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Palynofacies and calcareous nannofossils in the Upper Kimmeridgian, southeastern Paris basin (France)

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Key words. – Palynofacies, Calcareous nannofossils, Upper Kimmeridgian, Paris basin, Marine shallow-water deposits, Palaeoenvironments

Abstract. – The Upper Kimmeridgian Members "Calcaires blancs supérieurs" and the "Marnes à exogyres supérieures" of the southeastern Paris basin were investigated for their palynofacies and calcareous nannofossils. These members display alternating limestone-marl lithotypes and represent shallow marine palaeoenvironments. The lower carbonate member is interpreted as a proximal palaeoenvironment (palaeobathymetry = 5 to 10 m), where storm and swell deposits were prevalent and the salinity was occasionally weak. The relative richness of brown phytoclasts in this part is favoured by good preservation related to restricted conditions. These conditions would explain the dominance of the nannofossil *Cyclagelosphaera margerelii* in the nannofossil assemblages. The palynological data as those of the nannofossil assemblages show variations in the shift from carbonate member to marly member. The dominance of brown phytoclasts over black phytoclasts, the presence of amorphous organic matter (AOM), and the highest abundance and diversity observed within the nannofossil assemblages suggest that the maximum of distality occurred during this transition, at the basal part of the Marnes à Exogyres supérieures. The upper part of the section (marly member) characterized by storm deposits and storm-coquina beds is deeper (palaeobathymetry probably between 10 and 40 m depth) than the lower part. Oxidizing depositional conditions prevailed and explained the abundance of black particles found in this upper part, while proximate cysts and elevated non-placolith coccolith abundances indicate that relationships with the open sea were probably more significant compared to the lower part. Towards the top of the section, recurrences of restricted conditions are reflected by relatively elevated amounts of AOM and the abundance peak of the nannofossil *Biscutum ellipticum*. This study shows that micropalaeontological signals can be well recorded in vast lagunal domains. We speculate that salinity, nutrient supply, and oxygenation of the waters control microfossil associations. In shallow environments, these parameters are particularly fluctuating, especially when freshwater dilutes marine waters in surface, on the occasion of rainy periods or of intense arrival of continental waters.

Palynofaciès et nannofossiles calcaires du Kimméridgien supérieur du Sud-Est du bassin de Paris

Mots clés. – Palynofaciès, Nannofossiles calcaires, Kimméridgien supérieur, Bassin de Paris, Dépôts marins peu profonds, Paléoenvironnements.

Résumé. – Les membres des Calcaires blancs supérieurs et des Marnes à exogyres supérieures du bassin de Paris, datés du Kimméridgien supérieur ont été examinés pour leurs palynofacies et les nannofossiles calcaires. La succession des deux membres montre une alternance de calcaires et de marnes qui représente un paléoenvironnement marin peu profond. Les Calcaires blancs supérieurs, le membre inférieur, est interprété comme un paléoenvironnement très proximal (paléobathymétrie = 5 à 10 m), dans lequel prédominaient les tempêtes et dont la salinité était parfois faible. La relative richesse des phytoclastes bruns observée dans ce membre, argumente pour une bonne préservation qui serait liée au développement de conditions marines restreintes. Ces conditions restreintes expliqueraient la nette dominance de *Cyclagelosphaera margerelii* dans les assemblages de nannofossiles calcaires. Les données palynologiques et les assemblages de nannofossiles montrent de fortes variations des Calcaires blancs supérieurs aux Marnes à exogyres supérieures. La prédominance des phytoclastes bruns par rapport aux phytoclastes noirs, la présence de matière organique amorphe (MOA) et les plus fortes abondances et diversité observées dans les assemblages de nannofossiles suggèrent que le maximum de distalité est atteint lors de cette transition (partie basale des Marnes à Exogyres supérieures).

Après cette transition, le membre des Marnes à Exogyres supérieures, qui présente de nombreuses tempestites souvent enrichies en débris coquilliers, correspond à un milieu plus profond que celui du membre précédent (paléobathymétrie probablement entre 10 et 40 m). Des conditions oxydantes de dépôts ont prévalu et sont à l'origine de l'abondance des phytoclastes noirs, tandis que la forte proportion des kystes de dinoflagellés proximates, et celle des coccolithes non-placolithes plaident en faveur d'une meilleure communication avec la mer ouverte. Vers le sommet de la coupe, le retour à des conditions restreintes déjà rencontrées dans la partie inférieure est reflété par la présence de MOA et le pic d'abondance de *Biscutum ellipticum*. Cette étude montre que les enregistrements des signaux

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micropaléontologiques peuvent être de bonne qualité dans de vastes domaines lagunaires. Le niveau de la mer a paramétré les associations de microfossiles analysées mais ce facteur n'est pas unique ni majeur. Dans des environnements très peu profonds, comme celui qui est analysé, les paramètres salinité, oxygénation et nutriments sont particulièrement fluctuants, surtout lorsque les eaux douces diluent les eaux marines en surface, à l'occasion de périodes pluvieuses ou bien en raison de périodes d'intenses arrivées d'eaux continentales.

INTRODUCTION

In shallow marine environments (0 to 100 m water depth), characterized by elevated energy, the salinity of waters, nutrients, temperature and oxygenation (parameters conditioning the density of waters) strongly fluctuate and have an essential role on the productivity and composition of the microfossils [Smayda, 1983; Roth, 1994] as well as on the preservation of organic and mineral particles. Analysis of both palynofacies and nannofossils provides further informations about the parameters acting in shallow marine palaeoenvironments. They correspond to different groups, detrital particles (phytoclasts) and marine autochthonous elements (dinoflagellate cysts and nannofossils). As most phytoclasts (greater than 10 µm) entered the marine environment via river run-off, their proportion and morphotype variations reflected in part land surface runoff. In intervals characterized by low sea-level, high terrestrial palynodebris inputs are believed to be strong in surface water. The abundances of dinoflagellate cysts and calcareous nannofossils reflect primary productivity. This latter is controlled by the concentration in nutrients, also depending on the mixing of river and marine waters in very shallow environments. Oxygenation and salinity of the waters also governed the variations in phytoplanktonic assemblages.

During the late Kimmeridgian, sea-level decreased [Haq *et al.*, 1987]. In the Paris basin, a shallow marine palaeoenvironment prevailed (water depth shallower than 100 m), which was significantly subjected to wave actions and occasionally to storms, as is well recorded in the deposits [Guillocheau, 1991]. The purpose of this study is to investigate, in this basin, the significance of possible variations of both palynofacies and nannofossil assemblages associated to these shallow water deposits and to constrain the parameters controlling these variations. To date, no simultaneous palynological and nannofossil studies in the late Kimmeridgian of the Paris basin have been published.

REGIONAL GEOLOGY

The Loches section exposes over 44 m of the Kimmeridgian Marnes à *Exogyra virgula* Formation in the southeastern Paris basin (fig. 1). This formation, which extends from England to northern and western France and to northern Switzerland, is composed of black-grey marl and white limestone, with oyster shell beds and levels enriched in organic matter. The formation is subdivided into 3 members [Maubeuge, 1980; Menot, 1980] some of which are represented in the studied section. They are from bottom to top:

– the upper part of the Marnes à exogyres moyennes (Kimmeridgian δ)

– the Calcaires blancs supérieurs (Kimmeridgian ϵ)

– the Marnes à exogyres supérieures (Kimmeridgian ζ et η)

In these stratigraphic units, ammonites allow the dating of the Loches section as late Kimmeridgian (Eudoxus zone, Orthoceras sub-zone to sub-zone, Orthoceras horizon to Yo horizon, fig. 1). This indicates that the entire Eudoxus ammonite zone is represented in the Loches section. Hantzpergue [1993] assigns a duration of 1 Ma to the Kimmeridgian ammonite zone. Considering the works of Colombié and Strasser [2002] that recognized in the Eudoxus zone two medium scale sequences with a duration of 400 ka, the duration of the Loches section is estimated at 800 ka to 1 Ma. The thickness of the section being 38 meters, the sedimentation rate varies from 38 to 47 m/Ma. In the marly interval (samples Loch 8 to M11), the rates of terrigenous input varies from 22 to 39 m/Ma, considering a mean sedimentation rate (carbonate + terrigenous fractions) of 43 m/Ma.

The limestone marl alternations are fine bedded, this structure being continuous at the Paris basin scale [Guillocheau *et al.*, 2000]. The limestone/marl transition (Calcaires blancs supérieurs/Marnes à exogyres supérieures) was recorded throughout the Basin [Havre area section, Samson *et al.*, 1996].

Deposits corresponding to the Marnes à *Exogyra virgula* suggest a marginal sea opened during the upper Kimmeridgian Paris Basin, and located between (1) the London-Brabant continental massif in the north, supplier of sandy discharges in the Boulonnais region [Proust *et al.*, 1995], the Pays de Bray [Samson *et al.*, 1996], and (2) a carbonate shoal complex sometimes emersive in the south, reflected by the recifal and oolithic formations of the Jura mountains, oriented toward the open sea of the Tethys [Enay and Boullier, 2000].

The Calcaires blancs supérieurs Member represents a lowstand system tract of the third-order sequence Ki6 defined by Jacquin *et al.* [1999]. Numerous erosive wave structures and the absence of clay in the Calcaires blancs supérieurs Member are related to a restricted shallow depositional environment, influenced by permanent storms and swells (probably 5-10 m deep), and having variable surface salinities because of the presence of monospecific bivalve (ostreidae) fauna and ichnofauna. The transition to the Marnes à exogyres supérieures Member marks an increase of the sea-level and this member represents a transgressive system tract of the third-order sequence Ki6 [Jacquin *et al.* 1998]. This opening is suggested by oyster-rich, storm deposits (storm-coquina beds) [*sensu* Aigner, 1985]. These deposits characterize the upper offshore domain [depth 40 m; Guillocheau, 1991]. The Marnes à exogyres supérieures Member displays some levels rich in organic matter and related to weak water circulation conditions. In some levels this member presents storm-coquina beds correlated to strong circulation and mixing events.

METHODS

A total of 27 samples were analysed (fig. 1). For each sample, about 70 g were processed using non-oxidative palynological procedures [Courtinat *et al.*, 2003]. Palynofacies counts were made by traversing each slide.

Simple smear slides were prepared for nannofossil quantification. In the richest samples, 300 specimens were counted on the smear slide under a light polarising microscope, at 1560x magnification. In the poorest samples, specimens were counted following one or two longitudinal transverses. For each sample, the abundance of nannofossils per field of view is calculated taking into account the number of views necessary to count them and the density of material estimated on the smear slide, following the method of Pittet and Mattioli [2002]. Relative abundance of each species (percentage) is also calculated in each sample. 9 species are considered for the quantitative analysis. They represent together 78 to 100 % of the total nannofossil assemblage, which is composed of 16 species for the richest samples. The taxonomy used in this study for species identification follows the guidelines of Perch-Nielsen [1985] and Bown and Young [1997]. In particular, *Ellipsagelosphaera* NOËL, 1965 is considered to be a synonym of *Watznaueria* REINHARDT, 1964, so the former is not used. Preservation was evaluated with a light microscope. The nannofossil assemblage composition is also described by the Shannon index and evenness defined by Shannon and Weaver [1949]. The Shannon-Weaver index is a measure of the specific diversity and is expressed as $H' = -\Sigma\ pi\ \log_2 pi$ where pi is the relative abundance of each species. This index varies from 0 (presence of one species) to $\log_2 S$ (presence of all species with the same abundance) and S (the total number of species). Evenness (equitability) is a measure of dominance of species within the community ($Es = H'/\log_2 S$) and varies from 0, when the total number of specimens is represented by one species, to 1, when all species have the same abundance.

Results

Palynological data

The samples yielded a large quantity of phytoclast particles, black woody phytoclasts being predominant, sporomorphs that were mainly pollen included in the *Spheripollenites plexus*; a mean of 552 palynomorphs (136 to 1448 palynomorphs) per sample was recorded. 29 species (or species complexes) of dinoflagellate cysts and acritarchs were recorded. Amorphous organic matter [AOM; *sensu* Frank and Tyson, 1995] was present in few samples (fig. 2) and unusually substantial in samples Loch 18 and Loch 17. Palynomorph preservation was moderate to poor, particularly in samples characterized by enhanced bioturbation. Miospores were generally well preserved, probably owing to their more robust nature compared with the thinner-walled

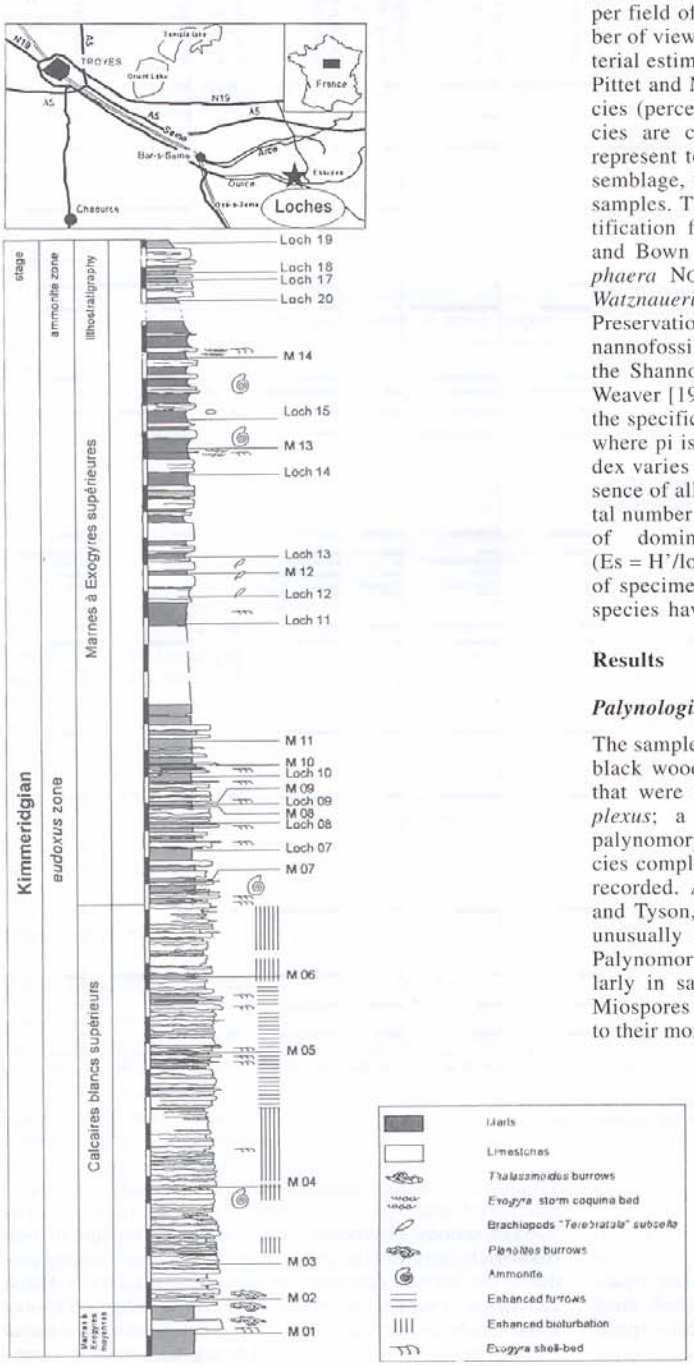

FIG. 1. – Location map, lithostratigraphic log and biostratigraphy of the Loches section.
FIG. 1. – *Carte de situation, lithologie et biostratigraphie de la coupe de Loches.*

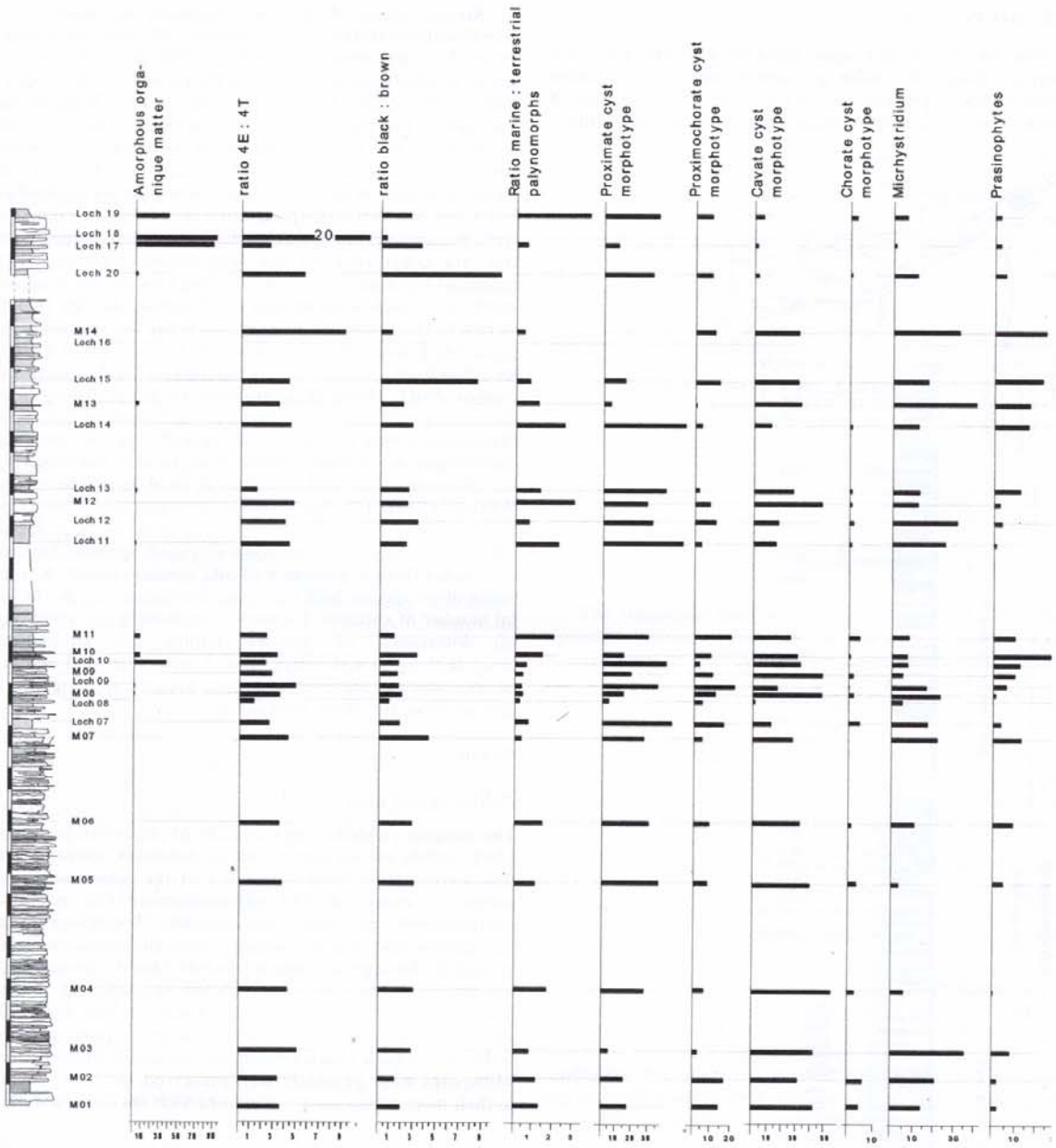

FIG. 2. – Variations of carbonate content and selected palynological parameters.
FIG. 2. – *Variations du carbonate de calcium et de quelques paramètres palynologiques significatifs.*

dinoflagellate cysts. These latter showed evidence of physical degradation; they were colourless and residues were recurrently composed of fragments of dinoflagellate cysts. Skolochorate cysts markedly were poorly preserved, most specimens having broken or twisted processes. Many specimens showed surface corrosion.

The woody phytoclasts were abundant except in true AOM-rich samples (fig. 2). As regards the black woody particles, the equant polygonal woody particles [*sensu* Frank and Tyson, 1995] were dominant (mean % RNF = 33; max = 68; min = 5). The other prevailing categories (to a lesser proportion) were the brown and black lath-shaped woody

particles (mean % RNF = 8.7; max = 38; min = 1 and mean % RNF = 8; max = 16; min = 0, respectively).

Proportions of palynomorphs, represented by both sporomorphs and organic-walled microplankton, greatly fluctuated (mean % RNF = 36; max = 91; min = 2). The ratio of marine: terrestrial palynomorphs was broadly unconnected to the phytoclast curve (fig. 2). The dinoflagellate cysts were classified into four morphotypes corresponding to the wall layer relations and the surface relief [Evitt, 1985]. These morphotypes were the proximate, proximochorate, chorate and cavate cysts. Acritarchs corresponded only to micrhystridids (indeterminate species of *Micrhystridium*). The last marine components were represented by the prasinophytes (*Leiosphaeridia* and chlorophyte algae).

Nannofossil data

All the samples investigated contained calcareous nannofossils and fluctuations in total abundance, preservation, species richness, diversity and evenness were important (fig. 3). Nannofossils are scarce in most layers but in some samples (M8 to M11 and M14) the inabundance strongly increases. The nannofossil total abundance is inversely correlated with the calcium carbonate content. Preservation is poor to moderate with 3 classes of preservation identified following the categories established by Roth [1973]. The poorly preserved specimens were observed in the lower part of the section (fig. 3). The nannofossil assemblages were composed of dominant coccolithophorids and of *Schizosphaerella* spp. (*incertae sedis*). A total of 16 species was identified and the composition showed great variations. Nannofloral species richness, diversity and evenness have parallel trends, similar to the preservation curve with a minimum in the lower part of the section and a maximum in the middle part (interval M8 to M11, fig. 3). The species diversity was low for the whole section, reflecting the dominance both in abundance (specimens per field of view) and in percentage of *Cyclagelosphaera margerelii*, with percentage peaks up to 95 % in samples with rare nannofossils (figs 3-4). The contribution of others was limited, but changes in abundance and percentage were observed (figs 3-4). *Schizosphaerella* spp. displayed an inverse distribution with respect to *C. margerelii* (figs 3-4).

DISCUSSION AND CONCLUSION

Palaeoecological significance of the phytoclasts

The phytoclasts represent the main component of the palynofacies (mean: 60 %; reaching up to 98 %). The black particles were generally more numerous than the brown particles (ratio black: brown of figure 2; M02, Loch 08, M11, Loch 14 and M18). Tyson [1995b], and Vincent and Tyson [1999] have postulated that in proximal palaeoenvironments, sediments being placed in more oxidizing conditions than in distal palaeoenvironments contained large amounts of woody phytoclasts, but also larger and more oxidized and carbonised woody phytoclasts (black particles). The more distal, and probably more reducing sediments had a relatively higher proportion of brown woody particles. In the Loches section, the ratio of equant– to lath-shaped (4E: 4T), black particles presented two weak values corresponding to the two samples with a low ratio of black to brown phytoclasts. Tyson and Follows [2000] demonstrated that the ratio 4E: 4T decreased with an increase of the distality factor. In the lower part of the section, where the brown particles were abundant, the depositional energy reflected by erosive wave structures was considerable. In the upper part, where black particles prevailed, storm deposits are significant. So, both parts of the sections are characterized by oxidizing depositional conditions. The presence of numerically significant brown particles (non oxidized particles) in the basal part of the Marnes à exogyres supérieures Member suggests an increase of the relative distality factor.

Palaeoecological significance of the dinoflagellate cysts and acritarchs

The palynological parameters (fig. 2) confirm that relatively proximal nearshore sedimentation was prevalent. This contention is supported by reduced plankton diversities and reduced marine: terrestrial palynomorphs ratios associated with a relatively high proportion of phytoclasts. The cavate cysts were numerous overall (fig. 2). Their abundance was diversely interpreted. They are typical of plankton-dominated assemblages from high energy, nearshore, and carbonate facies in the Albian-Cenomanian of west Texas [Scott and Kidson, 1977]. Sarjeant [1974] hypothesized the possibility that cavation of cysts was an adaptation to flotation and dispersal. It was also suggested that cavate cysts primarily reflected a relationship with upwelling rather than a flotation strategy [Courtinat, 1991]. Their variations of abundance could be directly linked to water level variations and the associated nutrient inputs in very shallow marine environments. The representatives of proximate cysts are compared to the cavate cysts, less numerous in Kimmeridgian deposits. Many of the proximate cysts are thick-walled cysts that were considered indicative of unstable, nearshore environments [Prauss, 1989], an opinion that is empirical and not validated by observations of the distribution of modern cyst types [Tyson, 1995a].

The representatives of *Micrhystridium* were abundant, which is common when referring to Kimmeridgian deposits. It was postulated that *Micrhystridium* may have found favourable conditions in deeper-water, lower energy palaeoenvironments as well as shallow restricted water [Wall, 1965; Lister and Batten, 1988] or brackish marginal conditions [Tyson, 1995a]. The discrepancies in the data indicate that the micrhystridids constituted a plexus of eurytopic forms that probably developed an « r-selected » life strategy [opportunistic organisms able to rapidly increase their population densities by early maturation and reproduction, Bucefalo Palliani and Riding, 1999]. The only representative of the Prasinophyte phycomata group was *Leiosphaeridia*. These thin-walled palynomorphs were overall not very abundant but their frequencies were sometimes elevated (up to 26 % of the organic walled microfossil assemblage). The abundance peaks did not correlate to the $CaCO_3$ percentages. Dominance of *Leiosphaeridia* was recorded from restricted lagoon and shallow water carbonate facies [Bernier and Courtinat, 1979] in the Upper Kimmeridgian.

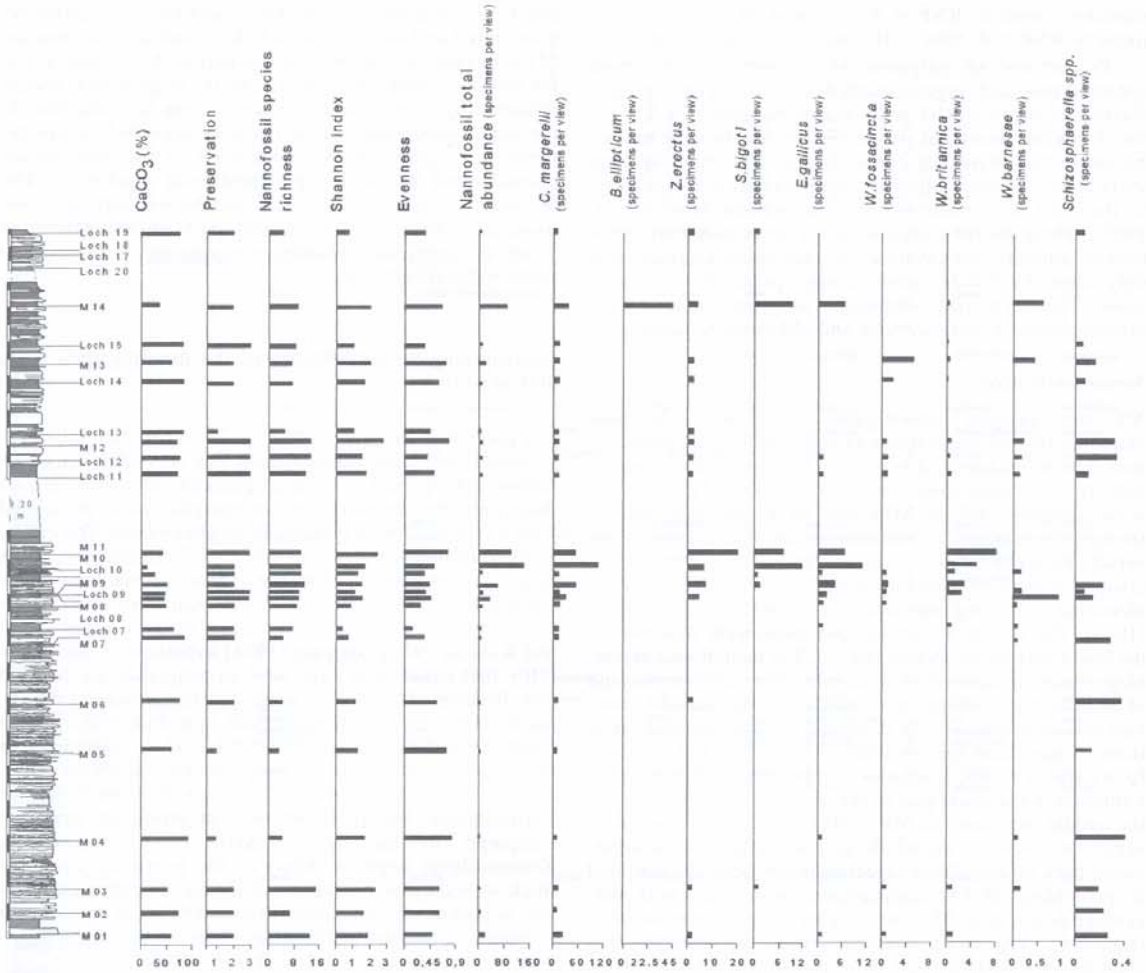

FIG. 3. – Variations of carbonate content and selected calcareous nannoplankton components.
FIG. 3. – *Variations du carbonate de calcium et de quelques composants significatifs du nannoplancton calcaire.*

Calcareous nannofossils preservation

In the Loches section, nannofossil abundance decreases with increasing carbonate content (fig. 3). Calcareous nannofossils are generally more abundant in marl than in limestone. This is interpreted as indicating that marly sediments preserve calcareous nannofossils better that limestone due to increasing diagenesis in limestone [Roth and Thierstein, 1972]. The composition of the assemblages also reflects the diagenetic overprint. Dissolution-resistant species usually are the large, thick placoliths with strongly imbricate elements [Hill, 1975]. Among these species, the *Watznaueria* group, consisting of rather robust placoliths, is considered as being more resistant to dissolution than other nannofossils. The dominance of *Watznaueria* in poorly preserved assemblages is recognized in many upper Jurassic sites. In the Kimmeridgian micritic limestones of the Ardèche margin, calcareous nannofossils are scarce, poorly preserved and the assemblage are dominated by *Watznaueria* (*W. barnesae* and *W. britannica*) followed by *C. margerelii* [Fauconnier *et al.*, 1996]. In the Upper Kimmeridgian and Lower Tithonian claystone sediments of the DSDP Sites 391C and 534A (Blake-Bahama basin, western North Atlantic), poorly preserved nannofossil assemblages are dominated by the *Watznaueria* group (*W. barnesae*, *W. communis*, *W. britannica*) followed by *Cyclagelosphaera* [Roth, 1983, for the site 534; Bralower *et al.*, 1989]. In the Loches section, preservation is generally not good and *W. fossacincta* is the species of the *Watznaueria* group that has the highest abundance per view and percentage recorded in badly-preserved samples (figs 3-4). Moreover, *Watznaueria* was not the dominant genus in this section. Because of its dominance in the early Jurassic nannofossil assemblages, and its high solution resistance, *Schizosphaerella* spp. is considered in terms of

diagenetic resistance as an equivalent of *W. barnesae* [Mattioli, 1997]. In the Loches section, *Schizosphaerella* spp. abundance and percentage increase with increasing carbonate content but are not correlated with preservation (fig. 3). Although diagenetic overprint has affected the total nannofossil abundance in the studied lithotypes, diagenesis is not thought to be the main factor controlling the nannofossil assemblage compositions.

Palaeoecological significance of calcareous nannofossils

The Loches section presents facies characteristics of a proximal shallow marine environment. Different studies on recent coccolithophorid distribution in plankton samples and sediment samples from marginal environments have shown the following common features: an increase in coccolithophorid abundance towards the deeper distal parts where the connection with the open ocean was better [British Honduras, Scholle and Kling, 1972], a decrease in species diversity with regard to the open ocean at the equivalent latitude [Asian marginal seas, Okada and Honjo, 1975; Honjo, 1977], the dominance of one or two species [Asian marginal seas, Okada and Honjo, 1975; Honjo, 1977; North sea, Houghton, 1993; Mediterranean sea, Cros, 2001], and the dominance of placolith-bearing coccolithophorids [Asian marginal seas, Okada and Honjo, 1975; Honjo, 1977]. At low latitudes, coastal coccolithophorid communities are dominated by placolith-bearing species [Young, 1994]. Shelf environments may also be characterized by sporadic blooms of non-coccolith nannofossils (nannoliths) [Young *et al.*, 2003].

We can deduce that, in the Loches section, the more distal conditions, characterized by high nannofossil abundance and high species richness and diversity, maxima in non-placoliths coccoliths, are recorded in sample M11 (fig. 3). In other levels, the nannofossil abundance, specific richness and diversity are not sufficient to allow us to define the evolution of palaeoenvironmental conditions. The nannofossil assemblage compositions can be informative, particularly some solution-resistant, common coccoliths that are useful facies indicators in the Upper Jurassic. In the Loches section, *C. margerelii*, the most abundant taxon, represents more than 50 % and up to 95 % of the calcareous nannofossil assemblages except in 6 samples (fig. 4). In Kimmeridgian palaeoenvironments of the boreal realm,

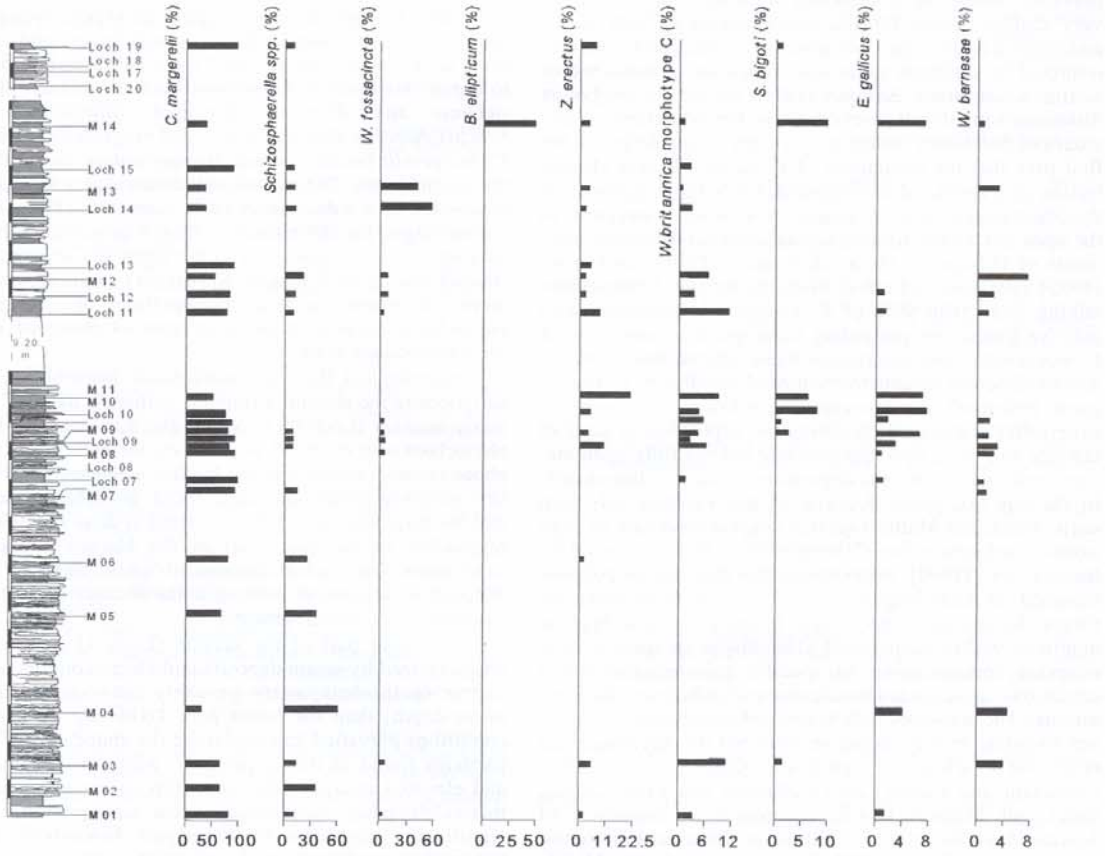

FIG. 4. – Relative abundances of selected calcareous nannofossil taxa.
FIG. 4. – *Abondances relatives des taxons significatifs de nannofossiles calcaires.*

Cyclagelosphaera margerelii dominates the calcareous nannofossil assemblages encountered in proximal shelf deposits [southeastern and southwestern Paris basin, this study and Samson, 2001 respectively], and in more distal shelf deposits [northwestern Paris basin, Cooper, 1989], whilst *Ellipsagelosphaera* (syn. *Watznaueria*) is dominant in distal deep shelf and epicontinental basin deposits [southern England, Medd, 1979; Cooper, 1989; Bown, 1998; southern Germany, Russia, Cooper, 1989; Bown, 1998]. The higher relative abundance of *Watznaueria* with respect to *C. margerelii* is also recognized in well-preserved assemblages recovered from pelagic sites. In the Upper Kimmeridgian-Lower Tithonian well-preserved nannofossil assemblages from the ODP site 261 (Argo Abyssal basin, northwestern Australia) *Watznaueria* is always abundant whilst *C. margerelii* is frequent [Bown, 1992]. Noël *et al.* [1994] in a synthesis on the contribution of calcareous nannofossils in the Middle-Upper Jurassic pelagic limestones have shown that *Ellipsagelosphaera* (syn. *Watznaueria*) dominates over *Cyclagelosphaera*. In the Kimmeridgian deposits of the western Paris basin, Janin *et al.* [1995], have shown an increase of circular forms (as *C. margerelii*) in the Watznaueriaceae assemblages in confined palaeoenvironments with important continental influences while the elliptic *Ellipsagelosphaera* (syn. *Watznaueria*) prevailed when the continental influences decreased. In very shallow Upper Jurassic environments of both boreal and tethyan realms, the dominance of *C. margerelii*, was interpreted by different authors as indicative of restricted or confined conditions. Keupp's [1976] studies on the Lower Tithonian nannofossil assemblages in the lithographic limestones of Solnhofen (southern Germany), considered for the first time that the dominance of *C. margerelii* was characteristic of a restricted environment, while the dominance of the *Watznaueria* species suggested a direct connection to the open sea. In the Kimmeridgian lagoonal limestone sediments of Orbagnoux (Jura, SE France), Tribovillard *et al.* [1992] have observed inframillimetric parallel laminae containing more than 90% of *C. margerelii* alternating with massive limestones presenting monospecific nannoflora of *C. margerelii*. They interpreted these alternations as the result of different palaeoenvironmental conditions in the lagoon: restricted and low-energy conditions with possible hypersaline water column during the deposition of parallel laminae and more open environment but not fully open marine conditions during the deposition of massive limestones. In the late Oxfordian deposits of the Swabian Alb deep shelf, Pittet and Mattioli [2002] suggest moderate to high trophic preferences for *C. margerelii* as it was inferred by Busson *et al.* [1992], who showed that this species possibly bloomed in high trophic conditions and fresh-water influxes. According to this review, *C. margerelii* can become dominant within nannofossil assemblages in specific time intervals corresponding to specific palaeoenvironmental conditions, as restricted conditions and/or high trophic conditions. The non-coccolith taxon *Schizosphaerella* spp. is not abundant in the Loches section, but its percentage can reach 60 % which is significant. Claps *et al.* [1995], Cobianchi and Picotti [2001], Mattioli and Pittet [2002], Pittet and Mattioli [2002] recognized a dominance of *Schizosphaerella* over coccoliths in Jurassic limestones. Cobianchi and Picotti [2001] have shown in Lower-Middle Jurassic pelagic limestones that the dominance of *Schizosphaerella* spp. co-occurred with a highly productive carbonate platform, while its relative abundance dropped in periods of platform demise and decrease of periplatform supply in the basin. The different authors considered *Schizosphaerella* as a taxon indicative of oligotrophic conditions.

Palynofacies vs. nannofossil assemblages: a convergent palaecological signal

The limestone-marl shift (Calcaires blancs supérieurs Member / Marnes à exogyres supérieures Member) suggests a proximal-distal shallow marine palaeoenvironment transition. The palynofacies components and calcareous nannofossils show that this transition is not regular and that small fluctuations of palaeoenvironmental conditions are recorded in each member.

The lower part of the section (carbonate member, M01 to Loch 07) is interpreted on the basis of sedimentological data as a shallow marine palaeoenvironment (palaeobathymetry probably between 5 and 10 meter-depth) where storm and swell deposits are prevalent and the salinity was sometimes weak, attested by stenospecific populations of Ostreidae. In this very shallow limestone palaeoenvironment brown phytoclasts and proximate cysts increase while the cavate cysts decrease. These data, according to literature, were quite divergent because of brown equant particles reflected distal facies, and on the other land, cavate cysts revealed proximal facies. From base to top of this interval, nannofossil total abundance, species richness and diversity decreased, *Watznaueria* and *Schizosphaerella* abundance declined progressively whereas *C. margerelii* became dominant representing up to 95% of the assemblages. The nannofossil assemblages show an increase and then a dominance of *C. margerelii*. These observations argue for the transition from a proximal carbonate environment still connected to the open sea towards a restricted marine environment. Restricted conditions could be more favourable to the preservation of the brown phytoclasts, explaining the discrepancies observed within the palynofacies data.

Palynological data and nannofossil assemblages show variations in the transition from the carbonate member to the marly member (Loch 08 to M11). The dominance of brown phytoclasts over the black phytoclasts, the presence of amorphous organic matter, and the highest abundance and diversity observed within the nannofossil assemblages suggest that the maximum of distality occurred in these samples, corresponding to the basal part of the Marnes à Exogyres supérieures. The gradual decrease of *Schizosphaerella* abundance also indicates an increase in the distance from shallow carbonate palaeoenvironments.

The upper part of the section (Loch 11 to Loch 19) characterized by storm deposits and storm-coquina beds is deeper (palaeobathymetry probably between 10 and 40 meter-depth) than the lower part. Oxidising depositional conditions prevailed and explained the abundance of black particles found in this upper part, while proximate cysts and elevated non-placolith coccolith abundances indicate that relationships with the open sea were probably more significant compared to the lower part. Towards the top of the section, maximum peaks in prasinophytes and woody phytoclasts along with low calcium carbonate content

(fig. 2) demonstrate the recurrence of brackish conditions associated to increased terrigenous input. These conditions could explain the sudden apparition of *Biscutum ellipticum*. Florishment of this genus was ascribed to strong upwelling or nutrient-rich, cold waters and possibly lower salinity due to partly restricted surface-water conditions [Roth and Bowdler, 1981; Noël *et al.*, 1987]. At the top, severe restricted conditions are reflected by relatively elevated amounts of amorphous organic matter, very low nannofossil abundance and strong dominance of *C. margerelii*.

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