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A *Lithocodium* and *Bacinella* signature of a late Hauterivian, local microbial event: the Urgonian limestone in South-East France

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ABSTRACT

Sediment binding crusts of Lithocodium aggregatum *and associated* Bacinella irregularis *abound in a shallow water limestone layer, in South–East France. The sudden appearance of these crusts denotes a local, conspicuous change in an otherwise balanced, open marine depositional environment. Based on regional correlation, the layer belongs to the Lower Hauterivian, Ligatus Zone, directly dated by an assemblage of orbitolinid foraminifera, and indirectly by a specimen of ammonite. It is older than the Faraoni oceanic anoxic event (OAE), (latest Hauterivian, Angulicostata auct. Zone), and presumably not linked with a global climate change. Two facies are recognized: (1)* Lithocodium *bindstone, with* Bacinella*, other microencrusters, and fluorescent automicrite of microbial origin; (2) floatstones containing numerous fragments of* Lithocodium *and accompanying biota. Coarse rhombohedral dolomite is locally present. Two modern analogues of microbial mediation are put forward to explain the* Lithocodium *event: (a) Lagoa Vermelha, in Brazil, along with anoxic, marginal marine conditions; (b) Highborne Cay, in the Bahamas, along with oxic, open marine conditions. A stack of four Upper Hauterivian parasequences is described: Parasequence 1 ends with oolitic deposits; the somewhat deeper water Parasequence 2 occurs only in the south-eastern part of the study area, towards the Subalpine depocenter; Parasequence 3 matches the layer with* Lithocodium *and* Bacinella*, of variable thickness (0.8 m – 11 m), resulting from syn-sedimentary tectonic activity in the area of the Vuache fault system which is a major feature; Parasequence 4 corresponds with the resumption of the normal, Urgonian carbonate factory.*

Keywords: *Lithocodium*, *Bacinella*, Urgonian, automicrite, dolomite, Hauterivian, Jura, Pre-Subalpine Domain

1. INTRODUCTION

Lithocodium aggregatum ELLIOTT and *Bacinella irregularis* RADOIČIĆ are problematic, micro-encrusting calcareous organisms, which are either associated or found separately in the Urgonian limestone. In the Middle East, they are important components of certain hydrocarbon bearing carbonate reservoirs. Extensive surface and subsurface studies were carried out to understand their habitat and depositional setting. The reader may refer to ELLIOTT (1963), BANNER et al. (1990), PASCAL (1979), KOCH et al. (2002), HILLGAERTNER et al. (2003) and IMMENHAUSER et al. (2004, 2005). According to IMMENHAUSER et al. (2005), in Oman, the *Lithocodium-Bacinella* association occurs with microbial-algal foraminiferal build-ups and bindstone facies corresponding to biologically out-of-balance communities. Chemostratigraphy shows that such intervals are coeval with the early Aptian oceanic anoxic event OAE1a ("Livello Selli"). They alternate with intervals dominated by rudist bivalves. The influence of nutrient gradients on carbonate platform community structures is considered the most likely model for the origin of the Oman build-up episodes, (IMMENHAUSER et al. 2005, p 20).

Herein, an older (Upper Hauterivian) layer containing abundant *Lithocodium*, *Bacinella* and other micro-encrusters, is described from the margin of the Urgonian platform, in South-

East France. The depositional setting matches a parasequence of bindstone layers, and/or the corresponding fragmented deposits. Automicrite and idiomorphous dolomite are found, implying microbial mediation. Here, the sequence stratigraphy, is locally applied to the *Lithocodium* and *Bacinella* layer, and interpreted and used as a dating tool by the present authors. More generally, the much debated issue of dating the Urgonian limestone in South-East France and adjacent Switzerland was recently reviewed by CLAVEL et al. (2007), combining published and new biostratigraphic data from ammonites, echinoids, orbitolinids, Dasycladalean algae, dinocysts and calcareous nannoplankton.

2. TALUS TO PLATFORM MARGIN TRANSECT

In the northern French and Swiss Jura, the Urgonian limestone consists of two informally defined formations: (1) the "Urgonien jaune", representing the first (external) phase of the platform setting, dominated by heterotrophic organisms; (2) the "Urgonien blanc", essentially made up of platform interior deposits dominated by photo-autotrophic organisms. These designations, although commonly used, do not apply to the southern Jura. The "Urgonien jaune" and its equivalents are basal Upper Hauterivian. They are made up of reefal deposits of platform margin origin. Rudists (*Pachytraga*) are present in an interior, but still open marine setting. *Lithocodium* and *Bacinella* are absent from the "Urgonien jaune".

The Upper Hauterivian *pro parte* to Lower Aptian *pro parte* "Urgonien blanc" (or "Urgonien s. str."), extends from the Jura to the Subalpine Domains. As shown by CHAROLLAIS et al. (2001), thick, prograding bioclastic deposits are present in the Pre-subalpine and Subalpine Domains, marking the installation of the platform on top of hemipelagic deposits. Vertically and laterally, they are followed by platform interior deposits with rudists (Urgonian facies s. str,) extending as far as the Swiss Cantons of Vaud and Neuchâtel. The *Lithocodium* and *Bacinella* layer which is the subject of this article,only occurs in the French Southern Jura. It is described from five field sections and an additional outcrop depicted in Fig. 2. Other locations, not dealt with herein, occur in the Valserine valley, north of Bellegarde-sur-Valserine, and on the Vuache Mountain, in a road cut described by BLONDEL (1990). Local correlations (Fig. 4) roughly run from north to south, across the still active Vuache fault system, a major tectonic feature known to be active since the Mesozoic (CHAROLLAIS et al., 1983; DONZEAU et al., 1998).

2.1. Platform talus, Pre-Subalpine Domain – Pic de l'Oeillette section

Location (Figs. 1, 3) is on the road between Saint-Laurent-du-Pont and Saint-Pierre-de-Chartreuse (massif de la Chartreuse, Savoie), at Lambert coord. 868.75/5027.15. The section was initially logged by ARNAUD-VANNEAU (1980). For dating elements and correlation with the nearby Pas du Frou section, see CLAVEL et al. (2007). The echinoderm *Toxaster retusus* and a specimen of *Plesiospitidiscus* gr. *ligatus* (Pl. I, Fig. A), an index ammonite, was collected just below the Urgonian limestone cliff. Assemblages of orbitolinids (Pl. I) including *Praedictyorbitolina busnardoi*, *P. claveli* and *P. carthusiana* occur straddling the base of the Urgonian cliff. The Urgonian limestone consists of talus deposits: wackestones with echinoderm debris, sponge spicules, *Lenticulina* sp. and small textularids, containing increasing admixtures of diverse, transported shallow water material including some oolites, bryozoan

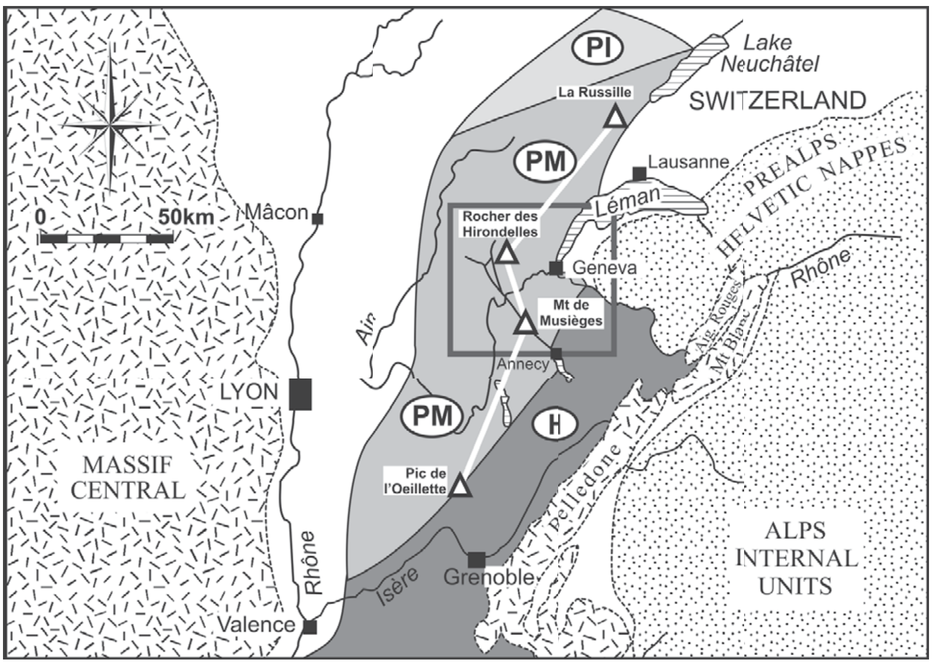


Figure 1: Geological setting and Upper Hauterivian depositional environments, at the datum time shown in Fig. 3 and 4. H: hemipelagic (basin *s.l.*). PM: platform margin and talus, shallow water, open marine. PI: platform interior, biotically restricted, with rudists; for details see CLAVEL et al. (2007). Palinspastic section: Fig. 3. Insert covering the extent of the layer with *Lithocodium* and *Bacinella*: Fig. 4.

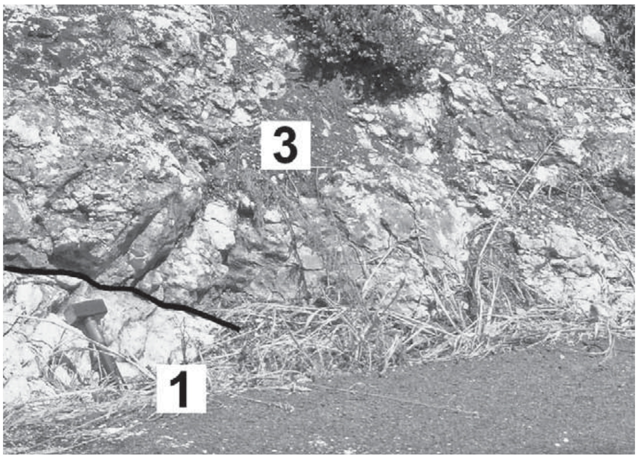


Figure 2: Fort de l'Ecluse Est (location Fig. 4). 1: Rock-solid oolitic limestone, at the top of Parasequence 1; the deeper water Parasequence 2 is missing. 3: Brecciated, fossiliferous Parasequence 3, matching the layer with *Lithocodium* and *Bacinella*.

debris, silicified bivalves, annelids, corals, small gastropods, rare calcareous green algae (*Piriferella paucicalcarea*, a dasycladale, *Boueina* sp.), and foraminifera. *Lithocodium* and *Bacinella* debris are absent.

2.2. Platform margin – Mont de Musièges section

Location (Figs. 1, 3) is in the Southern Jura, in the Haute-Savoie, close to and on the SW side of the Vuache fault-line. This section has also been studied by for example CONRAD (1969), CHAROLLAIS et al. (1989) and BLANC-ALÉTRU (1995). Four parasequences are logged at Mont de Musièges, on top of flooding surfaces showing no evidence of exposure. In the 10 m-thick Parasequence 1, the transgressive tract contains up to 30% detrital quartz, bryozoan debris and an assemblage of foraminifera (*Lenticulina* sp., small textularids, small miliolids etc.) denoting a typically deeper water environment, below the base of the euphotic zone. Oolites prevail in the highstand tract.

The 7 m-thick Parasequence 2 extends on top of a nodular oolitic limestone, above a quite inconspicuous flooding boundary. The transgressive tract consists of weakly glauconitic, echinoderm lime grainstones and packstones. Here also, the faunal content, with *Lenticulina* sp., small textularids, small miliolids and bryozoan debris, typically stands for an open sea, deeper water environment of deposition. Chert is present in the mid-part of the tract, indicating the maximum flooding interval. Oolites appear higher up the section, in the highstand tract.

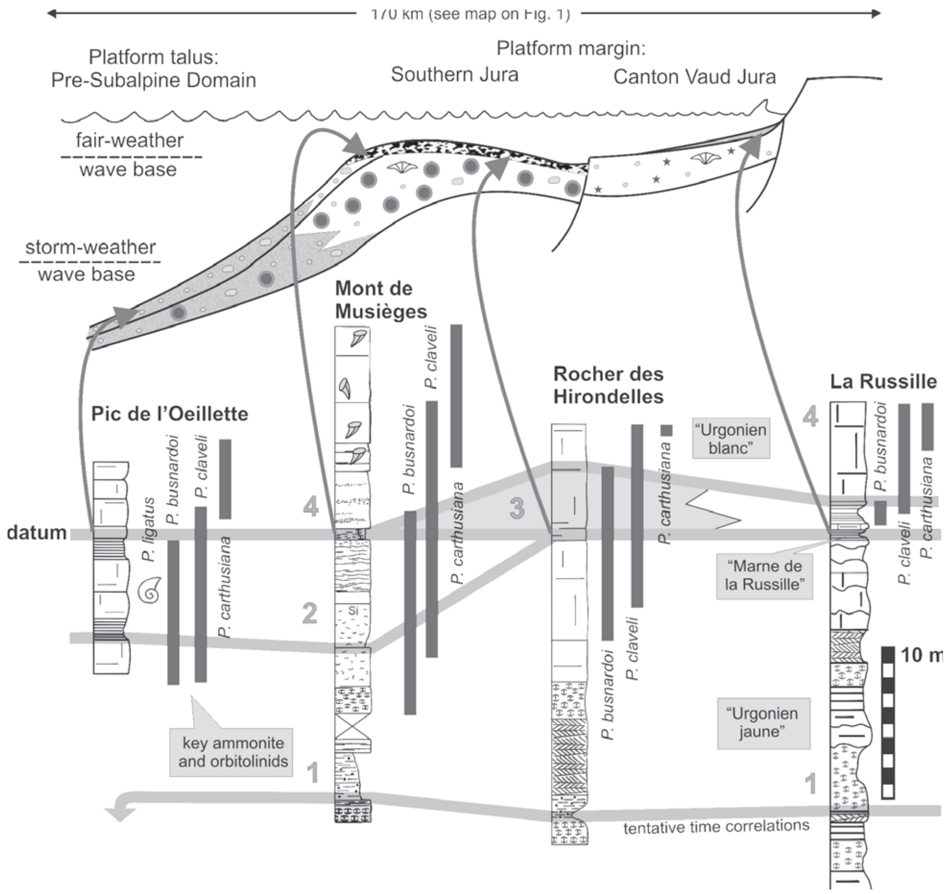


Figure 3: Regional correlations and palinspastic profile, from the talus to the margin of the Urgonian platform. Locations: Fig. 1. Datum time is Upper Hauterivian pro parte, Ligatus ammonite Zone. The distinction between the "Urgonien jaune", "Marne de la Russille" and "Urgonien blanc" units applies to the Vaud Jura Canton. The more general "Urgonien s. str." term applies to the Southern Jura and the Pre-Subalpine Domain. For symbols, additional field sections and close-up correlations in the Southern Jura see Fig. 4.

PLATE I

Key ammonite and key orbitolinids

Plesiospitidiscus ligatus (D'ORBIGNY)

A 136.1, Pic de l'Oeillette

Pr*aedictyorbitolina busnardoi* SCHROEDER et al.

B 136.0-4, Pic de l'Oeillette

C 136.0-3a, Pic de l'Oeillette

G 6548a4, Mont de Musièges

H 6548cb, Mont de Musièges.

I 6548a1, Mont de Musièges

M 250.1–1a, La Russille.

N 250.2–2a, La Russille

S MC 312a, Rocher des Hirondelles

Praedictyorbitolina claveli SCHROEDER

D 136.0-3b, Pic de l'Oeillette

E 136.1-3a, Pic de l'Oeillette

F 136.0-2a, Pic de l'Oeillette

J 6549a2, Mont de Musièges

K 6549a3, Mont de Musièges

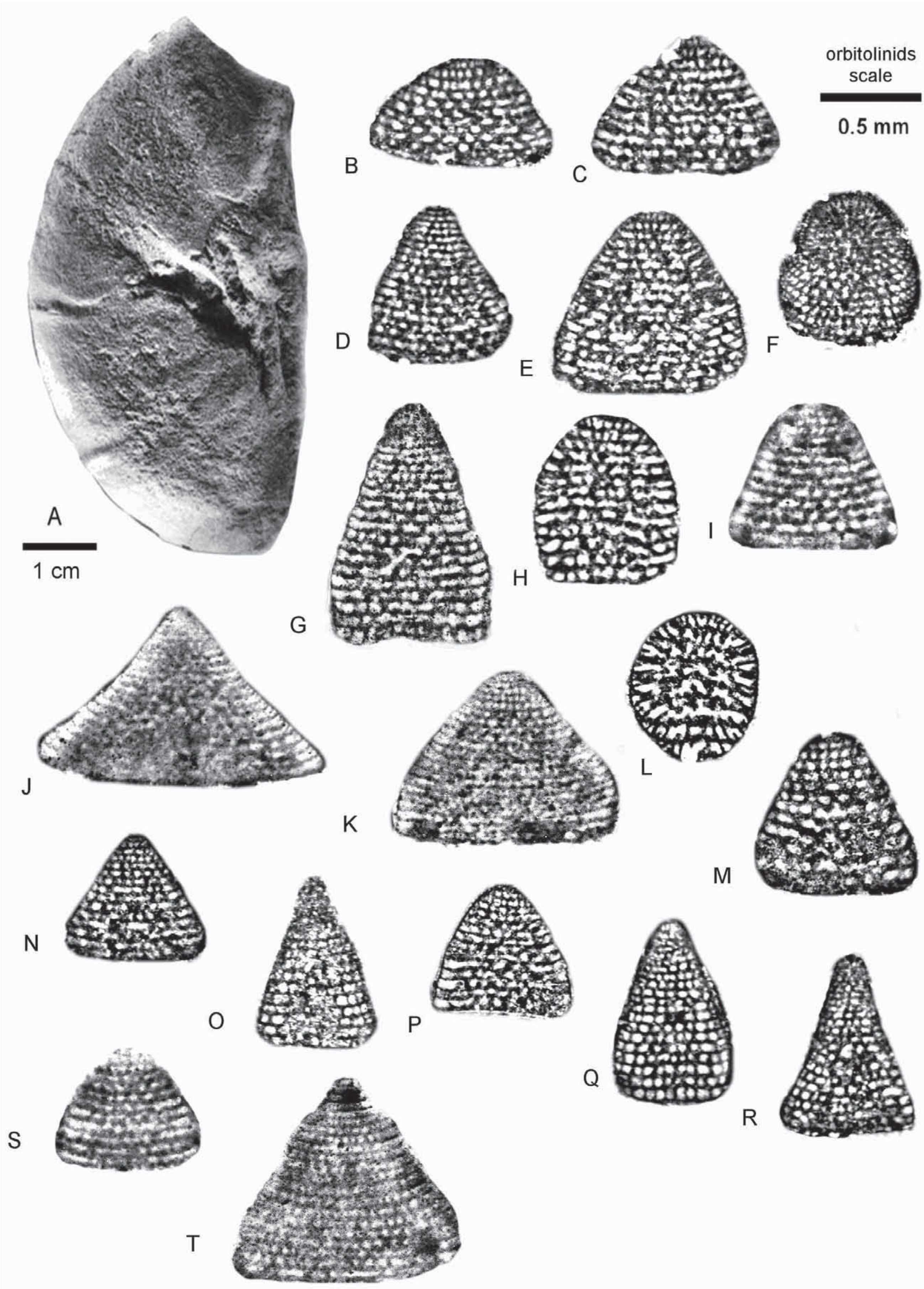
L 6548B, Mont de Musièges

O 7041-3, La Russille

P 7040-12a, La Russille

Q 7040-15a, La Russille

R 7040-14a, La Russille


orbitolinids scale
0.5 mm
A
1 cm
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T

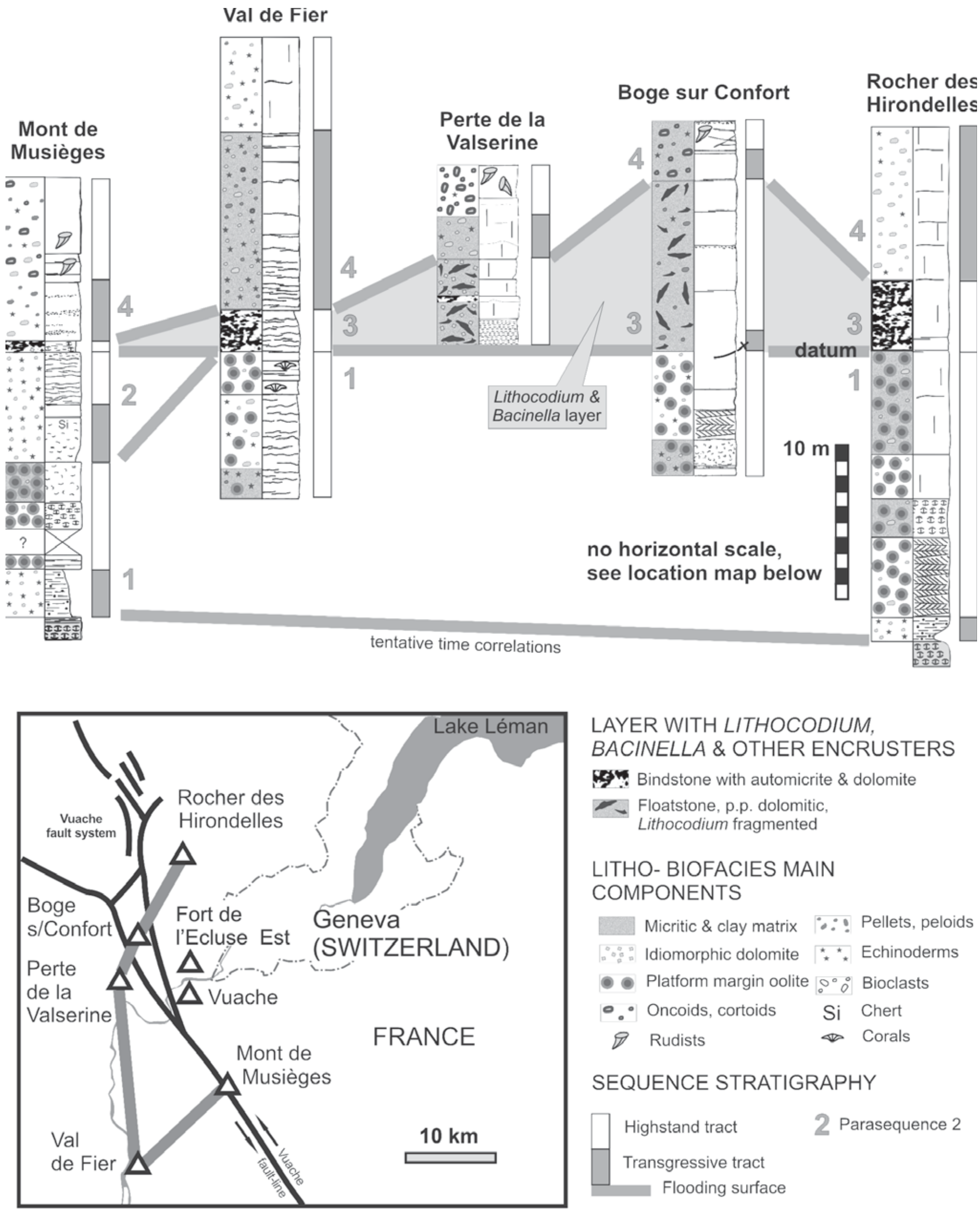


Figure 4: Local, detailed correlations in the lower part of the "Urgonien s.str." limestone. Considering the general palaeogeographical setting, approximately running in a SW–NE direction, the most external location is Mont de Musièges. Hence, it is placed on the left hand side in the profile. Vuache fault system according to DONZEAU et al. (1998). Rocher des Hirondelles section: see detailed log in CONRAD (1969). Other sections: logs are taken from the author's unpublished thesis manuscript.

Parasequence 3, only 0.8 m-thick, is visible in a small quarry, next to the D187 road (at Greenwich coord. 46.02616° N, 5.96355° E). It has a sharp boundary with the previous interval and consists of a knobbly limestone, free of detrital quartz, containing numerous *Lithocodium* crusts (Figs. 5, 6), acting as binders in a micropeloidal matrix of automicrite (see below). Transgressive deposits are absent. The accompanying biota includes subordinate amounts of *Bacinella*, a heterotrophic biota including bryozoans and sponges, small textularids, rare dasycladalean algae and key orbitolinids (see below). Quite large, idiomorphic dolomite crystals are also present. The *Lithocodium* and *Bacinella* layer is dated by orbitolinids at Mont de Musièges. As at Pic de l'Oeillette, an assemblage containing *Praedictyorbitolina busnardoi* and *P. claveli*, is overlain by the first specimens of *P. carthusiana*. Only part of the next, Parasequence 4 is shown in Figs. 3 and 4. The succession starts with 3.5 m-thick, angular and very coarse grained transgressive deposits, which are probably related to the adjacent Vuache fault system. Rudists occur in the highstand tract, with open sea influences decreasing progressively upsection.

2.3. Platform margin – Val de Fier section

Location (Fig. 4) is 4 km south of Seyssel (Haute-Savoie), on the D14 road, at the entrance of a tunnel (Lambert coord. 872.76/109.40). Parasequence 2 is missing. The 3 m-thick Parasequence 3 occurs above a flooding surface, in sharp contrast with the underlying, reefal oolitic grainstones belonging

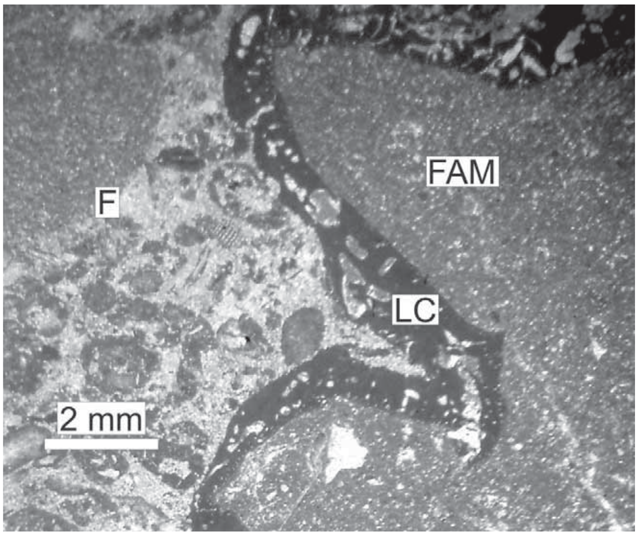


Figure 5: LC: *Lithocodium aggregatum* crust, sediment-binding. FAM: fluorescent pelletal automicrite. F: floatstone containing numerous lithoclasts of automicrite. Upper Hauterivian, Mont de Musièges (Haute-Savoie), sample Conrad 84, normal transmitted light.

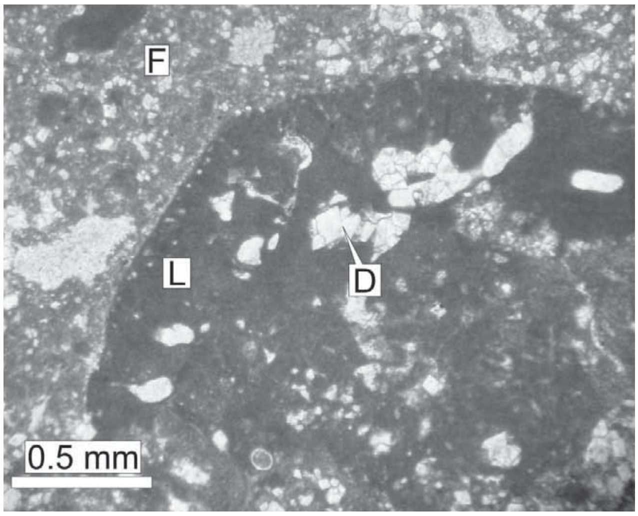


Figure 7: *Lithocodium aggregatum* floatstone. F: dolomitized matrix containing numerous fragments of *Lithocodium*. L: large fragment of *Lithocodium* crust. D: large dolomite crystal. Upper Hauterivian, Perte de la Valserine (Ain), sample Conrad 631, normal transmitted light.

to Parasequence 1. It consists of single or multiple *Lithocodium* and *Bacinella* crusts, binding a wackestone containing numerous bryozoans, echinoids, pelecypods and some transported ooliths. A basal transgressive layer is absent and there is no idiomorphic dolomite.

Paraquence 4 is observed next, on top of a conspicuous joint, marking the flooding surface. Only part of it is shown in Fig.4. The transgressive tract consists of deeper water, peloidal packstone, typically containing *Lenticulina* sp. and common *Choffatella decipiens*. Based on the literature, e.g. IMMENHAUSER et al. (2004), the latter foraminifera indicates open marine environments, below fair-weather wave base, but within the reach of storm waves. Biotic restriction occurs much higher up in the Urgonian limestone.

2.4. Platform margin – Perte de la Valserine section

Location (Fig. 4) is 1.7 km NNW of Bellegarde-sur-Valserine (Ain), at (Lambert coord. 868.87/131.50). Parasequence 1 is observed on the Valserine river bed and therefore remains inaccessible. The lack of Parasequence 2 can therefore only be inferred from nearby locations. The 6 m-thick Parasequence 3 consists of very numerous, angular fragments of *Lithocodium* crusts (Fig. 7), which are embedded in floatstones also containing encrusting bryozoans, numerous oyster and echinoid debris, including spines, microgastropods, and diverse foraminifera, *Coptocampylodon lineolatus* (incertae sedis), and common specimens of *Pseudoactinoporella fragilis*, a dasycladalean alga. Idiomorphous dolomite is present (Fig. 7) and a few, probably reworked ooliths are scattered in the sediment.

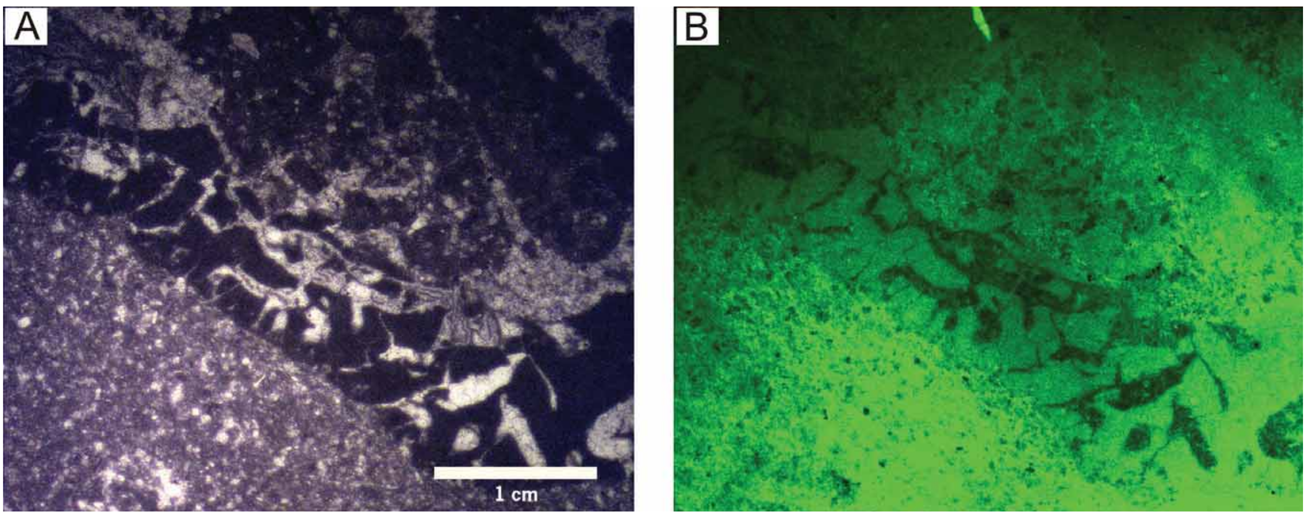


Figure 6: A: *Lithocodium aggregatum* crust, binding a pelletal automicrite; lithoclasts of pene-contemporaneously reworked automicrite; normal transmitted light. B: epifluorescence image of the same view. The automicrite fluoresces considerably, indicating the presence of primary organic matter. In contrast, the secondary, blocky calcite cement filling cavities in the *Lithocodium* crusts remains dark. Also the *Lithocodium* crust is fluorescent, supporting a calcimicrobial origin. Upper Hauterivian, Mont de Musièges (Haute-Savoie), sample Conrad 84.

A single, inconspicuous level of *Lithocodium* and *Bacinella* bindstone is present in the mid part of the interval. The pieces of *Lithocodium* are interpreted as having originated from bindstone deposits forming hard substrates, which were fragmented and re-deposited in an allomicrite.

In contrast to the Mont de Musièges and Val de Fier sections, normal marine biota such as bryozoan micro-encrusters and sponges are absent from the next, Parasequence 4 deposits. The transgressive tract begins abruptly with a 3 m-thick, low energy and burrowed wackestone, containing angular rudist debris, foraminifera and ostracods. Rudist biostromes (Urgonian facies s. str.) are located up-section, in the highstand tract.

2.5. Platform margin – Boge sur Confort section

Location (Fig. 4) is 5 km north of Bellegarde-sur-Valserine, on the D16 road (Lambert coord. 870.3/134.5). Here also, Parasequence 2 is missing. The 11 m-thick Parasequence 3 rests directly on an oolitic grainstone belonging to the top of Parasequence 1. As at Perte de la Valserine, it contains numerous, angular pieces of *Lithocodium*, with *Bacinella*, bryozoans, scattered corals debris, foraminifera including rare orbitolinids, and some dasycladalean algae. The transgressive tract displays a rather inconspicuous upward shoaling trend, first with a basal floatstone including *Lenticulina* sp., grading to grainstones containing an increasing number of dasycladalean algae such as *Pseudoactinoporella fragilis*. Both bindstone layers was dolomite are apparently missing.

As at Perte de la Valserine, an open sea biota is absent from the overlying Parasequence 4. The basal, slightly deeper water transgressive tract consists of a wackestone containing some transported ooliths. Rudist biostromes occur up-section, in the highstand tract.

2.6. Platform margin – Rocher des Hirondelles section

Location (Figs. 1, 3) is 15 km north of Bellegarde-sur-Valserine, on the D991 road (Lambert coord. 874.0/144.7). A detailed account of the section was first published by CONRAD (1969). For later developments, reference is made to CLAVEL et al. (2007). At the time of writing, the original thin section material was unfortunately missing, and therefore the following brief account is based on the literature. The level of interest (Parasequence 3) is 4–5 m-thick, occurring on top of an oolitic packstone belonging to Parasequence 1. Evidence of deeper water, transgressive deposits is missing. *Lithocodium* crusts suddenly appear in a basal grainstone also including some reworked ooliths. A *Lithocodium* bindstone occurs higher up, but without dolomite. Bryozoans, microgastropods and dasycladalean algae are present throughout the interval.

At Rocher des Hirondelles, the *Lithocodium* and *Bacinella* layer is dated by orbitolinids. Here also, a rich assemblage including *Praedictyorbitolina busnardoi* and *P. claveli* is followed, up-section, by the first specimens of *P. carthusiana*. Only part of the overlying Parasequence 4 is shown in Figs. 3 and 4. The succession begins abruptly with an exceptionally thick (52 m), transgressive sequence of grain- and lime rudstones, containing unaltered, angular debris represetnaing an open marine, shallow water biota. Presumably, these are scarp deposits related to the past presence of an active fault belonging to Vuache system. Up-section, in the Angulicostata ammonite Zone (Uppermost Hauterivian), they are followed by highstand deposits containing rudists.

2.7. Platform margin – La Russille and other NW Switzerland sections

Location (Fig. 1) is 7 km east of Vallorbe (Canton Vaud), on the road between Montcherand and Lignerolle, at Latitude 46.73° N, 6.48° E. The section (Fig. 3) is of historical interest. For a review, see for example CONRAD & MASSE (1989), BLANC-ALETRU (1995) and CLAVEL et al. (2007). Also at La Russille, a rich assemblage of orbitolinids including *Praedictyorbitolina busnardoi* and *P. claveli* straddles the "Urgonien jaune", the improperly called "Marne de la Russille" (a narrow argillaceous interval of regional extent) and the "Urgonien blanc". The first specimens of *P. carthusiana* occur 3 m above the base of the "Urgonien blanc".

The *Lithocodium* and *Bacinella* deposits are missing at La Russille and elsewhere in the Swiss Cantons of Vaud and Neuchâtel. A study comprising a number of mineralogical analyses was carried out by BLANC-ALETRU (1995) in this area, in an effort to understand the significance of several unconformities observed in the "Urgonien jaune", the "Marne de la Russille" and the "Urgonien blanc". At La Russille and Vallorbe, the "Urgonien jaune" consists of a bioclastic, partly oolitic shallow water limestone capped by coral biostromes. After BLANC-ALETRU (1995, fig. 84, 141), at Vallorbe, dolomite unexpectedly occurs at the top of the "Urgonien jaune", while carbonate dissolution is present, and kaolinite is the leading clay mineral, in the overlying, transgressive "Marne de la Russille". Here, these signals of terrestrial exposure are tentatively correlated with Parasequence 3, elsewhere forming the *Lithocodium* and *Bacinella* layer.

3. PALEONTOLOGICAL AGE DETERMINATION AND CORRELATION

In the Southern Jura, at Mont de Musièges and Rocher des Hirondelles, the *Lithocodium* and *Bacinella* layer is dated by an assemblage of three species of orbitolinids, combining part of the *Praedictyorbitolina busnardoi* and *P. claveli* concurrent range zone, a few metres below the appearance of *P. carthusiana*. *P. busnardoi* (Pl. I) is Upper Hauterivian pro parte, (Sayni to near the topof the Ligatus ammonite Zones); *P. claveli* (Pl. I) is Upper Hauterivian to Lower Barremian pro parte, (Sayni to Nicklesi pro parte); *P. carthusiana* (CLAVEL et al., 2007, pl. 3) is Upper Hauterivian pro parte to Lower Barremian pro parte, (top of the Ligatus to the base of the Caillaudianus). At Pic de l'Oeillette, in the Pre-Subalpine Domain, this assemblage occurs in talus deposits, directly dated by a specimen of *Plesiospitidiscus* gr. *ligatus,* an index ammonite (Pl. I). In the Swiss Canton of Vaud Jura, the same assemblage of orbitolinids straddles a narrow argillaceous interval (improperly called the "Marne de la Russille"), separating the "Urgonien jaune" from the "Urgonien blanc". In the same general area, at La Sarraz – Les Buis, the upper part of the "Urgonien jaune" is dated Upper Hauterivian by significant assemblages of dinocysts and calcareous nannofossils (CLAVEL et al., 2007).

As for the dasycladalean algae, at Val de Fier, the layer with *Lithocodium* and *Bacinella* contains the typically Hauterivian *Dissocladella hauteriviana*. At Mont de Musièges, a sample taken 3 m above the bindstone layer contains *Suppiluliumaella corbarica*. The species is Upper Hauterivian pro parte, (Sayni and Ligatus ammonite Zones), (CLAVEL et al., 2007). Based on these observations, the level with *Lithocodium* and *Bacinella* must be assigned to the Ligatus Zone which represents the mid part of the Upper Hauterivian.

The layer with *Lithocodium* and *Bacinella* is in between the Valanginian Weissert OAE and the latest Hauterivian (upper part of the Angulicostata auct. Zone), Faraoni OAE (for reference see for example BAUDIN & al., 2006). Hence, it seems unrelated to a large-scale, significant oceanographic event, and/or global climate change. It is more indicative of being a consequence of locally abnormal conditions, such as those resulting from a sudden influx of key nutrients, perhaps of nearby terrestrial origin.

4. SEQUENCE STRATIGRAPHY

Definitions introduced by SCHLAGER (2004, 2005) are used here. Based on bio- and lithofacies analyses, at least four units are present in the study interval (Figs. 3, 4). They are bounded by flooding surfaces, with no evidence of exposure, corresponding to Type-3 sequence boundaries. Still, these depositional parasequences, as described below, are succinctly compared to the subdivisions elaborated by CLAVEL et al. (1995), using the Exxon terminology. Parasequence 1 presents the onset of the Urgonian deposits. It is up to 18 m-thick, on top of a clear-cut flooding surface, followed by a conspicuous, quartz-bearing transgressive tract. The highstand tract, almost entirely oolitic, is capped by coral biostromes at Val de Fier. Using the terminology introduced by CLAVEL et al. (1995), Parasequence 1 corresponds to the Ha5 sequence lowstand tract, covering, for example the upper part of the "Urgonien jaune" at La Russille, in the Vaud Jura Canton.

The 7 m-thick Parasequence 2 was logged only at Mont de Musièges, in the southeastern-most part of the area, in the direction of the Subalpine depocenter. The depositional environment is markedly deeper than in the previous interval, with oolites appearing only near the top of the highstand tract. As shown by Fig. 3, the base flooding surface of Parasequence 2 is tentatively correlated with an argillaceous, hemipelagic interval at Pic de l'Oeillette, in the Pre-Subalpine Domain. At Mont de Musièges, the Parasequence 2 corresponds to the Ha5 transgressive tract, and the Ha5 highstand tract pro parte.

The bindstone and/or floatstone layer with *Lithocodium* and *Bacinella* matches Parasequence 3, abruptly interrupting Parasequence 2 at Mont de Musièges and, elsewhere, Parasequence 1. The thickness varies considerably, reaching an 11 m maximum measured at Boge sur Confort, in the area of the Vuache fault system. The base of Parasequence 3, taken as a datum, is considered as corresponding to a local, "instantaneous" M (microbial) carbonate factory event. It is tentatively correlated with the transgressive base of the improperly called "Marne de la Russille", in the Vaud Jura Canton. Alternatively, the top of the layer with *Bacinella* and *Lithocodium* may be locally diachronous and since masked by the rapid deposition of bioclastic debris. At Rocher des Hirondelles, Parasequence 3 corresponds to part of the Ha5 highstand tract.

Finally, Parasequence 4 corresponds to the onset of the Urgonian T (tropical) and photozoan carbonate factory, an important event of regional extent, traceable as far as the Pre-Subalpine Domain (Fig. 3) and beyond, at the base of the Urgonian cliff. At Val de Fier, a 12 m-thick, deeper water transgressive tract occurs on top of a conspicuous flooding surface. At Mont de Musièges and Rocher des Hirondelles, the transgressive succession consists of thick, angular, often coarse grained deposits the presence of which is interpreted as being linked to submarine escarpments of tectonic origin. In same area, corresponding to the Vuache fault system, more or less coeval deposits witness the impressive effect of such syn-sedimentary activity with, for example, highly heterogeneous channel-fills at Bellegarde-sur-Valserine. At La Russille (Canton Vaud Jura), the Parasequence 4 transgressive tract corresponds to the Ha6 lowstand tract.

5. INTERPRETATION OF THE LAYER WITH *LITHOCODIUM* AND *BACINELLA*

The layer was initially interpreted by CONRAD (1969) as a marine facies corresponding to the back flank of oolite shoals. In a draft version of the present article, the coarse, rhombohedral dolomite accompanying the *Lithocodium* crusts was considered as supporting the Dorag depositional model. This model (BADIOZAMANI, 1973) calls for dolomite precipitation in the marine and fresh water mixing zones, for example in the vicinity of islands subject to heavy rains. Actually, although possible, the Dorag model is rather unlikely. It is highly controversial (for a review, see MOORE, 2001) and still requires well-documented examples for support.

5.1. Epifluorescence tests

In the layer with *Lithocodium* and *Bacinella*, the binding-trapping mechanism is primarily performed by *Lithocodium* crusts, *Bacinella*, and other micro-encrusters denoting an open marine habitat, and by fine-grained, organo-mineralic deposits conceivably generated by microbes. Six epifluorescence tests were carried out in thin section, to check for the presence, at Mont de Musièges, of automicrite containing residual organic matter. The tests were carried out by B. Van der Kooij, at the Department of Sedimentology and Marine Geology Vrije Universiteit, Amsterdam. A Zeiss epifluorescence microscope was used mounted with an Hg vapour light and a bypass filters for the green wavelength. Both the automicrite matrix and the *Lithocodium* crusts are brightly luminescent (Fig. 6), indicating a high organic content. In contrast, the secondary, granular mosaic calcites filling up the pore spaces, are non luminescent, and hence devoid of organic material.

5.2. The microbial mediation, anoxic conditions model

A possible interpretation of the *Lithocodium* and *Bacinella* deposit is the sudden development, next to an otherwise normal, open marine environment, of anoxic conditions, leading to the formation of microbial mats and bacterially-driven, epigenetic dolomite. In such an unbalanced environment, *Lithocodium* and *Bacinella* were possibly acting as low-trophic, opportunistic calcifiers, at work in semi-enclosed pools. A possible modern analogue is the Lagoa Vermelha, a moderately hypersaline, high pH and anoxic lagoon located 90 km east of Rio de Janeiro, where dolomite precipitation occurs. Experiments carried out by WARTHMANN et al. (2000), on a particular strain of sulphate-reducing bacteria found in the Lagoa Vermelha, indicate that bacterial sulphate reduction can induce the precipitation of significant amounts of metastable, nonstoichiometric dolomite which, in the fossil record, may evolve as the central nucleus of larger, rhombohedral dolomite crystals.

A disadvantage of the Lagoa Vermelha model is that apart from the automicrite, clearly of microbial origin, the layer with *Lithocodium* and *Bacinella* contains no indices of meso- or eutrophic conditions, such as an impoverished biota with *Triloculina* sp., or euhaline assemblages with charophytes, brackish molluscs and ostracods. In contrast, the *Lithocodium* crusts are accompanied by numerous, freshly broken and unaltered fragments of a typically stenohaline biota.

5.3. The microbial mediation, oxic conditions model

Another possible model is based on Highborne Cay, in the Bahamas, where stromatolite build-ups and micritic crusts are presently forming and trapping oolites in open marine environments of normal salinity. The location is at the back of a fringing algal reef (REID et al., 2000 and references therein). Cyanobacteria are the primary producers in this eco-system. According to BAUMGARTNER et al. (2006), sulfate-reducing bacteria (SRB), although traditionally viewed as restricted to anoxic zones, can tolerate oxygen. Certain SRB strains not only survive in the oxic zone of microbial mats, but even exhibit some of their highest rates of sulfate reduction during oxic conditions.

Although it is yet to be confirmed, dolomite precipitation does not seem to occur at Highborne Cay, whilst epigenetic dolomite is locally found in the layer with *Lithocodium* and *Bacinella*. The origin of organogenic dolomites has been the object of a number of studies. Among several processes, anaerobic methane oxidation favours dolomite formation. In the study area, fine mud, and syngenetic dolostones are missing in the Urgonian limestone. However, besides the layer with *Lithocodium* and *Bacinella*, coarse rhombohedral, epigenetic dolomite, although rare, is also found higher up in the formation. Such an occurrence was described by CONRAD (1969, p. 24 and fig. 7), from a Barremian limestone with rudists, in the Subalpine Domain. Pervasive dolomitization occurs near the top of a small sequence, right below beach deposits overlain by mm-thick coal seams. *Lithocodium* and *Bacinella* are missing in this case.

5.4. Distribution of *Lithocodium* and *Bacinella*

Large *Lithocodium-Bacinella* build-ups, such as those interbedded with rudist banks in the Aptian of the Middle East, are lacking in South-East France. These organisms occur in the "Urgonien blanc" (or "Urgonien s. s.") in the following manner: (1) in the partly dolomitized layer dealt with in this article, *Lithocodium* crusts are found either alone or accompanied by other micro-encrusters including *Bacinella*; (2) *Bacinella* oncoids, up to several cm-large, are coated by *Lithocodium*; they commonly occur in non-dolomitic floatstones which are associated with, but separate from rudist boundstones, in platform interior deposits; similar oncoids were studied by VÉDRINE et al. (2000) in the Oxfordian of the Swiss Jura. According to these authors, the *Bacinella-Lithocodium* association characterizes lagoonal environments with oligotrophic conditions, in normal-marine waters; (3) *Bacinella* alone (*Lithocodium* missing) commonly occupies primary cavities in rudist biostromes; (4) in the Subalpine Domain, dolomitized lithoclasts formed by questionable *Lithocodium* debris, occasionally form a minor component of thick grainstones, forming sand waves on the margin of the platform. If related to the type (1) above, these lithoclasts may indicate small scale exposures of the platform, between the shoreline and the shelf break, followed by the erosion and re-sedimentation of temporary, in situ bindstone deposits.

With reference to the above, observations made by other authors confirm that *Lithocodium aggregatum* and *Bacinella irregularis* are taxonomically distinct organisms. As for *Lithocodium*, its origin remained controversial for decades. Recently CHERCHI & SCHROEDER (2006) have shown that it cannot be a loftusiacean foraminifera. Instead it is considered as representing a colony of calcified cyanobacteria. This interpretation is supported by our observation showing that the dark *Lithocodium* crusts have a high organic content.

6. CONCLUSIONS

The layer with *Lithocodium aggregatum* and *Bacinella irregularis* is found in the Southern Jura, in the lower part of the "Urgonien s.s." formation. Two variants occur: (1) bindstones containing fluorescent automicrite and epigenetic dolomite; (2) much thicker floatstones containing, inter alia, numerous fragments of *Lithocodium* crusts. By analogy with the modern Lagoa Vermelha, in Brazil, one interpretation calls for a sudden, local anoxic episode of microbial carbonate and dolomite precipitation, interrupting the normal marine carbonate factory. Another model calls for an analogy with the Highborne Cay area, in the Bahamas, where stromatolite build-ups and micritic crusts are presently forming, in an open marine environment of normal salinity.

Litho- and biofacies analyses show that the depositional setting, during the earliest development of the "Urgonien s. s." carbonate platform, consists of a stack of four, upward shoaling depositional parasequences, bounded by flooding surfaces. Parasequence 1 represents the initial onset of the "Urgonien s. s.". Parasequence 2 occurs in the south-eastern-most part of the area, in the direction of the subalpine depocenter. Parasequence 3 matches the layer with *Lithocodium* and *Bacinella*, abruptly interrupting Parasequence 2 or Parasequence 1, depending on location. Wide thickness variations (0.8–11 m) are interpreted as resulting from simultaneous tectonic activity, in the area of the currently still active Vuache fault system. Parasequence 4, finally, corresponds to the resumption of the normal, Urgonian carbonate factory. The *Lithocodium* and *Bacinella* event is of Upper Hauterivian age, in the Ligatus ammonite Zone. Dating elements are provided, directly, by an assemblage of three species of orbitolinids and, indirectly, by an index ammonite found in the Pre-subalpine Domain. Based on these elements, the *Lithocodium* and *Bacinella* event is correlated with platform talus deposits, in the Presubalpine Domain, and with the improperly called "Marne de la Russille", in the Swiss Jura. It is significantly older than the latest Hauterivian Faraoni anoxic event (OAE) and unlikely to be linked with global climate change.

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