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Minor changes in surface-water fertility across the oceanic anoxic event 1d (latest Albian, SE France) evidenced by calcareous nannofossils

Received: 1 August 2001 / Accepted: 9 February 2003 / Published online: 10 April 2003
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Abstract The latest Albian sediments deposited in the Vocontian basin in south-eastern France record the oceanic anoxic event (OAE) 1d, locally named the Breistroffer interval. They are represented by argillaceous marls and marls, containing organic matter (total organic carbon varying from 0.8 to 1%). Changes in calcareous nannofossil abundance and assemblage composition as well as macrofauna abundance, ichnofossil assemblage, and bioturbation intensity were analysed in order to evaluate the main palaeoenvironmental factors controlling the deposition of the OAE 1d sediments in this area. The pelagic carbonate production is limited and the carbonate fraction is predominantly of nektonic/benthic, and of allochthonous origin from carbonate platforms. The enrichment in organic carbon within the Breistroffer interval is weak and not associated with high surface-water productivity. The organic matter is mainly terrigenous. Its record is due to (1) a good preservation under dysoxic conditions within the sediments, and (2) a weak input of allochthonous carbonates. Eustatic fluctuations strongly influenced the variations of nannofossil and macrofauna abundances. Distinctive patterns in nannofossil assemblages and macrofauna abundances within the Breistroffer interval are also recognized, reflecting changes from mesotrophic to more oligotrophic conditions which are probably controlled by climate.

Electronic Supplementary Material Supplementary material is available for this article if you access the article at <http://dx.doi.org/10.1007/s00531-003-0319-x>. A link in the frame on the left on that page takes you directly to the supplementary material.

Keywords Latest Albian · OAE1d · Vocontian basin · Calcareous nannoplankton productivity · Carbonate/organic matter production · Macrofauna · Ichnofauna

Introduction

The oceanic anoxic event (OAE) 1d (latest Albian), characterized by organic carbon-rich deposits, was recently recognized as a significant interval of enhanced C_{org} burial for the Cretaceous period (Wilson and Norris 2001). The black-shale deposition and elevated carbon burial are attributed to an increase in surface-water productivity (Erbacher et al. 1996; Hofmann et al. 2000) due to an intensified vertical mixing of the water column (Wilson et al. 1999; Wilson and Norris 2001). However, the palaeoceanographic reconstructions of the OAE 1d are essentially based on geochemical and biological data from the North Atlantic (Erbacher et al. 1996; Hofmann et al. 2000; Wilson and Norris 2001). In particular, the global anoxia invoked by Wilson and Norris (2001) is in contradiction with the observations of other authors. Hofmann et al. (2000) recognized a clear separation during the late Albian into an anoxic part of the North Atlantic ocean along the eastern part off the coast of North Africa with the highest accumulation of organic matter, and a mostly oxic western part. This is also well demonstrated by the analysis of benthic foraminiferal assemblages by Holbourn et al. (2001) showing a productive belt and associated enhanced carbon flux export to the seafloor around the north-western African margin, which has been identified as a zone of vigorous coastal upwelling. In the eastern North Atlantic (DSDP Site 547), Nederbragt et al. (2001) recognized a major

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faunal turnover in planktonic Foraminifera but minor and gradual changes in nannofossil assemblage composition, and little changes in benthic foraminiferal assemblages across this event. They argued against a major change in surface-water productivity. In the eastern Tethys (south-eastern France, Br  h  ret 1988; Basque-Cantabrian Basin, northern Spain, Lopez-Horgue et al. 1999), the OAE 1d is characterized by sediments which are only slightly enriched in organic matter (total organic carbon content $\leq 2\%$). Holbourn et al. (2001) show that benthic foraminiferal assemblages from different onshore sections (Breggia area in Switzerland; Subbetic of southern Spain, and Vocontian basin in south-eastern France) reflect well-oxygenated, oligotrophic environments with a reduced carbon flux at the seafloor. The discrepancies existing in the literature concerning this event are evidence that, to improve our understanding of the OAE 1d formation, detailed multidisciplinary quantitative analyses in different locations are necessary.

This work aims to evaluate the main palaeoenvironmental factors controlling the deposition of the OAE 1d sediments in a poorly studied area, the Vocontian basin in south-eastern France. We analyse nannofossil assemblages for the plankton, macrofauna (ammonoid and benthos) abundances and ichnofacies, compared to carbonate and total organic carbon (TOC) contents. Our results will be integrated in a regional–global context.

Geological setting

The OAE 1d, named the Breistroffer interval in south-eastern France (Br  h  ret 1988), was investigated near Blioux (Alpes de Haute Provence), which is located at the southern margin of the Vocontian basin (Fig. 1). Because of the relatively proximal position of the Blioux section, the Breistroffer interval is devoid of the typical laminated black-shale horizons observed in the central part of the Vocontian basin (Br  h  ret 1997). However, the section studied is palaeogeographically located in a key position to record palaeoenvironmental changes both affecting proximal areas (platform environments) and the pelagic realm (open marine).

The Vocontian basin is a hemipelagic intrashelf basin of the European Tethyan passive margin. During the Albian, the tectonic regime in the south-eastern France basin was extensive with strike-slip movements. The Vocontian basin became a pull-apart basin marking the transition between the Bay of Biscay/Pyrenean rift in the SW and the Valaisan domain in the NE (Ferry and Rubino 1989). During the Albian, an uplift of all the basin margins occurred. This uplift was responsible for the emergence of the Durance Isthmus (Masse and Philip 1976; Fig. 1). Consequently, a strong differential subsidence occurred between the Provence shelf and the basin, and an increasing exposure of the hinterland enhanced terrigenous sediment supply to the Vocontian basin. The carbonate shelves surrounding the Vocontian basin are characterized by low accumulation rate, and carbonate

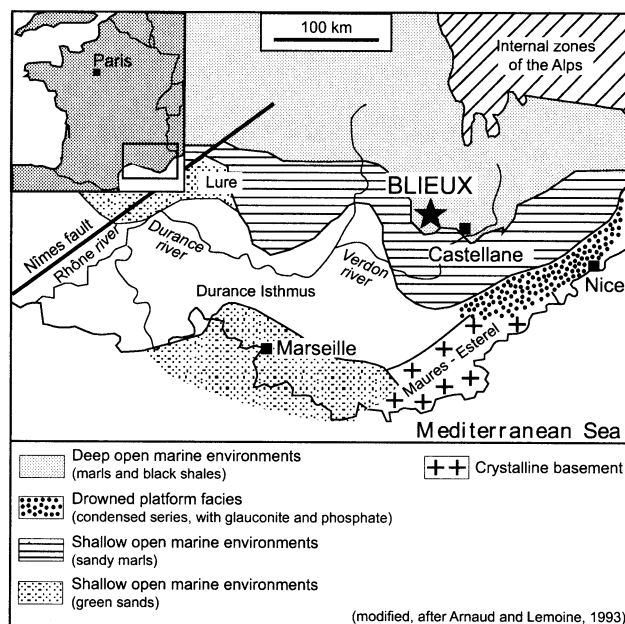


Fig. 1 Palaeogeographic map of the investigated area with location of the Blioux section

production by benthic organisms decreased while a siliciclastic regime became installed (Ferry and Rubino 1989). This period of severe platform crisis is recognized in different shallow settings in the Tethys, the Pacific and the Atlantic oceans, and indicates a sea-level rise of high amplitude in the late Albian *Rotalipora appenninica* Zone. Following this rise, black-shale deposits are recorded in the Vocontian basin (Breistroffer interval), the Atlantic Ocean and Canada (Gr  tsch et al. 1993).

The Aptian–Albian interval of the Vocontian basin is characterized by a thick marly sequence of the Marnes Bleues Formation, consisting of about 800 m of rather homogeneous, greyish dark-blue marls and shales. Nine laminated horizons containing 1 to 2% TOC have been identified in the 30-m-thick latest Albian Breistroffer interval of the Vocontian basin (Br  h  ret 1988).

The 88-m-thick Blioux section (Fig. 2) belongs to a continuous succession of nearly 500 m of sediments consisting of late Albian bioturbated marls, below the

Fig. 2 Carbonate and TOC contents, HI, trace fossils distribution, macrofauna abundances. Calcareous nannofossil total abundance, preservation, species richness, diversity and evenness plotted against lithology, ammonite, nannofossil and planktonic foraminiferal zones and events in the upper Albian Blioux succession. Ammonite biostratigraphy after this study, nannofossil zonation after Br  h  ret (1997), and planktonic foraminiferal zonation combined from Cotillon (1971) and Br  h  ret (1997). The position of samples studied for carbonate, total organic carbon contents, calcareous nannofossils, and macrofauna are reported. See text for explanation of ichnoassemblage A and ichnoassemblage B; the length of the *horizontal bars* corresponds to the relative abundance of the ichnofossils, from rare to common. Classes of nannofossil preservation: class 3 (bad preservation); class 4 (moderate preservation); classes 5 and 6 (good preservation)

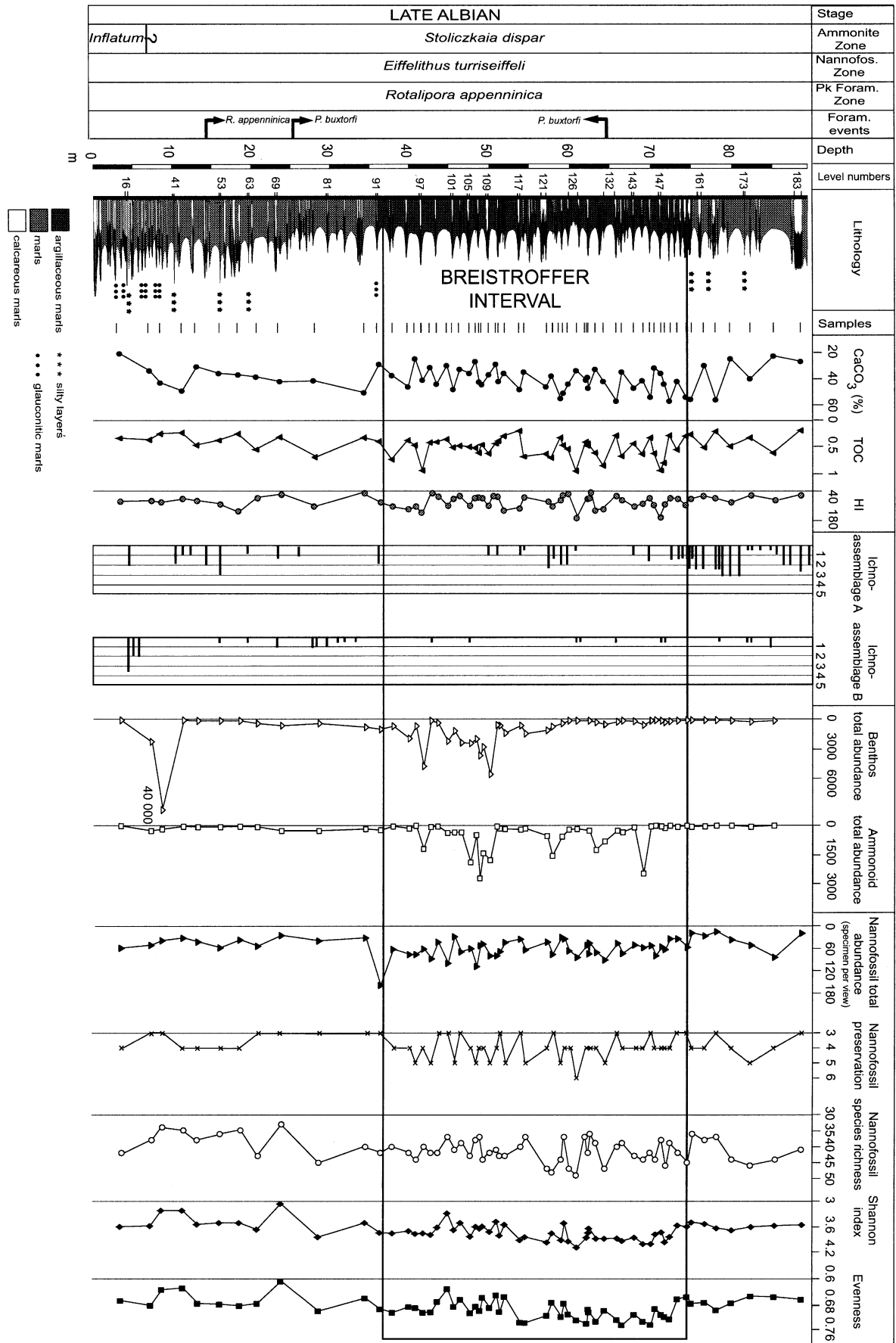




Fig. 3 Photograph of the Breistroffer interval in the Blieux section

Breistroffer interval, to mid-Cenomanian alternations of marly limestones and marls. The lower part of the studied succession is constituted by 20 m of alternating silty calcareous beds and marls. Upwards of the section, the succession becomes more marly and is capped by a silty layer rich in glauconite grains (level 91; Fig. 2). This glauconitic bed, which can be correlated at a regional scale (Bréhéret 1997), marks the beginning of the Breistroffer interval. The latter consists of 35 m of dark argillaceous marls alternating with thin, centimetric gray marls (Fig. 3). The Breistroffer interval contains abundant and diverse macrofossils including ammonoids, echinoderms, inoceramids and aucellines. The latter become sometimes abundant, thus forming the *Aucellina* beds. As already described by Cotillon (1971), Blieux is one of the rare outcrops of this interval where ammonoids are abundant and diverse. The Breistroffer interval is capped by silty marls in which coarser sandy layers are intercalated.

The ammonoid succession is documented in Fig. 2. The biostratigraphic subdivisions are based on the occurrence of various species of *Stoliczkaia* (Hoedemaeker and Bulot 1990; Latil 1996). The Dispar zone of the Mediterranean Region is divided into a lower subzone of *Stoliczkaia* (*Faraudiella*) *blancheti* (Pictet and Campiche; Breistroffer 1963) and an upper subzone of *Stoliczkaia* (*Stoliczkaia*) *dispar* (d'Orbigny; Owen 1975). This biostratigraphic scheme has been used by different Lower Cretaceous cephalopod teams since Hoedemaeker and Bulot (1990). The Upper Albian ammonoid assemblage of the Blieux section allows to recognize the Dispar zone and subzone (Fig. 2). According to Cotillon (1971), three important planktonic foraminiferal events occur in the Blieux succession (Fig. 2): (1) the occurrence of *Rotalipora appenninica* in the upper part of the alternating silty calcareous bed and marl succession, (2) the occurrence of *Planomalina buxtorfi* at the base of the marly part below the Breistroffer interval, and (3) the absence of the latter, above level 50 in the upper part of the Breistroffer interval.

Materials and methods

Carbonate and organic carbon contents

Carbonate and organic carbon contents were measured in 60 samples collected in the Blieux section (Fig. 2).

Calcium carbonate content was determined using the carbonate bomb technique. Total organic carbon content, as well as source and thermal maturation of the organic matter were estimated using a Rock-Eval instrument (Espitalié et al. 1985, 1986). Standard notations are used: total organic carbon (TOC) content is expressed in weight%, hydrogen index (HI) in mg hydrocarbon per g of TOC, and Tmax in °C.

The TOC content reflects the quantity of organic matter, although it should be kept in mind that organically bound oxygen, hydrogen, sulphur and nitrogen can contribute to the total sedimentary organic matter. In immature samples, 1 wt% TOC generally corresponds to 1.5 to 2.0 wt% organic matter (Baudin 1999).

Trace fossils

The density of the bioturbation has been estimated in every layers, both on bedding plane and bed sections, following the scale of relative abundance proposed by Olivero (1994). According to the percentage of bioturbated sectors and the relative position of each burrow, six classes of bioturbation intensity are thus recognized (Fig. 2).

- Class 0=no bioturbation;
- class 1=very rare (<10% of bioturbated sector), spaced burrows;
- class 2=rare (10 to 30%), no contacts between the different burrows;
- class 3=common (about 50%), no contacts between the different burrows;
- class 4=dense, burrows covering up to 70% of the surfaces, local contacts between the burrows; and
- class 5=very dense, burrows covering all the sectors, usually touching each other.

Macrofauna

The quantitative analysis of macrofauna (cephalopods, bivalves, echinoderms and gastropods) consists in an evaluation of the number of macrofossils per volume of rock, based on a regular and continuous stratigraphic sampling (Fig. 2). The macrofauna was extracted from 10- to 20-cm-thick layers.

The quantitative study of the macrofauna is based on more than 15,000 collected specimens, including 5,000 ammonoids. Both entire individuals and fragments of macrofauna have been counted. Entire shells are counted as one specimen whereas fragments are counted as parts of specimens. For example, a half, a quarter, a fifth of one shell were considered as 1/2, 1/4 and 1/5 specimen respectively; very small fragments of a shell were counted as 1/6 specimen, and the sum of the entire and fragmented specimens represents the abundance value obtained for each layer. These counts have the advantage of taking into account the fragmentation state of the material, and minimizing the effect of variable fragmentation between different layers. From these counts, the estimate of the macrofauna absolute abundance is standardised to a predefined quantity of rock (1 m³). The macrofauna counts are shown in the Appendix, part A.

Calcareous nannofossils

Calcareous nannofossil assemblages were analysed in the same samples which were used for carbonate and organic carbon measurements (Fig. 2).

Simple smear slides were prepared for nannofossil quantification. Samples were prepared as homogeneously as possible, so that particle density in different slides is comparable. However, this preparation technique does not guarantee a perfectly homogeneous distribution and constant quantity of material on the smear slide. Thus, the density on each smear slide was calculated as the mean density of material in 12 fields of view randomly chosen at 500 \times magnification. In each of these fields of view, the percentage of material on the smear slide was estimated using the plates of Baccelle and Bosellini (1965). Successive tests have shown that the error in mean density is lower than 5% (Pittet and Mattioli 2002).

Five hundred specimens were counted following the transverse on the smear slide under a light polarising microscope, at 1,560 \times magnification. The number of views needed to count them is used to calculate the total abundance of nannofossils. Total nannofossil abundance in each sample corresponds to the number of specimens divided by the number of views needed to count them. This abundance per view is then standardised to the density of material on the smear slide (Pittet and Mattioli 2002). The relative abundance of each species (percentage) is also calculated in each sample. The combination of these two abundance estimates allows an accurate interpretation of nannofossil assemblage changes (Williams and Bralower 1995). The nannofossil counts are given in the Appendix, part A.

The taxonomy applied herein follows the guidelines of Perch-Nielsen (1985) and Bown and Young (1997). A list of the cited taxa is given in the Appendix, part B. Forty species are considered for the quantitative analysis. They represent together 74 to 88% of the total nannofossil assemblage, which is composed of 90 species.

Four classes of preservation were identified under the light microscope following the categories established by Roth (1973).

The nannofossil assemblage composition is also described by the Shannon index and evenness, defined by Shannon and Weaver (1949). The Shannon index is a measure of the species diversity and is expressed as $H' = -\sum p_i \log_2 p_i$, where p_i is the relative abundance of each species. This index varies from 0 (presence of only one species) to $\log_2 S$ (presence of all species with the same abundance), with S being the total number of species. Evenness is a measure of dominance of species within the community ($E_s = H' / \log_2 S$) and varies from 0, when the totality of specimens is represented by one species, to 1 when all species have the same abundance.

Results

Carbonate and TOC contents

The samples studied contain 21 to 57% CaCO₃ and 0.2 to 0.97% TOC (Fig. 2). The lowest carbonate contents are recorded in the lower part of the Breistroffer interval (Fig. 2). The highest TOC values (>0.75%) are mainly recorded in the Breistroffer interval, where slightly enhanced organic matter contents are recorded when compared to the general background sedimentation in the section (Fig. 2). The organic content in the Breistroffer interval of the Blieux section is generally lower than in other sections of the Vocontian basin where TOC values can reach 2% (Br  h  ret 1997).

Information on the origin and composition of organic matter can be achieved by pyrolytic measurements (Espitali   et al. 1985, 1986). Although the type of organic

matter is usually defined by the mean of elemental analysis, the hydrogen index (HI) parameter approximates the H/C atomic ratio, which is determinant for typifying the organic matter (Tissot and Welte 1984). According to the low range of HI-values (43 to 164 mg HC/g TOC; Fig. 2), the organic matter deposited at Blieux can be attributed to types III and/or IV. Type III is usually related to terrestrial higher plant debris, whereas type IV corresponds to residual organic matter which can be either recycled from older sediments or deeply altered during settling.

Low HI values in organic-poor sediments can also be due to mineral matrix effects (e.g. adsorption on clay mineral surfaces of hydrocarbons generated during pyrolysis; Espitali   et al. 1985, 1986). To exclude this effect, 24 kerogen concentrates were prepared and analysed using a Rock-Eval pyrolysis. They yielded low amounts of hydrocarbons, i.e. low HI values (65 to 169 mg HC/g TOC) which are in the same range as bulk rock. This confirms that the samples from the Blieux section contain mainly type III and/or type IV organic matter. These two types of organic matter are usually well preserved even if the environment is fully oxygenated. The low organic carbon content of the studied samples, associated with low HI values, indicates that the organic matter mainly derived from terrigenous input, and has been deposited in oxic to weakly dysoxic environments.

The correlation between TOC and carbonate content is only slightly negative (Table 1), and various organic carbon values are recorded for one and the same carbonate content (Fig. 2). In the upper part of the Breistroffer interval, carbonate negatively covaries with organic carbon more consistently (Fig. 2). However, higher TOC content generally corresponds to carbonate content lower than 45% (Fig. 2).

Trace fossils

The Blieux succession is characterized by a common but poorly diversified ichnofauna. A pervasive, although undetermined, bioturbation is likely in all the beds and interbeds, with the primary fabric rarely visible. However, some burrows are better preserved and show clear outlines. These burrows were grouped into two ichnoassemblages (A and B), which are represented on Fig. 2. The typical burrows of the ichnoassemblage A are *Planolites*, *Palaeophycus* and *Thalassinoides*. The first two ichnogenera are considered as being eurybathic, and are most probably produced by polyphyletic vermiform deposit feeders, living in oxygenated environments (Uchman 1995; Monaco and Uchman 1999). *Thalassinoides* is characteristic of well-oxygenated, stable environments (mainly shallow waters) and periods of constant accumulation rate (Bromley 1996). Thus, the ichnoassemblage A should be typical of aerobic to upper dysaerobic substrates.

The typical burrows of the ichnoassemblage B are *Chondrites*, *Trichichnus* and *Zoophycos*. All these ichno-

Table 1 Correlation indices between the abundances of selected nanofossil taxa, nanofossil total abundance, species diversity and evenness, carbonate and TOC contents, and HI. All correlations are based on a dataset of 60 samples

	B. ellipticum	Pre-discosphaera spp.	D. rotatorius	D. rotatorius	Zeugrhabdotus spp.	T. orionatus	Cretarhabdotus spp.	Rhagodiscus spp.	Nannocoelus spp.	W. barnesae	Z. erectus	Eiffelithus spp.	Total abundance	Shannon index	Evenness	CaCO ₃ (%)	TOC	HI	
B. ellipticum	1.000																		
Prediscosphaera spp.	0.769	1.000																	
D. rotatorius	0.875	0.654	1.000																
Zeugrhabdotus spp.	0.766	0.453	0.747	1.000															
T. orionatus	0.697	0.378	0.661	0.802	1.000														
Cretarhabdotus spp.	0.430	0.292	0.393	0.492	0.547	1.000													
Rhagodiscus spp.	0.509	0.183	0.513	0.673	0.636	1.000													
Nannocoelus spp.	0.045	-0.180	0.151	0.259	0.281	0.315	1.000												
W. barnesae	0.546	0.247	0.502	0.641	0.710	0.653	0.642	1.000											
Z. erectus	-0.06	0.065	-0.100	-0.124	-0.163	0.185	-0.109	0.023	1.000										
Eiffelithus spp.	0.660	0.464	0.534	0.664	0.574	0.373	0.511	0.153	0.426	1.000									
Total abundance	0.939	0.653	0.886	0.890	0.838	0.588	0.677	0.210	0.738	0.698	1.000								
Shannon index	0.040	-0.005	0.192	0.397	0.352	0.435	0.279	0.343	0.111	-0.013	0.329	1.000							
Evenness	-0.066	-0.099	0.089	0.354	0.288	0.291	0.284	0.267	0.025	-0.031	0.183	0.906	1.000						
CaCO ₃ (%)	-0.554	-0.592	-0.411	-0.321	-0.346	-0.274	-0.523	0.087	-0.350	-0.062	-0.285	0.128	0.201	1.000					
TOC	0.228	0.080	0.282	0.355	0.397	0.457	0.230	0.196	0.373	-0.072	0.352	0.461	0.362	-0.264	1.000				
HI	0.095	-0.025	0.085	0.147	0.250	0.504	0.193	0.073	0.379	0.182	0.105	0.270	0.213	-0.158	0.459	1.000			

genera are produced by deep chemosymbiotic organisms exploiting organic matter which is well preserved in a dysaerobic to anaerobic substrate; they have open connections to the seafloor (Frey 1970; Wetzel 1983; Bromley and Ekdale 1984; Seilacher 1990; McBride and Picard 1991; Olivero 1996). In particular, *Chondrites* and *Zoophycos* are common in sediments bioturbated under dysoxic conditions (Bromley 1996). A lower oxygenation in the substrate is also suggested by the reduced diameters of the burrows. The ichnoassemblage B may be typical of lower dysaerobic to nearly anaerobic substrates.

Only few layers, observed in two intervals (levels 95 to 107 and 127 to 143; Fig. 2), are characterized by a preserved primary fabric due to the absence of bioturbation. They alternate with poorly bioturbated horizons, usually with small burrows belonging to the ichnoassemblage B. These layers could correspond to episodic anaerobic conditions in a generally oxygen-deficient substrate.

Locally through the whole succession, some layers are neither bioturbated nor have a preserved primary fabric. This could be the result of diagenetic processes.

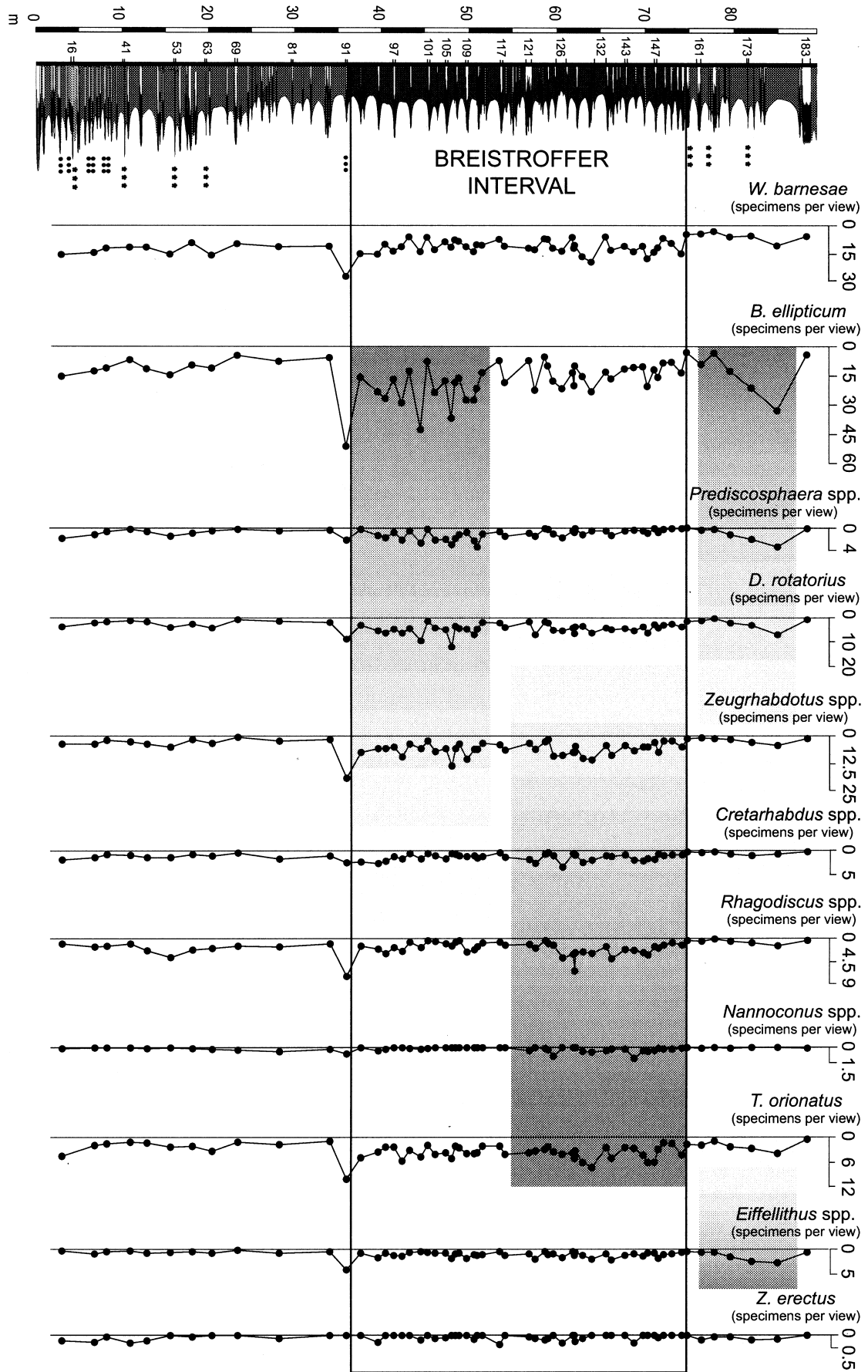
Macrofauna

The highest total abundance of macrofauna is recorded within the Breistroffer interval (Fig. 2). The abundance of benthic fauna varies generally from 25 to 5,000 specimens per m³ of rock, but more than 40,000 specimens have been counted in level 25. The abundance of ammonoids, which are mainly represented by heteromorphs, fluctuates from 5 to 2,591 specimens per m³ of rock. The taphonomy of specimens suggests rapid sinking and burial. Ammonoids are often complete (phragmocone and one-half whorl of body chamber), with rare mechanical damage except for the apertural end of the body chamber (peristome) which is frequently broken or not preserved. The specimens are rarely totally destroyed. The average adult-size of the ammonoids in the Bliex section do not exceed 10 cm in diameter. Chamberlain et al. (1981) suggest that nekroplanktonic drifting did not occur frequently for most ammonoids, especially for shells smaller than 10 cm in diameter. Consequently, the significant variations of ammonoid abundances recognized in the Breistroffer interval are probably not linked to a post-mortem selection of the shells, but more likely reflect a primary palaeoenvironmental control.

Calcareous nanofossils

Calcareous nanofossils are well preserved in the investigated succession (Fig. 2). Fluctuations in total abun-

Fig. 4 Abundance curves of selected nanofossil taxa. The abundance corresponds to the number of each selected nanofossil taxa in one field of view for a density of particles on one slide equal to 100%. Note the successive contribution of some taxa marked by the shaded bands



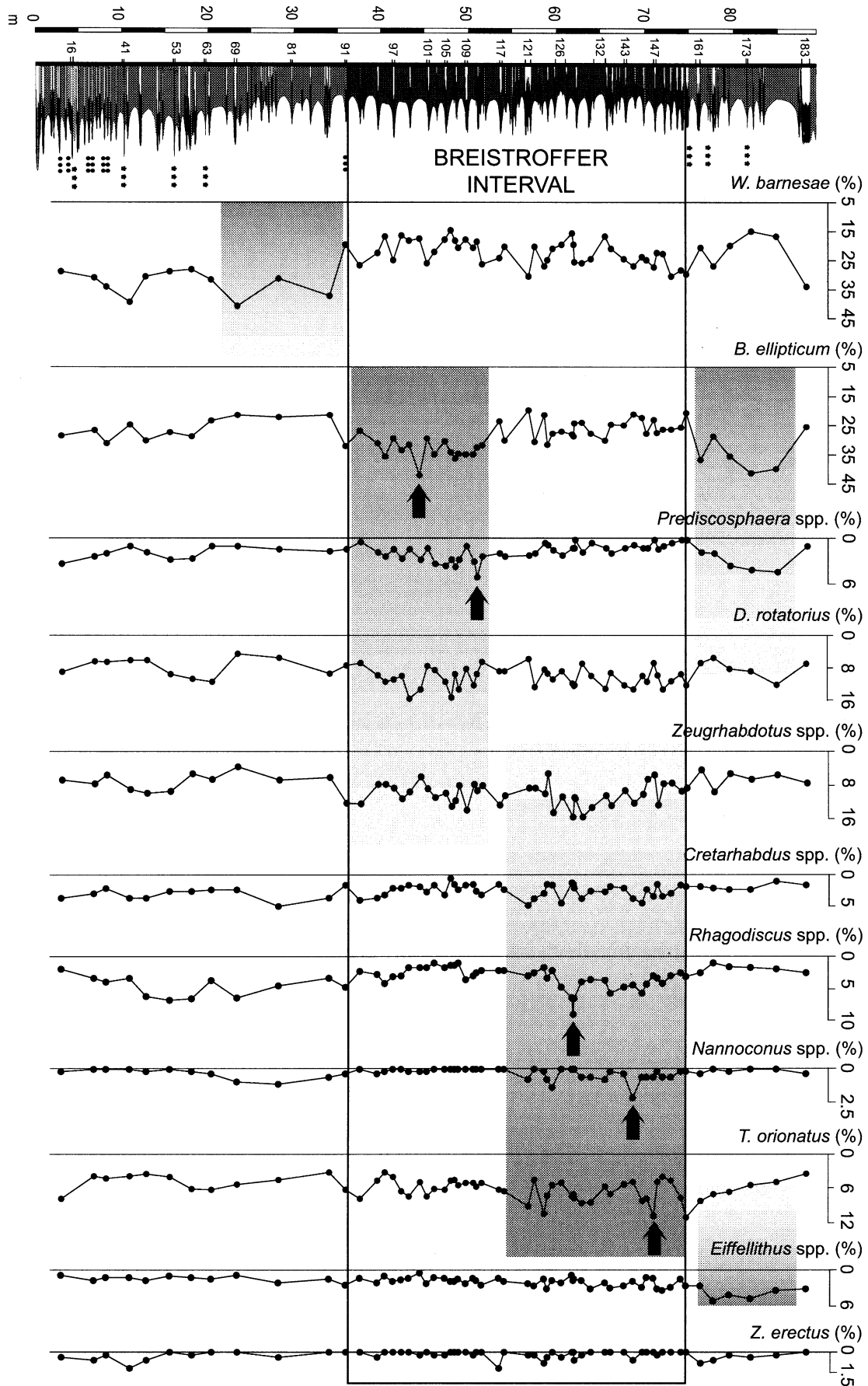


Fig. 5 Percentage curves of selected nannofossil taxa. Note the successive contribution of some taxa identified by the shaded bands, and the succession of dominant peak for the different species marked by closed arrows within the Breistroffer interval

Table 2 Correlation indices between the percentages of selected nannofossil taxa, nannofossil total abundance, species diversity and evenness, carbonate and TOC contents, and HI. All correlations are based on a dataset of 60 samples

	<i>B. ellipticum</i> (%)	<i>Pre-discosphaera</i> spp. (%)	<i>D. rotatorius</i> (%)	<i>Zeugrhabdotus</i> spp. (%)	<i>T. orionatus</i> (%)	<i>Cretarhabdus</i> spp. (%)	<i>Rhagodiscus</i> spp. (%)	<i>Nannococcus</i> spp. (%)	<i>W. barnesae</i> (%)	<i>Z. erectus</i> (%)	<i>Eiffellithus</i> spp. (%)	Total abundance	Shannon index	Evenness	CaCO ₃ (%)	TOC	HI
<i>B. ellipticum</i> (%)	1.000																
<i>Pre-discosphaera</i> spp. (%)	0.639	1.000															
<i>D. rotatorius</i> (%)	0.222	0.044	1.000														
<i>Zeugrhabdotus</i> spp. (%)	-0.141	-0.146	0.153	1.000													
<i>T. orionatus</i> (%)	-0.302	-0.315	-0.071	0.125	1.000												
<i>Cretarhabdus</i> spp. (%)	-0.445	-0.128	-0.335	-0.122	0.018	1.000											
<i>Rhagodiscus</i> spp. (%)	-0.384	-0.345	0.001	0.092	-0.046	0.118	1.000										
<i>Nannococcus</i> spp. (%)	-0.442	-0.382	-0.006	-0.033	0.047	0.326	0.166	1.000									
<i>W. barnesae</i> (%)	-0.672	-0.435	-0.526	-0.359	-0.041	0.367	0.210	0.281	1.000								
<i>Z. erectus</i> (%)	-0.107	0.001	-0.307	-0.058	-0.009	0.166	-0.089	-0.019	0.228	1.000							
<i>Eiffellithus</i> spp. (%)	0.129	0.049	-0.119	-0.052	0.027	-0.064	-0.209	0.034	-0.155	0.023	1.000						
Total abundance	0.385	0.227	0.279	0.377	-0.093	-0.172	0.052	-0.112	-0.546	-0.295	-0.160	1.000					
Shannon index	-0.269	-0.091	0.173	0.575	0.253	0.270	0.061	0.232	-0.418	-0.078	0.212	0.239	1.000				
Evenness	-0.351	-0.164	0.126	0.626	0.308	0.192	0.193	0.182	-0.351	-0.031	0.121	0.132	0.906	1.000			
CaCO ₃ (%)	-0.478	-0.476	0.050	0.098	0.208	0.131	0.040	0.209	0.258	0.106	0.176	-0.498	0.128	0.201	1.000		
TOC	-0.021	-0.090	0.023	0.228	0.112	0.181	0.008	0.124	-0.220	-0.223	0.034	0.367	0.461	0.362	-0.264	1.000	
HI	-0.135	-0.085	-0.143	0.046	0.089	0.346	0.073	-0.039	0.021	0.046	-0.103	0.212	0.270	0.213	-0.158	0.459	1.000

dance are quite low, with lower abundances below and above the Breistroffer interval, whereas the highest abundance (162 specimens per view) is recorded in the condensed glauconitic marls at the base of the Breistroffer interval (Fig. 2). The species richness follows the same trend as the abundance, fluctuating from 32 to 50 species per sample (Fig. 2). The nannofossil assemblages are dominantly composed of heterococcoliths, but rare holococcoliths are also present. Species diversity estimated by the Shannon index as well as by evenness fluctuates slightly throughout the succession. In the lower part of the succession, from level 1 to level 121, species diversity and evenness have low values (Fig. 2). These low values reflect the dominance (in decreasing order of abundance; number of specimens per view) of the following taxa: *Biscutum ellipticum*, *Watznaueria barnesae*, *Discorhabdus rotatorius*, and *Zeugrhabdotus* spp. (Figs. 4 and 5). In the upper part of the Breistroffer interval, from level 122 to level 149, species diversity and evenness are maximum (Fig. 2), representing a greater contribution in both abundance per view and percentage of the following taxa: *Tranolithus orionatus*, *Rhagodiscus* spp., *Cretarhabdus* spp., and *Nannoconus* spp. (Figs. 4 and 5). Above the Breistroffer interval, a decrease in species diversity and evenness is recorded (Fig. 2), reflecting the dominance (in decreasing order of abundance; number of specimens per view) of *B. ellipticum*, *W. barnesae*, *D. rotatorius*, and *Zeugrhabdotus* spp. (Figs. 4 and 5).

Table 1 and Table 2 show correlation indices between distinctive variables. Correlation coefficients between different species or group of species expressed as abundance per view are higher (Table 1) when compared with correlation coefficients between different taxa expressed as percentages (Table 2). Comparison of the total abundance values with the abundance of taxa per view shows positive correlations for most taxa, except for nannoconids and *Zeugrhabdotus erectus*. The lowest correlation coefficients ($r=0.7$) are found for the taxa representing less than 10% of the total assemblage.

In general, the fluctuations in abundance per view and percentage of the different species are limited in amplitude (Figs. 4 and 5). Nevertheless, the contribution of some species or groups of species varies through the succession. *Biscutum ellipticum*, the most abundant taxon, displays strong changes in abundance per view (from 3 to 51 specimens) and in percentage (from 17 to 41%). In the lower part of the Breistroffer and above it, *B. ellipticum* is the dominant species, having significant peaks in both abundance per view and percentage (Figs. 4 and 5). The abundance per view and percentage of *B. ellipticum* have significant positive correlations ($r=0.769$ and $r=0.639$ respectively) with the abundance per view and percentage of *Prediscosphaera* spp.

Watznaueria barnesae is the second most abundant species after *B. ellipticum* (Figs. 4 and 5). In the whole succession, its abundance per view fluctuates from 3 to 27, and its relative abundance from 10 to 40%; the number of specimens slightly decreases above the Breistroffer (Fig. 4). In the lower part of the succession,

the abundance per view of *W. barnesae* exhibits an inverse correlation pattern with respect to the percentages (Figs. 4 and 5). In this interval, *W. barnesae* represents up to 40% of the total assemblage (Fig. 5), and its fluctuations are probably the result of minima in relative abundances of *B. ellipticum* and *D. rotatorius*, which are both negatively correlated with *W. barnesae* ($r=-0.672$ and $r=-0.526$ respectively).

Abundance per view and percentage of *Discorhabdus rotatorius* fluctuate from 1 to 17 specimens and from 5 to 15.5% respectively. This taxon shows peaks both in abundance per view and percentage in the lower part of the Breistroffer interval (Figs. 4 and 5), and it is a characteristic component of the nannofossil assemblage.

Prediscosphaera spp. is not abundant in the Blioux section (from 0 to 4 specimens per view and from 0 to 5.5%) but, similarly to *B. ellipticum*, presents maximum peaks both in abundance per view and in percentage in the lower part of the Breistroffer and above it. Both *Prediscosphaera* spp. and *B. ellipticum* negatively correlate with the carbonate content, and their percentages show low negative correlations with *Nannoconus* spp., *Rhagodiscus* spp., and *T. orionatus* (Tables 1 and 2).

Zeugrhabdotus spp. abundance per view and percentage fluctuate from 1 to 20 and from 4 to 15.5% respectively. They exhibit their maximum values within the Breistroffer interval (Figs. 4 and 5). *Zeugrhabdotus* spp. relative abundance shows significant positive correlations with diversity ($r=0.575$) and evenness ($r=0.626$).

Tranolithus orionatus and *Rhagodiscus* spp. are common throughout the studied succession, with abundance per view varying from 1 to 10 and 0.5 to 8 specimens, and percentage from 3 to 11% and 1 to 9% respectively. *Cretarhabdus* spp. is frequent, with abundance per view ranging between 0.5 and 4 specimens, and percentage between 0.6 and 5%. Nannoconids are rare; their abundance per view fluctuates from 0 to 1.5 specimens, and their relative abundance from 0 to 2.5%. *Tranolithus orionatus*, *Rhagodiscus* spp., *Cretarhabdus* spp. and the nannoconids display low coefficient correlations with the different variables (Tables 1 and 2), but they also present highest values both in abundance and percentage in the upper part of the Breistroffer interval (Figs. 4 and 5).

Discussion

Calcareous nannofossils preservation

In the Blioux section, the lowest nannofossil abundances are observed in sedimentary intervals containing numerous silty levels, below and above the Breistroffer interval where the preservation index is generally low (Fig. 2). Slightly higher mean total nannofossil abundance is recorded in the samples having better preservation. However, the difference in mean abundance in the different classes of preservation is not significant (Fig. 6A).

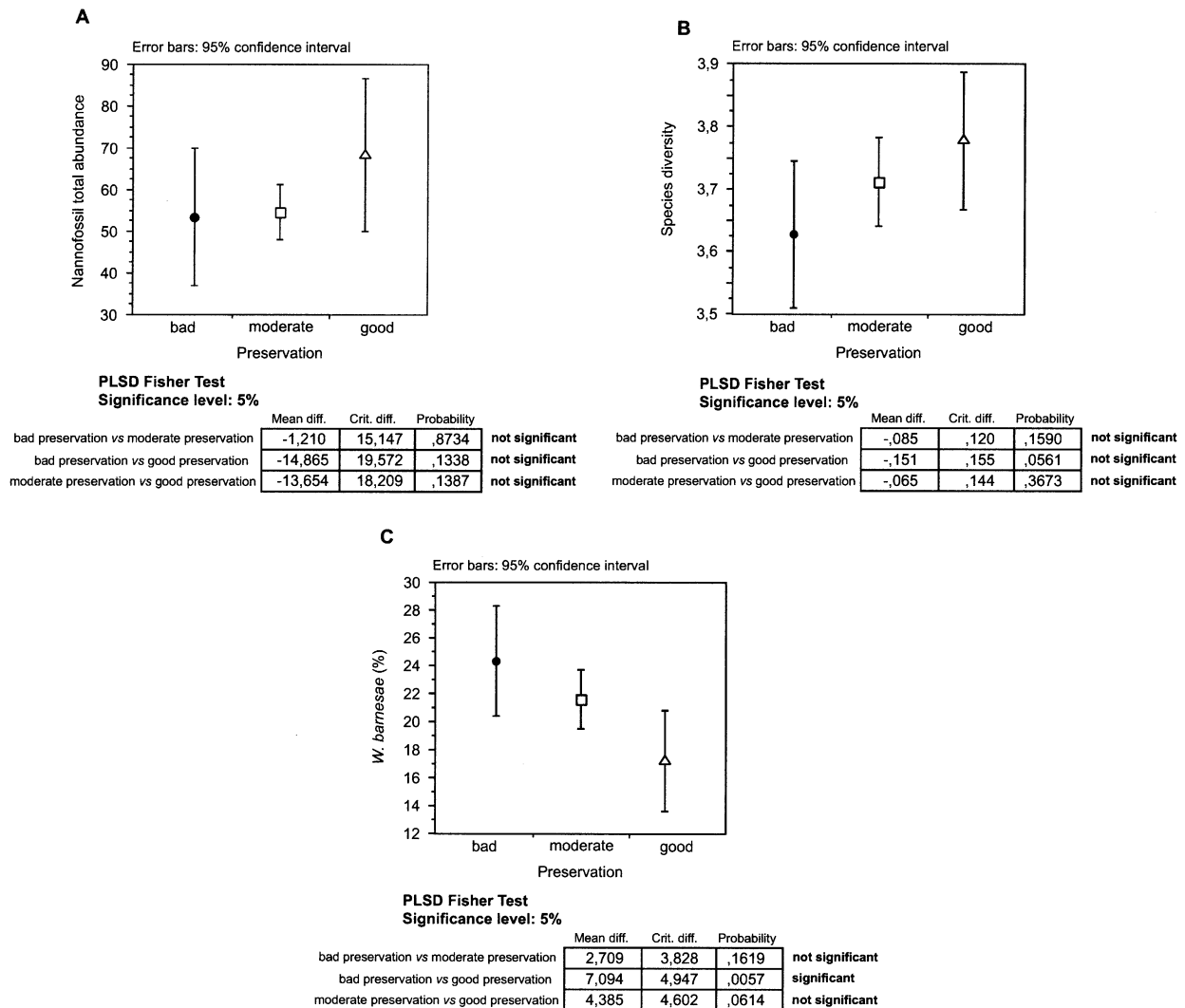


Fig. 6A–C Mean nannofossil total abundance (specimens per view) (A), mean species diversity (B), and mean relative abundance of *Watznaueria barnesae* (C) for different preservation state. Bad preservation=class 3; moderate preservation=class 4; good preservation=classes 5 and 6.

To estimate the significance of abundances and diversity variations, we applied to the data a PLSD Fisher test with a significance level at 5%

The relative abundance of individual taxa can change significantly with increasing dissolution, and dissolution ranking of Cretaceous calcareous nannofossils has been proposed by several authors (Hill 1975; Thierstein 1980; Roth and Krumbach 1986). Dissolution-resistant species are the large, thick placoliths with strongly imbricated elements (Hill 1975). Among these species, *Watznaueria barnesae* (thick coccolith, closed central area) is considered as being more resistant to dissolution than other nannofossils because of its robust morphology (Hill 1975; Thierstein 1980, 1981; Roth 1981; Roth and Bowdler 1981; Roth and Krumbach 1986). Thus, an increase of diagenetic alteration may imply an increase in the relative abundance of *W. barnesae* and a concurrent decrease in the diversity of the assemblage. In the Blioux section, species diversity is higher in moderately and well-preserved samples than in poorly preserved samples, but this difference in species diversity is not statistically

significant (Fig. 6B). The relative abundance of *W. barnesae* is slightly higher in the samples which have low preservation than in the moderately and well-preserved samples (Fig. 6C).

Calcareous nannofossils and carbonate production

In the Blioux section, a negative correlation between nannofossil total abundance and carbonate content is observed (Fig. 7A). The highest abundance of nannofossils is found in the condensed level 91 (glaucinitic horizon, Fig. 2), and the lowest abundances are observed in sedimentary intervals containing numerous silty levels, below and above the Breistroffer interval (Fig. 2). The contribution to the pelagic carbonate content by microorganisms other than the calcareous nannoplankton was investigated in thin sections in various samples repre-

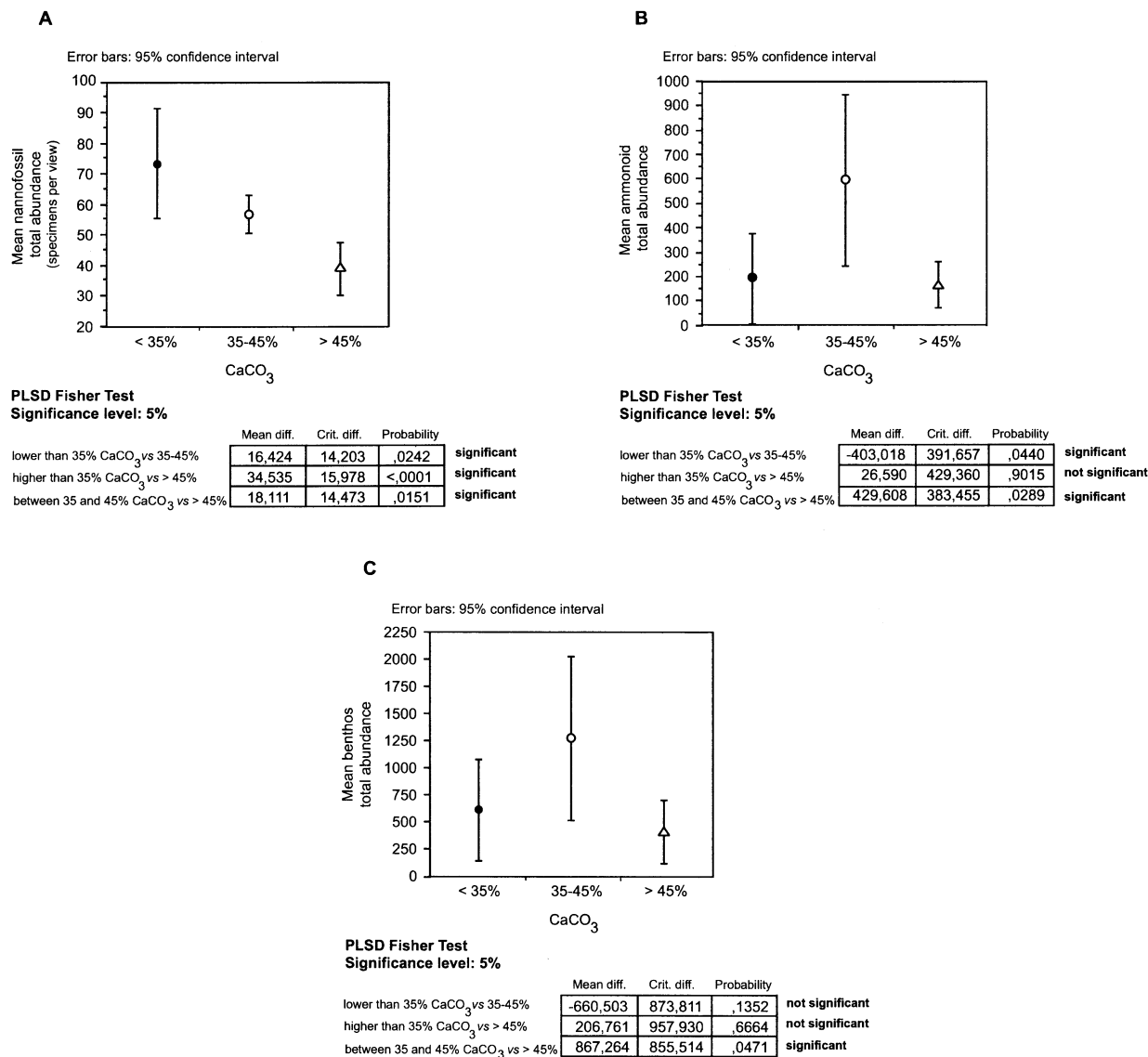


Fig. 7A–C Mean nannofossil total abundance (specimens per view) (A) mean ammonoid total abundance (specimens per m³) (B) and mean benthos total abundance (specimens per m³) (C) for

different intervals of calcium carbonate content. To estimate the significance of abundance variations, a PLSD Fisher test with a significance level at 5% has been applied

senting the entire range of calcium carbonate content (Appendix, part A). This analysis revealed that planktonic Foraminifera have a minor contribution to the carbonate fraction, and form less than 9% of the thin section surface. Benthic Foraminifera are rare. This suggests that the carbonate fraction is not predominantly produced by micro-organisms in the Blioux section. Thus, two hypotheses can be proposed.

The first hypothesis suggests that the carbonate fraction produced by microfossils was reduced in periods of enhanced accumulation rates, and the carbonate fraction had a predominantly allochthonous, carbonate-platform origin (Pittet et al. 2000; Pittet and Mattioli 2002). Also, Bralower et al. (1999) reported an increase in abundance of planktonic Foraminifera and coccoliths associated with a decrease in carbonate content during the

OAE 1a event (early Aptian) recorded in one Mexican section, which possibly reflected a decrease in dilution by detrital carbonate derived from adjacent platforms.

The second hypothesis proposes that the pelagic carbonates were diluted by a nektonic/benthic carbonate fraction. The Breistroffer interval contains abundant ammonoids and benthic organisms (Fig. 2). When the carbonate content increases up to 45%, nannofossil abundance decreases (Fig. 7A) whereas ammonoid abundance significantly increases (Fig. 7B) and benthos abundance slightly increases (Fig. 7C). This suggests that for a calcium carbonate ranging between 35 and 45%, the carbonate fraction could mainly be of nektonic origin in the Blioux section. For carbonate contents higher than 45% (upper part of the Breistroffer interval and just above it; Fig. 2), the abundances of nannofossils and macrofauna

significantly decrease (Fig. 7A–C), and probably both micro- and macro-organisms contribute little to the carbonate fraction. Consequently, a greater contribution of allochthonous carbonate can be invoked. The Blieux section was situated in a proximal part of the Vocontian basin in the Late Albian (Fig. 1), and could have been sensitive to changes in the intensity of the carbonate import from shallower water environments.

Calcareous nannofossils and their palaeoecological significance

In the Blieux section, the dominant taxa (*B. ellipticum*, *W. barnesae*) are placolith-bearing species, and display high abundances and percentages in intervals of low diversity and evenness of nannofossil assemblages (lower and upper parts of the succession, lower part of the Breistroffer interval). Low values in diversity and evenness may indicate unstable environmental conditions in which nutrients are used by few dominant taxa (Watkins 1989).

Watznaueria barnesae has been previously linked to low-fertility conditions (Roth 1986; Roth and Krumbach 1986). Mutterlose (1991) considered this taxon as the first to occupy new ecological niches. In the Blieux section, the abundance per view of *W. barnesae* is relatively constant throughout the succession whereas its percentage fluctuates. These fluctuations may be explained by the decrease or increase in the abundance of the other species; this can support the idea that *W. barnesae* is an ecologically robust form (Mutterlose 1991).

Biscutum spp. (mainly *B. constans* and *B. ellipticum*) and *Zeugrhabdotus* spp. (mainly *Z. erectus*) are considered as indicators of high surface-water fertility in unstable environments such as oceanic sites of upwelling or shelf areas where trophic conditions may have been enhanced by storm mixing or by runoff (Roth 1981, Roth and Bowdler 1981; Roth and Krumbach 1986). However, *Biscutum* (mainly *B. constans*) is considered as an indicator of less eutrophic conditions than *Zeugrhabdotus* spp. (Erba 1992). In the Blieux section, *Z. erectus* is very rare, whereas there is good correlation between abundances of *B. ellipticum* and *Prediscosphaera* spp. An increase of *Prediscosphaera* spp. is commonly observed when nutrient content is moderate in mesotrophic environments (Erba et al. 1995; Eshet and Almogi-Labin 1996).

Discorhabdus rotatorius is considered as an indicator of high-fertility conditions. In the Blieux section, it presents high abundances and percentages in intervals of high total abundance (Figs. 4 and 5) but also shows a low positive correlation with diversity and evenness (Tables 1 and 2). Abundant *D. rotatorius* could be triggered when trophic conditions passed from high to low mesotrophic.

Zeugrhabdotus spp. (including all zeugrhabdotids with major axis smaller than 5 µm, and not only *Z. erectus*) are markers of high-fertility surface waters (Erba et al. 1992; Williams and Bralower 1995). In the Blieux section, *Zeugrhabdotus* spp. are never abundant, and are charac-

teristic of nannofossil assemblages of moderate to high abundance/high diversity and evenness. All these observations support that mesotrophic conditions prevailed over eutrophic conditions during times of enhanced surface-water productivity.

Cretarhabdus spp., *T. orionatus* and *Nannoconus* spp. are classified as indicators of low-fertility conditions by different authors (*Cretarhabdus* spp., and *T. orionatus*, Watkins 1989; *Nannoconus* spp., Roth and Krumbach 1986; Erba 1994). In the Blieux section, these taxa are characteristic of low to moderate abundance/moderate diversity and evenness of nannofossil assemblages. An increase in the diversity may indicate stable environmental conditions in which nutrients were efficiently and evenly divided amongst a relatively large number of species (Watkins 1989).

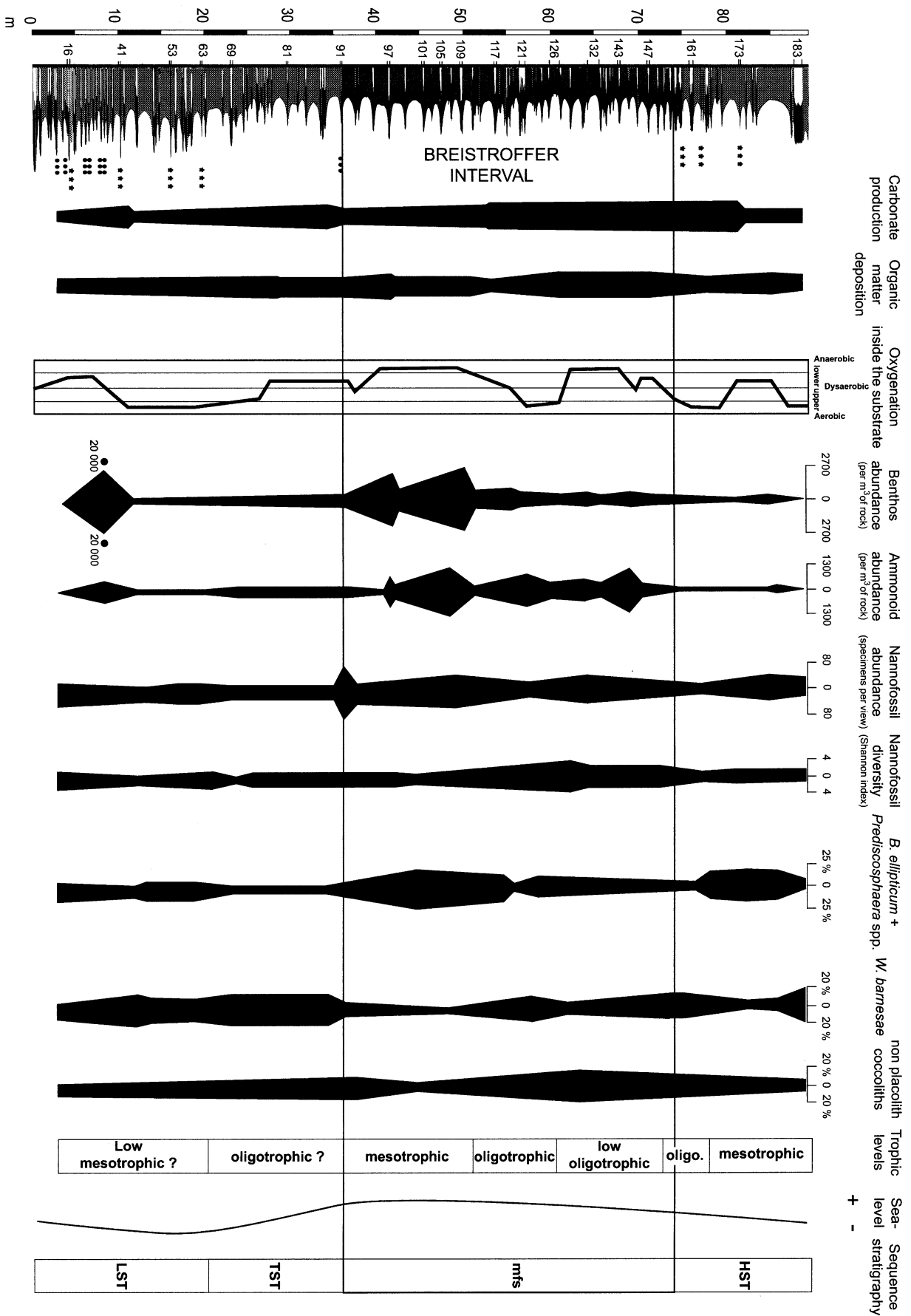
The notably low correlation observed between *Rhagodiscus* spp. and species diversity and evenness (Tables 1 and 2) can indicate that fluctuations in abundance of this taxon are independent from fertility fluctuations, as demonstrated by Erba et al. (1992).

Organic-rich levels

In the Blieux section, the enrichment in terrestrial organic matter is observed in the lowermost and in the upper parts of the Breistroffer interval, especially in carbonate-poor sediments (carbonate content between 35 and 45%, Fig. 2). Carbonates as well as clastics can have controlled the concentration of the organic matter deposited. The negative correlation between TOC and CaCO₃ contents is stronger in the upper part of the Breistroffer interval (Fig. 2) than in the lower part of the Breistroffer interval, when the allochthonous carbonate supply probably increased. This suggests that TOC accumulation was dependent on carbonate accumulation rate. Conversely, enrichment in organic matter was favoured during periods of low accumulation rate of imported, platform-derived carbonates.

The organic carbon-richest levels are characterized by the continuous presence of macrofauna, in particular benthic organisms which were very abundant in some of these levels (Fig. 8). This may imply that the water column never recorded low-oxygen conditions. The development of an abundant benthic fauna could have led to an increased flux of organic matter to the seafloor, and the oxidation of this excess of organic matter could have led to dysoxic conditions of the substrate. Moreover, the ichnofauna is indicative of a lower dysaerobic to nearly anaerobic environment, reflecting a decrease in oxygenation of the substrate in these levels (Fig. 8). Such conditions were thus favourable to organic matter preservation. The presence of pyrite is also indicative of fluctuations in palaeoredox conditions (Raiswell et al. 1988). In the Blieux section, pyrite is abundant in the organic carbon-richest levels.

The marked peaks of TOC are characterized by moderate to high abundance/moderate to high diversity



and evenness in nannofossil assemblages (Fig. 2), suggesting low mesotrophic conditions of the surface waters. In summary, decreasing carbonate import in the basin and seafloor redox conditions were the dominant mechanisms leading to the deposition and preservation of the organic carbon-richest levels within the Breistroffer interval, at times of not exceptional primary production.

Possible palaeoenvironmental scenario for the Breistroffer deposition in the Blieux succession

The distinctive patterns in biotic and geochemical data, recognized in the late Albian Blieux succession, point to changes in palaeoenvironmental conditions. In particular, second- and third-order relative sea-level variations (*sensu* Vail et al. 1987) recognized in the Aptian–Albian sediments of the Vocontian basin can have exerted an important control on the sedimentary evolution. The lower part of the studied succession was deposited during a sea-level lowstand (LST, Fig. 8; Bréhéret 1997), and is characterized by a high accumulation rate, as indicated by the frequent occurrence of turbiditic levels. The abundant benthic macrofauna observed in the level 25 (Fig. 2), and represented almost exclusively by bivalves (*Aucellina* beds) could be related to platform arrivals.

The bioturbated marls above the silty calcareous beds and marls represent transgressive deposits (TST; Bréhéret 1997; Fig. 8). In these intervals, the low macrofauna and nannofossil total abundances, and the poorly diversified nannofossil assemblages characterized by the dominance of the eurytopic taxon *Watznaueria barnesae* (Fig. 8) are probably indicative of unfavourable conditions in the water column.

Above this interval, terrigenous input progressively decreased up to the glauconitic level, which corresponds to an important condensed horizon which preceded the deposition of the Breistroffer interval. The Breistroffer interval corresponds to the maximum flooding stage (mfs) and is characterized by a slight increase in nannofossil total abundance and an important increase in macrofauna total abundance (Fig. 8). The increasing distality of the Blieux locality led to a decrease in sediment accumulation rate which can explain these enhanced abundances. It also led to better connections with the open ocean, and thus triggered the coccolithophorid population (Young 1994)

Fig. 8 Palaeoenvironmental interpretation of the Breistroffer interval in the Blieux section. The palaeo-oxygenation curve for the Blieux section is based on the ichnoassemblages and on the intensity and maximum diameter of the burrows, following the method of Savrda et al. (1991). Three environments can be distinguished: aerobic ($O_2 > 2.0$ ml/l), dysaerobic (0.3 ml/l $< O_2 < 2.0$ ml/l), and anaerobic ($O_2 < 0.3$ ml/l). General patterns for the macrofauna and the nannofossils show the enhanced abundance within the Breistroffer interval. Also shown are general trends of relative abundance of the high-fertility indices *Biscutum ellipticum* and *Prediscosphaera* spp., and their inverse relationship with the eurytopic taxon *Watznaueria barnesae* and the non-placolith-bearing species indicative of lower-fertility conditions

and increased the number of habitats suitable for the ammonoids. Distinctive patterns in nannofossil assemblage evolution are evidenced within this interval. These fluctuations could be climatically driven, since the Breistroffer deposits record a peak in clay input (essentially smectite) which could be explained by the development of contrasting seasonal climatic conditions (Bréhéret 1997).

1. In the lower part of the Breistroffer interval, from level 91 to level 109, the nannofossil species diversity stays low, and species indicative of higher-fertility conditions such as *B. ellipticum* and *Prediscosphaera* spp. increased in abundance (Fig. 8), reflecting relatively nutrient-rich surface waters. At that time, a relatively humid climate may have enhanced both runoff from the hinterland and nutrient input in the marine realm. This could explain the abundance of nannoplankton taxa characteristic of relatively nutrient-rich surface waters (mesotrophic conditions), and thus explain the abundance of other organisms like the ammonoids which are placed higher in the food chain. An increase in freshwater input in the marine realm could have episodically led to a density stratification of the water column, resulting in high nutrient concentration in deeper waters which could have favoured the development of an abundant benthic community of bivalves.
2. From level 110 to level 121, declines in nannofossil total abundance and in macrofauna abundances are recorded (Fig. 8). The nannofossil species indicative of relatively high productivity decreased in abundance, whereas *W. barnesae* was triggered (Fig. 8). A decrease of the nutrient availability both in oceanic surface waters and at the seafloor is suggested. Lower TOC values are also recorded, and this decrease could be the result of a weakened input of terrestrial organic matter. All these changes probably reflect low runoff at times of drier climatic conditions.
3. The upper part of the Breistroffer, from level 122 to level 149, displays an increase in both nannofossil and macrofauna total abundance (Fig. 8). In the macrofauna, the ammonoid group shows a strong increase in abundance whereas the benthic fauna shows a slight increase. The nannofossil diversity increases in this part and is correlated with an increase in the relative abundance of non-placolith-bearing species (Fig. 8), suggesting more oligotrophic conditions. *Rhagodiscus* spp., considered as an indicator of warm surface waters (Erba 1987; Mutterlose 1987, 1989; Crux 1991), increases in abundance (Fig. 5), possibly reflecting the onset of warmer climatic conditions. These conditions seem to be favourable to the ammonoids but the lower abundances of the benthic macrofauna could be explained by a reduced nutrient flux at the seafloor with respect to the lower part of the Breistroffer interval.

The stabilisation of the sea level (HST; Bréhéret 1997) occurred at the end of the Breistroffer episode, leading to

the progressive decrease of the distance between the depositional environment and the material sources. Increasing sedimentation rate immediately above the Breistroffer due to enhanced carbonate input from the shelves appears likely to have been the principal mechanism for the reduction of the nannofossil and macrofossil abundances as well as of the organic carbon content (Fig. 8). Enhanced carbonate input from the shelves could be indicative of increased platform productivity under drier climatic conditions. The dominance of the eurytopic taxon *W. barnesae* in the nannofossil assemblages at the top and just above the Breistroffer deposits (Fig. 8) could be the result of nutrient-depleted surface waters, in agreement with drier climatic conditions. The uppermost part of the succession is characterized by silty marls and sandy layers, and records an increase in nannofossil total abundance, moderate to high-fertility conditions (peak of *B. ellipticum*), TOC enrichment and decreased carbonate content (Fig. 8). The taxa indicative of warm marine waters were very scarce at that time. As sea level was still high (Bréheret 1997), wetter and cooler climatic conditions could lead to reduced platform productivity and increased runoff and associated nutrients and organic matter. According to Cotillon (1971), these abundant terrigenous inputs came from the west, probably from the Lure platform (north-western part of the Provence, Fig. 1).

Conclusions

Quantitative analyses of calcareous nannofossils compared to macrofauna abundance, ichnofauna abundance and assemblages, and carbonate and organic carbon contents across the Breistroffer interval (OAE 1d, latest Albian) investigated in the Blieux section (SE France) have revealed the following features.

1. Calcareous nannoplankton did not produce the bulk of carbonates. Carbonate was essentially derived of nektonic/benthic organisms and of allochthonous (platform) origin.
2. The fluctuations of fertility indices in the nannoplankton community do not evidence the development of conditions of high primary productivity during the deposition of the Breistroffer interval. The oxygenation conditions in the water column were always good, as demonstrated by the abundant nektonic and benthic organisms; oxygenation was low and only within the sediment, because of the oxidation of organic matter.
3. The Breistroffer deposits, which corresponded to a maximum flooding event, record higher abundances in macrofauna and nannofossils with respect to the rest of the succession. Reduced accumulation rates during the episode of maximum flooding partly explain the observed abundances. Increasing distality and associated increasing available habitats are also responsible for the increase of the nannofossil and ammonoid populations. Moreover, distinctive patterns in the

nannofossil assemblages and macrofauna abundances within the Breistroffer interval are recognized, reflecting changes in trophic conditions. Mesotrophic conditions suggested by low-diversity nannoplankton assemblages and great abundances of macrofauna prevailed in the lower part of the Breistroffer interval. More oligotrophic conditions demonstrated by higher diversity nannofossil assemblages, high ammonoid abundances and lower benthic macrofauna abundances prevailed in the upper part of the Breistroffer interval. This succession could be the result of climatic changes from periods of increased precipitation and runoff, corresponding to the lower part of the Breistroffer interval, to a period with drier conditions in the upper part of this interval.

4. This study shows that the Breistroffer deposits do not record a eutrophication of the marine surface waters associated to the expansion of an oxygen minimum zone. Also, the OAE 1d is not recognized as a major anoxic event in the Vocontian basin. These results are in agreement with conclusions of Holbourn et al. (2001) about the late Albian black-shale deposits in the eastern Tethys.

Acknowledgements This research was financed by ATI (Actions Thématiques Innovantes 1998–1999) INSU-SdU. This work is a part of a larger project on the evolutionary response of different biological groups during anoxic events of various intensity and extension, the late Albian OAE 1d and the latest Cenomanian OAE 2. We are extremely grateful to E. Mattioli for many useful suggestions. We thank C. Girard and S. Renaud for profitable discussion. Elisabetta Erba, Jorg Mutterlose and an anonymous reviewer are greatly acknowledged for their critical comments on the manuscript. We thank the Réserve Géologique de Haute Provence for the permission of sampling. We also acknowledge the collaboration of G. Sirven for field assistance, P. Desvignes for smear slides preparation, and F. Savignac for Rock-Eval analyses.

Appendix

Part A. Calcareous nannofossils counts, calcium carbonate and total organic carbon contents, hydrogen index measurements and macrofauna counts for the Blieux section

Preservation classes are class 3=bad preservation; class 4=moderate preservation; classes 5 and 6=good preservation.

Numbers for nannofossils refer to the raw counts. Some of taxa which exhibit similar morphology have been grouped. The *Cretarhabdus* group includes all species of the genera *Cretarhabdus* and *Retecapsa* (Roth and Krumbach 1986). All *Eiffellithus* species are combined under *Eiffellithus* spp. (Watkins 1989; Eshet and Almogi-Labin 1996). Nannoconids are grouped in *Nannoconus* spp. All *Prediscosphaera* species are combined under *Prediscosphaera* spp. (Erba et al. 1995; Eshet and Almogi-Labin 1996). The *Rhagodiscus* group includes *R. achlyostaurion*, *R. asper* and *R. splendens* (Roth and Bowdler 1981; Thierstein 1981; Roth and Krumbach 1986; Crux 1991). All zeugrhabdotids (except *Z. erectus*) with major axis smaller than 5 µm are combined under *Zeugrhabdotus* spp. (Roth 1986; Watkins 1989).

Numbers for macrofauna refer to the raw counts considering entire shells as one specimen and fragments as parts of specimens.

Investigated samples for planktonic benthic Foraminifera and radiolarians abundance estimations in thin sections are shown.

Numbers for planktonic Foraminifera refer to the percentage of material estimated on the thin section using the plates of Baccelle and Bosellini (1965).

Total abundance classes for benthic Foraminifera and radiolarians are C=common (1–10 specimens in one field of view); F=frequent (1 specimen in 1–10 fields of view); R=rare (1 specimen in 11–100 fields of view).

Part B. Taxonomic list of calcareous nannofossils

These data are available as Electronic Supplementary Material.

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