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Stratigraphical and lateral distribution of sedimentary organic matter in Upper Jurassic carbonates of SE France

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Abstract

A detailed analysis of sedimentary organic matter (SOM) has been carried out in Upper Jurassic deep-water marls and carbonates of the Vocontian Basin (SE France). Its main purpose is to analyse the vertical and lateral trends of SOM distribution, in order to better understand processes and factors controlling the accumulation and preservation of organic constituents in basinal environments. The Vocontian Basin is characterized by widespread oxic depositional environments in the Upper Jurassic, as confirmed by the very low total organic carbon content (less than 0.25 wt.%). For such organic-poor deposits, palynofacies analysis represents the best tool to investigate SOM. Stratigraphic analysis of palynofacies trends has been performed within a pre-established sequence stratigraphic framework, defined by means of field sedimentology and, subsequently, complemented through lateral correlations, biostratigraphical constraints and geochemistry. This approach highlights the vertical signatures which are directly related to relative sea level changes. Furthermore, lateral correlations of palynofacies trends, at the scale of 3rd and 2nd order cyclicity, permit the signatures observable at basin scale to be distinguished from those detectable only at local scale. The former are controlled by factors affecting the whole basin, such as eustasy, regional tectonics and climate.

The palynofacies signatures at the scale of 3rd order cyclicity reflect relative sea level changes and the degradation state of SOM. Taking into account the preservation state of organic constituents leads to a better understanding of the relationship between SOM and sequence stratigraphy. Usually, condensed sections about maximum flooding surfaces are characterized by a decrease in the relative proportion of the terrestrial organic constituents. As far as sequence boundaries are concerned, they are marked by an increase in the relative proportion of continental organic matter, which results from a renewal of the erosion related to relative sea level fall. An increase in fresh woody debris has not been systematically observed at sequence boundaries. Nevertheless, the abundance of fresh woody debris tends to decrease stratigraphically towards maximum flooding intervals and laterally in a distal direction. The vertical palynofacies signatures at the scale of 2nd order cyclicity appear to be controlled by tectonics. In the Upper Oxfordian to Lower Kimmeridgian interval, these signatures confirm the hypothesis of a regional uplift of the hinterland and/or a differential basin subsidence related to the intense rifting activity in the Proto-Atlantic or to the westward opening of the Tethys.

Keywords: carbonates; sequence stratigraphy; organic matter; Upper Jurassic; France

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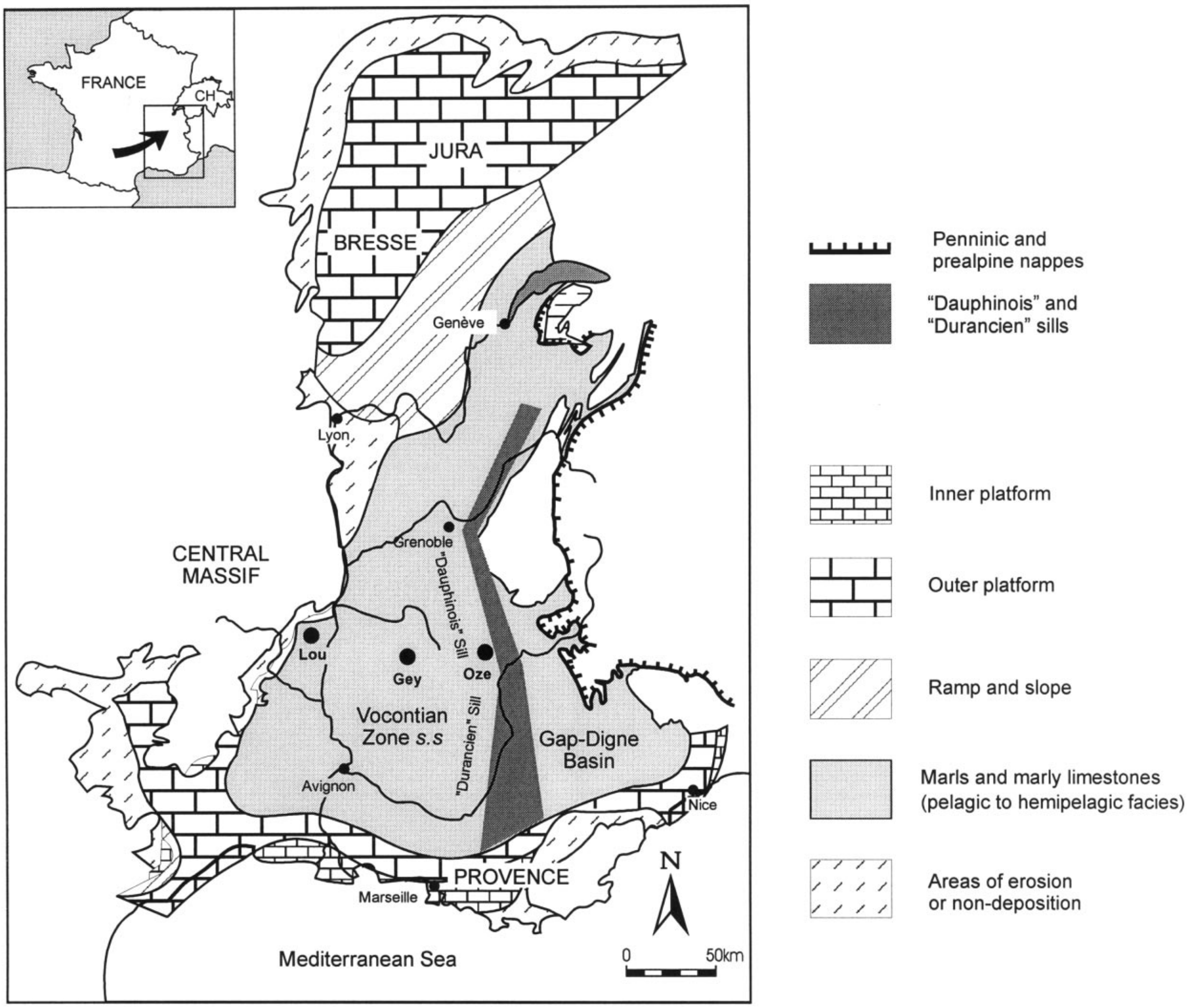


Fig. 1. Early Kimmeridgian palaeogeography of the Vocontian Basin *s.l.* (from Enay, 1984). Oze = Châteauneuf d'Oze section, Gey = Gorges de l'Eygues section, Lou = Louyre section. According to Baudrimont and Dubois (1977), a major sill (the "seuil dauphinois Gap-Sisteron") divided the southern part of the Vocontian Basin *s.l.* into two areas: the Vocontian Zone *s.s.* and the Gap-Digne Basin.

1. Introduction

The relationships between relative sea level change, palaeoenvironmental conditions, and composition and amount of sedimentary organic matter (SOM) have been investigated by many authors. Most of these works focus on organic-rich facies and study the best conditions for accumulation and preservation of organic matter, in order to define sedimentary models predicting occurrence and type of source-rocks (e.g. Müller and Suess, 1979; Demaison and Moore, 1980; Ibach, 1982; Habib, 1983; Tyson, 1987; Tissot, 1989; Klemme and Ulmishek, 1991; Creaney and Passey, 1993).

More recently, there has been an increasing interest in the contribution of SOM to the interpretation of depositional environment and sequence stratigraphy. During the past 15 years, many studies have shown how organic matter is able to record variations in eustasy, climate, oxycity, sedimentation rate, etc. even in organic-poor sediments (e.g. Habib and Miller, 1989; Powel et al., 1990; Gorin and Steffen, 1991; Pasley et al., 1991; Gregory and Hart, 1992;

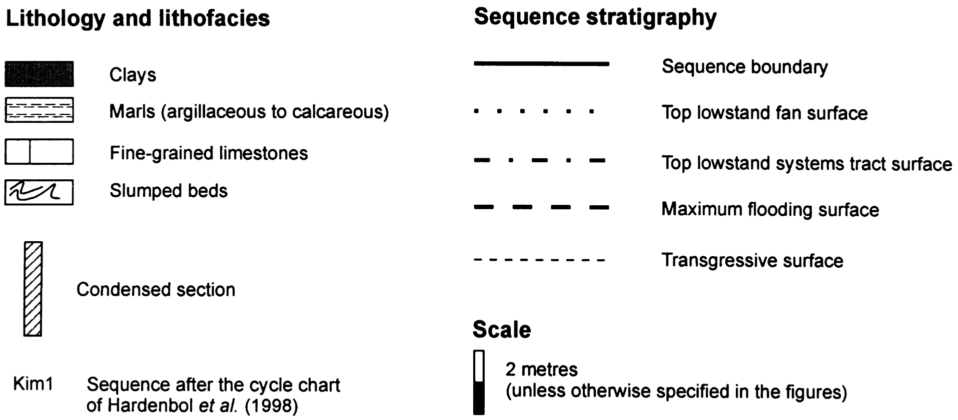


Fig. 2. Lithological and sequence stratigraphic legend for the description of the studied sections.

Partington et al., 1993; Blondel et al., 1993; Steffen and Gorin, 1993a,b; Tyson, 1993, 1995 and 1996; Sittler and Ollivier-Pierre, 1994; Pittet and Gorin, 1997; Waterhouse, 1998). These studies do not necessarily focus on source-rock occurrence. Considering organic facies analysis as a simple tool, they attempt to provide a complementary method for integrating and, eventually, improving standard sedimentological observations in both shallow-water and deep-water deposits. The present work can be ascribed to this latter category. By using detailed palynofacies analyses, its general purpose is to describe how SOM contributes to both environmental and sequence stratigraphic interpretation of Upper Jurassic deep-water sediments of the Vocontian Basin (SE France). More precisely, it aims at: (1) identifying which SOM signatures are directly related to third order relative sea level changes; and (2) identifying which SOM signatures are controlled, at least partially, by other palaeoenvironmental factors, such as climate, tectonics and degradation.

In order to identify the organic signatures controlled by relative sea level changes, SOM has been analysed with respect to a pre-established sequence stratigraphic framework. The latter has been defined by means of field sedimentological observations and subsequently calibrated with the cycle chart of Hardenbol et al. (1998) using biostratigraphic data from dinoflagellate cysts (Jan du Chêne, personel communication) and ammonites (Atrops, 1982 and personel communication).

2. Description of studied sections

2.1. Geological setting

The Vocontian Basin is located on the northwestern margin of the Tethys; its evolution is essentially related to the opening of the Ligurian Ocean. During the Late Jurassic, the studied area was characterized by synsedimentary tectonics and horst and graben structures. Carbonate platforms developed on the northern (Bresse and Jura) and southern rims (Provence). The details of the basin morphology in the Late Jurassic are not well known. This work refers essentially to the morphological framework depicted by Baudrimont and Dubois (1977). According to these authors, a major sill (the “seuil dauphinois Gap-Sisteron”) divided the southern part of the Vocontian Basin *s.l.* into two areas: the Vocontian Zone *s.s.* and the Gap-Digne Basin (Fig. 1).

2.2. Lithology

The lithology of the Upper Jurassic interval is very homogeneous and consists essentially of fine-grained carbonate and marl alternations, and slumps (Figs. 2–4). Microfacies do not display a great variability, most limestones being pelagic to hemipelagic mudstones/wackestones. Consequently, the sedimentological descriptions are very simple and mainly focused on bedding pattern and on concentration of bioclasts, bioturbation and authigenic minerals.

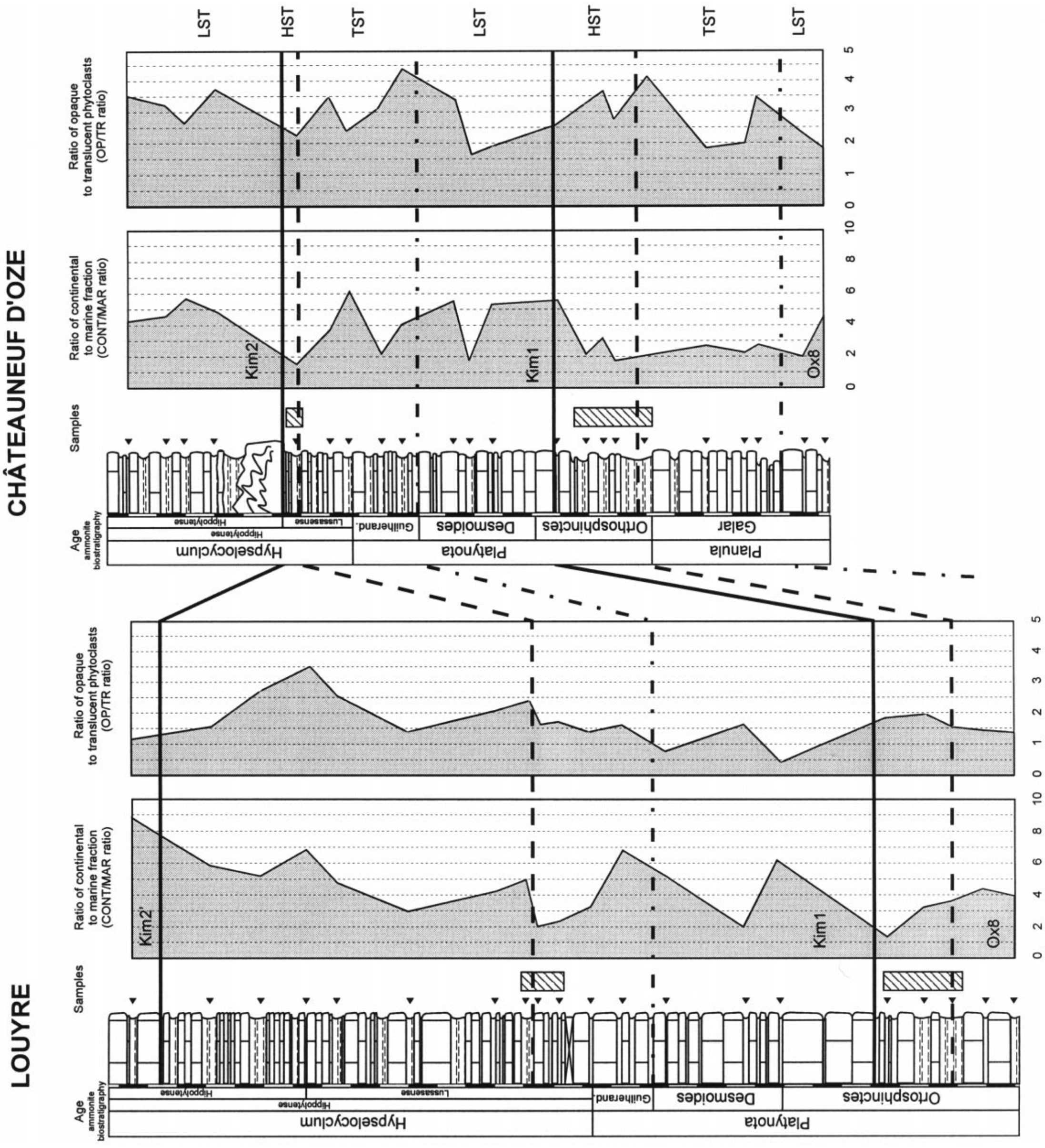


Fig. 3. Lithology, sequence stratigraphy and lateral correlation of the ratios of continental to marine fraction (CONT/MAR ratio) and opaque to translucent phytoclasts (OP/TR ratio) for the sections of Louyre and Châteauneuf d'Oze in the interval spanning maximum flooding surface Ox8 to sequence boundary Kim2′. See Fig. 1 for location and Fig. 2 for legend. LST = lowstand systems tract, TST = transgressive systems tract, HST = highstand systems tract.

As far as the origin of fine-grained deposits is concerned, two different sources are possible. Strohmenger and Strasser (1993) interpret the wackestones in the Berriasian of the Vocontian Basin as being formed by a more or less continuous "rain" of sediments supplied by planktonic organisms and only by minor platform-derived carbonate mud. Their interpretation is supported by the SEM observation of abundant nannoplankton (*Nannoconus*). On the contrary, in the Late Oxfordian deep shelf deposits of southern Germany (Pittet and Strasser, 1998), the carbonate mud is thought to be exported from the shallow platform. This is supported by the scarcity of nannofossils and insignificant bioerosion in autochthonous sponge reef. In the Upper Jurassic sections of the Vocontian Basin, the problem of distinguishing between these two different sources of carbonate remains unsolved. Although the nannoplankton productivity is supposed to start becoming important during this time period, there is no evidence in literature of nannofossil-bearing limestones in the Upper Jurassic of the Vocontian Basin.

Fine-grained limestones. They are grey to dark grey. Their texture is mudstone/wackestone. Bioclasts are mainly of pelagic nature: calcisphaerulids, Globochaetids, pelagic crinoids (*Saccocoma*), tests of radiolarians replaced by calcite, bivalve *filaments*, sponge spicules and fragments of ammonites. Benthic foraminifera are quite rare. Bioturbation is generally intense. It is highlighted by Fe-oxide and pyrite impregnations and appears as dark grey stains without any preferential orientation. Only two ichnofossils have been recognized: *Chondrites* and *Planolites*. The interpreted depositional mechanism is pelagic and/or hemipelagic settling.

Marls. They are generally dark grey and finely laminated. Bioturbation is intense and shows the same ichnofacies as in the fine-grained limestones. The carbonate content varies between 60 and 90%. Accordingly, they can be defined as calcareous marls and marly limestones. The depositional mechanism is pelagic and/or hemipelagic settling.

Limestone–marl alternations. The transition between the two lithofacies is generally quite gradual. Limestone–marl alternations can be created through varying carbonate productivity (dependent on terrigenous nutrient input, upwelling and water temperature) and/or through varying clay input, the whole possibly enhanced by diagenetic carbonate migration (Einsele and Ricken, 1991). In the Vocontian Basin, Lower Cretaceous limestone-marl alternations have been interpreted as the result of high frequency climatic cyclicity (Cotillon et al., 1980; Cotillon and Rio, 1984).

Slumps. This type of gravity deposits has been observed in all the studied sections. As already mentioned by Atrops and Ferry (1987), slump deposits are more likely to occur in specific stratigraphic intervals. This aspect will be addressed below.

2.3. Châteauneuf d'Oze section (Figs. 3 and 4)

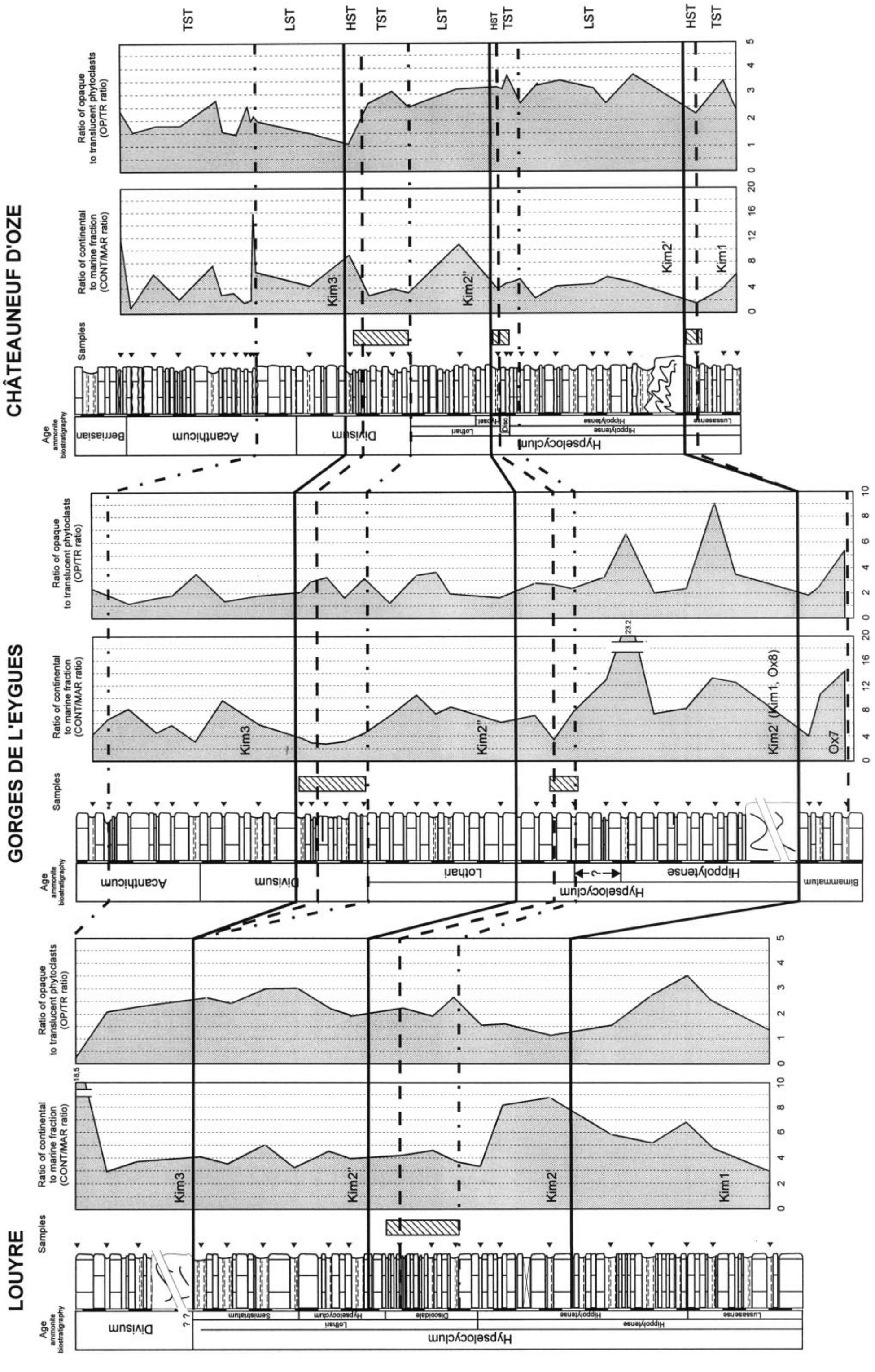
This section is located in the southern part of the Hautes Alpes area, some 50 km south of Grenoble (Fig. 1), along the D20 road between Veynes and Châteauneuf d'Oze (geographical coordinates 44°31′N–5°52′E; geological map 1:50.000 Gap 869). The studied section is ca. 45 m thick and spans the Late Oxfordian (Bimammatum Zone) to the Late Kimmeridgian (Acanthicum Zone) time interval. It has been studied by Atrops (1982) for the ammonite biostratigraphy and by de Rafélis Saint-Sauveur (1996) for the geochemistry.

The lithology mainly consists of massive limestones and calcareous marl–limestone alternations. Some intervals are particularly rich in ammonites and the whole section displays bioturbation. The most intense bioturbation occurs in condensed sections about maximum flooding surfaces. A slump is present at the base of the sequence Kim2′, in the Hypselocyclum Zone (Hippolytense Subzone). Its lithofacies is similar to that observed in the overlying and underlying sediments.

An important hiatus occurs in the upper part of the section (Acanthicum Zone): the Berriasian directly overlies Upper Kimmeridgian sediments. This hiatus appears as a thin disconformity within a single bed and is not marked by a lithological change. Enay (1984) interpreted this stratigraphic discontinuity as resulting from the erosional activity of a submarine canyon. Seguret et al. (1998) and Moussine-Pouchkine et al. (1998) associate this discontinuity with the erosion by currents of sediments liquefied by storm waves.

2.4. Gorges de l'Eygues section (Fig. 4)

This section is located in the Drôme Provençale area (Fig. 1), near Rémuzat (geographical coordinates 44°25N′–5°20′E; geological map 1:50.000 Nyons XXXI-39). The studied interval is ca. 52 m thick and spans the Late Oxfordian (Bimammatum Zone) to the Early Kimmeridgian (Acanthicum Zone) time interval. The sedimentology, geochemistry and sequence stratigraphy have been studied by Piuz (1997).


CHÂTEAUNEUF D'OZE
GORGES DE L'EYGUES
LOUYRE
Age ammonite biostratigraphy
Samples
Ratio of continental to marine fraction (CONT/MAR ratio)
Ratio of opaque to translucent phytoclasts (OP/TR ratio)
TST
LST
HST
Berriasian
Acanthicum
Divisum
Hypselocyclum
Lothari
Hippolytense
Lussasense
Semistriatum
Discoidale
Bimammatum
Kim3
Kim2''
Kim2'
Kim1
Kim2' (Kim1, Ox8)
Ox7
23.2
18.5

The lithology is very homogeneous and essentially made of calcareous marl–limestone alternations. Bioturbation is common throughout the studied interval but does not display variations as large as those observed in the Châteauneuf d'Oze section. No major concentrations of fossils and authigenic minerals have been encountered. The stacking pattern of the marl–limestone alternations is quite regular. The only gravity deposits observed consist of a ca. 20 m thick slump at the base of the sequence Kim2′, in the Hypselocyclum Zone (Hippolytense Subzone). Its erosional base overlies sediments of the Bimammatum ammonite Zone. The lithofacies in the slump are similar to those in the overlying and underlying sediments.

2.5. Louyre section (Figs. 3 and 4)

This section is located in the Ardèche area (Fig. 1), near Aubenas, between Lussas and Saint Privat along the Louyre River (geographical coordinates 44°36′N–4°28′E; geological map 1:80.000 Privas 198). The studied interval is ca. 56 m thick. It spans the Late Oxfordian (Planula Zone) to the Late Kimmeridgian (Acanthicum Zone) time interval. The ammonite biostratigraphy has been studied by Atrops (1982).

The lithology is essentially composed of calcareous marl–limestone alternations dominated by thick limestone beds. Ammonites and bioturbation are common throughout the section, but are more abundant in the marly intervals. No authigenic mineral concentrations have been encountered. A 6.5 m thick slump, marking the base of the sequence Kim3, has been encountered between the Divisum ammonite Zone and the Lothari ammonite Subzone. Lithofacies in the slump are similar to those in the overlying and underlying sediments.

3. Sequence stratigraphic framework

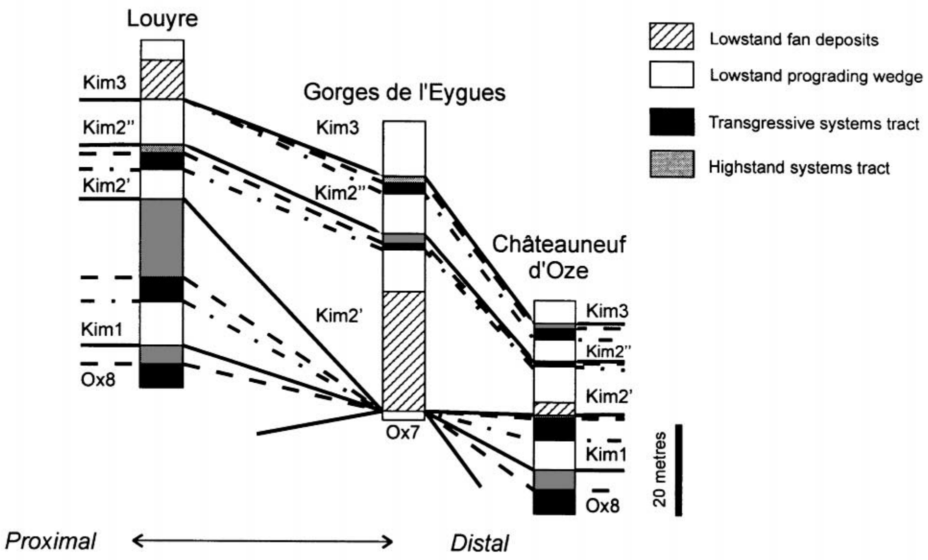
3.1. Sedimentological concepts

The Cretaceous sedimentary record in the Vocontian Basin appears to be consistent with the "classical" sequence stratigraphic model for carbonates described by Sarg (1988) and Vail et al. (1991). The sequences recognized by Strohmenger and Strasser (1993) and Jan du Chêne et al. (1993) in the Lower Cretaceous of the Vocontian Basin are essentially composed of thick lowstand deposits. Jacquin et al. (1991) stated that the carbonate platform in the southern Vercors (France) supplied clastic material to the basin during periods of relative sea level falls, forming lowstand systems tracts. In a similar way, the 3rd order sequences recognized in the two more distal sections (i.e. Gorges de l'Eygues and Châteauneuf d'Oze) are represented by well-developed lowstand systems tracts and thin transgressive and highstand systems tracts. This pattern is less evident in the more proximal section (i.e. Louyre), where the sequence Kim1 displays a thick highstand systems tract (see below).

The sedimentological concepts used for establishing the sequence stratigraphic framework are basically the same as those used by Strohmenger and Strasser (1993) and the Lower Cretaceous Working Group in the Vocontian Trough (Jan du Chêne et al., 1993). Their studies showed how sedimentary textures (e.g. mudstone/wackestone vs. floatstone/rudstone), structures and bedding pattern (e.g. varying thicknesses of limestone beds and marly interbeds) reflect eustatic sea level variations and synsedimentary regional tectonics. More precisely, the sedimentological interpretation and the proposed sequential subdivision of the studied sections are mainly based on lithofacies analysis, concentration of fossils, authigenic minerals, bioturbation and bedding pattern. Based on these concepts, a sequence stratigraphic interpretation of the Upper Jurassic section at Châteauneuf d'Oze has already been proposed by Jan du Chêne et al. (in press) (see below).

Lowstand systems tracts (*LSTs*). During lowstand periods, carbonate production shifts basinwards (Haq, 1991) and the terrigenous input of clay increases (Haq, 1991; Vail et al., 1991). Rapid progradation can lead to oversteepening of slopes and to slump deposits. The intervals characterized by slumps have been interpreted as lowstand fan deposits. Intervals dominated by calcilutites and forming thick limestone

Fig. 4. Lithology, sequence stratigraphy and lateral correlation of the ratios of continental to marine fraction (CONT/MAR ratio) and opaque to translucent phytoclasts (OP/TR ratio) for the sections of Louyre, Gorges de l'Eygues and Châteauneuf d'Oze in the interval spanning sequence boundary Kim2′ to sequence boundary Kim3. See Fig. 1 for location and Fig. 2 for legend. LST = lowstand systems tract, TST = transgressive systems tract, HST = highstand systems tract.



Ammonite biostratigraphy			Sequence stratigraphy
Zones	Subzones	Horizons	
Divisum			Kim3
Hypselocyclum	Lothari	Perayensis Semistriatum Hypselocyclum Discoidale	Kim2''
	Hippolytense	Hippolytense	Kim2'
		Lussasense	
Platynota	Guilherandense		
	Desmoides		
	Orthosphinctes		Kim 1

Fig. 5. Lateral correlation and table summarizing the sequence stratigraphic interpretation of the Lower Kimmeridgian in the Vocontian Basin. See Fig. 2 for sequence stratigraphic symbols.

beds and thick limestone–marl alternations have been attributed to lowstand prograding wedges.

Transgressive surfaces. Some transgressive surfaces are characterized by concentrations of fossils (essentially ammonites and belemnites), pyrite and intense bioturbation. However, most of the transgressive surfaces can only be inferred from their stratigraphic position between the lowstand systems tract (below) and the transgressive systems tract (above).

Transgressive systems tracts (*TST*'s). The increase in carbonate production and sedimentation on the platform leads to carbonate depletion and condensation in basinal environments (Haq, 1991). This interval is characterized by a thinning-upward trend of the limestone beds and marl–limestone alternations. Higher order transgressive surfaces, related to parasequences, have been frequently observed in this type of interval.

Maximum flooding surfaces. Maximum flooding surfaces generally occur within condensed sections (CS) corresponding to the upper part of the transgressive systems tracts and the lower part of the highstand systems tracts (primary condensed sections *sensu* Loutit et al., 1988). They record starved conditions and are marked by concentrations of fossils, pyrite and intense bioturbation. The primary condensed sections are generally represented by marl-dominated intervals or thin limestone-marl alternations. Generally it is quite difficult to precisely identify the maximum flooding surface. In fact, in most condensed sections there are two or three surfaces displaying sedimentary features of maximum flooding surfaces.

Highstand systems tracts (*HSTs*). As mentioned above, the early highstand deposits are generally condensed. The relative sea level fall during the late highstand systems tract is characterized by a thickening-upward tendency of limestone beds and of marl–limestone alternations. Usually, this interval is quite thin with respect to the lowstand deposits and is inferred from its stratigraphical position between the maximum flooding surface and the sequence boundary.

Sequence boundaries. Erosive surfaces at the base of slumps and gravity flows are interpreted as sequence boundaries. Boundaries between marl-dominated intervals (or thin limestone–marl alternations) and limestone-dominated intervals (or thick limestone–marl alternations) have been interpreted as abrupt increases in the sedimentation rate and, consequently, as sequence boundaries. In fact, they record a basinward shift of carbonate production and sedimentation, and/or an increase in the terrigenous input of clay.

3.2. Sequence stratigraphic interpretation

The sequential interpretation presented here for the interval spanning the latest Oxfordian to the Lower Kimmeridgian (Figs. 3–5) is a slightly modified version of the sequence stratigraphic framework established by Jan du Chêne et al. (in press). The only difference is the position of the maximum flooding surface of the sequence Kim1: it has been placed in the lowermost Hypselocyclum Zone (Hippolytense Subzone), instead of the uppermost Platynota Zone (Guilherandense Subzone) (Bombardiere and Gorin, 1998). We have chosen a different interpretation, ignoring the biostratigraphical constraints of Hardenbol et al. (1998), because of field sedimentological data (see below).

According to Jan du Chêne et al. (in press), the sequence Kim2 has been divided into two sequences. They have been called Kim2′ and Kim2″ to avoid any confusion with Hardenbol et al. (1998). This interpretation is confirmed by geochemical data and correlation with another proximal section in the Vocontian Basin. The sequence boundary Kim2″, occurring in the lower part of the Hypselocyclum Horizon, is supported by the manganese content curves at Châteauneuf d'Oze (de Rafelis Saint-Sauveur, 1996) and Gorges de l'Eygues (Piuz, 1997). Moreover, in the Ardèche area, it is laterally correlated with a slump in the section of Crussol (Atrops, 1982), located on the western margin of the basin.

The sequential interpretation of the interval spanning from the maximum flooding surface of the sequence Ox8 to the sequence boundary of the sequence Kim3 is schematically described below for the three studied sections.

3.3. Châteauneuf d'Oze (Figs. 3 and 4)

Ox8: the maximum flooding surface has been placed in a thick marly interbed characterized by intense bioturbation and concentration of ammonites. This marly interval is an event of regional importance and can be recognized in the whole basin and in other northern Tethyan domains (Atrops, 1982; Atrops and Elmi, 1984; Atrops and Ferry, 1987).

Kim1. The sequence boundary Kim1 is marked by a sudden lithological change and has been placed at the base of a limestone-dominated interval interpreted as a lowstand prograding wedge. The top lowstand surface has been picked in a marly interbed representing a bedding change. The maximum flooding surface has been chosen in a marly interbed displaying strong evidences of condensation, such as concentration of ammonites, intense bioturbation and presence of glauconite.

Kim2′. The sequence boundary has been chosen at the base of a slump, interpreted as a lowstand fan deposit. The transgressive systems tract displays clear sedimentary and biostratigraphical evidences of condensation. The Discoidale ammonite Horizon, which marks the base of the Lothari Subzone, is strongly condensed and characterized by a concentration of ammonites and bioturbation. The maximum flooding surface has been placed in the upper part of this thin interval.

Kim2″. The sequence boundary is marked by a bedding change and is confirmed by lithological and biostratigraphical lateral correlation. At Crussol (see above) it corresponds to a slump deposit. The overlying limestone-dominated interval has been interpreted as a lowstand prograding wedge. The maximum flooding surface has been placed in a condensed marly interval. The latter is observable across the whole basin (Atrops, 1982; Atrops and Elmi, 1984; Atrops and Ferry, 1987).

Kim3. The sequence boundary has been chosen at the base of a limestone-dominated interval, interpreted as a lowstand prograding wedge.

3.4. Gorges de l’Eygues (Fig. 4)

In the monotonous section of Gorges de l’Eygues, characterized to a large extent by regular aggradation, some surfaces have been inferred from lithological and biostratigraphical lateral correlation with the other sections. The sequences Ox8 and Kim1 have been eroded by the lowstand deposits of the sequence Kim2′.

Kim2′. The base of the thick slump in the lower part of the section, interpreted as a lowstand fan deposit, has been chosen as the sequence boundary Kim2′. The top lowstand and maximum flooding surfaces have been essentially inferred from lithological and biostratigraphical lateral correlations with the other sections.

Kim2″. The sequence boundary has been inferred from lateral correlations with the other sections. The top lowstand surface is marked by a bedding change. The maximum flooding surface has been placed in a marl-dominated interval.

Kim3. The base of a massive limestone bed has been picked as the sequence boundary Kim3. The overlying thick marl–limestone alternations represent the lowstand prograding wedge.

3.5. Louyre (Figs. 3 and 4)

Ox8: the maximum flooding surface has been placed in a marly interval characterized by a concentration of ammonites and intense bioturbation.

Kim1. The sequence boundary is marked by a bedding and lithological change. The overlying limestone-dominated interval has been interpreted as a lowstand prograding wedge. The maximum flooding surface has been picked in a marl-dominated interval characterized by intense bioturbation.

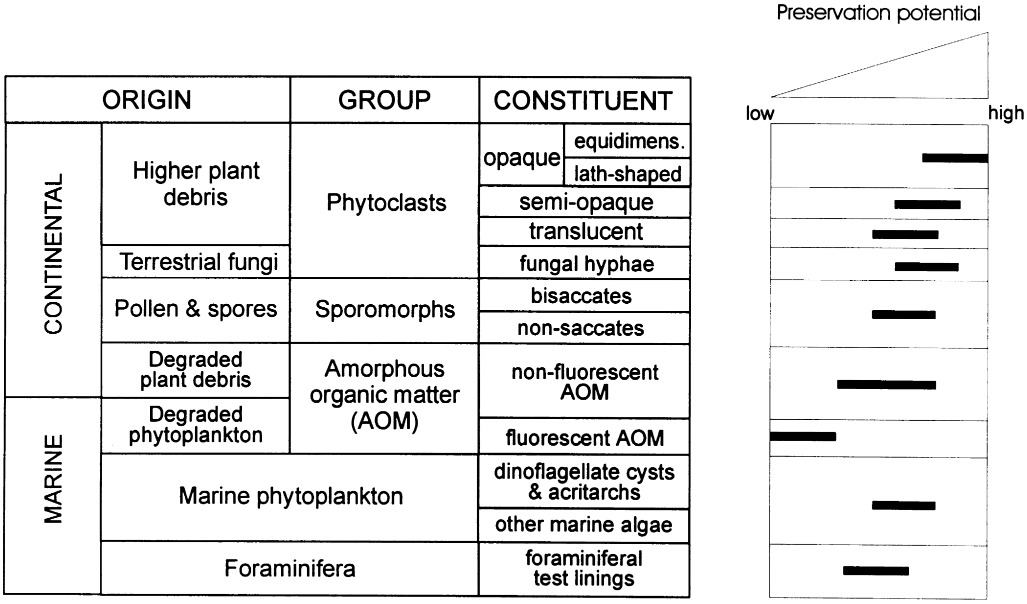
Kim2′. The sequence boundary, located at the base of a limestone-dominated interval, is marked by a bedding change. The overlying limestone-dominated interval represents the lowstand prograding wedge. The top lowstand surface is characterized by a bedding change. The maximum flooding surface is highlighted by a decrease in the thickness of beds and interbeds.

Kim2″. The sequence boundary is placed at the base of an undulating surface and it is marked by a bedding change. The thick limestone-marl alternations of the overlying interval represent the lowstand prograding wedge. The remaining part of the sequence has been eroded by the basal deposits of the sequence Kim3.

Kim3. The sequence boundary is placed at the base of the slump interpreted as a lowstand fan deposit.

The correlations of the depositional sequences and systems tracts highlight the following points (Fig. 5):

- the Châteauneuf d’Oze section is condensed with respect to the Gorges de l’Eygues and Louyre sections, especially in the transgressive and highstand systems tracts;
- lowstand fan deposits are mostly confined to the Kim2′ lowstand systems tract;



ORIGIN		GROUP	CONSTITUENT	
CONTINENTAL	Higher plant debris	Phytoclasts	opaque	equidimens.
				lath-shaped
			semi-opaque	
			translucent	
	Terrestrial fungi		fungal hyphae	
	Pollen & spores	Sporomorphs	bisaccates	
			non-saccates	
	Degraded plant debris	Amorphous organic matter (AOM)	non-fluorescent AOM	
MARINE	Degraded phytoplankton		fluorescent AOM	
	Marine phytoplankton		dinoflagellate cysts & acritarchs	
			other marine algae	
	Foraminifera		foraminiferal test linings	

Fig. 6. Palynofacies classification used in this study and preservation potential (modified from Bombardiere and Gorin, 1998). Sporomorphs, marine phytoplankton and foraminifera constitute the palynomorph group. The preservation potential of each palynofacies constituent is illustrated on the right hand side.

- the sequence boundary Kim2′ is related to a major relative sea level fall and is probably a sequence boundary of type 1 (in Normandy, Jan du Chêne et al.,1995, recognized a sequence boundary of type 1 at the base of Kim2′); and
- the top lowstand surface of Kim2′ is a major transgression in the Lower Kimmeridgian sequential evolution of the Vocontian Basin.

4. Methods and concepts of palynofacies analysis

The study of the organic matter has been performed by means of detailed palynofacies analyses. In fact, the total organic content in the studied sections is generally very low (less than 0.25 wt.%; Bombardiere and Gorin, 1998) and, in such organic-poor sediments, palynofacies analysis represents the best tool to investigate SOM. Palynofacies analysis is defined as the study of organic facies using transmitted light microscopy (Tyson, 1993). It involves the identification of palynomorphs, plant debris and amorphous components, their relative (and absolute) abundance, size spectra and preservation state (Combaz, 1964, 1980).

Percentage (based on particle number) has been established by counting at least 300 particles in each slide. Moreover, in order to estimate their preservation state, organic constituents have been also analysed in incident blue light microscopy, using a 450–490 nm excitation filter. The organic residues were produced by following the standard palynological procedure described by Steffen and Gorin (1993a,b). In order to determine the minimum significant difference in the numerical palynofacies parameters used in this work (see below), additional counts have been repeated in six slides. The recalculation of these parameters displays a deviation lower than 8% and, consequently, their level of significance is expected to be ±8%. The percentages based on counting less than 50 elements have been considered as insignificant.

In order to minimize the palynofacies variations related to 5th and/or 6th order cyclicity (i.e. limestone–marl alternations), most samples have been taken in marly interbeds. Anyway, the variations observed in limestone–marl alternations appear to be minor when compared to those observed at the scale of parasequences and sequences.

4.1. Classification and general principles

There are many classifications of SOM (e.g. Combaz, 1964,1980; Staplin, 1969; Burgess, 1974; Bujak et al., 1977; Parry et al., 1981; Whitaker, 1984; Boulter and Riddick, 1986; Hart, 1986; Powell et al., 1990; Davies et al., 1991; Steffen and Gorin, 1993a; see Tyson, 1987 for a correlation between the main organic groups). In the present study, the classification proposed by Steffen and Gorin (1993a) and modified by Bombardiere and Gorin (1988) has been used (Fig. 6). It can be considered as a modified version of the classification defined by Whitaker (1984), known as the “Shell Palynomaceral Classification”.

The continental fraction comprises opaque phytoclasts (oxidized debris of higher plants), semi-opaque phytoclasts (partially oxidized debris of higher plants), translucent phytoclasts (non-oxidized debris of higher plants), terrestrial fungal hyphae, terrestrial sporomorphs (land plant pollen and spores) and amorphous organic matter (AOM) derived from the degradation of terrestrial constituents. Opaque phytoclasts consist of usually uniformly black or almost black, equidimensional or lath-shaped, structureless particles. They are essentially composed of charcoal and biochemically oxidized wood. In spite of their high density (Van der Zwan, 1990), they display a high portability and can undergo long distance transport. Opaque phytoclasts have been divided into equidimensional and lath-shaped particles because of their different hydrodynamic behaviour, the latter being characterized by the highest portability (Parry et al., 1981; Whitaker, 1984; Steffen and Gorin, 1993a). Lath-shaped opaque phytoclasts consist of elongate particles whose length to width ratio is higher than two. Semi-opaque phytoclasts consist of brown to dark brown, equidimensional or lath-shaped particles, with or without visible structure (commonly structureless). They mostly include material derived from partial oxidation of cortex, stem and root tissues. Their density is relatively high and their portability is supposed to be low (Van der Zwan, 1990). Translucent phytoclasts consist of brown to orange, usually structured particles. They are composed of leaf, stem, cortex and root tissues. Leaf debris appears as thin, transparent, structured sheet (cuticles). Translucent phytoclasts, and especially leaf debris, are characterized by a low density and their portability is supposed to be higher than that of semi-opaque phytoclasts (Van der Zwan, 1990).

The marine fraction is composed of dinoflagellate cysts, other marine algae, foraminiferal linings and AOM derived from the alteration of marine constituents. In thermally immature sediments, fluorescent AOM is considered to be of algal/bacterial origin and characterizes low-energy, oxygen-depleted environments (Staplin, 1969; Bujak et al., 1977; Tyson, 1987). On the other hand, non-fluorescent AOM may be derived from the degradation of both marine and terrestrial material.

The most efficient mechanism of organic matter degradation is the bacterial oxidative breakdown. The rate of consumption is related to the availability of electron acceptors (the most important of which is oxygen). In pre-depositional degradation, exposure time to microbial activity is proportional to bathymetry and distance from the source area (e.g. shoreline for the continental fraction and upwelling zones for the marine fraction). In post-depositional degradation, exposure time is mainly controlled by sedimentation rate, bioturbation and reworking (Müller and Suess, 1979; Ibach, 1982; Tyson, 1987; Huc, 1988).

Organic matter displays different preservation potentials according to its original composition (Huc, 1980; Tegelaar et al., 1989; de Leeuw and Largeau, 1993). Generally, lignin-rich and lipid-rich compounds are quite resistant to degradation, whereas carbohydrate-rich and protein-rich compounds display very high decomposition rates and are usually not preserved (Huc, 1980). Opaque phytoclasts are considered as the most refractory material. Fig. 6 attempts to assess the relative preservation potential of palynofacies constituents on the basis of both supposed biochemical composition and optical evidences. Relative preservation potential of organic constituents suggests that palynofacies residues affected by strong degradation are likely to contain a high proportion of lignin-rich organic matter such as opaque phytoclasts, whereas lipid-rich constituents such as dinoflagellate cysts are more likely to occur in less degraded SOM.

In the studied sections, the continental fraction is essentially composed of phytoclasts and sporomorphs and the marine fraction almost totally of dinoflagellate cysts. The relative abundance of non-fluorescent

AOM is generally low, whereas fluorescent AOM is totally absent.

4.2. Parameters used in this work

In this study palynofacies variations have been investigated using the following quantitative and qualitative parameters: (1) the ratio of continental to marine fraction (CONT/MAR ratio, see Fig. 6); (2) the ratio of opaque to *s.l.* translucent phytoclasts (OP/TR ratio, see Fig. 6); (3) the fluorescence and morphological preservation of palynomorphs (i.e. phytoplankton and sporomorphs); and (4) the size and shape of phytoclasts. The *s.l.* translucent phytoclasts comprise semi-opaque phytoclasts, *s.s.* translucent phytoclasts and fungal hyphae. The use of ratios is a procedure recommended for routine investigation of percentage data. In fact, ratios are unaffected by data closure effects.

1. The *ratio of continental to marine fraction* is laterally and stratigraphically related to proximal-distal trends (Tyson, 1993; Steffen and Gorin, 1993a; Pittet and Gorin, 1997) and degradation, because of the overall better preservation potential of the continental fraction (Fig. 6). If the marine fraction is not strongly affected by degradation, this parameter tends to decrease laterally in a distal direction, and stratigraphically in transgressive phases. On the other hand, if strong degradation of marine constituents occurred, these trends can be inverted and palynofacies becomes dominated by opaque phytoclasts (Bombardiere and Gorin, 1998). Consequently, when degradation is quite intense, the CONT/MAR ratio, which is normally a good indicator of progradational–retrogradational trends of a shoreline, may become quite misleading. In this study, AOM has not been taken into account for the calculation of the ratio of continental to marine fraction. In most samples, the relative abundance of this constituent is very low and does not significantly affect the ratio.
2. The *ratio of opaque to s.l. translucent phytoclasts* is also related to proximal–distal trends and tends to increase in a distal direction (Summerhayes, 1981; Tyson, 1989, 1993, 1995; Pittet and Gorin, 1997). The opaque phytoclasts are mainly derived from oxidation of higher plant debris in subaerial environments. In fact, there is little evidence that this process takes place in subaqueous environments (Tyson, 1995). Consequently, the increase of the ratio of opaque to translucent phytoclasts in a distal direction appears to be essentially related to a preferential degradation of the translucent phytoclasts in the water column during prolonged transport and in the depositional environment.
3. Both *morphological preservation and fluorescence of palynomorphs* are controlled by thermal maturation (Robert, 1988) and degradation (Tribovillard and Gorin, 1991; Tyson, 1995). If sediments are immature or early mature, changes in these parameters can be directly related to the intensity of degradation. More precisely, the fluorescence and morphological preservation state of palynomorphs display a negative correlation with the degradation intensity.
4. As far as *size and shape of phytoclasts* are concerned, terrestrial organic matter can be considered as any other sedimentary grains (Huc, 1988). Its distribution is affected by the energy of the depositional environments. Most fine organic particles are hydrodynamically similar to clay and silt (Tyson, 1987). Similarly to inorganic particles, shape is an important factor influencing the relative portability of the terrestrial organic particles: the portability of lath-shaped debris is higher than that of equidimensional debris of similar size. Nevertheless, caution should be applied when attempting an estimation of the energy of depositional environments. Size, sorting and rounding (i.e some of the main criteria used by “mineral” sedimentologists for assessing the energy conditions) are also largely affected by degradation occurring in the watermass and at the sediment–water interface.

5. Results of palynofacies analysis

5.1. Variations at the scale of 3rd order cyclicity

5.1.1. Description of vertical variations (Figs. 3 and 4)

In the studied sections, the following vertical signatures have been observed at the scale of 3rd order cyclicity. In some cases they reveal clearly recognizable variations related to the sequence stratigraphic framework. The size of most opaque phytoclasts is between 35 and 60 μm. Both size and shape of phytoclasts do not display significant variations. The palynomorph preservation state is moderate to high.

Ratio of continental to marine fraction. The condensed sections about maximum flooding surfaces are marked by low values of the CONT/MAR ratio. Moreover, in these intervals, the marine fraction is characterized by an increase in the specific diversity of dinocysts. By contrast, the sequence boundaries usually are marked by an increasing proportion of terrestrial constituents. This signature has not been observed in two cases: in the Louyre section, the sequence boundaries Kim2$''$ and Kim3 do not display any increase of the CONT/MAR ratio (Fig. 4). The sequence boundary Kim2$'$ is also marked by an abrupt increase in the sporomorph percentage.

Ratio of opaque to translucent phytoclasts. Usually this ratio increases slightly in primary CS. This trend can be better seen in the average values displayed in Figs. 7–9. In the maximum flooding surface of the sequence Kim1 at Châteauneuf d'Oze, this signature has not been observed. As far as sequence boundaries are concerned, they are not systematically marked by a decrease of the OP/TR ratio. For instance, the sequence boundary Kim2$'$ at Châteauneuf d'Oze and Gorges de l'Eygues is marked by an increase in the proportion of opaque phytoclasts (Fig. 4).

Quantitative palynology. In all the studied sections, a complementary analysis has been carried out on the major dinocyst morphogroups (i.e. simple chorate cysts, complex chorate cysts, proximate cysts, cavate cysts and *Gonyaulacysta* complex). No clear correlations have been observed between the sequence stratigraphic trends and the vertical distribution of these major dinocyst morphogroups. In particular, no relative increase in chorate dinocysts has been observed in the distal, condensed palynofacies, although they are considered as being indicative of more distal conditions (e.g. Scull et al., 1966; Partington et al., 1993). Nevertheless, when the dinocyst distribution is studied in more detail (at least at the level of genera and species), it displays interesting relationships with the sequence stratigraphic framework (Jan du Chêne et al., in press). In the Châteauneuf d'Oze section, the quantitative study of species and genera has allowed the identification of the assemblages preferentially associated with lowstand or transgressive settings. For instance, in the sequences Ox8 and Kim1, *Gonyaulacysta jurassica* is more abundant in TSTs and primary CS, whereas *Rhynchodiniopsis cladophora* is more abundant in LSTs.

5.1.2. Description of lateral variations (Figs. 3, 4, 7–9)

As observed above, the vertical signature of the OP/TR ratio reflects only partially 3rd order regressive–transgressive trends, whereas the CONT/MAR ratio appears to fit better with the sequence stratigraphic framework. The correlations described below have been focused on these two parameters.

Size of phytoclasts and proportion of lath-shaped opaque phytoclasts do not display lateral trends in the sections and interval studied here. Also the palynomorph preservation state does not display any clear lateral trend. It has been analysed also with respect to the thickness of systems tracts, but no lateral patterns have been observed.

The correlations of the sections are displayed in Figs. 3, 4, 7–9. In the last three figures, the average values of both ratios have been used for the LSTs and primary CS. They have permitted the verification of both stratigraphical and lateral trends. In the sequence Ox8, whose LST has not been investigated, the primary CS has been compared with the TST. In the sequence Kim3, whose maximum flooding interval has not been investigated, the LST has been compared with part of the TST. The positions of the intervals interpreted as primary CS have been indicated in Figs. 3 and 4.

Ox8 (Figs. 3 and 7): only the TST and the CS have been correlated. In the Louyre section, the CONT/MAR ratio is higher in both TST and primary CS. It is considerably higher in the TST than in the CS, whereas, in the Châteauneuf d'Oze section, it does not vary significantly between the two intervals. The OP/TR ratio is much higher in the Châteauneuf d'Oze section for both investigated intervals. In both sections, the primary CS shows a slightly higher value than the TST.

Kim1 (Figs. 3 and 7): in both sections, the sequence boundary Kim1 is characterized by a major increase in the CONT/MAR ratio and a decrease in the OP/TR ratio. In both sections, the CONT/MAR ratio displays higher values in the LST. In both investigated intervals, this parameter is higher in the Louyre section. The OP/TR ratio of both investigated intervals is

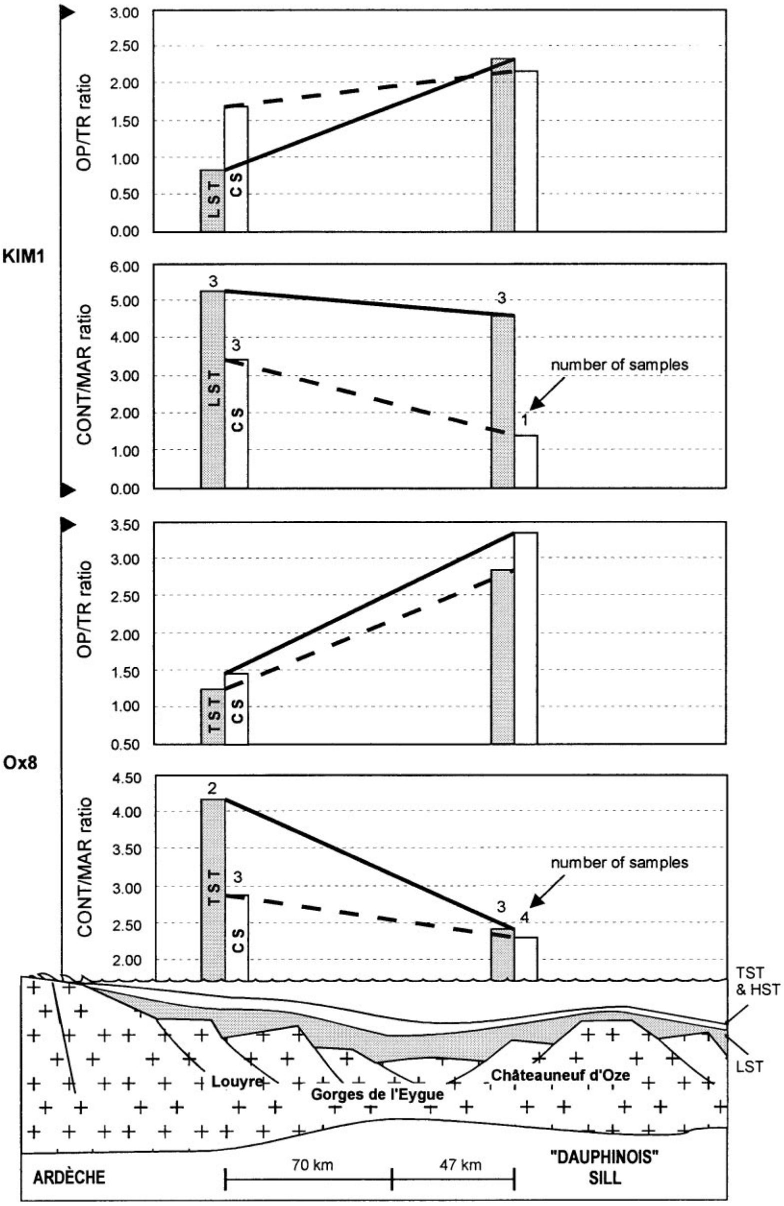


Fig. 7. Lateral correlation of the average values of the ratios of continental to marine fraction (CONT/MAR ratio) and opaque to translucent phytoclasts (= OP/TR ratio) for the sequences Ox8 and Kim1 at Louyre and Châteauneuf d'Oze. LST = lowstand systems tract, TST = transgressive systems tract, CS = primary condensed section, HST = highstand systems tract. See Fig. 1 for location and Fig. 2 for legend. The distances between the sections refer to the present-day position.

higher in the Châteauneuf d'Oze section, thereby indicating a higher proportion of translucent phytoclasts in the Louyre section. In the latter section, the OP/TR ratio is higher in the primary CS, whereas in the Châteauneuf d'Oze it is slightly higher in the LST.

Kim2′ (Figs. 4 and 8): the sequence boundary Kim2′ does not display the same signature in the

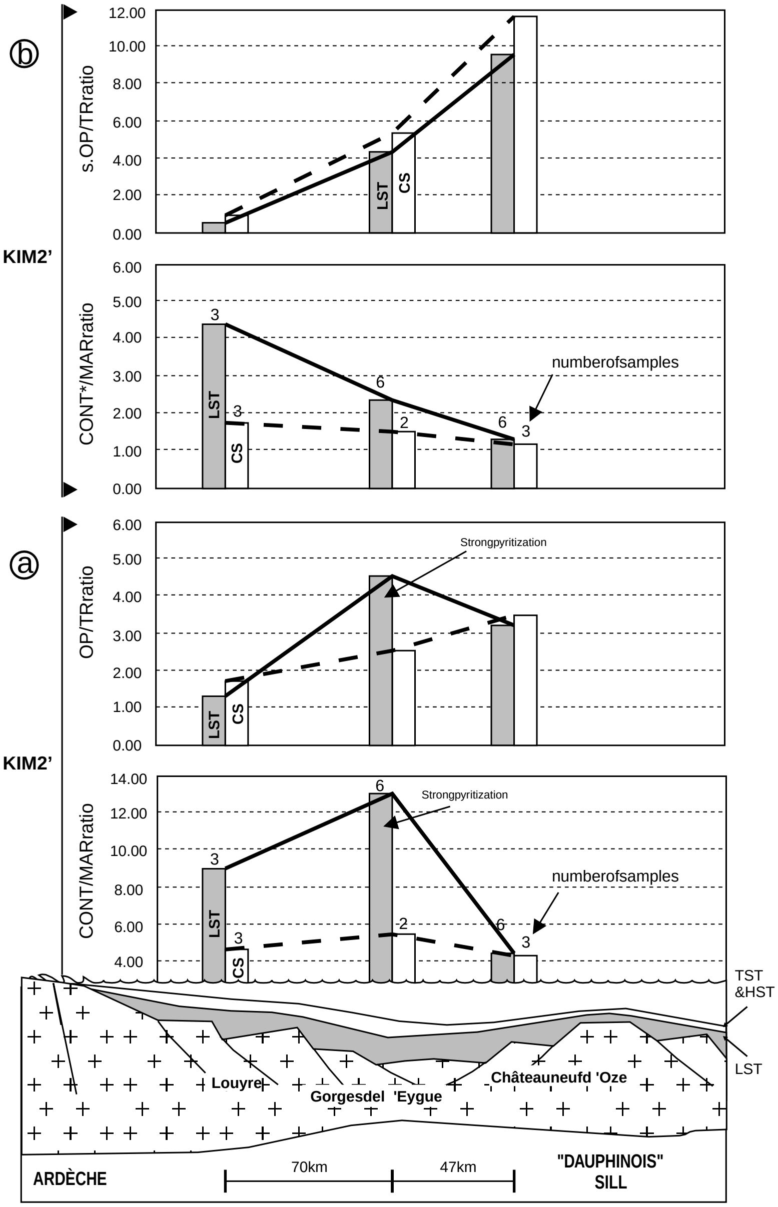


Fig. 8. (a) Lateral correlation of the average values of the ratios of continental to marine fraction (CONT/MAR ratio) and opaque to translucent phytoclasts (OP/TR ratio) for the sequence Kim2′ at Louyre, Gorges de l'Eygues and Châteauneuf d'Oze. LST = lowstand systems tract, TST = transgressive systems tract, CS = primary condensed section, HST = highstand systems tract. See Fig. 1 for location and Fig. 2 for legend. The distances between the sections refer to the present-day position. (b) Same as (a), but in this case, for the calculation of both ratios, opaque phytoclasts have not been taken into account. CONT*/MAR ratio = (semi-opaque phytoclasts + translucent phytoclasts + fungal hyphae + sporomorphs)/(marine phytoplankton + foraminiferal linings); s.OP/TR = semi-opaque phytoclasts/(translucent phytoclasts + fungal hyphae).

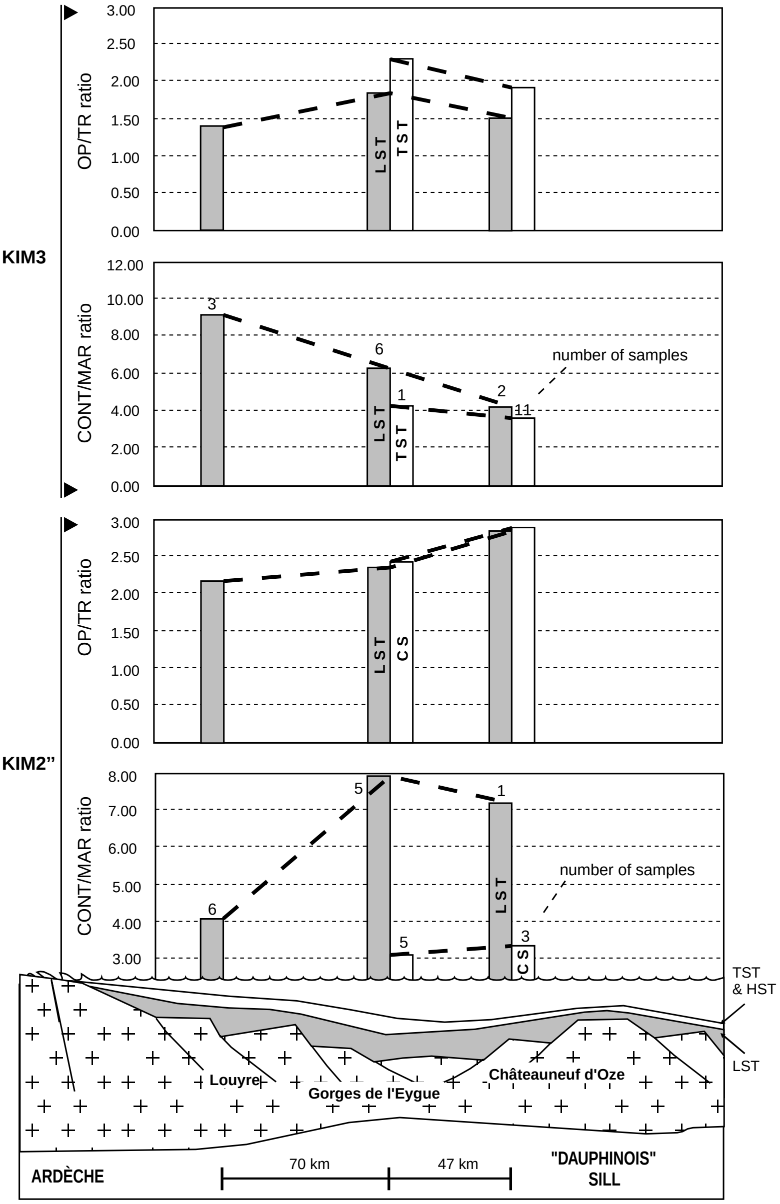


Fig. 9. Lateral correlation of the average values of the ratios of continental to marine fraction (CONT/MAR ratio) and opaque to translucent phytoclasts (OP/TR ratio) for the sequence Kim2″ and Kim3 at Louyre, Gorges de l'Eygues and Châteauneuf d'Oze. LST = lowstand systems tract, TST = transgressive systems tract, CS = primary condensed section, HST = highstand systems tract. See Fig. 1 for location and Fig. 2 for legend. The distances between the sections refer to the present-day position.

three sections. It is always marked by an increase in the CONT/MAR ratio, but at Louyre the OP/TR ratio decreases, whereas at Gorges de l'Eygues and Châteauneuf d'Oze it increases. These different signatures, observed in the two more distal sections, may be partially associated with the presence of slumps and, consequently, erosion. At Châteauneuf d'Oze, only a very thin part of the HST of the underlying sequence

Kim1 is preserved and, at Gorges de l'Eygues, the whole sequence Kim1 and most of the HST of the sequence Ox8 have been eroded.

In Fig. 8a, the ratios in the LST of the Gorges de l'Eygues section display anomalously high values, because palynofacies counts are partially biased by an intense pyritization. Therefore, only the values from Louyre and Châteauneuf d'Oze should be compared in these two diagrams. In order to compare the three sections, the ratios have been recalculated without taking into account the opaque phytoclasts and by using the semi-opaque instead of the opaque phytoclasts in the OP/TR ratio (Fig. 8b). In the three sections, the CONT*/MAR ratio (the ratio of continental to marine fraction without opaque phytoclasts) in both intervals decreases from Louyre (more proximal) to Châteauneuf d'Oze (more distal). This ratio is higher in the LST than in the CS, the difference between the two intervals decreasing from Louyre to Châteauneuf d'Oze. This confirms the trends in the original ratios of Fig. 8a observed at Louyre and Châteauneuf d'Oze. In the three sections, the s.OP/TR ratio (the ratio of semi-opaque to translucent phytoclasts) increases from Louyre to Châteauneuf d'Oze (Fig. 8b). This ratio is lower in the LST than in the CS, the difference between the two values increasing from Louyre to Châteauneuf d'Oze. This confirms the trends observed in the original ratios of Fig. 8a at Louyre and Châteauneuf d'Oze.

Kim2″ (Figs. 4 and 9). At Louyre, because of the erosion associated with the slump at the base of the sequence Kim3, only part of the LST is preserved in the sequence Kim2″. The sequence boundary Kim2″ is marked by an increase in the CONT/MAR ratio at Châteauneuf d'Oze and Gorges de l'Eygues. No particular change of this ratio has been observed at Louyre. At Châteauneuf d'Oze and Gorges de l'Eygues, the CONT/MAR ratio is generally higher in the LST than in the CS. The OP/TR ratio increases distally overall, but does not show any significant difference between the LST and the primary CS of each individual section.

Kim3 (Figs. 4 and 9): the sequence boundary Kim3 is not characterized by a homogeneous signature. At Louyre, this discontinuity occurs between two LST and no clear trends have been observed. At Gorges de l'Eygues and Châteauneuf d'Oze, it is marked by an increase in the CONT/MAR ratio and a decrease in the OP/TR ratio. The CONT/MAR ratio is higher in the LST than in the TST at Gorges de l'Eygues and Châteauneuf d'Oze. It decreases distally overall. The OP/TR ratio is higher in the TST than in the LST at Gorges de l'Eygues and Châteauneuf d'Oze. In the LST, the highest ratio is at Gorges de l'Eygues, but, in this case, the proportion of opaque phytoclasts does not appear to be biased by pyritization.

5.1.3. Discussion

The palynomorph preservation state does not display any clear lateral trend, even with respect to the thickness of systems tracts. This demonstrates that different sedimentation rates (and, consequently, differential burial rates) do not explain all the lateral variations observed in the palynomorph preservation state. Consequently, local palaeo-oxygenation, bioturbation and reworking are other important factors controlling microbial degradation in the studied sections.

Size of phytoclasts does not display lateral trends. The studied sections may not record a distal decrease because they are too close to each other or already too distal to display any evidence of a hydrodynamic influence.

As far as the CONT/MAR and OP/TR ratios are concerned, their vertical and lateral trends at the scale of 3rd order cyclicity are discussed below and summarized in Figs. 11a and 12.

Ratio of continental to marine fraction. Generally, the relative proportion of the continental fraction appears to reflect both regressive–transgressive trends and the relative proximal–distal position of the sections. The CONT/MAR ratio is lower in CS and decreases distally. Fig. 11a displays three palynofacies signatures related to three 3rd order depositional sequences with primary CS showing increasing degradation intensity. Usually, primary CS are characterized by a decrease in the CONT/MAR ratio as a result of a decrease in the continental fraction input and an increase in dinocyst accumulation (Fig. 12). When degradation is very intense, this trend can be reversed (Bombardiere and Gorin, 1998).

As far as sequence boundaries are concerned, they are marked by an increase in the CONT/MAR ratio as a result of a renewal of the erosion related to the relative sea level fall. In the Louyre section, the sequence boundaries Kim2″ and Kim3 do not display a significant signature of the CONT/MAR ratio. In the case of the latter boundary, the absence of an increase in the continental fraction may be due to the fact that the sequence boundary is located between two LST.

The decrease in the CONT/MAR ratio in a distal direction is controlled by the degradation of translucent phytoclasts, hydrodynamics and dinocyst accumulation. As far as the latter is concerned, in the modern sediments of the northeastern Pacific Ocean, the highest concentration of dinocysts has been observed in shelf edge and slope deposits (Heusser and Balsam, 1977). In the modern sediments of the Namibian continental margin, the middle to outer shelf deposits show the highest abundance of dinocysts (Davey and Rogers, 1975). These trends are essentially controlled by primary productivity, energy and redeposition. In the studied area, because the relative proportion of the continental fraction decreases in a distal direction, the dinocyst accumulation is supposed to increase (or decrease more slowly than the continental fraction). The LST of the sequence Kim2$''$ represents the only exception to the lateral trend of the CONT/MAR ratio. This may be related to a major dinocyst accumulation in a proximal setting.

Ratio of opaque to translucent phytoclasts. The vertical trend of the OP/TR ratio cannot be readily interpreted only in terms of sequence stratigraphy. According to the model of Steffen and Gorin for deep-water Berriasian carbonates (1993a and 1993b, see also Gorin and Steffen, 1991; Steffen, 1993), maximum flooding surfaces should be associated with the highest values, whereas sequence boundaries should be marked by decreasing values.

The latter signature has not been systematically observed at sequence boundaries. In average, the OP/TR ratio is lower in the LST than in the primary CS as a result of a decrease in supply of fresh macrophyte debris and an increase in degradation towards maximum flooding intervals (Fig. 12). The degradation is controlled by a greater distance from the source of phytoclasts and a decrease in sedimentation rate.

At Châteauneuf d'Oze, the maximum flooding surface of the sequence Kim1 has been associated with a depositional environment more favourable to organic matter preservation than that of both underlying and overlying sediments, hence a higher proportion of translucent phytoclasts. This interpretation is supported by an increase in the palynomorph preservation.

As far as the lateral variations are concerned, this parameter is clearly marked by an increase in a distal direction. This lateral variation can be interpreted as the result of selective transportation or preferential degradation of translucent phytoclasts. The latter hypothesis is preferred on the basis of the following observations, which do not point to hydrodynamic selection of phytoclasts:

- the proportion of lath-shaped opaque phytoclasts does not increase in a distal direction;
- the size of phytoclasts does not display a clear lateral variation; and
- in the sequence Kim2$'$, the ratio of semi-opaque to translucent phytoclasts increases considerably in a distal direction (see Fig. 8b). Semi-opaque phytoclasts are thought to be less buoyant and more resistant to degradation than translucent phytoclasts.

Degradation of translucent phytoclasts occurs in the water column and at the sediment–water interface. The long residence time in the degrading conditions at the latter interface implies that most organic matter is destroyed at the bottom (Müller and Suess, 1979; Tyson, 1987). Nevertheless, our data suggest that the lateral variability in the OP/TR ratio is essentially related to pre-depositional degradation (i.e. that occurs during transport). In fact, if the lateral trend of this parameter were the result of a more intense post-depositional degradation in distal environments, dinocyst degradation would increase distally. This is not the case.

The vertical and lateral trends of both ratios, at the scale of 3rd order cyclicity, have also been analysed with respect to climate. An arid phase as well as a relative sea level rise are expected to be associated with a decrease in the continental fraction and an increase in the proportion of opaque phytoclasts (Summerhayes, 1987; Caratini et al., 1983; Diester-Haas, 1983) (Fig. 11b). In the studied sections, this type of signature has been mostly observed about maximum flooding surfaces. It has not been possible to directly separate and quantify the effects of climate and relative sea level rise. According to Leinfelder (1993), sea level highstands should be characterized in the Upper Jurassic by humid conditions. Consequently, a climatic influence about maximum flooding surfaces does not seem to be expressed in the organic signature, which has been preferentially interpreted as being related to relative sea level change rather than climate.

5.2. Variations at the scale of 2nd order cyclicity

5.2.1. Description (Fig. 10)

In the three sections, the time interval spanning the top lowstand surface of the sequence Ox8 to the top lowstand surface of the sequence Kim3 (from the Planula to the Acanthicum ammonite zones), is marked by a general increase in the CONT/MAR and OP/TR ratios.

5.2.2. Discussion

These palynofacies trends do not match with the 2nd order transgression expected for this time interval in the cycle chart of Hardenbol et al. (1998). It is important to highlight that this interval is lithologically characterized by limestone–marl alternations and slump deposits, whereas the underlying and overlying sediments are dominated by fine-grained limestones. In the same time interval, Leinfelder (1993) has recognized an increase in siliciclastic input across the northern Tethyan shelf of western Europe and, partially, in boreal domains. This author has correlated limestone and marlstone-dominated intervals in the Upper Jurassic of southern Germany, North Sea and southern England, Paris Basin, Vocontian Basin, southern Spain and the Lusitania Basin. His correlation shows that, although the clay-rich sedimentation is roughly correlatable, its exact timing is clearly diachronous in the different locations. According to this author, the diachronous character of the marlstone-dominated intervals indicates that their distribution is largely controlled by tectonics. More precisely, the Lower Kimmeridgian would reflect episodes of regional uplift of the hinterland and/or differential basin subsidence related to the intense rifting activity in the Proto-Atlantic or to the westward opening of the Tethys. The palynofacies signature at the scale of 2nd order cyclicity appears to confirm this hypothesis. The increase in the terrestrial organic matter supply matches with a rejuvenation of relief and an increase in the continental erosion. As far as the OP/TR ratio is concerned, different geomorphological settings may control the relative input of opaque and translucent phytoclasts into the basin. From a general point of view, the major sources of phytoclasts are threefold (Di Giovanni et al., 1997):

- vegetation, which produces translucent phytoclasts;
- soils, which are characterized, in the upper layer, by a large proportion of translucent phytoclasts and, in the lower layer, by a large proportion of opaque phytoclasts; and
- previously deposited sediments, whose phytoclast content is usually rich in the opaque fraction.

Although the last two sources of phytoclasts can be considered as indirect (phytoclasts are directly produced only by vegetation), they may be quantitatively very important, especially during a phase of relief rejuvenation. In Papua New Guinea, the Lower Pliocene mudstones of the Orubadi Formation are characterized by a large amount of reworked palynomorphs, which has been related to tectonically induced changes in altitude and fluvial transportation affecting the hinterland (Waterhouse, 1998). In the Lower Kimmeridgian, a regional uplift of the hinterland and/or a differential basin subsidence may have increased the initial OP/TR ratio.

This hypothesis may also explain the 2nd order trend of the manganese content observed in the Upper Oxfordian and Lower Kimmeridgian by de Rafelis Saint-Sauveur (1996) and Emmanuel (personel communication) in the Châteauneuf d'Oze section. Fig. 10 also shows the general trends of the manganese content in the limestone beds of the Châteauneuf d'Oze section. The clay-rich interval is clearly marked by an increase in the manganese content. Basically, the sources of manganese in basinal environments are linked to the hydrothermal activity of the oceanic ridge or the erosion of emerged land (Emmanuel and Renard, 1993). Therefore, in both cases, it confirms the hypothesis of a tectonic phase associated with the opening of the Proto-Atlantic or with the westward propagation of the Tethys.

Consequently, in this time interval, relative sea level changes probably had an important tectonic component and some sedimentary signatures in the sequence stratigraphic framework may have been tectonically enhanced. In the southern part of the Vocontian Basin, in the Alpes de Haute Provence

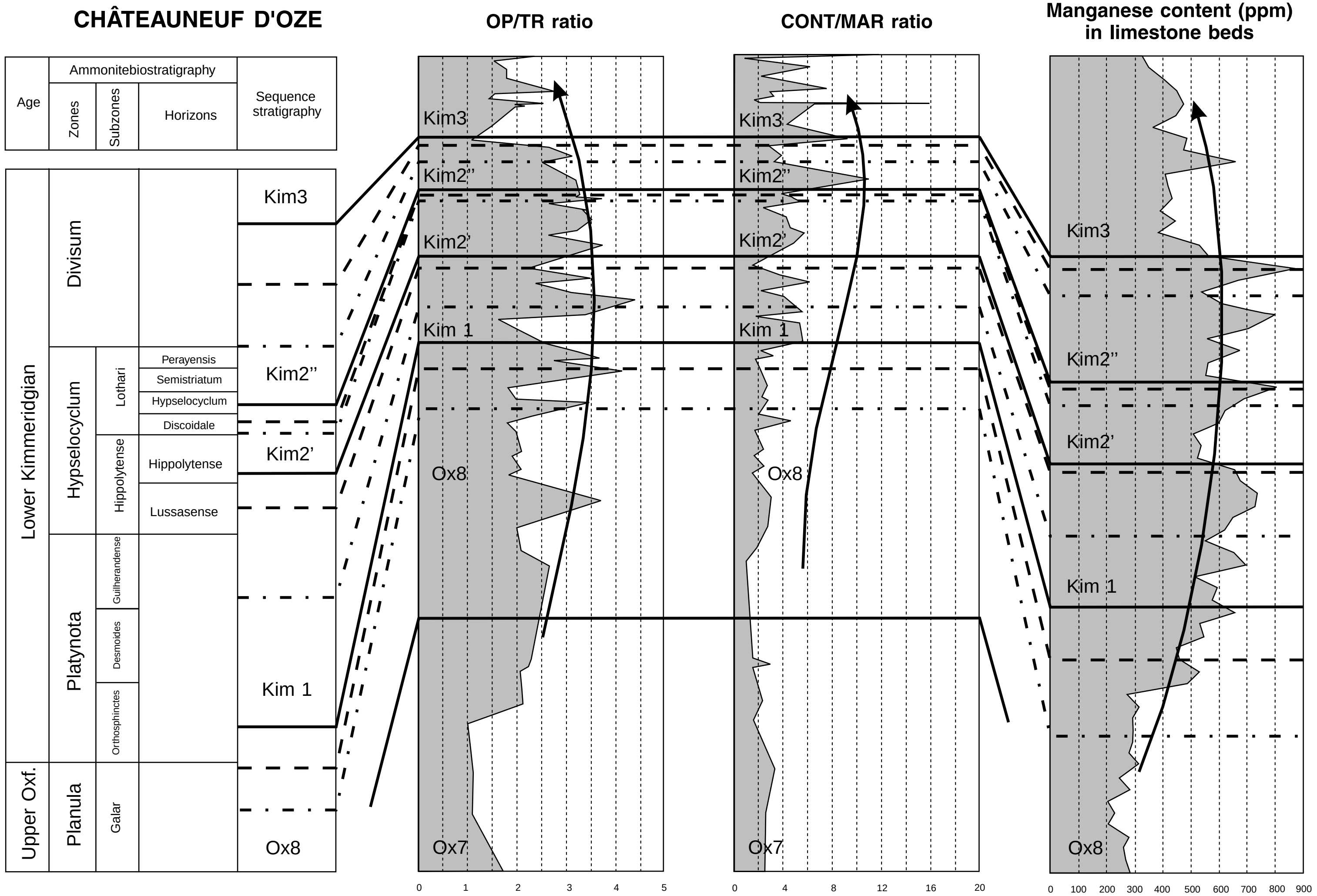


Fig. 10. Trends, at the scale of 2nd order cyclicity, of the ratio of continental to marine fraction (CONT/MAR ratio), the ratio of opaque to translucent phytoclasts (OP/TR ratio) and manganese content (fromde Rafélis Saint-Sauveur, 1996), for the Châteauneuf d'Oze section. See Fig. 1 for location and Fig. 2 for legend.

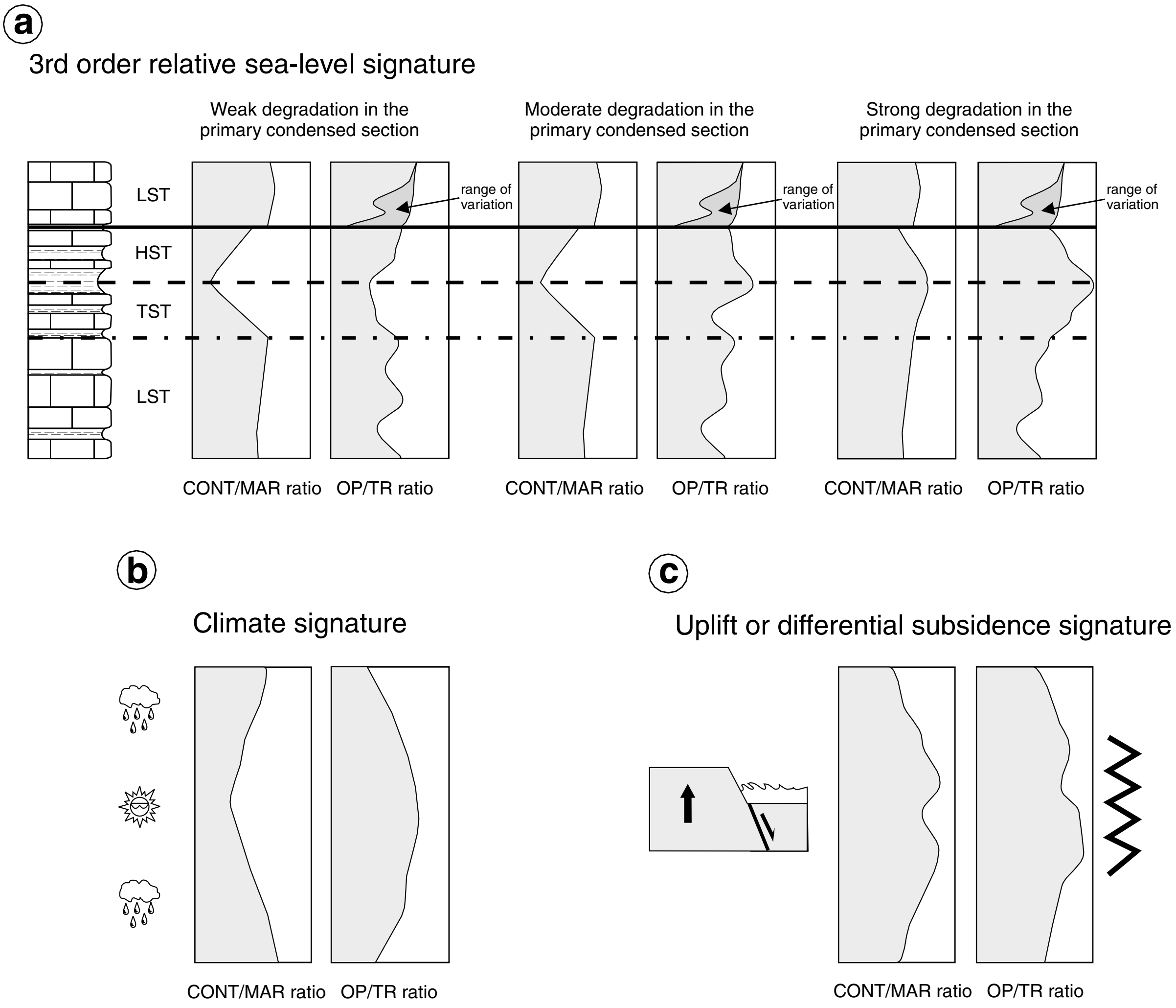


Fig. 11. Summary of palynofacies signatures related to: (a) 3rd order relative sea level changes and degradation; (b) climate (based on bibliographical data: Summerhayes, 1987; Caratini et al., 1981; Diester-Haas, 1983); and (c) uplift and/or differential subsidence. CONT/MAR ratio = ratio of continental to marine fraction, OP/TR ratio = ratio of opaque to translucent phytoclasts, LST = lowstand systems tract, TST = transgressive systems tract, HST = highstand systems tract. See Fig. 2 for legend.

area, the Lower Kimmeridgian is largely represented by hiatuses and gravity deposits (Pellaton and Ullrich, 1997). The sequence boundary Kim2′ is characterized by slump deposition in the basin. In Normandy, Jan du Chêne et al. (1995) have recognized a type 1 sequence boundary at the base of Kim2′. All these observations indicate that this discontinuity marks a major relative sea level fall. The increase in opaque phytoclasts, which characterizes this sequence boundary at Châteauneuf d'Oze and Gorges de l'Eygue, is probably associated with significant erosion of the geological substratum.

6. Conclusions

This study of SOM focuses on the Kimmeridgian deep-water carbonates of the Vocontian Basin. The latter are characterized by widespread oxic depositional environments, as confirmed by the very low

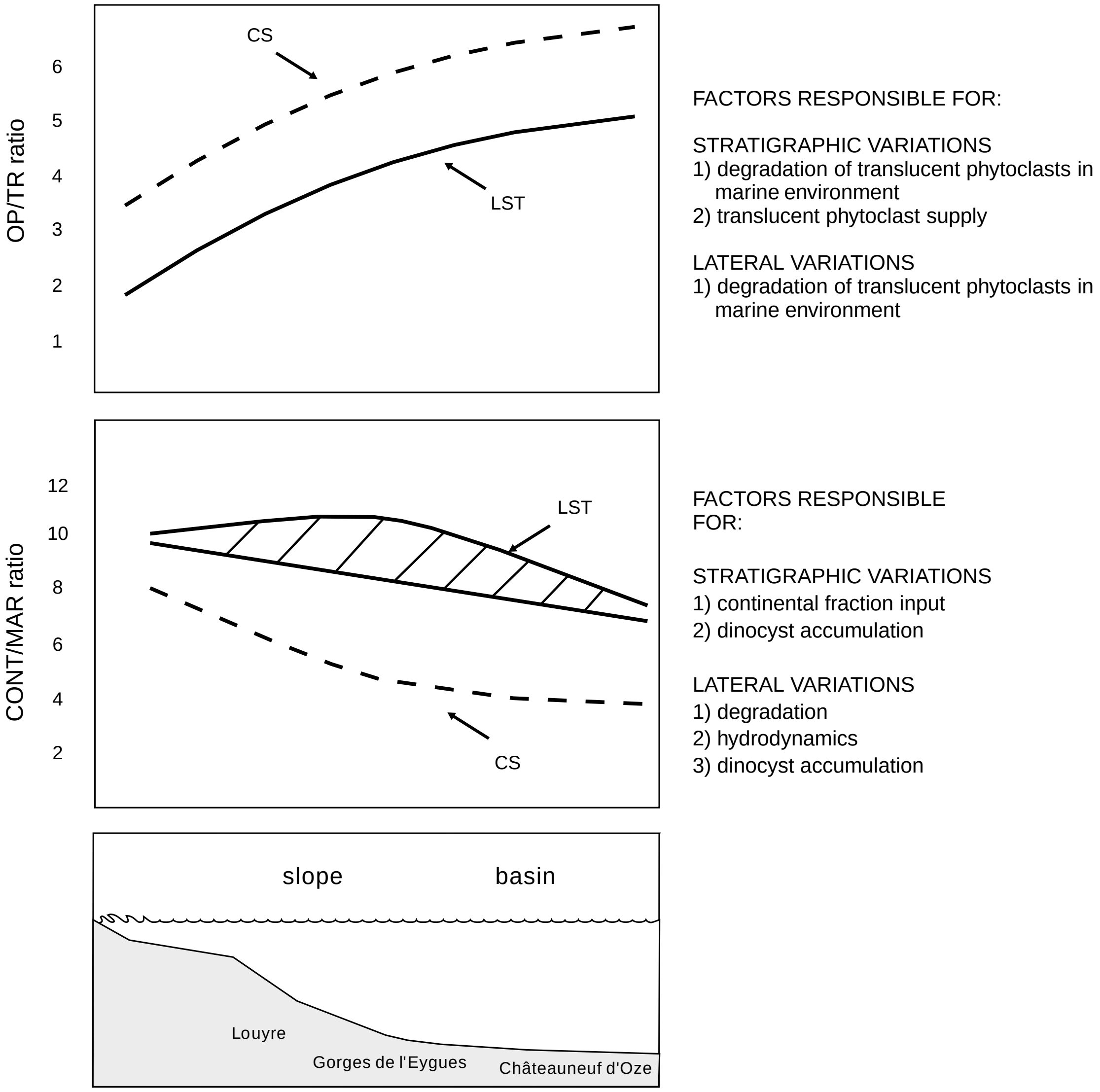


Fig. 12. Lateral and vertical variations of the ratios of opaque to translucent phytoclasts (OP/TR ratio) and continental to marine fraction (CONT/MAR ratio). CS primary condensed section, LST = lowstand systems tract.

total organic carbon content (less than 0.25 wt.%). For such organic-poor deposits, palynofacies analysis represents the best tool to investigate SOM. This research has contributed the following new results:

- the documentation of vertical and lateral trends of SOM composition and distribution; and
- the interpretation of processes and factors controlling some of the delineated SOM trends.

Palynofacies signatures at the scale of 3rd order cyclicity have been associated with relative sea level changes and degradation. No stratigraphic signature clearly related to climate has been observed in the studied sections at this scale. The vertical trends of organic constituents at the scale of 2nd order cyclicity appear to depend on tectonics.

Although most palynofacies signatures are well documented, the restricted number of studied sections suggests that caution should be applied when attempting to generalize the detected trends. Moreover, most data have been collected in the Vocontian Basin and none of the observed trends have been verified in other settings. These signatures can be summarized as follows (Figs. 11 and 12):

- Generally, the relative proportion of the continental fraction appears to reflect both regressive–transgressive trends and the relative proximal–distal position of the sections. The vertical variations in the CONT/MAR ratio are, to a large extent, controlled by continental fraction input and dinocyst accumulation. The decrease of this ratio in a distal direction is controlled by the degradation of translucent phytoclasts, hydrodynamics and dinocyst accumulation.
- The vertical variations of the OP/TR ratio can often not be interpreted only in terms of relative sea level changes. They are controlled by degradation of translucent phytoclasts in the marine environment and by translucent phytoclast supply. On the other hand, this parameter is clearly marked by an increase in a distal direction. This is due to the concentration of the more resistant opaque constituents through degradation of translucent phytoclasts, which occurs either in the water column or at the sediment–water interface. There is no evidence of hydrodynamic selection of phytoclasts during transport.
- The trends in palynofacies observed at the scale of 2nd order cyclicity support the hypothesis of a phase of uplift and/or differential subsidence occurring in the Lower Kimmeridgian (Leinfelder, 1993). The increase in both ratios agrees with a rejuvenation of relief and an increase in the continental erosion.

  The relative proportion of phytoclasts may provide a tool to distinguish sedimentary signatures essentially controlled by tectonics from those dominated by eustasy. Anyway, the recycling of opaque phytoclasts from underlying sediments should be confirmed by biostratigraphical evidence (i.e. recycling of dinocysts) and reflectance study. The latter method might allow the identification of two populations (contemporaneous and recycled) in both opaque and translucent phytoclasts.

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References

Atrops, F., 1982. La sous famille des Ataxioceratinae (Ammonitina) dans le Kimmeridgien inférieur du sud-est de la France. Systématique, évolution, chronostratigraphie des genres Orthosphinctes et Ataxioceras. Doc. Lab. Lyon 83, 463.

Atrops, F., Elmi, S., 1984. Bordure ardéchoise. In: Debrand-Passard, S., Courbouleix, S., Lienhardt, M.J. (Eds.). Synthèse géologique du SE France, Mém. Bur. Rech. Géol. Min., vol. 125(1), pp. 250–257.

Atrops, F., Ferry, S., 1987. Les glissements sous-marins kimméridgiens du bassin subalpin, témoins possibles de variations eustatiques négatives. Géologie Alpine h.s. 13, 179–185.

Baudrimont, A.F., Dubois, P., 1977. Un bassin mésogéen du domaine péri-alpine: le sud-est de la France. Bull. Centre Rech. -Expl. Elf-Aquitaine Pau-SNPA 1 (1), 261–308.

Blondel, T.J.A., Gorin, G.E., Jan du Chêne, R., 1993. Sequence stratigraphy in coastal environments: sedimentology and palynofacies of the Miocene in central Tunisia. In: Posamentier, H.W., Summerhayes, C.P., Haq, B.U., Allen, G.P. (Eds.). Sequence Stratigraphy and Facies Association, vol. 18. Spl. Publ. Int. Ass. Sediment, pp. 161–179.

Bombardiere, L., Gorin, G.E., 1998. Sedimentary organic matter in condensed sections from distal oxic environments: examples from the Mesozoic of SE France. Sedimentology 45, 771–788.

Boulter, M.C., Riddick, A., 1986. Classification and analysis of palynodebris from the Paleocene sediments of the Forties Field. Sedimentology 33, 871–886.

Bujak, J.P., Barss, M.S., Williams, G.L., 1977. Offshore eastern

Canada-Part I: offshore east Canada’s organic type and color and hydrocarbon potential. The Oil Gas J. 75, 198–201.

Burgess, J.D., 1974. Microscopic examination of Kerogen (dispersed organic matter) in petroleum exploration. Geol. Soc. Am. Spl. Paper 153, 19–30.

Caratini, C., Bellet, J., Tissot, C., 1983. Les palynofaciès: représentation graphique, intérêt de leur étude pour les reconstitutions paléogéographiques. In: d’Orgon À Misedor (Ed.). Géochimie Organique des Sédiments Marins Profonds, Centre National Res. Sc, Paris, pp. 327–351.

Combaz, A., 1964. Les palynofaciès. Revue de Micropaléontologie 7, 205–218.

Combaz, A., 1980. Les kérogènes vus au microscope. In: Durand, B. (Ed.). Kerogen: Insoluble Organic Matter from Sedimentary Rocks, Ed. Technip, Paris, pp. 55–111.

Cotillon, P., Ferry, S., Gaillard, C., Jautee, E., Latreille, G., Rio, M., 1980. Fluctuation des paramètres du milieu marin dans le domaine vocontien (France S.E.) au Crétacé inférieur: mise en évidence par l’étude des formations marno-calcaires alternates. Bull. Soc. géol. France 22 (5), 735–744.

Cotillon, P., Rio, M., 1984. In: Buffler, R.P., Schlager, W. (Eds.). Cyclic sedimentation in the Cretaceous of Deep Sea Drilling Sites 535 and 540 (Gulf of Mexico), 534 (central Atlantic) and in the Vocontian Basin (France), 77. Init. Repts. D.S.D.P. US Government Printing Office, Washington, DC, pp. 339–376.

Creaney, S., Passey, Q.R., 1993. Recurring patterns of total organic carbon and source rock quality within a sequence stratigraphy framework. Bull. Am. Assoc. Petrol. Geol. 77 (3), 386–401.

Davey, R.J., Rogers, J., 1975. Palynomorph distribution in Recent offshore sediments along two traverses off South West Africa. Mar. Geol. 18, 213–225.

Davies, J.R., McNestry, A., Waters, R.A., 1991. Palaeoenvironments and palynofacies of a pulsed transgression: the Late Devonian and Early Dinantian (Lower Carboniferous) rocks of south-east Wales. Geol. Mag. 28, 355–380.

de Leeuw, J.W., Largeau, C., 1993. A review of macromolecular organic compounds that comprise living organisms and their role in kerogen, coal and petroleum formation. In: Engel, M.H., Macko, S.A. (Eds.). Organic Geochemistry: Principles and Applications, Plenum, New York, pp. 23–72.

Demaison, G.J., Moore, G.T., 1980. Anoxic environments and oil source bed genesis. Bull. Am. Assoc. Petrol. Geol. 64 (8), 1179–1209.

de Rafélis Saint-Sauveur, M., 1996. Géochimie des carbonates pélagiques et stratigraphie séquentielle: le contrôle des séquences de troisième ordre au cours du Jurassique supérieur (exemple du Domaine Vocontien). Unpublished Degree, Pierre et Marie Curie University, Paris VI, 29pp.

Diester-Haas, L., 1983. Differentiation of high oceanic fertility in marine sediments caused by coastal upwelling and/or river discharge of NW Africa during the Late Quaternary. In: Suess, E., Thiede, J. (Eds.). Coastal Upwelling: Its Sediment Record. Part B: Sediment Records of Ancient Coastal Upwelling., NATO Conference Series IV, 10b, Plenum, New York, pp. 399–419.

Di Giovanni, C., Bertrand, P., Campy, M., Disnar, J.R., 1997. Contribution de la matière organique méso-cénozoïque dans un flux organique terrigène tardi et post-glaciaire (bassin de Chaillexon, Doubs, France). Bull. Soc. géol. France 168 (1), 83–92.

Einsele, G., Ricken, W., 1991. Limestone–marl alternation—an overview. In: Einsele, G., Ricken, W., Seilacher, A. (Eds.). Cycles and Events Stratigraphy, Springer, Berlin, pp. 23–47.

Emmanuel, L., Renard, M., 1993. Carbonate geochemistry (Mn^{13}C, ^{18}O) of the Late Tithonian–Berriasian pelagic limestone of the Vocontian Trough (S.E. France). Bull. Centres Rech. Explor. - Prod. Elf-Aquitaine 17 (1), 205–221.

Enay, R., 1984. Jurassique supérieur: Malm. In: Debrand-Passard, S., Courbouleix, S., Lienhardt, M.J. (Eds.). Synthèse Géologique du SE France, 125(1). Mém. Bur. Rech. Géol. Min., pp. 223–286.

Gorin, G.E., Steffen, D., 1991. Organic facies as a tool for recording eustatic variations in marine fine-grained carbonates-example of the Berriasian stratotype at Berrias (Ardèche SE France). Palaeogeogr. Palaeoclimatol. Palaeoecol. 85, 303–320.

Gregory, W.A., Hart, G.F., 1992. Towards a predictive model for the palynologic response to sea level changes. Palaios 7, 3–33.

Habib, D., 1983. Sedimentation rate dependent distribution of organic matter in the North Atlantic Jurassic–Cretaceous. In: Sheridan, R.E., Gradstein, F.M. (Eds.). Initial Reports of Deep Sea Drilling Project, vol. 76. US Government Printing Office, Washington, DC, pp. 781–794.

Habib, D., Miller, J.A., 1989. Dinoflagellate species and organic facies evidence of marine transgression and regression in the Atlantic coastal plain. Palaeogeogr. Palaeoclimatol. Palaeoecol. 74, 23–47.

Haq, B.U., 1991. Sequence stratigraphy, sea level change, and significance for the deep sea. In: MacDonald, D.I.M. (Ed.). Sedimentation, Tectonics and Eustacy, vol. 12. Spl. Publ. Int. Ass. Sediment, pp. 3–39.

Hardenbol, J., Thierry, J., Farley, M.B., Jacquin, T., de Graciansky, P.-C., Vail, P.R., 1998. Mesozoic and Cenozoic Sequence Chronostratigraphic Framework of European Basins. In: de Graciansky, P.-C., Hardenbol, J., Jacquin, T., Vail, P.R. (Eds.). Mesozoic and Cenozoic Sequence Stratigraphy of European Basins, Soc. Econ. Paleontol. Mineral. Spl. publ, p. 60.

Hart, G.F., 1986. Origin and classification of organic matter in clastic systems. Palynology 10, 1–23.

Heusser, L.E., Balsam, W.L., 1977. Pollen distribution in the northeast Pacific Ocean. Quaternary Res. 7, 45–62.

Huc, A.Y., 1980. Origin and formation of organic matter in recent sediments and its relation to kerogen. In: Durand, B. (Ed.). Kerogen: Insoluble Organic Matter from Sedimentary Rocks, Technip, Paris, pp. 445–474.

Huc, A.Y., 1988. Sedimentology of organic matter. In: Frimmel, F.H., Christman, R.F. (Eds.). Humic Substances and their Role in the Environment, Wiley, Chichester, pp. 215–243.

Ibach, L.E.J., 1982. Relationship between sedimentation rate and total organic carbon content in ancient marine sediments. Bull. Am. Assoc. Petrol. Geol. 66 (2), 170–183.

Jacquin, T., Arnaud-Vanneau, A., Arnaud, H., Ravenne, C., Vail, P.R., 1991. System tracts and depositional sequences in a carbonate setting: a study of continuous outcrops from platform to basin at the scale of seismic lines. Mar. Petrol. Geol. 8, 122–139.

Jan du Chêne, R., Atrops, F., Emmanuel, L., de Rafélis, M., Renard, M., 2000. Palynology, ammonites and sequence stratigraphy in the Tethyan Middle Oxfordian to Lower Kimmeridgian, SE France. Comparison with the Boreal realm. Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine (in press).

Jan du Chêne, R. Baudin, F., Bombardiere, L., Deconinck, J.F., Emmanuel, L., Galbrun, B., Geyssant, J., Gorin, G., Hantzpergue, P., Proust, J.N., Quillevere, F., Renard, M., Saint-Gennesm, Saint-Sauveur, M., Samson, Y., Terpeau, L., Vidier, J.P., 1995. Approche pluridisciplinaire de la stratigraphie séquentielle du Jurassique supérieur français (Bassin de Paris, Aquitaine et Bassin du Sud-Est). Palynologie et changements globaux, 14ème Symp Ass. Palyn. Lang. Fr., Paris, 18–20 September 1995, abstract, p. 54.

Jan du Chêne, R., Busnardo, R., Charollais, J., Clavel, B., Deconinck, J.F., Emmanuel, L., Gardin, S., Gorin, G., Manivit, H., Monteil, E., Raynaud, J.F., Renard, M., Steffen, D., Steinhauser, N., Strasser, A., Strohmenger, C., Vail, P.R., 1993. Sequence stratigraphy interpretation of the Upper Tithonian—Berriasian reference sections in South East France: a multidisciplinary approach. Bull. Centres Rech. Explor.-Prod. Elf-Aquitaine 17 (1), 151–181.

Klemme, H.D., Ulmishek, G.F., 1991. Effective petroleum source rocks of the world: stratigraphic distribution and controlling depositional factors. Bull. Amer. Assoc. Petrol. Geol. 75 (12), 1809–1851.

Leinfelder, R.R., 1993. Upper Jurassic reef types and controlling factors. A preliminary report. Profil 5, 1–45.

Loutit, T.S., Hardenbol, J., Vail, P.R., 1988. Condensed sections: the key to age determination and correlation of continental margin sequences. In: Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A., Van Wagoner, J.C. (Eds.). Sea Level Changes—an Integrated Approach, vol. 42. Soc. Econ. Paleontol. Mineral. Spl. Publ, pp. 183–215.

Moussine-Pouchkine, A., Seguret, M., Bouchette, F., Atrops, F., 1998. Stacked oblique sets of coarse carbonate breccia in the progradational unit of Ceuse (Tithonian wave degeneration ramp. Bassin du Sud-Est, France. 15th International sedimentological Congress, Alicante (Spain). pp. 566–568.

Müller, P.J., Suess, E., 1979. Productivity, sedimentation rate, and sedimentary organic matter in the ocean—I. Organic carbon preservation. Deep-Sea Res. 26A, 1347–1362.

Parry, C.C., Whitley, P.K.J., Simpson, R.D.H., 1981. Integration of palynological and sedimentological methods in facies analysis of the Brent Formation. In: Illing, L.V., Hobson, G.D. (Eds.). Petroleum Geology of the Continental Shelf of North-West Europe, Heyden, London, pp. 205–215.

Partington, M.A., Copestake, P., Mitchener, B.C., Underhill, J.R., 1993. Biostratigraphic calibration of genetic stratigraphic sequences in the Jurassic lowermost Cretaceous (Hettangian to Ryazanian) of the North Sea and adjacent areas. In: Parker, J.R. (Ed.). Petroleum Geology of Northwest Europe: Proceeding of the 4th Conference, Geological Society of London, Bath, pp. 371–386.

Pasley, M.A., Gregory, W.A., Hart, G.F., 1991. Organic matter variation in transgressive and regressive shales. Organic Geochemistry 17, 483–509.

Pellaton, C., Ullrich, S., 1997. Etude multidisciplinaire du Jurassique supérieur de la région de Castellane (SE de la France). Unpublished Degree, University of Geneva, 191pp.

Pittet, B., Gorin, G., 1997. Distribution of sedimentary organic matter in a carbonate-siliciclastic platform environment: Oxfordian deposits from the Swiss Jura Mountains. Sedimentology 44, 915–937.

Pittet, B., Strasser, A., 1998. Depositional sequences in deep-shelf environments formed through carbonate-mud import from the shallow platform (Late Oxfordian German Swabian Alb and eastern Swiss Jura). Eclogae geol. Helv. 91, 149–169.

Piuz, A., 1997. Etude multidisciplinaire du Jurassique supérieur de la région de Nyon (Sud-Est de la France). Unpublished Degree, University of Geneva, 143pp.

Powell, A.J., Dodge, J.D., Lewis, J., 1990. Late Neogene to Pleistocene palynological facies of the Peruvian continental margin upwelling, Leg 112. In: Suess, E., Von Huene, R. (Eds.). Proceedings of the Ocean Drilling Project, Scientific Results. College Station, TX, USA, vol. 112, pp. 297–321.

Robert, P., 1988. Organic Metamorphism and Geothermal History: Microscopic Study of Organic Matter and Thermal Evolution of Sedimentary Basins, Reidel, Dordrecht 311pp.

Sarg, J.F., 1988. Carbonate sequence stratigraphy. In: Wilgus, C.K., Hastings, B.S., Kendall, C.G.St.C., Posamentier, H.W., Ross, C.A., Van Wagoner, J.C. (Eds.). Sea Level Changes—an Integrated Approach, vol. 42. Soc. Econ. Paleontol. Mineral. Spl. Publ, pp. 155–181.

Scull, B.J., Felix, C.J., McCaleb, S.B., Shaw, W.G., 1966. The interdiscipline approach to paleoenvironmental interpretation. Trans. Gulf Coast Assoc. Geol. Soc. 16, 81–117.

Seguret, M., Moussine-Pouckine, A., Raja Gabaglia, G., Bouchette, F., 1998. A wave degeneration carbonate ramp model based on the Tithonian of the Bassin du Sud-Est. 15th International sedimentological Congress, Alicante (Spain). pp. 711–712.

Sittler, C., Ollivier-Pierre, M.F., 1994. Palynology and palynofacies analyses: some essential clues to assess and identify West European Tertiary depositional environments in term of relative high or lowstand. Application to the case of three Eocene and Oligocene sections in France. Bull. Centre Rech. -Expl. Elf-Aquitaine Pau-SNPA 18 (2), 475–488.

Staplin, F.L., 1969. Sedimentary organic matter, organic metamorphism, and oil and gas occurrence. Bull. Can. Petrol. Geol. 17, 47–66.

Steffen, D., 1993. Influence des variations eustatiques sur la distribution de la matière organique dans le roches sédimentaires: example des dépôts berriasiens des Bassins Vocontien, Ultrahelvétique et du Yorkshire. Public. Dépt. Géol. -Paléont., 13, PhD thesis, University of Geneva, 116pp.

Steffen, D., Gorin, G.E., 1993a. Palynofacies of the Upper Tithonian-Berriasian deep-sea carbonates in the Vocontian Trough (SE France). Bull. Centre Rech. -Expl. Elf-Aquitaine Pau-SNPA 17 (1), 235–247.

Steffen, D., Gorin, G.E., 1993b. Sedimentology of organic matter in Upper Tithonian–Berriasian deep sea carbonates of South East France: evidence of eustatic control. In: Katz, B., Pratt, L.

(Eds.). Source Rocks in a Sequence Stratigraphic Framework, 37. A.A.P.G. Studies in Geology, pp. 49–65.

Strohmenger, C., Strasser, A., 1993. Eustatic controls on the depositional evolution of the Upper Tithonian Berriasian deep water carbonates (Vocontian Trough SE France). Bull. Centre Rech. -Expl. Elf-Aquitaine Pau-SNPA 17 (1), 183–203.

Summerhayes, C.P., 1981. Organic facies of Middle Cretaceous Black Shales in Deep North Atlantic. Bull. Amer. Assoc. Petrol. Geol. 65 (11), 2364–2380.

Summerhayes, C.P., 1987. Organic-rich Cretaceous sediments from the North Atlantic. In: Brooks, J., Fleet, A.J. (Eds.). Marine Petroleum Source Rocks, 26. Geol. Soc. London Spl. Publ, pp. 301–316.

Tegelaar, E.W., Derenne, S., Largeau, C., de Leeuw, J.W., 1989. A reappraisal of Kerogen formation. Geochim. Cosmochim. Acta 3, 3103–3107.

Tissot, B., 1989. Effect on prolific petroleum source rocks and major coal deposits caused by sea level change. Nature 277, 463–465.

Tribovillard, N.P., Gorin, G.E., 1991. Organic facies of the Early Albian Niveau Paquier, a key black shale horizon of the Marnes Bleues Formation in the Vocontian Trough (Subalpine Ranges, SE France). Palaeogeogr. Palaeoclimatol. Palaeoecol. 85, 227–237.

Tyson, R.V., 1987. The genesis and palynofacies characteristics of marine petroleum source rocks. In: Brooks, J., Fleet, A.J. (Eds.). Marine Petroleum Source Rocks, 26. Geol. Soc. Spl. Publ, pp. 47–67.

Tyson, R.V., 1989. Late Jurassic palynofacies trends, Piper and Kimmeridge Clay Formations, UK onshore and northern North Sea. In: Batter, D.J., Keen, M.C. (Eds.). Northwest European Micropalaeontology and Palynology, British Micropal Soc. Series, Ellis Horwood, Chichester, pp. 135–172.

Tyson, R.V., 1993. Palynofacies analysis. In: Jenkins, D.J. (Ed.). Applied Micropalaeontology, Kluwer, Dordrecht, pp. 153–191.

Tyson, R.V., 1995. Sedimentary organic matter, Chapman & Hall, London pp. 615.

Tyson, R.V., 1996. Sequence-stratigraphical interpretation of organic facies variation in marine siliciclastic systems: general principles and applications to the onshore Kimmeridge Clay Formation, UK. In: Hesselbo, S.P., Parkinson, D.N. (Eds.). Sequence Stratigraphy in British Geology, 108. Geol. Soc. Spl. Publ, pp. 75–96.

Vail, P.R., Audemard, F., Bowman, S.A., Eisner, P.N., Pérez-Cruz, C., 1991. The stratigraphic signature of tectonics, eustacy and sedimentology—an overview. In: Einsele, G., Ricken, W., Seilacher, A. (Eds.). Cycles and Events in Stratigraphy, Springer, Berlin, pp. 617–659.

Van der Zwan, C.J., 1990. Palynostratigraphy and palynofacies reconstruction of the Upper Jurassic to lowermost Cretaceous of the Draugen Field, offshore mid Norway. Review. Palaeobot. Palynol. 62, 157–186.

Waterhouse, H.K., 1998. Palynological fluorescence in hinterland reconstruction of a cyclic shallowing-up sequence Pliocene, Papua, New Guinea. Palaeogeogr. Palaeoclimatol. Palaeoecol. 139, 59–82.

Whitaker, M.F., 1984. The usage of palynology in definition of Troll Field geology. In: Reduction of Uncertainties in Innovative Reservoir Geomodelling, 6th Offshore Northern Seas Conference and Exhibition, Stavanger 1984, Norsk Petroleums-forening, Paper G6, 44pp.