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Continental late Pliocene paleoclimatic history recorded in the Bresse Basin (France)

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ABSTRACT

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We present results to show that the Beaune P & C borehole, cored in the Bresse Basin (France), records late Pliocene climatic variations. Pollen analysis allows precise correlations with northern and southern European stratigraphies. Using Kukla et al.'s (1981) climate index, we show that cold climate phases occur during the Brunssumian, at around 3.2, 3.6 and 5.2 Myr B.P., respectively, in agreement with Atlantic core results. The onset of a general cooling trend is felt early in the Reuverian, at about 3 Myr B.P. which corresponds to the end of a warm event characterized by high percentages of oak. This is followed by minor climatic pulses of increasing magnitude since about 2.7 Myr B.P., that are also recorded in marine sediments. Finally a major cooling occurs at about 2.4 Myr B.P., corresponding to the beginning of the Praetiglian.

Introduction

The Bresse Basin, a geological area located in Eastern France orientated from north to south, lies in an Oligocene tectonic zone (Fig. 1A) belonging to the west-European rift (Bonvalot et al., 1984). The geology is well documented and has been studied intensively, mainly for the late Tertiary and lower Pleistocene deposits (Bonvalot et al., 1984). The structure and morphology of the Bresse Basin show two dissymetries. The first one is a gradient orientated north to south. It shows a decrease of the topographic surface, an increase of the thickness of the Tertiary deposits from north to south, and a sharp difference between the plain level and the surrounding borders. This north to south gradient played a main role in the drainage of the basin since the Eocene (Rat, 1984). The second dissymetry is orientated west to east which induced the geometry of the Pliocene-Pleistocene deposits (Rat, 1984). The history of the basin began during the Upper Eocene and the Lower Oligocene. The most important period of tectonic movement and collapse was during the Oligocene. During the Miocene, the north to south gradient is accentuated with deposits in the southern part and the lack of sedimentation in the north. The north tended to uplift while the south continued to collapse. According to Rat (1984), a gap in

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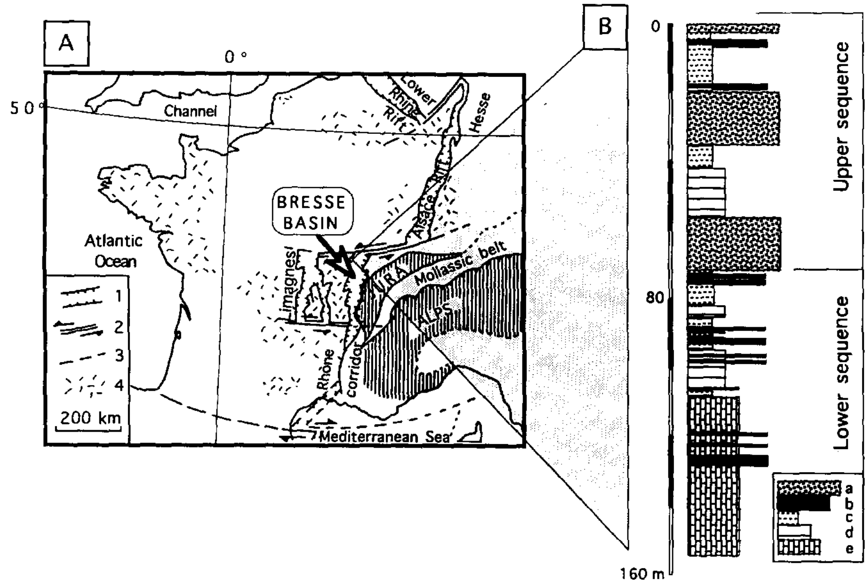

Fig. 1. A. Core location in Bresse Basin within the West-European rift. *1* = tectonic rift; *2* = transform zone; *3* = transform direction; *4* = outcrop areas of Hercynian substratum (after Rat, 1984, modified).
B. Lithology of P & C core: *a* = calcareous; *b* = organic; *c* = shaly; *d* = silty; *e* = conglomeratic sediment (after Clair and Puisségur, *in*: Bachiri Taoufiq, 1988, modified).

sedimentation occurred between the late Miocene and the late Pliocene due to the Jura mountain folding in the east associated with the emergence of the basin. Post-folding sedimentation should have started again during the late Pliocene and continued during the Pleistocene.

Numerous cores containing Pliocene-Pleistocene sediments were taken in the entire basin and have been studied for sedimentology, geomorphology, palynology and palaeontology (Bonvalot et al., 1984). High-resolution biostratigraphical investigations of rodent, mollusc and pollen remains permit the development of a chronological sequence (Chaline, 1984; Puisségur, 1984; Farjanel, 1984, 1985). Good correlations based mainly on pollen and rodent assemblages (Chaline and Farjanel, 1990), are made with the North-European (Zagwijn, 1975) and Mediterranean (Combourieu-Nebout, 1987; Suc, 1982, 1984) chronologies that may have global significance.

The Beaune Pont-et-Chaussées (P & C) Record

Here we focus on the climatic signal provided by pollen analysis of the Beaune P & C borehole (47°2′ N and 4°53′ E) (Fig. 1B), which is climatically the most significant because he provides detailed record of Reuverian and Praetiglian phases. Moreover, sedimentological, molluscan and pollen analyses were performed on this core. The sediments, consisting of alternating fluviatile sands and gravels, silt, shale, peat and calcareous deposits, allow us to define the geodynamical framework of the basin in the Beaune area (Petit, 1988). Two mega-sequences have been defined which correspond to two different sedimentological dynamics. The lower one is mainly marked by calcareous and shaly deposits, the upper by detritical fluviatile ones (Fig. 1B). Fourteen sporopollenic assemblages were recognized (Bachiri Taoufiq, 1988; Méon et al., 1989) which gathered together into four main pollen zones according to the occurrence of dominant elements in the microflora (Fig. 2).

The first pollen zone BI is characterized by variations in the percentages of trees, mainly those of Abietaceae, *Pinus*. The rest of the arboreal strata comprises *Engelhardtia*, *Myrica*, *Carya*, Palmae, Taxodiaceae, Cupressaceae, and *Platycarya*. Herbaceous angiosperms mainly are Amaranthac-

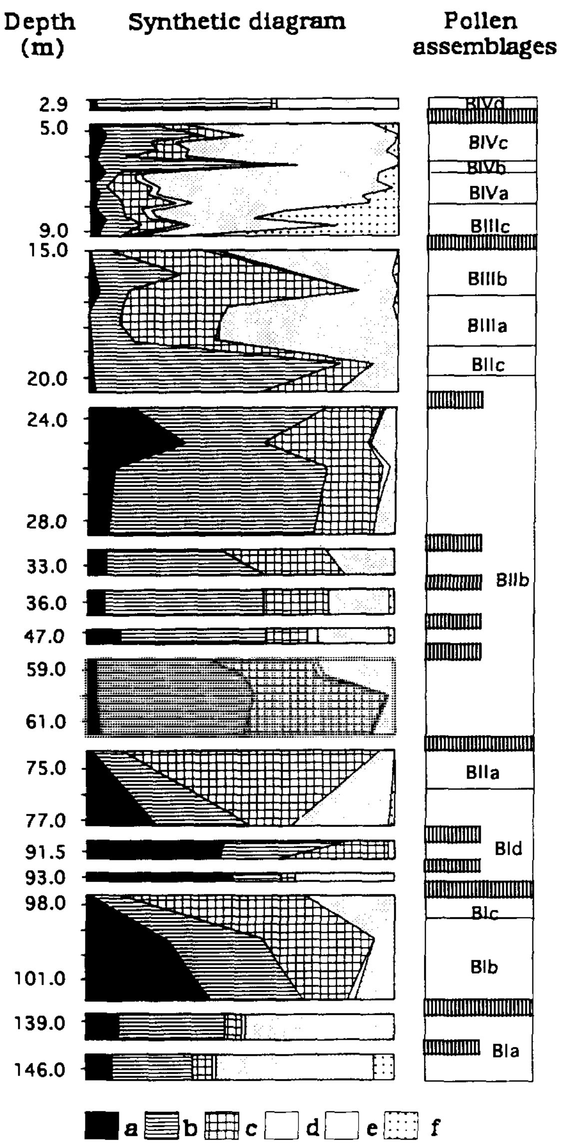

Fig. 2. Synthetic diagram of the Beaune P&C core. *a* = Taxodiaceae, Taxodiaceae-Cupressaceae, *Engelhardtia*, *Platycarya*, *Myrica*, Myrtaceae; *b* = *Carya*, *Pterocarya*, *Quercus*, *Fagus*, *Carpinus*, *Ulmus*, *Alnus*, *Acer*, *Tsuga* ...; *c* = *Pinus*, cf. *Cathaya*, cf. *Cedrus*,... Abietaceae; *d* = Taxa without precise ecological significance (Rosaceae, Plantaginaceae, Labiatae,...); *e* = aquatic plants, Cyperaceae, Gramineae, Compositae, Amaranthaceae-Chenopodiaceae, Caryophyllaceae, *Ephedra*; *f* = *Artemisia*. (after Bachiri Taoufiq, 1988, modified) The dashed zones correspond to barren sediments.

Four pollen zones are recognized noted BI, BII, BIII, and BIV. The indexes *a–d* correspond to the different primarily determined sproropollenic assemblages (total of fourteen) in the core.

eae-Chenopodiaceae. Four assemblages are defined (Fig. 2).

— BIa, dominance of Amaranthaceae-Chenopodiaceae.

— BIb, dominance of arboreal pollen,

— BIc, dominance of Abietaceae and decrease of *Engelhardtia*, and other trees except Salicaceae and *Ulmus*.

— BId, development of Taxodiaceae-Cupressaceae, *Myrica*, cf. *Olea*.

In the BI zone, the occurrence of thermophilous or mesophilous taxa indicates a warm climate in agreement with the associated molluscs (Méon et al., 1989).

The second zone, BII, shows the disappearance of *Engelhardtia*, *Platycarya* and Myrtaceae. The spectra indicate high percentages of Abietaceae (mainly *Pinus*), Quercus, *Ulmus*, *Fagus*, *Alnus*, *Carya* and *Pterocarya*. Three assemblages are defined (Fig. 2).

— BIIa, disappearance of *Engelhardtia*, but no re-appearance of *Quercus*.

— BIIb, appearance of *Fagus*, re-appearance of *Quercus*, *Carpinus*, *Betula* and *Pterocarya*, present in BIa. Deciduous trees are abundant and diverse.

— BIIc, large increase of *Alnus* and *Salix*, decrease of Abietaceae. *Fagus* disappears, as do *Carya* and *Pterocarya*.

In the BII zone, the climate is interpreted as being cooler than in the previous BI zone as indicated by the disappearance of the most thermophilous taxa.

The third zone, BIII, shows a clear increase in herbs, Gramineae, Cyperaceae, and *Artemisia*. Deciduous trees become rare. Three assemblages are defined (Fig. 2).

— BIIIa, herbaceous dominant with Gramineae and Cyperaceae

— BIIIb, herbaceous pollen are abundant but they are not always dominant.

— BIIIc, high percentages of *Artemisia* in the lower part.

In the BIII zone, the climate is interpreted to becoming progressively colder and drier.

The fourth zone, BIV, shows a progressive increase in arboreal pollen. Four assemblages are defined (Fig. 2).

— BIVa, herbs still dominate but *Artemisia* decreases.
— BIVb, large increase of *Alnus* and *Artemisia* disappears.
— BIVc, spectra quite similar to that of BIVa.
— BIVd, low percentages of Abietaceae, absence of Taxodiaceae, *Alnus, Carya*. Trees are only represented by *Carpinus*, *Corylus*, *Quercus* and *Myrica* which re-appears.

This sequence of palynological change is in agreement with that already defined by Farjanel (1985) and Jan du Chêne (1974) in the Bresse Basin, and by Zagwijn (1975) and Suc (1982, 1984) in northern and southern Europe, respectively. Molluscs assemblages in assemblages BIIIa and BIIIc to BIVd also indicate cool environments, in agreement with the pollen sequence (Méon et al., 1989). The dynamics in the succession of the assemblages appears to be complete, in particular in the upper part, so that correlations can be made with northern and southern reference stratigraphies (Bachiri Taoufiq, 1988; Méon et al., 1989). The sequence spans the time from the Brunssumian to Tiglian periods in agreement with the Zagwijn (1975) and Suc (1982, 1984) stratigraphies and will compensate the absence of palaeomagnetic record in this core. Consequently, zone BI is equivalent to the Brunssumian, BII Reuverian, BIII a and b Upper Reuverian, BIIIc lower Praetiglian, and BIV upper Pratiglian and lower Tiglian (Fig. 3).

Climate index

In evaluating climatic history from pollen data for periods when megamesothermic taxa are present, the use of transfer functions is not possible. Therefore we use the climatic derived index (*CI*) proposed by Kukla et al. (1981) to which these authors attribute a global significance.

Its calculation is simple because it includes few but nevertheless climatically significant data. Climatic cycles can be determined like the succession of interglacial to glacial periods. The former, i.e. warm and moist climatic phases, allowed arboreal vegetation to completely develop. During these phases, *Quercus* (*Q*) is one of the most significant trees. For the early Pliocene in the diagram, *Engelhardtia* (*E*) could be considered to have

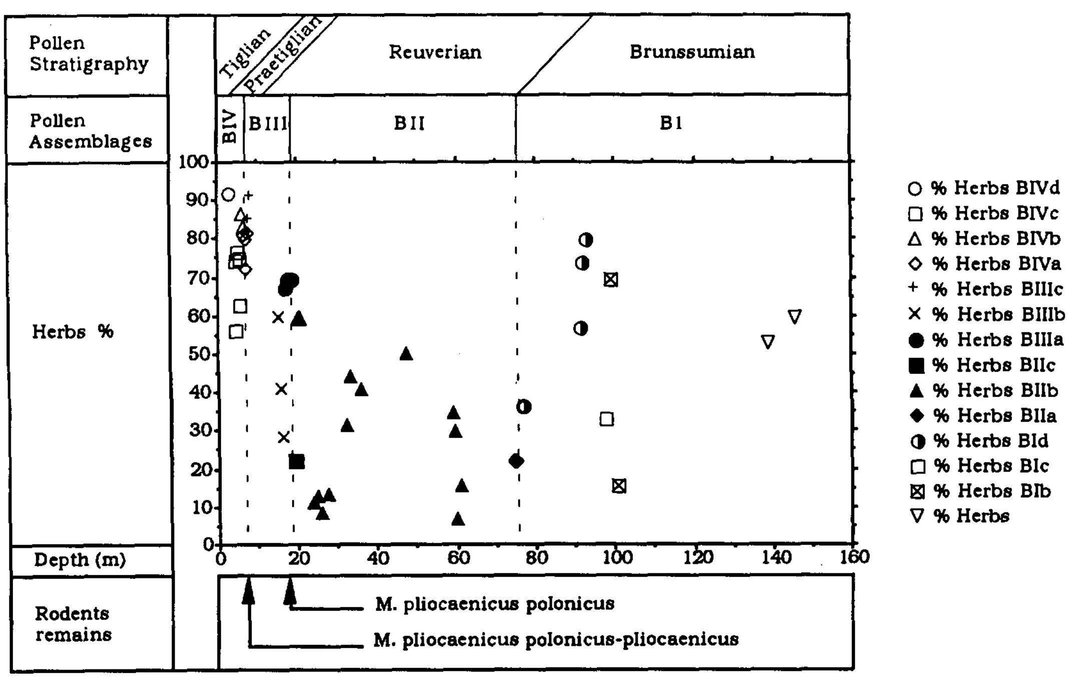

Fig. 3. Variations in herb pollen percentages against depth (in m) according to sporopollenic assemblages in European pollen stratigraphy. Location of rodent remains in the core. The different symbols correspond to the initial pollen groups determined by Bachiri Taoufiq (1988).

played this role. The later phases, in contrast, were extremely long and cold. This resulted in the disappearance of forest and its replacement by steppe vegetation. Thus, herbs characterize these periods. Finally, the transition between warm to very cold periods is the domain of the boreal forest which is characterized by *Pinus* (*P*).

In the mid northern latitudes, and particularly in Europe, most of the pollen analyses show that changes in the vegetation throughout the Quaternary roughly corresponded to alternating open environments, mainly with herbs, and forests where *Pinus and Quercus* dominated. This assumption was used to arbitrarily define the coefficient used for the calculation of the index. For the Beaune P & C core, the Climate Index was calculated as following: $CI = T + 2P + 4Q + 4E$ with $T=$ 100-herbs, *P*: *Pinus*, *Q*: *Quercus* and *E*: *Engelhardtia*. The different coefficients exaggerate the climatic signature of *Pinus* and Quercus, which never exceed 35% and 30% (Fig. 4). *Engelhardtia* may have played the same role as *Quercus* during the Brunssumian age (Lower Pliocene), and we assigned a similar coefficient to this taxon. The variations are bounded by 0. Values approaching zero reflect the climatic signal of a glaciation. The other extreme is 400, which characterizes warm periods of interglacial character during the late Pliocene and the Quaternary (Fig. 5).

Because of correlations between the Bresse pollen records and northern and southern European pollen stratigraphies, and since the limits of each pollen stage are palaeomagnetically dated (Suc and Zagwijn, 1983) the duration of each stratigraphical unit is interpolated by using a thickness-age ratio controlled by sedimentological and mollusc analyses in the Bresse basin (Petit, 1988, Puisségur, 1984) (Fig. 5). Although we recognize the problem of aliasing in the geological record (Pisias and Mix, 1988), only the results for the portion 2.2–2.8 myr B.P. are discussed in detail.

Results

By correlation with the precise pollen stratigraphy of western Europe (Suc and Zagwijn, 1983), the Brunssumian, as recorded in the Beaune core, does not provide numerous significant variations if one relies on the above method. The climatic

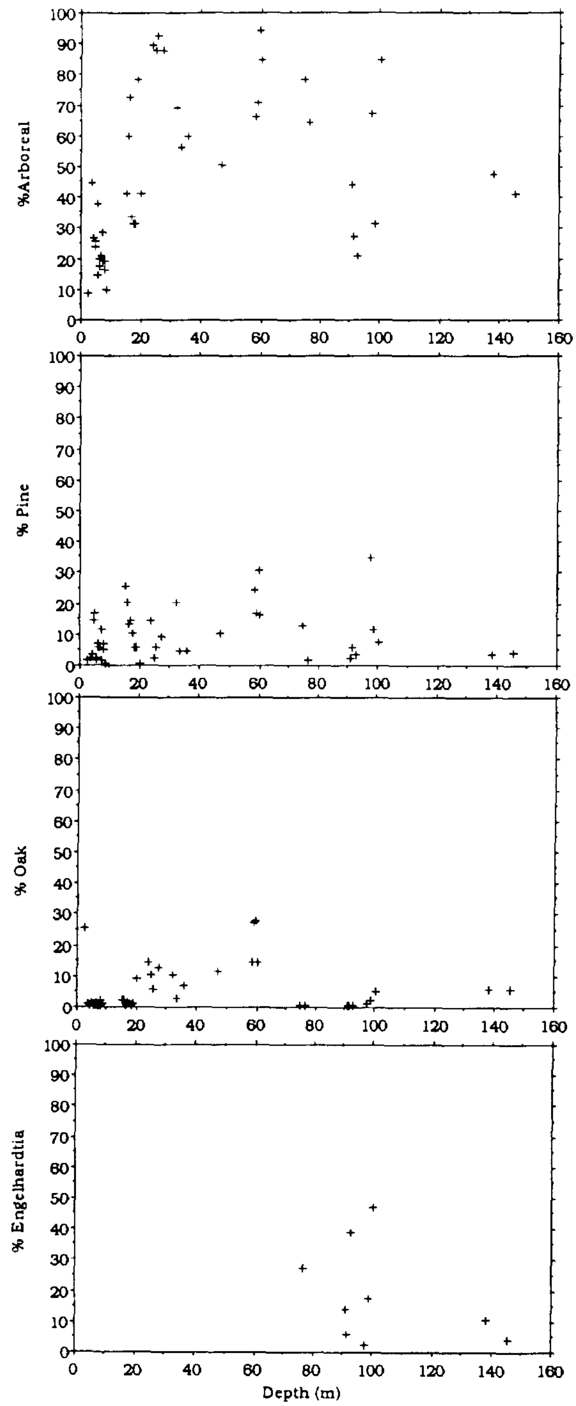

Fig. 4. Variations in total arboreal, *Pinus*, *Quercus* and *Engelhardtia* pollen percentages at the P & C Beaune core plotted against depth (in m).

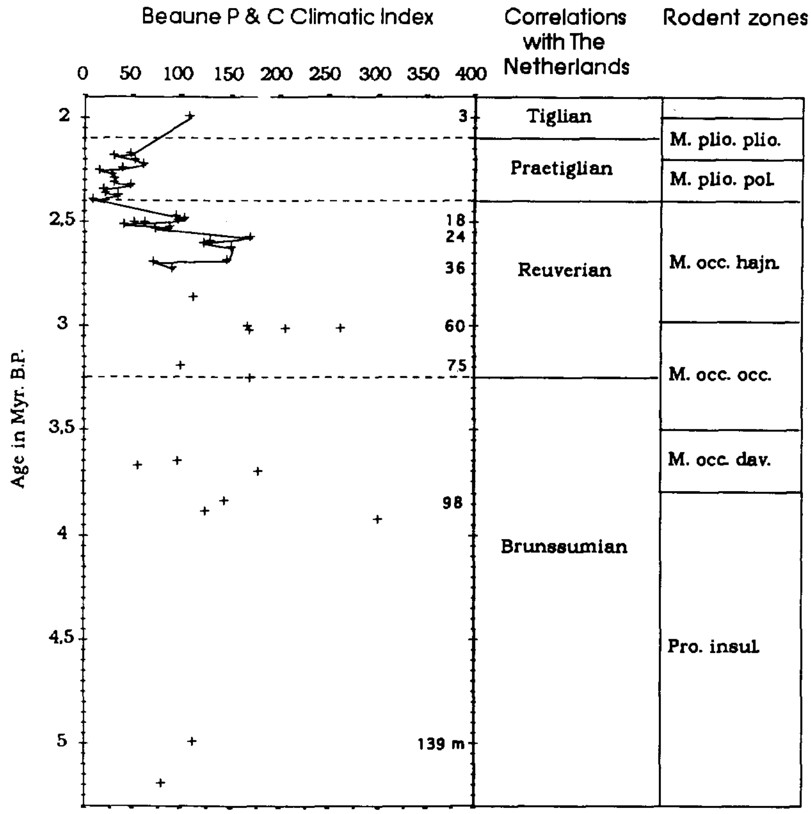

Fig. 5. Variations in Climatic derived Index (*CI*) at the P & C Core plotted against time and depth. Because of the poor preservation in the lower part of the core, the different calibrated levels were not joined up. The biostratigraphic scale is based on correlations between rodents and palynostratigraphy (after Chaline and Farjanel, 1990; Mein, 1990). *M. plio. plio.* = *Mimomys pliocaenicus pliocaenicus; M. plio. pol.* = *Mimomys pliocaenicus polonicus; M. occ. hajn.* = *Mimomys occitanus hajnackensis M. occ. occ.* = *Mimomys occitanus occitanus; M. occ. dav.* = *Mimomys occitanus davakosi; Pro. insul.* = *Promimomys insuliferus.*

signal, which is incomplete due to difficulties in sampling cannot be reconstructed more precisely up to the Reuverian (Upper Pliocene). Then the signal is not a linear one but it indicates three minima, with stronger cooling corresponding to younger intervals (Fig. 5). The maximum of cooling is indicated by the extensive development of the steppe formation, in which *Artemisia* is dominant. This record is important because it indicates the first development (Farjanel, 1984; Méon et al., 1989) of steppe vegetation during the Praetiglian in the Bresse Basin in agreement with north-European and Mediterranean data (Suc and Zagwijn, 1983). This cool event occurred throughout mid-low latitudes in Europe.

From pollen stratigraphy, Zagwijn (1992) concluded that the early Quaternary was initiated by a cold event which allowed steppe to develop over large parts of southern Europe. This cold episode, named the Praetiglian, is characterized in the Bresse area by the lack of thermophilous trees, the persistence of *Pinus*, *Betula* and *Alnus* and the high dominance of herbs, especially *Artemisia*. In the northwestern Mediterranean region, this episode is reflected by a pollen assemblage which indicates a diminishing amount of tree pollen and increasing percentages of Compositae, mainly of *Artemisia*. This cold episode is dated at 2.4–2.1 myr B.P., and began after the Gauss/Matuyama boundary (Combourieu-Nebout, 1987). This episode, according to Suc and Zagwijn (1983), and Zagwijn and Suc (1984), represents the earliest phase of a cold steppe formation in central and western Europe. This is corroborated by the first appearance of ground-squirrel (*Citellus polonicus*) and lemmings (*Synaptomys europaeus*) as well as by the development of vole lineages in Rebielice (Poland) (Chaline, 1973).

What does the Beaune core record (Fig. 5)? The lower part is not very informative because of the badly preserved fossils in the calcareous sediments. Two cold minima seem to occur at around 5.2 and 3.6 m.y. However, such an interpretation could be temperated for the first pollen spectra. Indeed they are rich in Amaranthaceae-Chenopodiaceae (more than 30%) which could correspond to an edaphic change resulting in littoral vegetation when the lowermost Pliocene marine transgression reached the Lyon area, which is 140 km south of Beaune. The intensity of this change is not important compared to the well known Late Pliocene and Quaternary glacial stages. A warm interval is distinguished by high percentages of *Engelhardtia* at about 3.9 m.y., which indicates forest development in warm and moist conditions.

A thermal maximum, in the lower Reuverian, at around 3 myr B.P., corresponds to high values of *Ouercus*, and low values of herbs. Tree pollen exceeds 90%, 30.5% for *Pinus*. After this warm climate optimum, the signal indicates changes in the climatic trend. Three minima are clearly defined at about 2.7, 2.5 and 2.4 myr B.P. respectively, with an increasing intensity at younger ages. These minima correspond to a decrease of arboreal pollen, as low as 9.5% in the coldest event correlative with the occurrence of *Artemisia* (Fig. 5).

Discussion

Is this continental record consistent with other ones on the globe? Indeed similar events in the other parts of the world agree with the main cold event at about 2.4 myr B.P. In North China, the Gauss/Matuyama boundary corresponds to the transition from a coniferous and broad-leaved mixed forest to steppe vegetation (Li and Wang, 1983). The pollen study from the Yanqing basin provides a similar result (Qian et al., 1983). Kukla's (1987) study of magnetic susceptibility of loess sequences in Central China also recognized this event which corresponds to the onset of the loess sedimentation on the loess plateau. In Africa, Durand (in Lang et al., 1990) recognizes this event as the onset of aeolian sedimentation in the Lake Tchad area, in agreement with pollen analyses from East Africa (Bonnefille, 1983; Bonnefille and Vincens, 1985). In Israel, Horowitz (1989) points to a major shift in pollen assemblages at 2.4 myr corresponding to lower temperatures and higher rainfall. In North and South America, this limit also corresponds to changes in the vegetation as revealed by pollen analyses in Tule Lake, California (Adam et al., 1989), and in the Bogota-Funza cores, Columbia (Hooghiemstra, 1989).

In addition to these findings in continental records, marine sediments provide data concerning this particular 2.4 myr B.P. event. The first important development of *Artemisia* occurred during the Praetiglian in the Crotone series (Combourieu-Nebout, 1990; Combourieu-Nebout and Vergnaud Grazzini, 1991). Data from several cores indicate that a strong cooling occurred at that time. DSDP sites 552 (Zimmerman et al., 1985), 606–609 (Ruddiman et al., 1987b) in the North Atlantic, 657–668 (Ruddiman et al., 1989) in the Eastern Tropical Atlantic, 522 and 523 (Weissert et al., 1984) in the South Atlantic, 576 and 578 (Janecek, 1985) in the Pacific Ocean, ODP sites 642–644 in the Norwegian Sea (Thiede et al., 1989) and 653 in the Tyrrhenian Sea (Rio et al., 1990), indicate that the onset of major ice build-up in the Northern Hemisphere took place at this time. This shift was characterized by a large change in the $\delta^{18}O$ and $\delta^{13}C$ values which occurs after the Gauss/Matuyama boundary dated at 2.47 myr B.P. A shift in the mode of eolian deposition from the Asian monsoon, determined from ODP site 721 and 722 in the Arabian Sea (deMonacal et al., 1991) may also associated with this event. Moreover in Atlantic as well as in Mediterranean sequences, the different isotopic curves show the occurrence of several minor peaks, like those of the Beaune P & C record, which correspond in the latter record to climatic pulses. These events indicate a progressive intensity of cooling from early to late Pliocene times. Moreover, recent pollen investigations of the Semaforo series in Italy (Combourieu-Nebout, 1990; Combourieu-Nebout and Vergnaud Grazzini, 1991) show that since 2.47 myr B.P., the vegetation changes clearly record real interglacial-glacial cycles that confirm once more that the climatic events occurring around 2.4 myr B.P. are well recorded in both marine and continental sediments. However, Jansen and Sjoholm (1991) found that glaciers were large enough to reach the sea level of the Norwegian Sea since already 5.5 myr B.P.

Conclusion

Several cooling events in the Beaune P&C core, of varying magnitude recognized between 3.2 and 2.1 myr B.P., are in agreement with marine, (Atlantic an Pacific Oceans, Mediterranean and Arabian), and continental records. Because they were defined in completely different ways and in different contexts, the correspondence between all these records implies their global value and indicate that the climatic changes may have occurred almost simultaneously in continental and marine environments. This global value thus supports Zagwijn's proposal for the definition of the Neogene-Quaternary boundary at 2.4 myr B.P., as claimed also by Chinese Quaternary stratigraphers, and could recommend a revision of the IUGS (International Union of Geological Sciences) official Pliocene-Pleistocene boundary at 1.66 myr B.P. (27th International Geological Congress Moscow, 1984).

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