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Continental climatic changes in Normandy (France) between 3.3 and 2.3 Myr B.P.

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Abstract

Pollen analysis of the La Londe sequence indicates that several environmental and climatic changes occurred during the interval between 3.3 and 2.3 Myr. The use of two pollen indices, the Climate Severity Index (CSI) and the Continental Biomass Index (CBI) permits the characterization of these changes. They illustrate significant climatic variations throughout the considered time interval. At the base of the record, the CSI indicates the occurrence of an important warming associated with an increase of the plant biomass. This event might be also associated with an important event recorded in Antarctica and in the Arctic ocean at the same time and increases in both oxygen and carbon isotope records from DSDP 552 A cores. A general cooling trend, punctuated by cold peaks leads to a major cooling at around 2.4 Myr, associated with low values of plant biomass.

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1. Introduction

Before the build up of the major North Hemisphere ice sheets between 2.6 and 2.4 Myr, climatic variations were mainly driven by Antarctic ice sheets oscillations (Raymo et al., 1987; Ruddiman et al., 1989; Weissert et al., 1984). Analyzing variations in $\delta^{18}O$ and $\delta^{13}C$ from both Atlantic and Pacific cores, Raymo et al. (1992) indicate that, between 3 and 2 Myr, an increase in the equator-to-pole temperate gradient associated with the onset of northern hemisphere glaciation did not intensify deep water production in the North Atlantic but rather the opposite occurred. So North Atlantic Deep Water (NADW) formation seems not to have been the fundamental driver of climatic changes as the theory of the conveyor belt of Broecker (1990) indicates for more recent intervals. Nevertheless, interpretations of DSDP 552 core records (Shackleton and Hall, 1985; Shackleton et al., 1984) indicate that NADW was also produced following the same process as today at around 3.5 Myr. Different Atlantic circulation could have consequently affected also NADW production, and then, because of the ocean–atmosphere heat exchanges, the surrounding continents. Analyzing a continental sequence covering the 3.3–2.3 Myr interval can then indicate how the continents recorded these important environmental changes. Our purpose is to focus on a continental record, located in Europe, that provides a continuous sequence of the late Pliocene.

2. The La Londe record

Besides the marine cores recovering the late Pliocene (between 3.5 and 2.4 Myr B.P.), few

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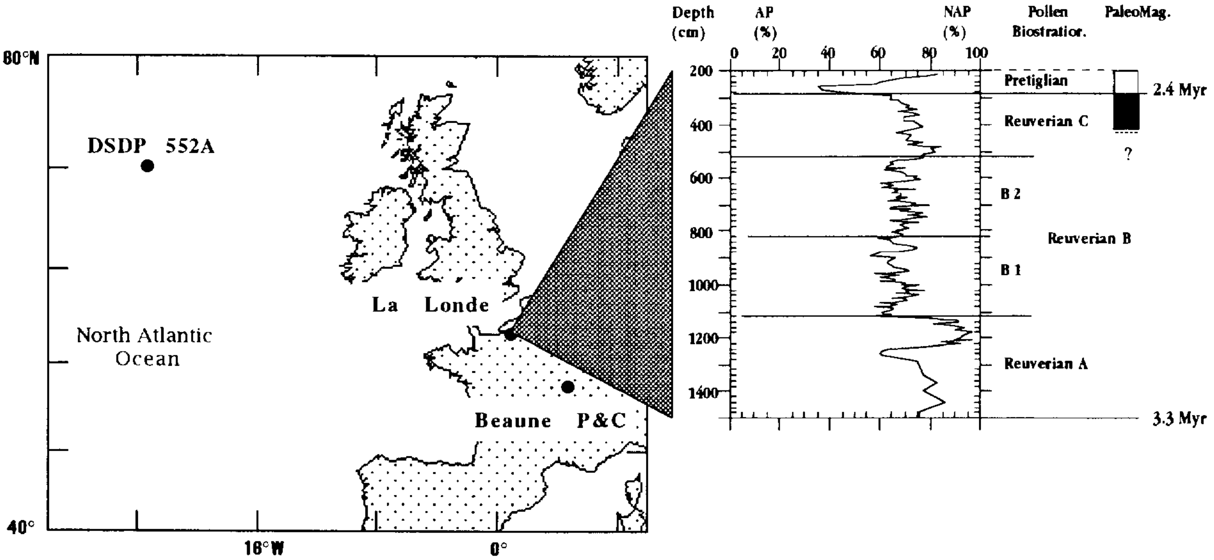


Fig. 1. Location of La Londe, Beaune P and C and DSDP 552A boreholes. Synthetic diagram of AP–NAP variations against depth. *Pinus* is included in the AP percentages (modified from Clet, 1983).

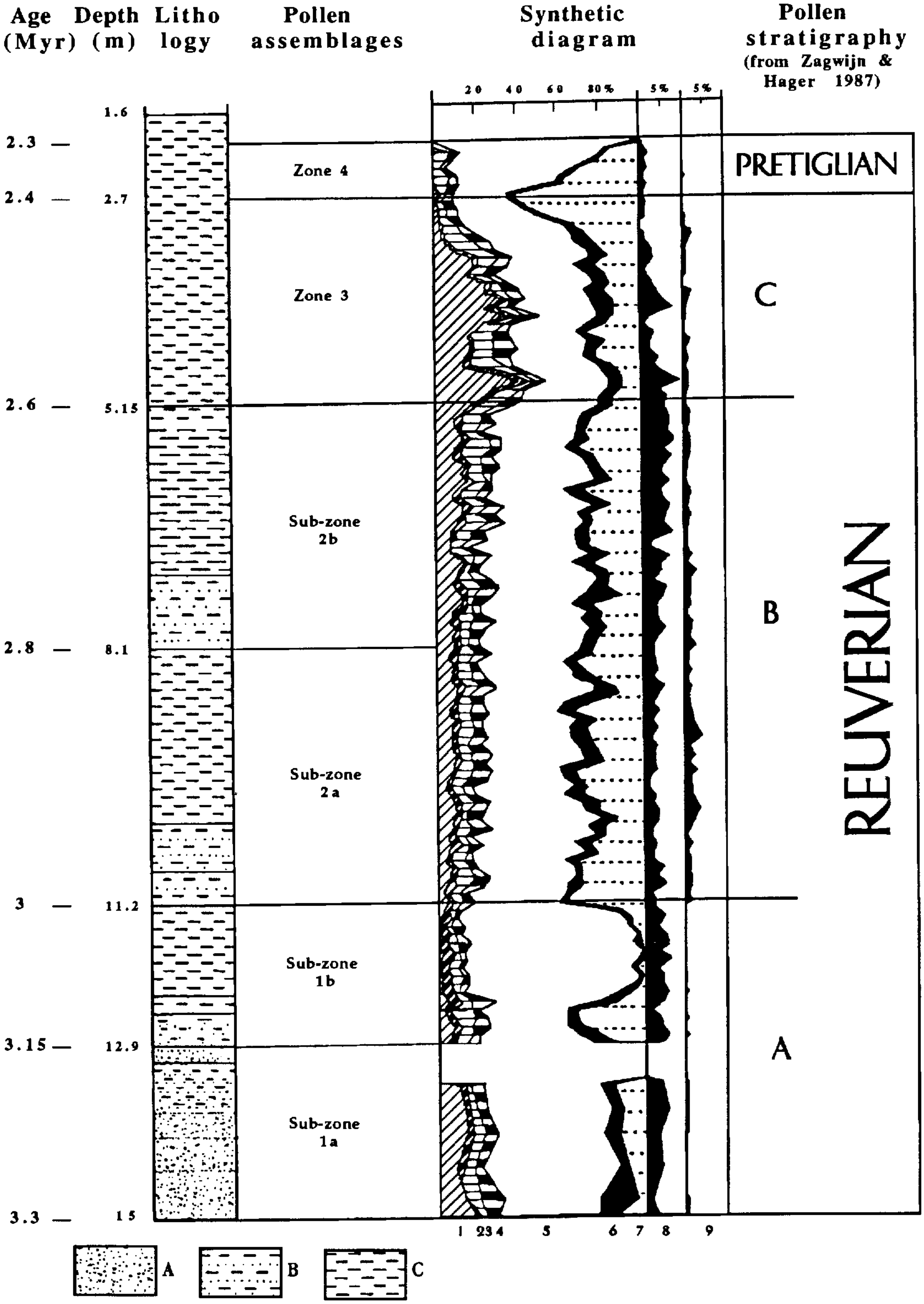
continental records show detailed reconstructions (Adam et al., 1989; Hooghiemstra, 1989; Horowitz, 1989). Among them, the La Londe sequence is located in Normandy, France, in the Seine valley at an elevation of 100 m (Fig. 1). The sediments of the studied sequence were trapped in a rift and consist mainly of silts and clays (Fig. 2). A borehole provided a 15 m thick stratigraphical sequence within the silt and clay sequence from which paleomagnetism studies determined that the top recorded the Gauss–Matuyama boundary (Biquand and Lautridou 1979). No other paleomagnetic events, such as the Kaena or Gilbert subchrons, were registered in the lower stratigraphy. Pollen analysis, however, determined four main zones (Clet, 1983; Clet and Huault, 1987). From the clay and shale sequence, 200 pollen samples were analyzed (Clet, 1983). A numerical zonation made on a data set corresponding to all the stratigraphical levels (one pollen spectrum for one stratigraphical level), using Goeury procedure (De Beaulieu and Goeury, 1987) confirms this biostratigraphy in four main pollen zones which groups several sub-zones.

2.1. Zone 1 (−15 to −11.2 m)

Sub-zone 1a : From the base of the core up to 12.9 m, the pollen content shows few variations at the bottom in the composition. The mean percentage of trees is relatively high. *Pinus sylvestris* type is the dominant species. *Sequoia* shows relatively important percentages at the base of the core, and *Sciadopitys* is often over 1%.

Sub-zone 1b: Between −12.9 and −11.2 m, the percentages of Ericaceae increase. Taxodiaceae and

Fig. 2. Lithology and synthetic pollen diagram of the La Londe core (after Clet 1983 modified). Lithology: *A* = sand; *B* = sandy clay; *C* = clay. Synthetic diagram 1, Tertiary taxa disappearing at the beginning of Pretiglian: Taxodiaceae, *Sequoia*, *Liquidambar*; 2, Tertiary taxa disappearing at the lower Pleistocene: *Carya*, *Pterocarya*, *Eucomia*, *Pinus haploxylon*, *Tsuga*, *Nyssa*, *Sciadopitys*, *Castanea*, *Juglans*; 3, *Alnus*; 4, *Corylus*, *Quercus*, *Tilia*, *Ulmus*, *Carpinus*, *Fraxinus*, *Ilex*, *Myrica*; 5, *Pinus sylvestris*, *Abies*, *Picea*, *Betula*, *Salix*, *Ephedra*, Cupressaceae; 6: Herbs; 7 Ericaceae; 8: curve of the sum *Abies*+*Picea*+*Tsuga*; 9: Chenopodiaceae. Four pollen zones are recognized noted L1, L2, L3, L4. The indices a–b correspond to the different primarily determined sporopollinic assemblages in the core. The biostratigraphy of the sequence is determined by comparison with Dutch pollen sequence of Zagwijn and Hager (1987).


Age (Myr)
Depth (m)
Lithology
Pollen assemblages
Synthetic diagram
Pollen stratigraphy (from Zagwijn & Hager 1987)
20 40 60 80%
5%
5%
2.3
2.4
2.6
2.8
3
3.15
3.3
1.6
2.7
5.15
8.1
11.2
12.9
15
Zone 4
Zone 3
Sub-zone 2b
Sub-zone 2a
Sub-zone 1b
Sub-zone 1a
PRETIGLIAN
C
B
A
REUVERIAN
1 234 5 6 7 8 9
A
B
C

thermophilous trees on the contrary decrease. Between −12.4 and −12.05 m, the Taxodiaceae and *Alnus* show a strong decrease, as do the Ericaceae. Between −12 and −11.2 m, an increase in *Pinus sylvestris* type occurs that reaches 75%.

2.2. Zone 2 (−11.2 to −5.15 m)

Sub-zone 2a (between −11.2 and −8.1 m): This zone is characterized by the progressive weak increase of the percentages of Taxodiaceae, thermophilous trees, and the decrease of *Pinus*. A climatic warming is clearly indicated. The occurrence of halophilous plants (the Chenopodiaceae curve becomes continuous and reaches its highest percentages between −10.2 and −8.1 m), and the occurrence of halophilous and euhalobous diatoms (Clet and Huault, 1987) indicate the presence of a high paleosalinity, and the proximity of a marine coast or an estuary.

Sub-zone 2b: Between −8.1 and −5.15 m, the pollen diagram still shows the persistence of Chenopodiaceae but with lower values. Between −6.9 and −6.3, the curves of *Alnus* and Taxodiaceae show a weak negative inflexion.

During zones 2a and 2b, the vegetation does not show major changes. The different species stay with identical percentages.

2.3. Zone 3 (−5.15 and −2.7 m)

During the interval between −5.15 and −4.25 m, the Tertiary species decrease in the pollen diagram, especially the Taxodiaceae that had important values between −5.25 and −4.8 m. Above −4.3 m, *Sequoia* indicates increasing values. Despite the decrease in the Taxodiaceae percentages after −4.8 m, their values remain higher than in the lower part of the record. However, the species indicating a moist environment decrease to the profit of species that prefer drier substratum, i.e. *Sequoia*, but which have their maximum development under a very moist climate. At −4.1 m, the Cupressaceae have a continuous representation.

2.4. Zone 4 (−2.7 to the top of the core)

The Taxodiaceae and *Sequoia* disappear. The curve of herbs increases and the percentages of Ericaceae strongly increase. Following a drying up of the environment, the Ericaceae increase, followed by an important increase of pine-trees that colonize again the environment. In this pine forest appear cold and dry taxa as *Hippophae* appear.

A comparison with the classical North European late Pliocene pollen biostratigraphy (Zagwijn and Hager, 1987) indicates that the La Londe sequence shows the continuous record of Reuverian (zones 1, 2 and 3) and early Pretiglian (zone 4) pollen stages (Clet, 1983; Clet and Huault, 1987). Taking into account the palaeomagnetic inversion on top of the sequence, and using the age of the base of the Reuverian pollen stage estimated at 3.3 Myr (Zagwijn and Hager, 1987) (Fig. 1), we assume that this continental sequence lasts the time interval between 3.3 and 2.3 Myr (Figs. 1 and 2).

3. Palaeoenvironmental indices

Interpreting pollen data in terms of climate reconstruction is classical for recent time intervals because of the use of quantitative methods (Guiot, 1990). For older intervals, such as late Pliocene, the reference to modern environments, and then climatic quantification are more difficult. Moreover, the percentage representation of AP–NAP is also not satisfying, because these groups, even if representing different types of vegetation, are not necessarily in phase with abrupt climatic changes (Magri, 1994; Magri and Follieri, 1992).

The climate severity index (CSI) (Kukla et al., 1981; Rousseau et al., 1992) is another way to reconstruct climatic changes through pollen data. It consists in grouping selected taxa in a simple index (CSI) which is characteristic for the geographic domain considered. CSI calculation is the following, $CSI = T + 2P + 4Q$, where T is % of trees, P is the % of pine, and Q % of oak. *Pinus, Quercus*, the selected taxa, show today a high climate indicative capacity (Grandjouan et al., 1993) in Europe implying that their use is climatically pertinent. In cold conditions CSI values are low while high in warm ones.

The different coefficients, 4, 2, and 1, respectively applied to these three sets, correspond to a geometric series defined to introduce a logarithmic scale, and consequently exaggerating the differences between boundary conditions. In cold conditions, CSI varies between 0 and 150, and on the contrary, during warmer conditions, the values tend to vary between 250 and 400. While summing up these different vegetal groups, one can at first sight be consider these as being non-logical. However, temperate conditions are mainly characterized by the expansion of forest environments under the European mid-latitudes. Taking into account *Quercus* percentage and giving it 4 as a coefficient will produce an exaggeration of its representation. In temperate conditions, if few herbs occur in the pollen diagram, then adding them to the tree values in the CSI calculation, will only imply slight difference compared to the lonely tree values. On the contrary, during cold conditions during which pollen diagram indicate grasslands, sometimes with few trees or shrubs, including the tree values in the CSI calculation will mark eventual interstadials that could occur in the series. What is also important to point out are the transition intervals between interglacial and glacial conditions that mainly are expressed by *Pinus* (P). This is the reason why 2 is used as a coefficient.

Such an attempt was already made for another European Pliocene pollen sequence (Rousseau et al., 1992, see this paper for the discussion of the selected taxa) that showed climatic variations over the Pliocene, with particular emphasis for the end of this period. We applied this index to the La Londe pollen data. We decided also to pay particular attention to the continental phytomass, expressed by the *CBI* index = AP/NAP ratio (Magri, 1994).

The *CBI* index is different from the classical AP–NAP representation of pollen data: in the AP–NAP diagram, the percentages of AP are considered with reference to 100%; in the CBI, the AP percentages are divided by the NAP percentages. So if AP = 60%, and consequently NAP = 40%, then *CBI* = 1.5 (Fig. 3).

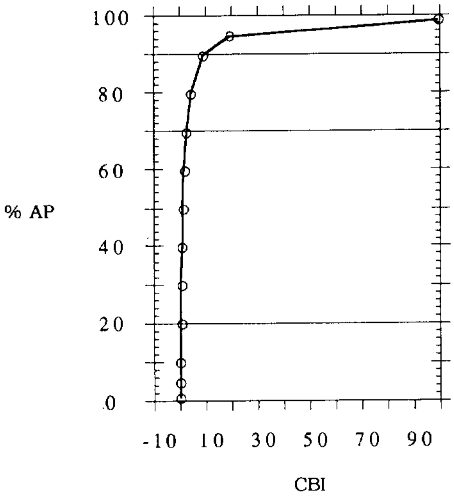


Fig. 3. Relationship between the percentage of arboreal taxa (AP) and the *CBI* (continental biomass index), corresponding to the AP/NAP ratio. Note that small increases in the AP percentages when these are higher than 70% imply important changes in the *CBI* values.

4. Results

Plot of *CSI* against time (Fig. 4) shows that the sequence recorded significant changes through time. After a cooling trend at the base, *CSI* varies between 210 to 130, an interval with high CSI values is centered at around 3.1 Myr (*CSI* = 260) (Fig. 4). Low values (*CSI* = 140) occurred just after this event, before 3 Myr. Then *CSI* values oscillate between 180 and 110 until around 2.4 Myr when a major cooling is well marked (*CSI* = 85). The oscillating values to the major cooling do not show any particular trend (Fig. 4). Such evolution in time differs from the oscillating trend punctuated by cold peaks of increasing negative magnitude described in another French pollen sequence, the Beaune P and C core, in the Bresse Basin (Fig. 1), located Southward from La Londe (Rousseau et al., 1992). In the Bresse record, a cooling trend is expressed between 2.7 and 2.4 Myr, with the occurrence of three *CSI* minima clearly defined at 2.7, 2. 6, 2.5 and 2.4 Myr B.P. respectively, showing an increasing intensity at younger ages.

The vegetation, through pollen spectra, recorded environmental changes. Increase (decrease) in indi-

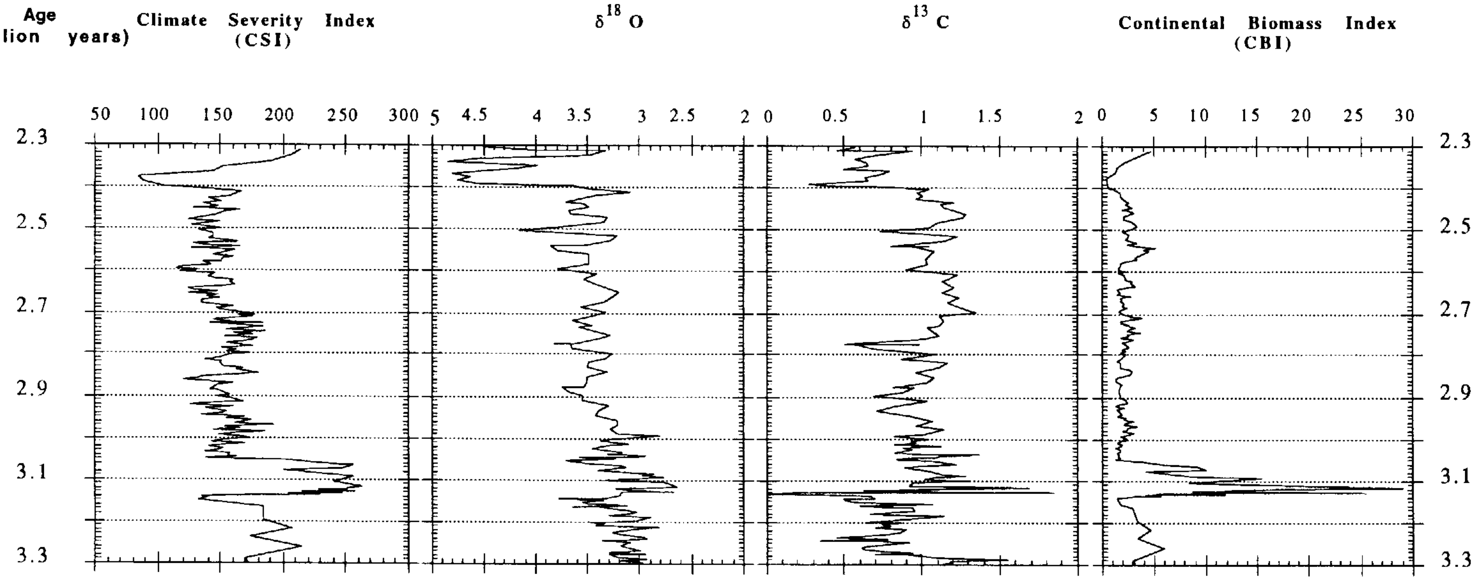


Fig. 4. Comparison between marine isotope ($\delta^{18}O$ and $\delta^{13}C$: from Shackleton and Hall, 1985, modified) and continental climate indices (*CSI*: climate severity index and *CBI*: continental biomass index—solid lines) through time. The two diagrams on the left show the relatively good agreement between the climate oscillations as reconstructed by *CSI* and those determined from variations in the oxygen isotope. The two diagrams on the right show the immediate response of the vegetation during transitions from glacial to interglacial conditions. *CBI* expresses variations in forest biomass following an exponential rate during the climatic transition as shown by Magri (1994), Magri and Follieri (1992). These rising variations of *CBI* are correlated with the important warming up of climatic conditions as determined by *CSI* values.

cators such as the *CBI*, during a determined interval, is supposed to represent variations in the forest biomass. Two main changes of the *CBI* are recorded in the La Londe record (Fig. 4). The first one occurred during the forest phase at around 3.1 Myr: *CBI* increases in an exponential way. Analyzing the long term exponential growth of plant populations in the Valle di Castiglione record near Rome, Magri (1989) indicates that under suitable conditions of temperature, moisture and light for the development of a given plant population, growth will depend on soil fertility. This, in turn, may increase as the population grows. Such a process thus produces in the long run an increase of phytomass and hence of the organic carbon stored in it. In the La Londe record, the second main change of *CBI* is found at around 2.4 Myr: in correspondence to a major cooling recorded by the *CSI*, there is an appreciable drop (Fig. 4). At the end of the record the forest biomass shows a new increase, parallel to a change of the *CSI* (Fig. 4).

According to the two indices used in this study, the La Londe sequence recorded two particular events, the first one, showing high values in *CBI* and *CSI*, at around 3.1 Myr that allows an increase in the biomass, and the second one, corresponding to the lowest values in *CBI* and *CSI*, at around 2.4 Myr that shows the strongest values in the biomass index and corresponds to an important cooling. Between these two events, the *CSI* shows oscillating values while the biomass indicator remains low, even if some small positive peaks can be noted which however do not characterize temperate conditions, but reflect better conditions after another cooling, i.e. the interval between 2.5 and 2.6 Myr. Moreover, the base of the sequence indicates cool conditions that deteriorated to a cold peak, just before the occurrence of the particular interval centered at around 3.1 Myr. This cooling trend is marked also by a decrease in the biomass indicator (Fig. 5).

5. Discussion

Since we recognized in the La Londe sequence records the complete north-European pollen biostratigraphy, indicating that it provides a continuous record of the late Pliocene, then the climatic variations that we observe might be observed in other records on the globe. No doubt should be raised about the final cooling in the La Londe sequence as an evidence of a global event recorded in both marine and continental environments (Adam et al., 1989; Bonnefille, 1983; Bonnefille and Vincens, 1985; Combourieu-Nebout, 1987, 1990; Combourieu-Nebout and Vergnaud Grazzini, 1991; De Menocal et al., 1991; Hooghiemstra, 1989; Horowitz, 1989; Janecek, 1985; Kukla, 1987; Lang et al., 1990; Li and Wang, 1983; Qian et al., 1983; Raymo et al., 1987, 1992; Rio et al., 1990; Rousseau et al., 1992; Ruddiman et al., 1987a–b; Ruddiman et al., 1989; Shackleton and Hall, 1985; Shackleton et al., 1984; Thiede et al., 1989; Weissert et al., 1984; Zimmerman et al., 1985). However, what status can be proposed to the particular interval indicating the highest values in both *CSI* and *CBI*? *Pinus* shows high percentages during this time span, i.e., around 100 kyr, while *Abies*, *Picea*, *Tsuga*, *Alnus* and *Corylus* indicate no trend. However, this interval corresponds also to a decrease in Taxodiaceae, *Sequoia* and *Nyssa* percentages on the one hand, and to decreasing values, or punctually a disappearance, of Ericaceae on the other hand. We do not know present analogues of such vegetal structure. We propose nevertheless such sporopollinic assemblages to characterize an environment occupied by gymnosperms and mesophilous taxa, an impoverished replicate of the Miocene coniferous and mesophilous-trees formations described by Bessedik (1985). A similar trend in *Pinus* percentages, was described in Reuverian A levels from the Lanrinou sequence, in Brittany, about 380 km west from La Londe (Morzadec-Kerfourn, 1982). In the Reuverian A of this sequence, *Pinus* percentages reach 80% of the total trees during a marine phase.

Investigations in Antarctica (Barrett et al., 1992) indicate evidence of warm conditions at around 3 Myr, which confirm that East Antarctica was affected by a strong deglaciation at that time. On the contrary, a controversial paper by Marchant et al. (1993) suggests continuous cold and dry

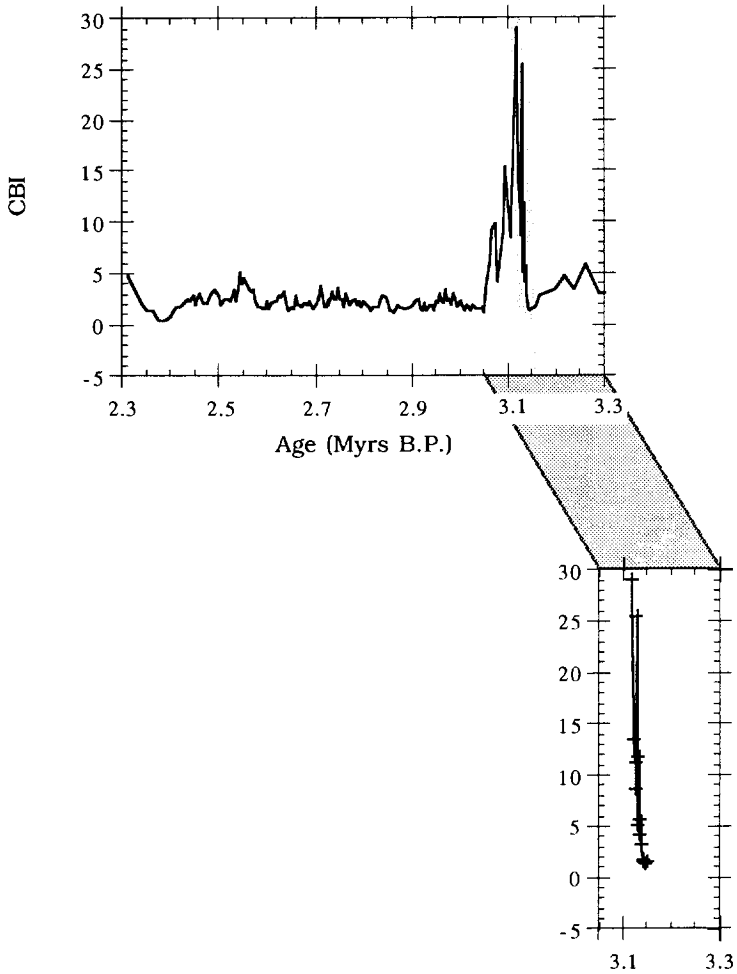


Fig. 5. Characterization of the exponential growth of the *CBI* at the onset of the "interglacial"-like event centered at 3.1 Myr.

climatic conditions for the last 4.3 Ma in the East-Antarctic ice-sheet. Cronin et al. (1993) indicate elevated water temperatures in the Arctic Ocean between 3.5 and 3.0 Myr suggesting warm ocean and adjacent continents at this time, associated with increased meridional heat flow towards North Atlantic. The Beaune P and C core records also a strong warming at around 3.1 Myr, especially marked by the highest values of *Quercus* (up to 30%) (Rousseau et al., 1992). Other European continental records show also a significant warming occurring at around 3.1 Myr and bordered by mild conditions (Zagwijn and Hager, 1987). Such observations are in agreement with the La Londe record and seem to confirm the warming event evidenced in Antarctica. The recognition of a similar continental signal in both the Northern and Southern Hemispheres indicates that this warming may have been intensive enough to have a global significance.

Moreover, the major climatic events recognized in the La Londe record indicating changes in climate (*CSI*) and plant biomass (*CBI*), also occur, for the climatic signal, in some marine records, although less marked. DSDP core 552 A, 56°02.56′N and 23°13.38′W, (Shackleton and Hall, 1985; Shackleton et al., 1984), in the North Atlantic, is located at a latitude that is roughly similar to that of the La Londe sequence. This open ocean sequence shows low $\delta^{18}O$ and high $\delta^{13}C$ values at around 3.1 Myr (Fig. 4). This could lead us to interpret the La Londe 100 kyr interval at the base as a warm one despite its particular vegetal composition. The return to cool conditions at the end of the interval with high *CSI* and *CBI* values in the continental sequence is correlative to an increase in bentic $\delta^{18}O$ values (Shackleton et al., 1984). This cooling also corresponds to Northern cold conditions that led to glaciation in Iceland (McDougall and H. Wensik, 1966) at around 3 Myr. Almost stable conditions occurred between 3 and 2.4 Myr as indicated in both marine and continental records (Fig. 4). The important cooling is marked at around 2.4 Myr by a significant increase in the $\delta^{18}O$ and a decrease in $\delta^{13}C$. *CSI* and *CBI* values (Fig. 4).

6. Conclusion

The climatic interpretations of the La Londe record are in strong agreement with different records from marine and continental environments, from both hemispheres.

The cooling trend, indicated after an almost 100 kyr interval of high values in both *CSI* and *CBI*, centered at around 3.1 Myr, appears to be in relatively good agreement with the variations in both the bentic $\delta^{18}O$ and $\delta^{13}C$ from Atlantic and Pacific records that Raymo et al. (1992) interpreted as indicating that the global cooling over this interval was associated with increasing suppression of NADW formation. We propose also to correlate the climatic events recognized at the base of the La Londe record with fluctuations in the expansion of ice, in both Antarctica and the Artic ocean, which would have influenced the NADW production rate. During this time interval, before 2.4 Myr, only Antarctica should have showed a significant ice body (Ruddiman et al., 1989) while the Arctic ocean did not present any perennial sea ice cover prior to 2.4 Myr (Raymo et al., 1992; Cronin et al., 1993). The occurrence of warmer sea surface temperature at around 3.1 Myr in the Arctic ocean implies that it was seasonally ice free at this time inducing an increase in the NADW production rate.

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References

Adam, D.P., Sarna-Wojcicki, A.M., Rieck, H.J., Bradbury, J.P., Dean, W.E. and Forester, R.M., 1989. Tulelake, California: the last 3 million years. Palaeogeogr. Palaeoclimatol. Palaeoecol., 72: 89–103.

Barrett, P.J., Adams, C.J., McIntosh, W.C., Swisher, C.C. and Wilson, G.S., 1992. Geochronological evidence supporting Antarctic deglaciation three million year ago. Nature, 359: 816–818.

Beaulieu, J.L. de and Goeury, C., 1987. Zonation automatique appliquée à l'analyse pollinique: exemple de la Narse d'Ampoix (Puys de Dôme, France). Bull. Assoc. Fr. Et. Quat., 29: 49–61.

Bessedik, M., 1985. Reconstitution des environnements miocènes des régions nord-ouest méditerranéennes à partir de la palynologie. Thesis. Univ. Sci. Tech. Languedoc, Montpellier, 162 pp.

Biquand, D. and Lautridou, J.P., 1979. Détermination de la polarité magnétique des loess et sables pléistocènes de Haute-Normandie: premiers résultats. Bull. Assoc. Fr. Quat., 42–43: 75–81.

Bonnefille, R., 1983. Evidence for a cooler and drier climate in the Ethiopian uplands towards 2.5 Myr ago. Nature, 303: 487–491.

Bonnefille, R. and Vincens, A., 1985. Apport de la palynologie à l'environnement des Hominidés d'Afrique orientale. In: L'environnement des Hominidés au Plio-Pléistocène. Masson, Paris, pp. 237–278.

Broecker, W.S., 1990. Salinity history of the northern Atlantic during the last deglaciation. Paleoceanography, 5: 459–467.

Clet, M., 1983. Le Plio-Pléistocène en Normandie: apports de la palynologie. Thesis. Univ. Caen, 135 pp.

Clet, M. and Huault, M.F., 1987. Les dépôts lagunaires du reuvérien dans les argiles de La Londe (Normandie, France). Bull. Assoc. Fr. Quat., 32: 195–202.

Combourieu-Nebout, N., 1987. Place de la première glaciation boréale vis-à-vis de la limite Plio-Pléistocène en Méditerranée.

Analyse du Pliocène de Semaforo (Crotone, Italie). C. R. Acad. Sci. Paris, 304 (Ser. 2): 533–538.

Combourieu-Nebout, N., 1990. Les cycles glaciaire–interglaciaire en région méditerranéenne de −2.4 à −1.1 Ma: analyse pollinique de la série de Cotone (Italie méridionale). Paléobiol. Cont., 17: 35–59.

Combourieu-Nebout, N. and Vergnaud Grazzini, C., 1991. Late Pliocene Northern Hemisphere glaciations: The continental and marine responses in the Central Mediterranean. Quat. Sci. Rev., 10: 319–334.

Cronin, T.M., Whatley, R., Wood, A., Tsukagoshi, A., Ikeya, N., Brouwers, E.M. and Briggs, W.M., 1993. Microfaunal evidence for elevated Pliocene temperatures in the Artic Ocean. Paleoceanography, 8: 161–173.

DeMenocal, P., Bloemendal, J. and King, J., 1991. A rock-magnetic record of monsoonal dust deposition to the Arabian sea: evidence for a shift in the mode of deposition at 2.4 Ma. In: W.L. Prell, N. Niitsuma et al., Proc. ODP Sci. Res., 117: 389–407.

Grandjouan, G., Cour, P. and Gros, R., 1993. Climatic calibration of 80 aeropollinic taxa along a European transect. Vegetatio, 109: 107–124.

Guiot, J., 1990. Methodology of the last climatic cycle reconstruction from pollen data. Palaeogeogr. Palaeoclimatol. Palaeoecol., 80: 49–69

Hooghiemstra, H., 1989. Quaternary and upper-Pliocene glaciations and forest development in the tropical andes: evidence from a long high-resolution pollen record from the sedimentary basin of Bogotá, Colombia. Palaeogeogr., Palaeoclimatol., Palaeoecol., 72: 11–26.

Horowitz, A., 1989. Continuous pollen diagrams for the last 3.5 m.y. from Israel: vegetation, climate and correlation with the oxygen isotope record. Palaeogeogr. Palaeoclimatol. Palaeoecol., 72: 63–78.

Janecek, T.R., 1985. Eolian sedimentation in the northwest Pacific Ocean: a preliminary examination of the data from Deep Sea Drilling Project sites 576 and 548. In: G.R. Heath, L.H. Burckle et al. Init. Rep., DSDP: 86: 589–603.

Kukla, G., 1987. Loess stratigraphy in central China. Quat. Sci. Rev., 6: 191–219.

Kukla, G., Berger, A., Lotti, R. and Brown, J., 1981. Orbital signature of interglacials. Nature, 290: 295–300.

Lang, J., Kogbe, C., Alidou, S., Alzouma, K.A., Bellion, G., Dubois, D., Durand, A., Guiraud, R., Houessou, A., Romann, E., Salard-Cheboldaeff, M. and Trichet, J., 1990. The Continental Terminal in West Africa. J. Afr. Earth Sci., 10: 79–99.

Li, H.M. and Wang, J.D., 1983. Palaeomagnetic study on drill core from northern Bohai coastal plain. Geochimica, 2: 196–204 (in Chinese with English abstract).

McDougall, I. and Wensik, H., 1966. Paleomagnetism and geochronology of the Pliocene–Pleistocene lavas in Iceland. Earth Planet. Sci. Lett., 1: 232–236.

Magri, D., 1989. Interpreting long-term exponential growth of plant populations in a 250 000-year pollen record from Valle di Castiglione (Roma). New Phytol., 112: 123–128.

Magri, D., 1994. Late-Quaternary changes of plant biomass as recorded by pollen-stratigraphical data: a discussion of the problem at Valle di Castiglione, Italy. Rev. Palaeobot. Palynol., 81: 311–323.

Magri, D. and Follieri, M. 1992. Transitions from interglacial to glacial in the pollen record from Valle di Castiglione (Roma). In: G. Kukla and E. Went (Editors), Start of a Glacial. Springer, Berlin, pp. 23–36.

Marchant, D.R., Swisher, C.C., Luw, D.R., West, D.P. and Denton G.H., 1993. Pliocene paleoclimate and East Antactic ice-sheet history from surficial ash deposits. Science, 260: 667–670.

Morzadec-kerfourn, M.T., 1982. Datation pollinique et conditions de sédimentation de l'argile plio-pléistocène de Lanrinou en Landernau (Finistère, France). Bull. Assoc. Fr. Quat., 12: 179–184.

Qian, F., Ma, X.H. and Wu, X.H., 1983. Preliminary study on the Quaternary magnetic stratigraphy of China. Mar. Geol. Quat. Geol., 3: 17–29 (in Chinese with English abstract).

Raymo, M.E., Hodell, D. and Jansen, E., 1992. Response of deep ocean circulation to initiation of northern hemisphere glaciation (3–2 Ma). Paleoceanography, 7: 645–672.

Raymo, M.E., Ruddiman, W.F. and Clement, B.M., 1987. Pliocene–Pleistocene paleoceanography of the North Atlantic at Deep Sea Drilling Project site 609. In: W.F. Ruddiman, R.B. Kidd, E. Thomas et al., Init. Rep. DSDP, 94: 895–901.

Rousseau, D.D., Bachiri Taoufiq, N., Petit, C., Farjanel, G., Méon, H. and Puisségur, J.J., 1992. Continental late Pliocene paleoclimatic history recorded in the Bresse Basin (France). Palaeogeogr. Palaeoclimatol. Palaeoecol., 95: 253–261.

Rio, D., Sprovieri, R., Thunell, R., Vergnaud Grazzini, C. and Glaçon, G. 1990. Pliocene–Pleistocene paleoenvironmental history of the Western Mediterranean: a synthesis of ODP site 653 results. In: K.A. Kastens, J. Mascle et al., Proc. ODP Sci. Res., 107: 695–704.

Ruddiman, W.F., Backman, J., Baldauf, J., Hooper, P., Keigwin, L., Miller, K., Raymo, M. and Thomas, E., 1987. Leg 94 paleoenvironmental synthesis. In: W.F. Ruddiman, R.B. Kidd, E. Thomas et al., Init. Rep. DSDP, 94: 1207–1215.

Ruddiman, W.F., McIntyre, A. and Raymo, M., 1987b. Paleoenvironmental results from North Atlantic sites 607 and 609. In: W.F. Ruddiman, R.B. Kidd, E. Thomas et al., Init. Rep. DSDP, 94: 855–878.

Ruddiman, W.F., Sarnthein, J., Backman, J., Baldauf, J., Curry, W., Dupont, L.M., Janecek, T., Pokras, E.M., Raymo, M.E., Stabell, B., Stein, R. and Tiedemann, R., 1989. Late Miocene to Pleistocene evolution of climate in Africa and the low-latitude Atlantic: overview of Leg 108 results. In: W. Ruddiman, M. Sarnthein et al., Proc. ODP Sci. Res., 108: 463–484.

Shackleton, N.J., Backman, J., Zimmerman, H.B., Kent, D.V., Hall, A. and Roberts, D.G., 1984. Oxygen isotope calibration of the onset of ice-rafting and history of glaciation in the North Atlantic region. Nature, 307: 620–623.

Shackleton, N.J. and Hall, M.A., 1985. Oxygen and isotope stratigraphy of deep sea drilling project hole 552A: Plio-

Pleistocene glacial history. In: D.G. Roberts, D. Schnitker et al., Init. Rep. DSDP, 81: 599–609.

Thiede, J., Eldholm, O. and Taylor, E. 1989. Variability of Cenozoic Norwegian–Greenland Sea paleoceanography and Northern Hemisphere paleoclimate. In: O. Eldholm, J. Thiede, E. Taylor et al., Proc. ODP Sci. Res., 104: 1067–1118.

Weissert, H.J., McKenzie, J.A., Wright, R.C., Clark, M., Oberhänsli, H. and Casey, M., 1984. Paleoclimatic record of the Pliocene at Deep Sea Drilling Project sites 519, 521, 522 and 523 (Central South Atlantic). In: K.J. Hsü, J.L. LaBrecque et al. Init. Rep. DSDP, 73: 701–715.

Zagwijn, W.H. and Hager, H. 1987. Correlations of continental and marine Neogene deposits in the south-eastern Netherlands and the lower Rhine district. Meded. Werkgr. Tert. Kwart. Geol., 24: 59–78.