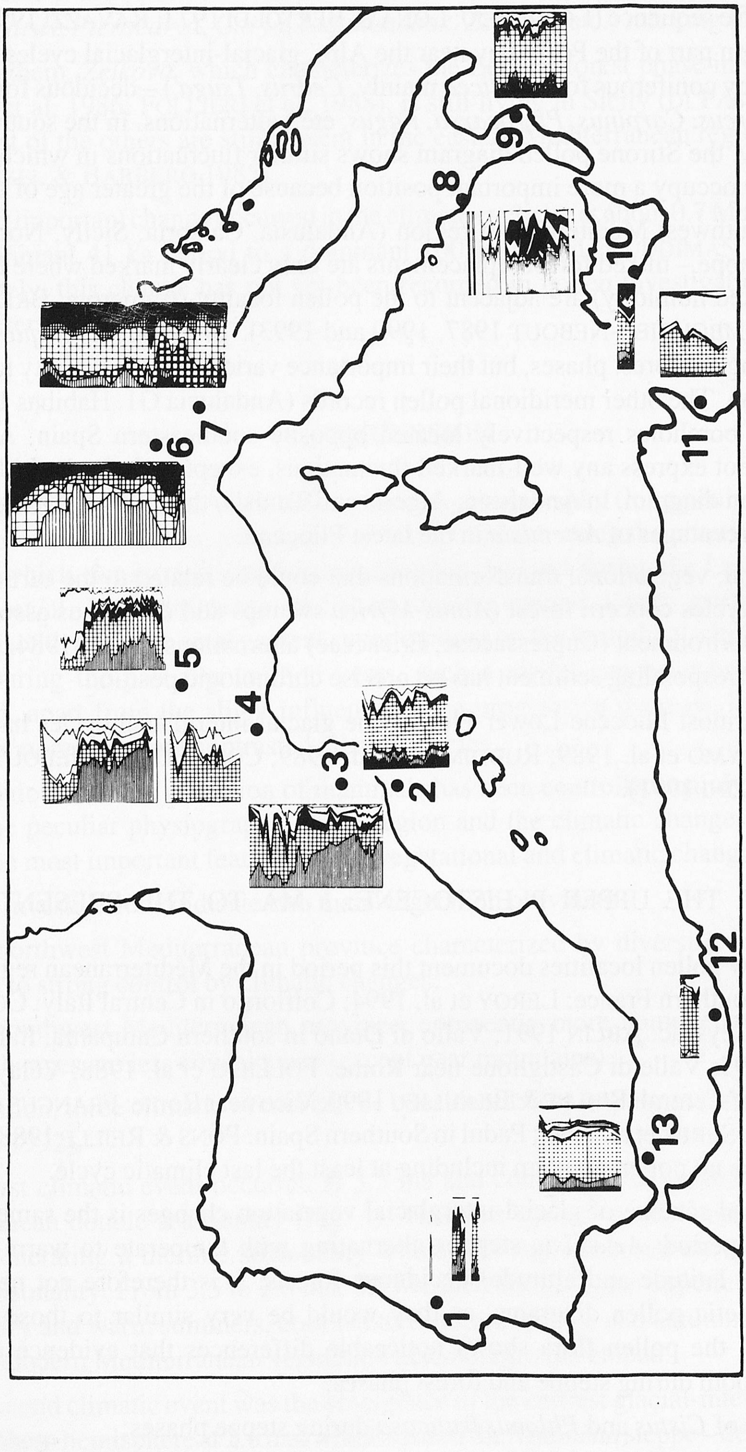

Fig. 3. Selected synthetic pollen diagrams belonging to the period 2.6-1 ma (late Pliocene and Lower Pleistocene in the West Mediterranean region. 1, Rio Maior (F 58 borehole); 2, Tarragona E2 (borehole); 3, Garraf 1 (borehole); 4, Bernasso (outcrop); 5, Ceyssac (outcrop); 6, Leffe (outcrop and borehole); 7, Stirone (outcrop); 8, Camerota (outcrop); 9, Crotone (Semaforo outcrop); 10, Lido Rossello (outcrop); 11, Jiriba 1 (borehole); 12, Habibas 1 (borehole); 13, Andalucia G1 (borehole). Pollen assemblages: see the general pollen legend. Explanations of the synthetic pollen diagrams as in Fig. 2.

of such alternations could be explained by relatively high altitudes near the locality in the Iberian dry plateau context.

In the Leffe sequence (LONA 1950; LONA & BERTOLDI 1973; RAVAZZI 1993), located in the northern part of the Po Valley near the Alps, glacial-interglacial cycles are mainly represented by coniferous forest (*Picea* mainly, *Cedrus*, *Tsuga*) – decidous forest (*Carya* mainly, *Quercus*, *Carpinus*, *Pterocarya*, *Fagus*, etc.) alternations. In the southern part of the Po valley, the Stirone pollen diagram shows similar fluctuations in which *Taxodium* and *Cathaya* occupy a more important position because of the greater age of the section.

In the southwest Mediterranean region (Andalusia, Calabria, Sicily, North Africa), *Artemisia* steppe – mixed forest replacements are only clearly marked where high reliefs (and correlated humidity) are adjacent to the pollen locality (Camerota: BRENAC 1984; Crotone: COMBOURIEU-NEBOUT 1987, 1990 and 1993). Taxodiaceae (*Sequoia*) are still present during the forest phases, but their importance varies with the vicinity to relief and with elevation. The other meridional pollen records (Andalucia G1, Habibas 1 and Jiriba 1: off-shore boreholes respectively located opposite southeastern Spain, Algeria and Tunisia) do not express any well-marked fluctuations, except perhaps the Lido Rossello (Sicily) pollen diagram. In Andalusia, Algeria and Tunisia, the only change concerns the increased percentages of *Artemisia* in the latest Pliocene.

In Portugal, vegetational transformations that could be related to the earliest glacial-interglacial cycles concern forest (*Alnus-Myrica* swamps and deciduous associations) – more open environment (Cupressaceae, Ericaceae) alternations (DINIZ 1984a). Unfortunately the corresponding sediment has no precise chronologic position.

The uppermost Pliocene-Lower Pleistocene glacial-interglacial cycles have a 41 ka duration (RAYMO et al. 1989; RUDDIMAN et al. 1989; COMBOURIEU-NEBOUT & VERGNAUD GRAZZINI 1991).

IV. THE UPPER PLEISTOCENE: 1 MA TO THE PRESENT

Only a few pollen localities document this period in the Mediterranean region (Saint-Macaire in Southern France: LEROY et al. 1994; Colfiorito in Central Italy: COLTORTI et al. in prep.; Ceyssac: ABLIN 1991; Vallo di Diano in southern Campania, Italy: RUSSO-ERMOLLI 1993; Valle di Castiglione near Rome: FOLLIERI et al. 1988; Velay, southern French Massif Central: REILLE & BEAULIEU 1990; Vico near Rome: FRANCUS et al. 1993, LEROY 1993, SERET et al. 1993; Padul in Southern Spain: PONS & REILLE 1988). In North Africa there is no pollen diagram including at least the last climatic cycle.

The general scheme of glacial-interglacial vegetation changes is the same as during the previous period: *Artemisia* steppes alternating with temperate to warm-temperate (according to latitude and altitude) deciduous forests. It is therefore not necessary to present synthetic pollen diagrams, as they would be very similar to those of Fig. 3. Nevertheless, the pollen flora shows noticeable differences that evidence decreasing temperature both during steppe and forest phases:

- absence of *Cistus* and *Phlomis fruticosa* during steppe phases;
- regular presence of *Hippophaë rhamnoides* during steppe phases;

– record of *Koenigia islandica* at Colfiorito (steppe phase);

– progressive disappearance (from north to south) of thermophilous trees (*Parrotia persica*, *Cedrus*, *Pterocarya*, *Carya*, *Liquidambar*, *Zelkova*, etc.) marking forest phases.

Among them, *Zelkova*, which characterizes the Eemian forest phase in Central Italy (FOLLIERI et al. 1986; FOLLIERI et al. 1988), is still living in Sicily (DI PASQUALE et al. 1992). Most of the others are still present in the eastern Mediterranean region (ZOHARY 1973; QUÉZEL & BARBERO 1985).

Another important change occurred in the climate cyclicity at about 0.7 Ma: the passage from a dominant 41 ka period to a dominant 100 ka period (RUDDIMAN et al. 1989). Unfortunately, this change has not yet been recorded in pollen investigations from the West Mediterranean region.

V. DISCUSSION

The high diversity of the West Mediterranean physiography (long peninsulas; mountains of various orientations; presence or absence of plains along the coastline; influence of the sea which, for instance, widely transgressed the land during the Lower Pliocene: CLAUZON et al. 1990; influence of Sahara desert) created a very great diversity in vegetation, with a mosaic arrangement superimposed on the latitudinal-altitudinal organization. During the past five million years, such a model can be considered almost unchanged, apart from the slight influence of the progressive decrease in temperature along with more and more contrasted climatic cycles.

It is obvious that the evolution of mammals has been controlled mainly by these two factors: the peculiar physiography of the region and the climatic changes. Fig. 4 summarizes the most important features of the vegetational and climatic changes.

Pollen investigations indicate two main vegetation provinces:

– the northwest Mediterranean province characterized by diversified biotopes and submitted to strong control by climatic changes;

– the southwest Mediterranean province, apparently more homogenous, where the climatic changes are less conspicuous (except near mountains).

In addition, three climatic events can be considered very important (SUC 1986, 1989; SUC et al. 1992).

The first climatic event occurred at 3.5 ma and concerned the establishment of the Mediterranean double seasonality (Fig. 4). This was caused by the emergence of cool winters generating a thermic seasonality which was superimposed on the pre-existing hydric seasonality. From 3.5 to 2.6 ma, the Mediterranean region experienced a modern climate (dry and warm summers, cool winters, humid springs and autumns). During that time, the modern Mediterranean vegetation assemblages developed.

The second climatic event was the emergence of the earliest glacial-interglacial cycles in the northern hemisphere at 2.6 ma, which caused the *Artemisia* steppe – deciduous forest replacements almost everywhere in the North Mediterranean region (Fig. 4). From that

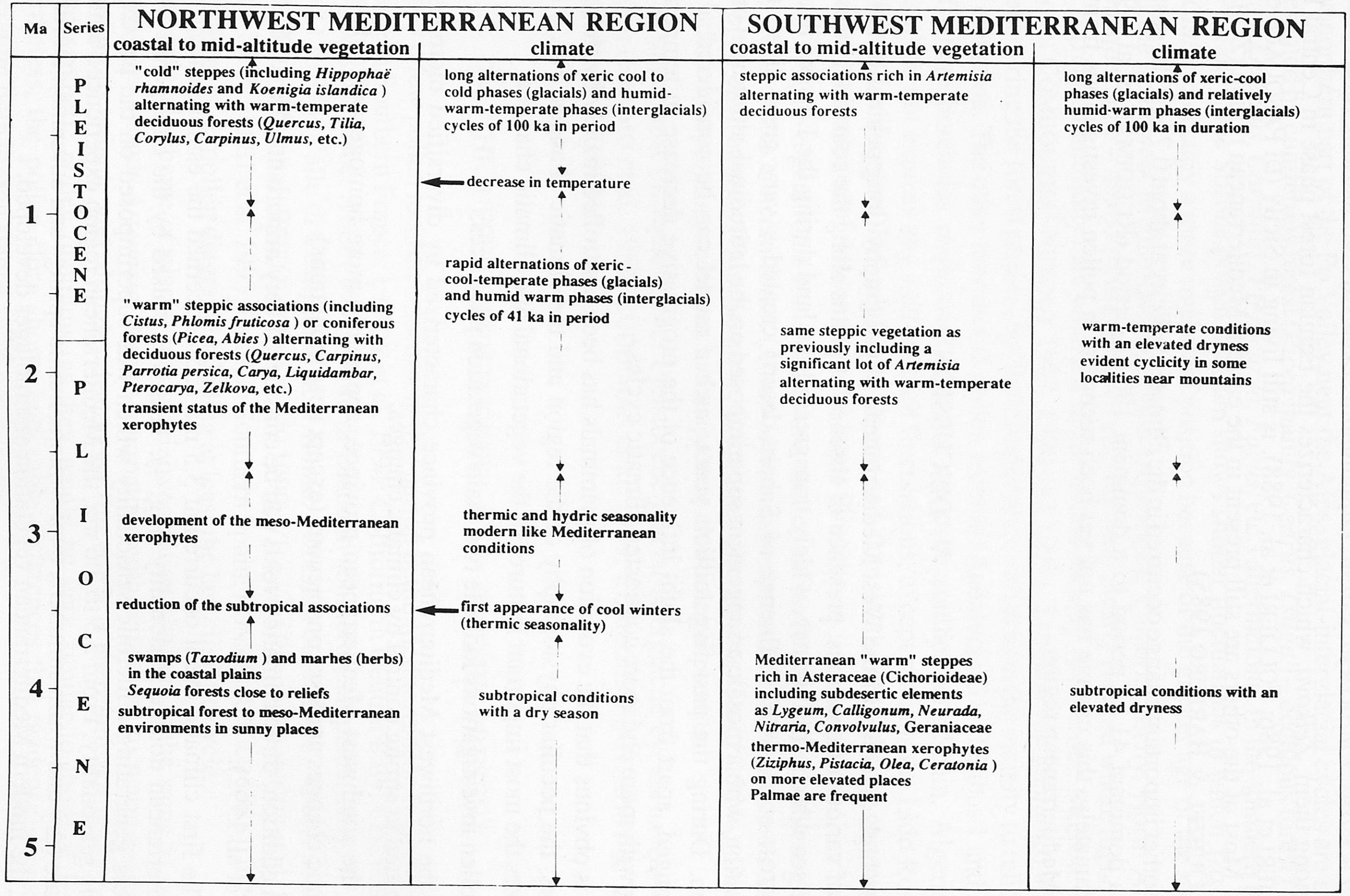

Fig. 4. General scheme of coastal to mid-altitude vegetation and climate evolution in the West Mediterranean region from 5.3 ma according to pollen records.

time onward, the seasonal Mediterranean climate reached its modern status, which is generally considered as only attained at the glacial-interglacial and interglacial-glacial transitions (HAMMEN et al. 1971).

The third climatic event, which occurred at about 1 ma, involves a marked decrease in temperature (Fig. 4). It caused the progressive elimination of thermophilous trees, which have a present-day relict distribution in the eastern Mediterranean region.

Finally, it is clear that the typical Mediterranean vegetation structure dates back more than 5.3 ma, in spite of floristic revolutions that mainly concerned the trees (disappearance of many taxa) and encouraged the development of the typical modern Mediterranean vegetation assemblages. South Mediterranean steppes are traditionally interpreted as having an anthropic origin. Without dismissing the impact of man, one must consider the natural predisposition of the area toward an open vegetation.

VI. CONCLUSIONS

Because of the close relationship between plants and climate, palynology is the most reliable method for reconstructing past continental climatic conditions. In addition, both pollen analyses and oxygen isotopes can be measured in parallel and directly compared at long, continuous coastal marine sections (COMBOURIEU-NEBOUT & VERGNAUD GRAZZINI 1991; LEROY & DUPONT in press) and the climatic signal allows long distance correlations, such as for the Lower and early Upper Pliocene (SUC & ZAGWIJN 1983).

Two vegetational provinces are clearly in evidence from the beginning of the Pliocene:

– the northwest Mediterranean province, a domain of high physiographic contrasts, marked by very important and well-known changes, the chronology of which is precisely known;

– the more simple southwest Mediterranean province, where the vegetation hardly changed from the earliest Pliocene onwards.

The contrast between the two provinces cannot be caused by the lower number of pollen localities in the South Mediterranean region, because several additional unpublished records (Andalusia: S. WARNY, J.-P. SUC; northwest Morocco: S. WARNY; Algeria: S.M. ABDELMALEK) fully confirm its great palynological homogeneity.

Past vegetation reconstructions demonstrate that the high variability of northwest Mediterranean landscapes is old, dating at least from the early Pliocene. On the other hand, the widespread open xeric vegetation in the South Mediterranean region shows a relative permanence, dating back more than 5.3 ma.

Such contrasts in space and time certainly greatly constrained the evolution and migration of mammals.

A c k n o w l e d g e m e n t s . The authors are indebted to Prof. A. PONS for reviewing the manuscript. This paper is contribution n° 95-009 of Institut des Sciences de l'Evolution (URA 327 C.N.R.S.). This work was also supported by D.G.I.C.Y.T. (agreement n PB 90-0489) (J.-P. S.).

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