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SEDIMENTOLOGY OF THE BIEUMONT MEMBER: INFLUENCE OF THE LION MEMBER CARBONATE MOUNDS (FRASNIAN, BELGIUM) ON THEIR SEDIMENTARY ENVIRONMENT

Marc HUMBLET & Frédéric BOULVAIN

(6 figures, 1 table and 2 plates)

Géologie-Pétrologie-Géochimie, B20, Université de Liège, Sart Tilman, B-4000 Liège
fboulvain@ulg.ac.be

ABSTRACT. This is a sedimentological study of Middle Frasnian Bieumont Member fore-reef and off-reef carbonate sediments exposed in the Chimay-Couvin region (Belgium). It is based on four stratigraphic sections: the Lompret quarry, the Frasnes railway section, the Leus quarry and southern parts of the Lion quarry. The Lompret section is here described for the first time and represents the main focus of this work. The Bieumont Member consists of a bedded sequence of argillaceous and bioclastic limestone. At Lompret, the Member is exposed with a thickness of 48 m (the basal contact is not exposed). The Member consists of 6 lithological units (in stratigraphic order): 1. argillaceous limestone with episodic intercalations of reef debris (distal reef talus), 2. an alternation of marl and argillaceous limestone (basinal background sediment), 3. thickly-bedded bioclastic limestone (channel deposits), 4. a sequence of argillaceous limestone (inter-channel deposits), 5. bioclastic limestone with sporadic occurrence of framestone (proximal fore-reef deposits) and 6. fine-grained, bioclastic limestone interbedded with prominent layers of reef debris (distal fore-reef deposits). Within unit 5, an isolated reef block transported down the paleoslope is present. Microfacies analysis revealed 16 microfacies units which together with the lithological subdivisions were used to reconstruct the dynamic sedimentary history of the Bieumont Member at Lompret. There are two orders of depositional rhythmicity. The reef growth cycle starts with the first significant influx of reef-related facies at the beginning of unit 3 and from thereon is well differentiated from the Bieumont Member stratotype which largely consists of lithologies equivalent to units 1 and 2. Progradation was directed to the South and related shallowing-upward conditions culminated during the deposition of unit 5. On a lower scale, rhythmic bedding within units 2 and 4 could be related to orbitally forced cycling. The vertical and lateral variations of facies within the Bieumont Member were used to reconstruct a depositional model for the Lompret area. In addition, the documentation of facies variation on a regional scale was enhanced by using data from the Focant borehole and geological surveys of Han-sur-Lesse and Barvaux regions.

KEYWORDS: Frasnian, carbonate mound, fore-mound facies, palaeoenvironments, sedimentology, Belgium.

1. Introduction

1.1. Purposes and methods

This work details the sedimentology of a section exposing most of the Bieumont Member in a quarry located close to the village of Lompret, in the area of Chimay (Fig. 1). The Bieumont Member is considered as a lateral "off-reef" equivalent of the reefal Lion Member (Fig. 2). Three other sections were also studied for comparison: all are located near Frasnes (Fig. 1). These sections are successively the Bieumont Member stratotype in the railway trench of Frasnes, a section located at the south end of the Lion quarry, and a section close to the Nord quarry (Leus quarry in Boulvain & Coen-Aubert, 1997).

In addition to the illustration of sedimentary environments in the vicinity of a Lion Member mound, until now poorly studied, the purpose of this work is to identify possible high frequency sequences (5th and 6th orders) in the Bieumont Member. High frequency sequences are apparently missing within the mounds (Boulvain & Herbosch, 1996).

A summary of researches concerning the Frasnian mounds of Belgium follows. As these works approach only very superficially the influence of the mounds on their sedimentary environment, it proved to be interesting to propose a short outline of the main characteristics of peri-reefal environment.

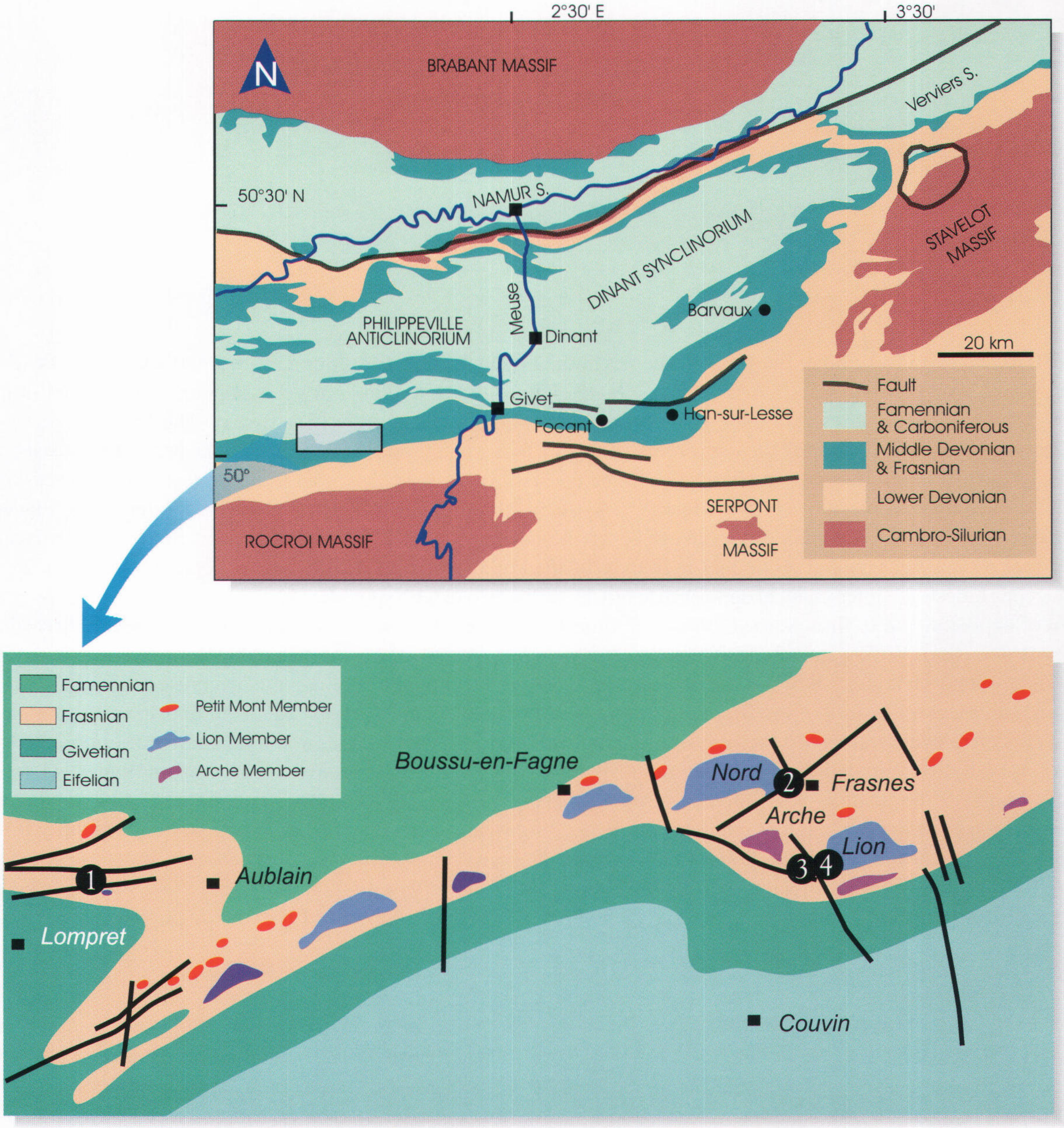


Figure 1. Schematic geological map of southern Belgium and southern border of Dinant Synclinorium, with location of Lompret quarry (1), Leus quarry near Nord quarry (2), Frasnes railway section (3) and Lion quarry (4). Grid references (Belgian Lambert system) are as follow:

- Lompret section : X = 151,44 ; Y = 84,23 ; Z = 210 m ;
- Frasnes railway section: X = 159,81 ; Y = 84,46 ; Z = 180 m ;
- Lion S: X = 160,57 ; Y = 84,41 ; Z = 185 m ;
- Leus section: X = 159,78 ; Y = 85,31 ; Z = 210 m.

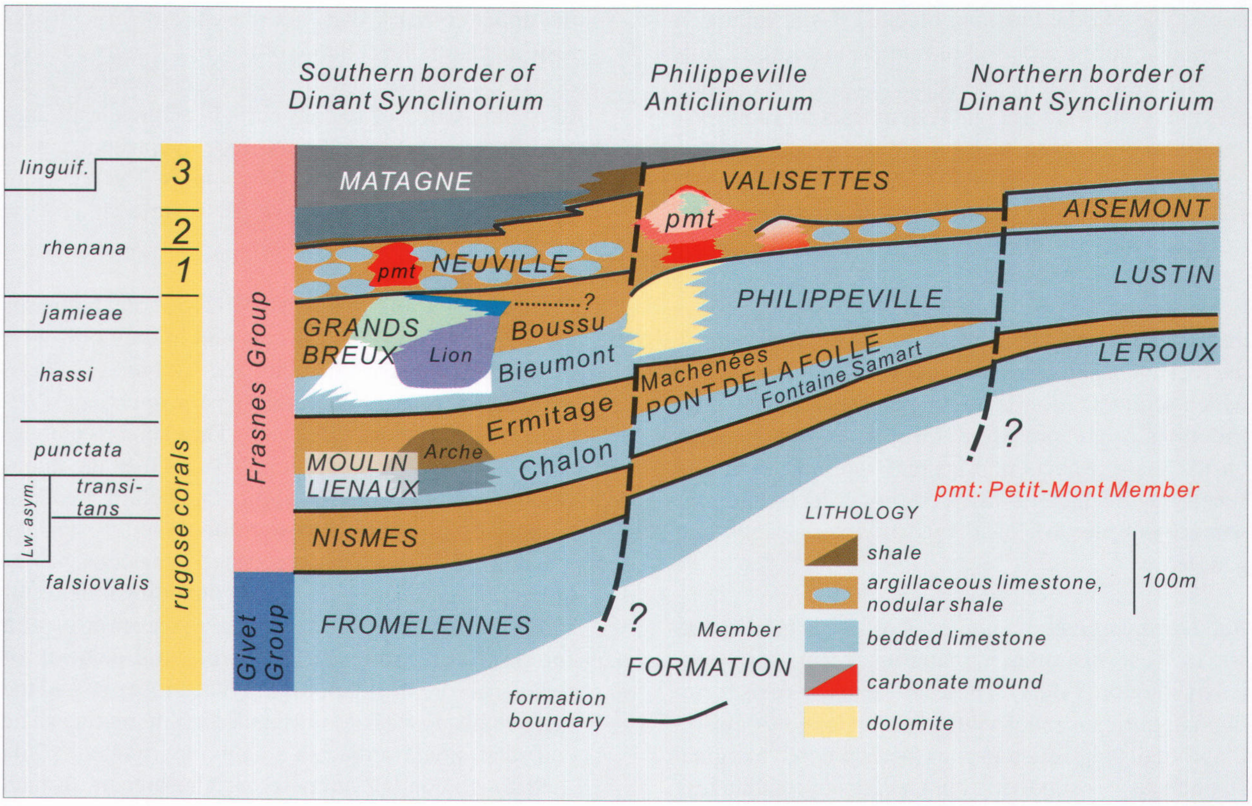


Figure 2. N-S section in the Frasnian sedimentation basin before Variscan deformation. Conodonts after Bultynck *et al.* (1998).

1.2. Short history of research

Very rapidly, the interest shown in the reefal phenomenon has led to the identification of three generations of reefs at the southern border of the Dinant Synclinorium (see Boulvain, 1993): the Arche Member, the Lion Member and the Petit-Mont Member (Boulvain *& al.,* 1999).

Lecompte (1956) deduced from his studies of the Petit-Mont Member mounds that they developed well below the sea level, below turbulence zone, during a high subsidence period. He considered that Lion Member build-ups developed during lower subsidence but of a sufficient amplitude to prevent them from reaching sea surface. The stromatoporoid zone occurring at the top of these reefs attests of a reduction in bathymetry.

Tsien (1977) supported the idea that the succession of epeirogenic movements was responsible for alternation of terrigenous and carbonated phases. He distinguished the reefs developing during relatively stable phases (tectonic calm), from the reefs growing during transgressive phases. In the first category, he placed the first two generations of mounds (Arche and Lion Members, respectively R3a and R3b), lenticular build-ups growing in the subsident basin, contemporary of biostromes (R4) and of "patch reefs" (R2) on the relatively stable platform. The morphology of these mounds was controlled by the growth rate of organisms and the rate of subsidence. R3a type build-ups show a vertical facies variation whereas those of R3b type are characterized by a lateral variation of facies.

Boulvain & Coen-Aubert (1997b) carried out a sedimentological study of the Nord mound. Moreover, the research related to the mounds from the southern border of the Dinant Synclinorium (Lion and Petit-Mont Members) and in the Philippeville Anticlinorium (Petit-Mont Member only) led to the definition of 9 lithofacies and 18 microfacies (Boulvain & Herbosch, 1996; Boulvain, 2001; Boulvain *et al.,* 2001). This sedimentological synthesis together with the study of the geometry of the build-ups allowed to recognize several types of mounds. Four models were developed. Two of them represent build-ups located in the Philippeville Anticlinorium and thus belonging to the third mound generation. The two others relate to build-ups located at the southern border of the Dinant Synclinorium and belonging either to the second generation (Lion type), or to the third generation (Saint-Rémy type). These various types of mounds are characterized by their age, their geometry, and their architecture. The 9 lithofacies have been interpreted in terms of palaeoenvironnement. Facies evolution in terms of sequential stratigraphy provided a model of system tracts. The Middle Frasnian mounds (Lion Member), developed during a period of relative sea-level stability, and show a complete sequence of deposit (transgressive system tract, high system tract and low system tract).

1.3. Sedimentation in peri-reefal environments: examples and synthesis

Let us define the so-called "fore-reef" environment as the transition zone facing the open-sea located between the reef and a point (more or less well defined) beyond which sedimentation is no longer influenced by contributions originating from the reef. Before focusing on the main aspects of fore-reef sedimentation and specifying the factors which control it, let us consider some examples of build-ups of diverse ages and geometries.

The Devonian reefal complexes of the "Canning Basin", a West Australian intracratonic basin, were studied by Playford (1984). These are "barrier" reefs forming a significant relief with a steep slope basinward. Playford distinguishes various facies whose "marginal slope facies" is subdivided in "reefal slope subfacies" and "fore-reef subfacies", farther away from the reef and characterized by a more gentle slope. Broadly, this facies consists of coarse debris and isolated allochton blocks. The debris flows are channellized by channels incised on the partially lithified slopes of the reefal front. The flows may originate either from the collapse of the platform margins, or from the breakdown of the slope itself. In this last case, the slope must be rather strong and debris flows can be triggered by an earthquake, eventually followed by a tsunami. Grain flows can also be at the origin of breccia and megabreccia. Moreover, the turbulence generated by debris flows reaching the bottom of the slope may induce turbidity currents.

The Silurian reefal complexes of Gaspé, in Quebec (Bourque *& al.,* 1986) provide us with another example of a reefal barrier. The "fore-reef" equivalent of the lower reefal complex (West Point Formation) is made of fine-grained siliciclastic deposits and several units of debris flows. The majority of these units are confined close to the reef. Bourque *et al.* (1986) classify them in three groups. The first relates to the debris originating from the reefal margin, very badly sorted and included in a siliciclastic mud. The second is characterized by debris flows of plurimetric thickness and containing blocks of variable lithology, cm to m-scale, included in a fine-grained calcareous matrix. The third group relates to chaotic masses of large blocks embedded in a siliciclastic mud, originating from the breakdown of the early lithified reefal talus. Contrary to the lower complex, the fore-reef slope of the upper complex does not present any large blocks resulting from the collapse of the reef. It only consists of siliciclastic mud and fine sand with several episodes of accumulation of reefal debris in a siliciclastic matrix. Bourque *et al.* (1986) exclude the presence of an escarpment in the upper reefal complex. The reef front presents a relatively gentle slope, as suggested by the orientation of geopetal fillings.

The peri-reefal environment of Triassic coral bioherms located in the west of Slovenia and in the north-west of ex-Yugoslavia is characterized by breccia deposited on the slopes of the build-ups or in channels between the reefs (?ar *et al.*, 1981). The elements of these breccia are poorly sorted and have an average diameter of 2 cm. They consist of bio- and pelmicrites with fragments of organisms commonly encrusted by nonskeletal algae. This brecciated limestone passes laterally to laminar biopelmicrite including mm to cm-scale intraclasts. Bioturbation is common and foraminifera, molluscs and rare calcified tests of radiolarian are the main fossils. The bioherms and the peri-reefal deposits are surrounded by alternating shale and sand. Shale settled in a calm environment while sandstone beds are tempestites. The breccia formed during episodical decrease of subsidence. The continuous growth of the build-ups allowed their upper part to reach a zone of stronger water agitation.

The Latemar reef (Middle Triassic Dolomites, North of Italy), studied by Harris (1994), is a 4 km broad circular carbonated build-up whose upper part is a platform with a central zone protected by a massive limestone rim. Near the platform margins, the slope reaches 30 to 35 degrees. On the slopes, breccia form massive plurimetric units locally overlain by thinner limestone beds with smaller grains (rudstones, grainstones, and more rarely packstones and even wackestones). Well sorted inframetric grainstone beds are observed at the bottom of the slopes and pass laterally to fine-grained basinal carbonated sediments. The well sorted grainstones are interpreted as proximal turbidites, probably induced by storms. For Harris (1994), slope sedimentation would be related to high frequency sea level changes (fourth and fifth order). The well sorted grainstones would have developed during high sea level (inundation of the platform) whereas the formation of breccia would have take place during platform inundation or during emersion (respectively high level and low level). However, due to the episodic character of the slope sedimentation, high frequency cycles are not recorded. On the contrary, on the platform, the shallow water sediments show periodic facies variations which record a high frequency cyclicity.

These examples show clearly the highly variable character of fore-reef sedimentation. Not only does the nature of the sediments vary according to their distance from the reef, but it also varies from one example to another. The fundamental factors that control the sedimentation on fore-reef slopes seem to be geometry and lithification degree of the reefs, water energy (depth-related) and slope steepness. Two parameters are necessary to characterize the sediments: their nature and the mechanism of deposition. The two principal transport mechanisms are the gravity flows (fall of blocks from the reefal margin, slumps, turbidites, debris flows and grain flows)'and the settling of fine-grained sediments. These clastic rocks consist of blocks originating from the breaking of the reef margins, of bioclasts or other carbonated grains, of micritic intraclasts whose proportion increases towards the open sea because they primarily come from the reworking of the slope deposits (Scholle *and al.*, 1983), of carbonated mud produced in variable amount by reefal activity or exported from the internal platform, and of terrigenous sediments whose abundance depends directly on the regional geological context. These sediments are thus characterized by a broad spectrum of lithologies, ranging between two opposites: argillaceous or carbonated basin sediments and reefal carbonates.

2. Geological context and location of sections

The sections from Lompret, Frasnes railway trench, Leus quarry and from the southern part of the Lion quarry belong to the western part of the southern border of the Dinant Synclinorium (Figs. 1 & 3). Like the lateral stratigraphic equivalent Lion Member mounds, they represent the northern end of the "Calestienne" or "Fagne calcaire". morpho-structural unit The Lion Member mounds are build-ups of significant size (150 m high for a km-scale diameter). Primarily located at the southern border of the Dinant Synclinorium, some examples were observed in the southern part of the Philippeville Anticline (Dumoulin *et al.,* 1998).

3. Sections and microfacies

3.1. Lompret section

3.1.1. Description

The Lompret quarry exploits bedded limestone from the Bieumont Member (Pl. 1A). The studied section is located at the east end of the quarry. It is an old exploitation front, roughly North-South and perpendicular to the direction of the strata. Unfortunately the base of the Bieumont Member is not exposed. The direction of the strata is N 105° E with a dip of 22°N.

The section starts with 5 m of dark grey argillaceous limestone (Fig. 4). This first unit is rather homogeneous. Fauna is not abundant and is poorly diversified. This limestone resembles the Bieumont Member exposed in the railway trench near Frasnes, except for the local presence of bioclastic beds, including crinoids, and cm-scale stromatoporoids and tabulate corals.

This unit is overlain by approximately 12 m of an alternation of limestone and argillaceous limestone. Organisms are even less abundant. Small brachiopods, trilobites, tentaculitids, gastropods, ostracods and crinoids are observed. The solitary rugose coral *Metriophyllum*, typical of open marine facies is present.

The third unit, a little more than 4 m thick, overlays bed 29. It is a very fine-grained pyrite-rich limestone with argillaceous joints. The facies changes dramatically with the following bed. Indeed, compared to the first two units, the limestone shows a much more massive and grainy character. These strata are very rich in bioclasts and show locally fining upward graded beds. At the scale of the unit, a coarsening upward tendency is obvious. Bed 33 is a rudstone where bioclasts commonly reach cm-scale dimension (Pl. 2A), and the bases of beds 32 and 34 is a breccia with dm-scale elements (dark grey micritic lithoclasts). The base of beds 30, 31 and 32 shows undulations with a plurimetric wavelength. Those are irregularly spaced and of variable amplitude, suggesting a system of channels. The thickness of bed 33 increase gradually towards the south. Its base does not present any undulation. It is probably a much broader channel than the three previous beds.

The next unit marks the return to an alternation of argillaceous limestone and limestone (unit 4). These 8,5 m thick strata are darker and fossils of reefal organisms are uncommon.

The following unit, the fifth, begins with bed 45, whose base is erosive and is deeply incised in the subjacent schistous layer. The filling consists of fragments of reefal organisms and micritic lithoclasts in a fine matrix. It corresponds to a debris flow with transported elements supported by a clay and water matrix; this sediment is characterized by the absence of texture (Cojan & Renard, 1999). The upper part of this bed contains many small fenestrae. Bed 47 also shows this type of structure, indicating again the existence of a channel system (narrower and shallower than previously: this could be explained by the different nature of the substrate on which they were developed). The three following beds show a tendency towards a reduction of debris size and of the importance of flows. The system evolved to a mixed clay-carbonated sedimentation (bed 50). Beds 53 to 59 are inaccessible due to a fault, shifting the strata several meters. The first half of bed 60 is a boundstone. The presence of dm-

Figure 3. Geological map of Chimay with location of Lompret quarry; geological map of Couvin with location of Leus quarry (2), Frasnes railway section (3) and Lion quarry (4).

Figure 4. Lithological log and microfacies of the Lompret section. Explanation of symbols, see Fig. 5.

PLATE 1

A. Upper part of the Lompret section. "f": fault; "b": base of Boussu-en-Fagne Member.

B. Limestone lens in the uppermost part of the Bieumont Member; E-W, south facing wall of the Lompret quarry. Thickness of the lens is approximately 1,5 m.

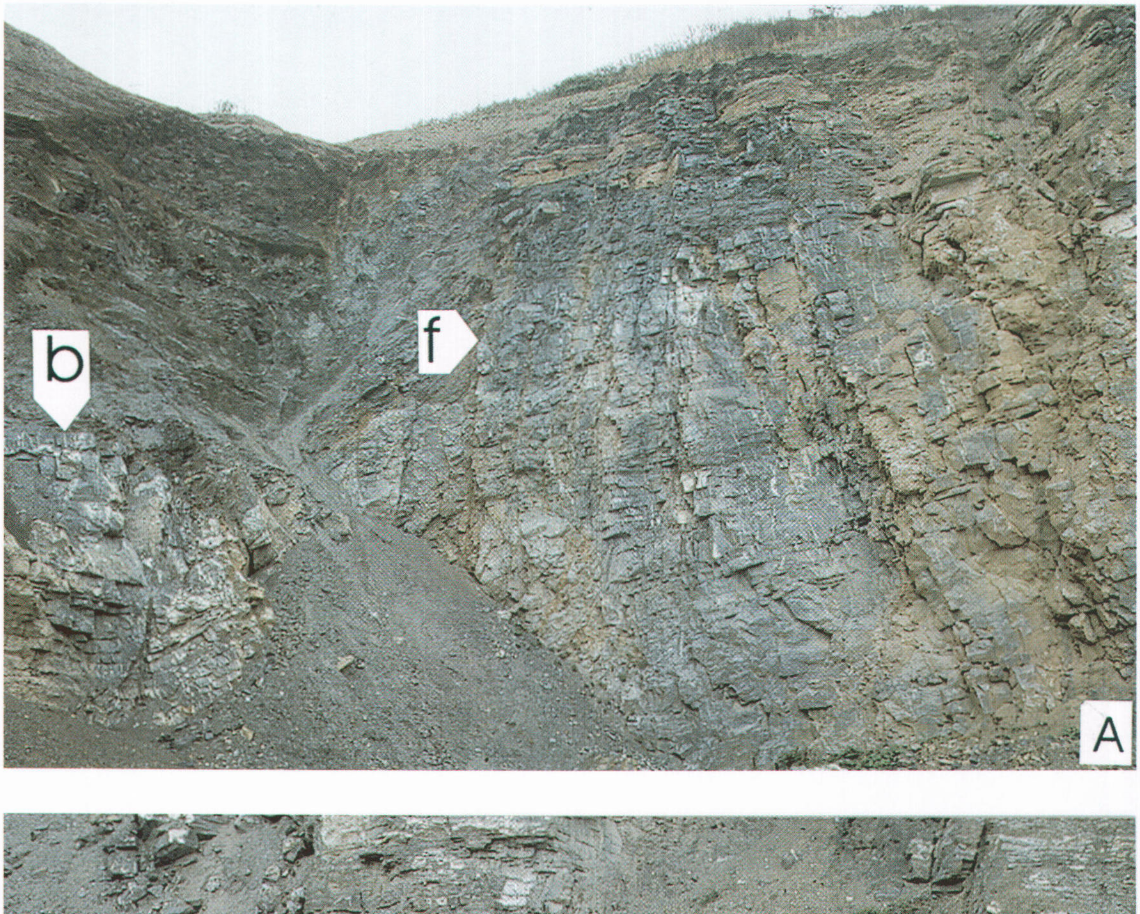

b
f
A
B

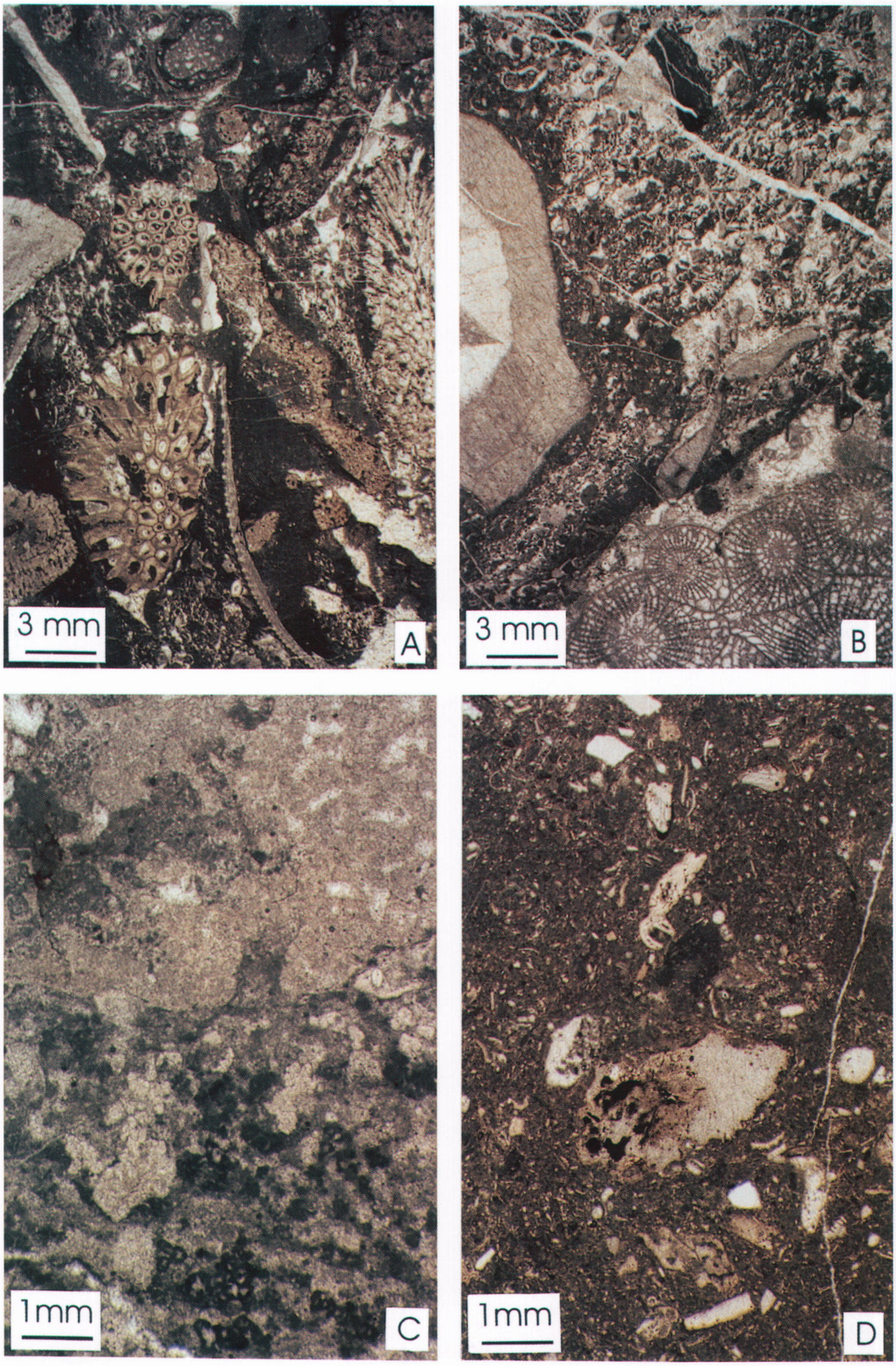
PLATE 2

A. floatstone with tabulate corals and branching stromatoporoids (unit 3, microfacies Lp8), Lompret, section 33b. Plane polarized light.

B. rudstone with crinoids and massive rugose coral (*Hexagonaria mirabilis*) (unit 6, microfacies Lp16), Lompret, section 65b, Plane polarized light.

C. bindstone/bafflestone with stromatoporoids, thrombolite, *Renalcis, Palaeomicrocodium* (allochtonous block), Lompret, section A, Plane polarized light.

D. wackestone with crinoids (microfacies Fr1), Frasnes railway section, section 3, Plane polarized light.


3 mm
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D

scale cavities partially filled with sediments suggests some kind of synsedimentary cohesivity. The fifth unit ends with bed 65. Beds 61 to 65 are composed of bioclastic limestone (Pl. 2B). The debris accumulated in lenses (beds 62 and 63) or filled channels.

The transition with the next unit is unfortunately not visible. Approximately 8 m of section are inaccessible. This last unit consists of darker and finer limestone. However, bioclastic material still influenced sedimentation, as indicated by the sporadic presence of grain flows (beds 65, 69, 76 and 77). The flows are thinner and narrower than those of the third and the fifth unit. There are no structures indicating the presence of channels. Accumulations of bioclasts constitute whole beds (68 and 77), or dm-thick units localised at the top of the beds (65, 67 and 70), or lenses of limited lateral extension (69, 75 and 76). The sixth and last unit ends with bed 80. The contact with the schist of the Boussu-en-Fagne Member is very sharp (Pl. 1A).

We must also emphasise the presence of a plurimetric limestone lens, most probably of reefal origin, located in the middle of the east-west, south-facing wall of the quarry (Pl. 1B). The presence of a small boundstone lens within the Bieumont Member is not an exception and was mentioned in the Eastern part of the southern border of the Dinant Synclinorium by Coen (1974) (see below, "lateral variations of the Bieumont Member").

3.1.2. Allochtonous block

To end the description of this section, it is necessary to mention the presence of a light grey boundstone block, whose allochton character could be demonstrated by overturned geopetal structures. The visible part of the block is approximately 3.5 m in width and 5 m in height. It exceeds the top of bed 65 by 3.4 m. Nine samples were taken in this block. Facies consists of bindstone with microbial structures and lamellar stromatoporoids and, less commonly, of bafflestone with branching stromatoporoids. Large massive stromatoporoids and well-developed bushes of *Renalcis* are common (Pl. 2C). The abundance of stromatoporoids and *Renalcis*, as well as the presence of microbial structures and thrombolites indicate that this facies corresponds to lithofacies S8 already described by Boulvain & Coen-Aubert (1997b) in the Nord quarry. The upper part of the block seems to be richer in branching stromatoporoids. According to the sedimentological model of the Lion Member mound in the Nord quarry, it is not surprising to find an allochton block with lamellar stromatoporoids and *Renalcis*, since this facies constitutes the major part of the reefal margin, towards open sea.

3.1.3. Microfacies

a) Unit 1

Lp1: wackestone or fine grained packstone with peloids, brachiopods, crinoids, trilobites, burrows (often filled with pyrite). Little diversity. Locally, peloidal grainstones with calcispherids, *Renalcis,* fenestellids, *Sphaerocodium,* brachiopods, echinoderm spines, corresponding to coarser lenses.

Lp2: floatstone or rudstone with lamellar and branching stromatoporoids or tabulates debris. Matrix is constituted by peloidal packstone with calcispherids, crinoids, fenestellids.

b) Unit 2

Lp3: wackestone or mudstone containing small debris of brachiopods, crinoids and trilobites. Locally, burrows are observed.

Lp4: fine-grained bioclastic wackestone with brachiopods, gastropods, crinoids, ostracods, trilobites. Locally, sponge spicules and bryozoans.

Lp5: peloidal grainstone with calcispherids, brachiopods, crinoids, branching stromatoporoid debris, *Sphaerocodium.*

Lp6: floatstone with crinoids, brachiopods, tabulate corals, calcispherids, peloids, encrusted stromatoporoid debris, algae (chlorophyta, rhodophyta?).

Lp7: fine-grained wackestone or packstone with crinoids, brachiopods, trilobites, gastropods, subordinate *Girvanella* and *Sphaerocodium.* Bioclastic rudstone lenses with peloids, crinoids, brachiopods, *Renalcis*, bryozoans, *Egosiella* (locally coated by cyanobacteria), lamellar and branching reworked stromatoporoids.

Lp8: rudstone with abundant large branching tabulate corals, stromatoporoids, brachiopods (Pl. 2A).

Lp9: breccia with dm-scale elements.

c) Unit 4

Lp10: packstone, locally fine-grained bioclastic grainstone with peloids, calcispherids, brachiopods, ostracods, crinoids, trilobites, sponge spicules.

d) Unit 5

Lp11: lithoclastic packstone (peloidal grainstone, grainstone with tabulate corals, fine-grained wackestone with sponge spicules). Matrix includes bryozoans, gastropods, brachiopods, peloids, calcispherids, stromatoporoids debris, *Girvanella*, *Sphaerocodium*.

Lp12: packstone or wackestone with peloids, calcispherids, brachiopods, bryozoans, crinoids, ostracods, foraminifers, *Girvanella*. This packstone is associated with lenses of peloidal rudstone containing calcispherids, branching stromatoporoids, *Egosiella*, fenestellids, brachiopods, gastropods, crinoids, ostracods, *Renalcis*, *Girvanella*, *Bevocastria*, udoteaceae.

Lp13: biostrome with fenestrae, internal sediment, fibrous cement. Bindstone and floatstone with lamellar and branching stromatoporoids (sometimes coated, mainly by *Sphaerocodium*), tabulate corals, *Renalcis*, *Nuia*, *Girvanella*, *Sphaerocodium*, brachiopods, lithoclasts and peloids.

Lp14: grainstone or rudstone with peloids and calcispherids, *Girvanella*, coated debris of udoteaceae. Rudstones include coated debris of stromatoporoids, brachiopods, and crinoids.

e) Unit 6

L15: packstone or wackestone with peloids and calcispherids, small bioclasts of ostracods, brachiopods, crinoids, trilobites, minor stromatoporoids (lamellar and branching).

L16: rudstone or grainstone with lithoclasts, peloids and calcispherids, tabulate corals, stromatoporoids (branching and lamellar, locally coated), crinoids. Locally, bryozoans, brachiopods, *Renalcis*, trilobites, rugose corals, sponge spicules (Pl. 2B).

3.2. Frasnes railway section

3.2.1. Description

Whereas in the Lompret section, light grey bioclastic limestone or even boundstone are observed, the stratotype of the Bieumont Member near Frasnes shows only dark grey fine-grained argillaceous limestone with argillaceous intercalations (Fig. 5). It's possible to subdivide the section in two distinct units (Coen-Aubert, 1994):

- the first 16 m consist of dark fine-grained bioclastic limestone, relatively argillaceous, locally subnodular;
- the member ends with 21 m of fine-grained very argillaceous limestone, with numerous argillaceous intercalations.

3.2.2. Microfacies (concerns the lower part of the stratotype)

Fr1 : wackestone or packstone with peloids, reworked cri-noids, gastropods, trilobites, brachiopods, bryozoans, ostracods, *Girvanella*, foraminifers, sponge spicules (Pl. 2D). Locally, grainstone lenses with peloids, coated bioclasts (probably including chlorophyta), ostracods, brachiopods, trilobites, branching stromatoporoids.

Fr2 : dolomitic packstone (pressure-solution) with peloids, calcispherids, *Girvanella*, *Bevocastria*, brachiopods, ostracods, small bioclasts.

Fr3 : wackestone or mudstone with small trilobites debris, brachiopods, bryozoans, burrows, sponge spicules.

3.3. South section of Lion quarry

3.3.1. Description

This section is located in the southernmost part of the Lion Quarry, near the frontal part of the mound (Fig. 3, 5). The study relates to 19 m of limestone consisting in rudstones, grainstones and packstones locally very rich in bioclasts (Renard, 1999).

3.3.2. Microfacies

Li1 : wackestone or packstone, rarely grainstone with brachiopods, ostracods, crinoids, trilobites, bryozoans. Crinoids are deeply bored. Locally, sponge spicules, gastropods, tabulate corals debris, stromatoporoids and *Sphaerocodium*.

Li2 : rudstone or grainstone, locally packstone, with peloids and calcispherids, tabulate corals debris, reworked branching stromatoporoids. Algae could be abundant (coated green algae, *Sphaerocodium*, *Girvanella*, *Bevocastria*, *Wetheredella*, *Renalcis*, *Nuia*, palaeosiphonocladal algae). Subordinate brachiopods, bryozoans, crinoids, trilobites, and ostracods.

Li3 : fine-grained packstone with peloids and calcispherids, crinoids, brachiopods, trilobites, gastropods, ostracods, sponge spicules. Minor debris of rugose corals, stromatoporoids and tabulate corals. Bioturbation.

3.4. Leus quarry section

3.4.1. Description and microfacies

The abandoned "Leus" quarry is located 800 m east of the Nord quarry, at the east end of the hill (Fig. 3). The

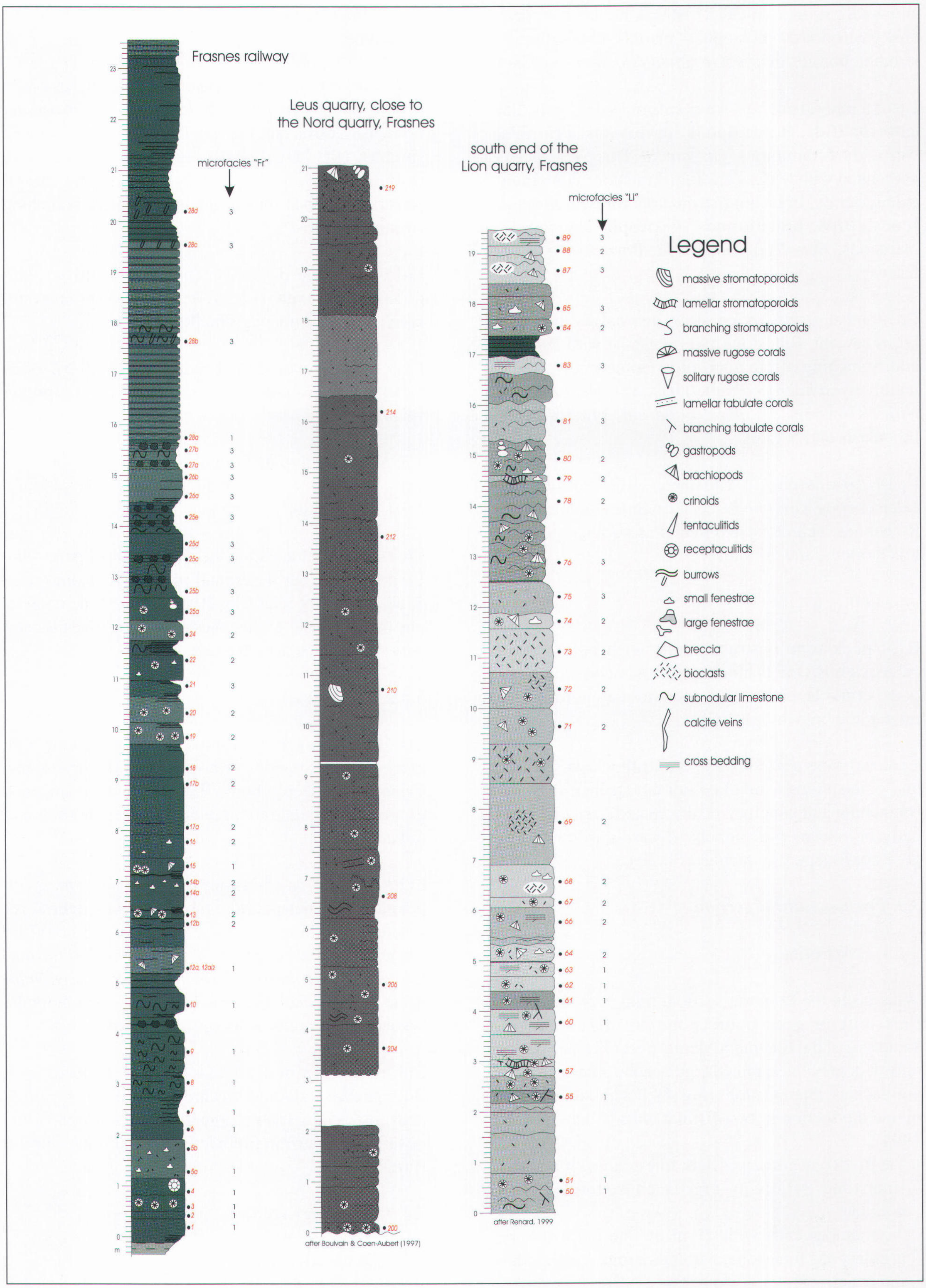

Figure 5. Lithological logs and microfacies of the Frasnes railway section, of the Leus quarry and of the southern end of the Lion quarry.

study was carried out by Boulvain & Coen-Aubert (1997b) together with the sedimentological study of the Lion Member mound of the Nord quarry. This section consists of 21 m of a rather monotonous dark grey bedded limestone in m-scale beds (Fig. 5). This limestone always presents a bioclastic character. Relatively well-sorted packstones and grainstones dominate (only bed 200 shows an accumulation of poorly sorted elements). Locally, microbreccia are observed.

The microscopic study reveals the presence of a large quantity of peloids, calcispherids, bioclasts and a variable proportion of intraclasts. Bioclasts consist of reworked branching stromatoporoids, crinoids, palaeosiphonocladal algae, brachiopods and ostracods. Very locally, fenestellids and *Renalcis* are observed (concentrated in bed n° 200 near the base of the section).

4. Sedimentological interpretation of the Lompret section

The Lompret section presents a large variety of lithologies. The presence of an isolated allochtonous block, of breccia with dm-scale elements and of channelized or sheet-like debris flows clearly indicate a fore-reef slope environment. Facies extend from open marine to reefal environment. Vertical facies variability is important.

4.1. Classification of microfacies

The lithological curve highlights the sedimentary breaks as well as the evolution of the environment in terms of proximity to a reef. To create this curve, it is necessary to order the microfacies on the basis of their relative position compared to the mound. This operation is carried out by using indices of proximality and distality. In this work, the microfacies sequence was established on the basis of distality index such as the relative quantity of trilobites, gastropods, sponge spicules, or the relative content of clay (determined by the texture of the rocks and observation under the microscope) and of indices of proximality such as the proportion of algae, calcispherids, stromatoporoids, tabulate corals. This classification also takes into account the granulometry of the reef-derived bioclasts.

It is interesting to note that the microfacies of Lompret correspond rather well to the standard microfacies of Wilson (1975), covering the zone extending from the deep platform to the reef (represented in Lompret section by the biostromes). Each facies recognized in Lompret belong to the following belts of facies: SFB 2, SFB 3, SFB 4 and SFB 5. The first represents the "open sea shelf" (deep platform), with fossiliferous limestone and marl alternation. The second corresponds to the "deep shelf margin" (slope base), with fine-grained bioclastic limestone. The next two belts are respectively associated with the "foreslope", characterized by brecciated limestone and bioclastic sands, and with the reefal environment, characterized by boundstones.

4.2. Microfacies interpretation

We propose here a microfacies classification, from an open marine environment, free from reefal supply, to a fore reef environment (Table 1).

4.3. Palaeoenvironmental reconstruction

The whole set of observations made on the outcrop and in thin sections allow to propose a model of facies repartition for the Lompret section (Fig. 6). This model illustrates the five main types of facies observed in this section: the deep platform sediments, the bioclastic debris flows, the platform sediments between the channels, the allochtonous block and the autochthonous reefal facies. Each environment is associated with one or more lithological units defined in Lompret. The model also proposes the diagrammatic representation of six bioclastic facies each one corresponding to a particular bed of the Lompret section. Let us note that the stratigraphic order of these beds is not respected.

4.4. Origin of bioclastic material

The question of the localization of the source of bioclastic material was not fully solved. Several hypothesis are possible. The sediments could come either from a mound located approximately 900 m west of the Lompret section, which seems nevertheless to far to be really the origin of the bioclastic debris flows, or from a bioherm located to the north, defined as a mound of the Petit-Mont Member (Marion & Barchy, Geological map Chimay-Couvin, 1999). But, as this mound presents an unusual grey facies, it could belong to the Lion Member, displaced via a fault. Another assumption would allot the origin of the bioclastic sediments to a build-up located near the Lompret quarry, apart from present day topographic surface.

5. Sequences

5.1. Two orders of rhythmicity

Two orders of rhythmicity are observed in the Lompret section:

- the argilo-carbonated sequences ("high frequency"), of m-scale thickness, are observed only in the more argillaceous units, i.e. units 2 and 4. These sequences consist of the alternation of a massive and a very argillaceous limestone bed;

Micro-facies	Description	Facies belt
Lp3	Fine-grained argillaceous wackestone to mudstone. Bioturbation is common. Faunal diversity is very low (small crinoids, brachiopods, trilobites)	SFB2
Lp4	wackestone with more bioclasts, locally more grainy. Trilobites are frequent. Some bryozoans.	SFB2
Lp1	Fine-grained wackestone to packstone, locally bioturbated. Trilobites, brachiopods, crinoids. Some bioclastic lenses (grainstone with calcispherids, stromatoporoids, *Renalcis* and *Sphaerocodium)*	SFB2 or 3
Lp10	packstone to fine-grained grainstone. Peloids, calcispherids, sponge spicules, bioclasts (crinoids, brachiopods, trilobites)	SFB2 or 3
Lp7	wackestone to fine-grained packstone with bioclasts. Lenses of rudstone containing peloids, crinoids, bryozoans, *Renalcis*, tabulate corals and branching or lamellar stromatoporoids	SFB2 or 3
Lp15	packstone or wackestone with peloids and calcispherids, ostracods, brachiopods, trilobites. Small debris of branching and lamellar stromatoporoids	SFB 3
Lp11	lithoclastic packstone. Some peloids, calcispherids, stromatoporoids, tabulate corals, *Girvanella* and *Sphaerocodium*	SFB 3
Lp12	packstone (wackestone) with peloids, calcispherids, bryozoans, *Girvanella*. Lenses of rudstone containing algae, stromatoporoids and tabulate corals	SFB3 or 4
Lp2	floatstone to rudstone with peloids, calcispherids, stromatoporoids and tabulate corals	SFB 4
Lp5	grainstone or rudstone with branching stromatoporoids, bryozoans, *Sphaerocodium*, peloids and calcispherids	SFB4
Lp16	rudstone or grainstone with peloids, tabulate corals, crinoids, branching, lamellar and massive stromatoporoids	SFB4
Lp6	floatstone with tabulate corals and stromatoporoids, recristallized algae (green, red?)	SFB4
Lp14	grainstone or rudstone with peloids, calcispherids, algae, tabulate corals and stromatoporoids	SFB4
Lp8	rudstone with tabulate corals. Transitional facies with the biostrome (L13)	SFB4
Lp9	breccia with dm-scale elements	SFB 4
Lp13	biostrome	SFB 5

Table 1: Synthesis of microfacies from the Lompret section and comparaison with the facies belts of Wilson (1975).

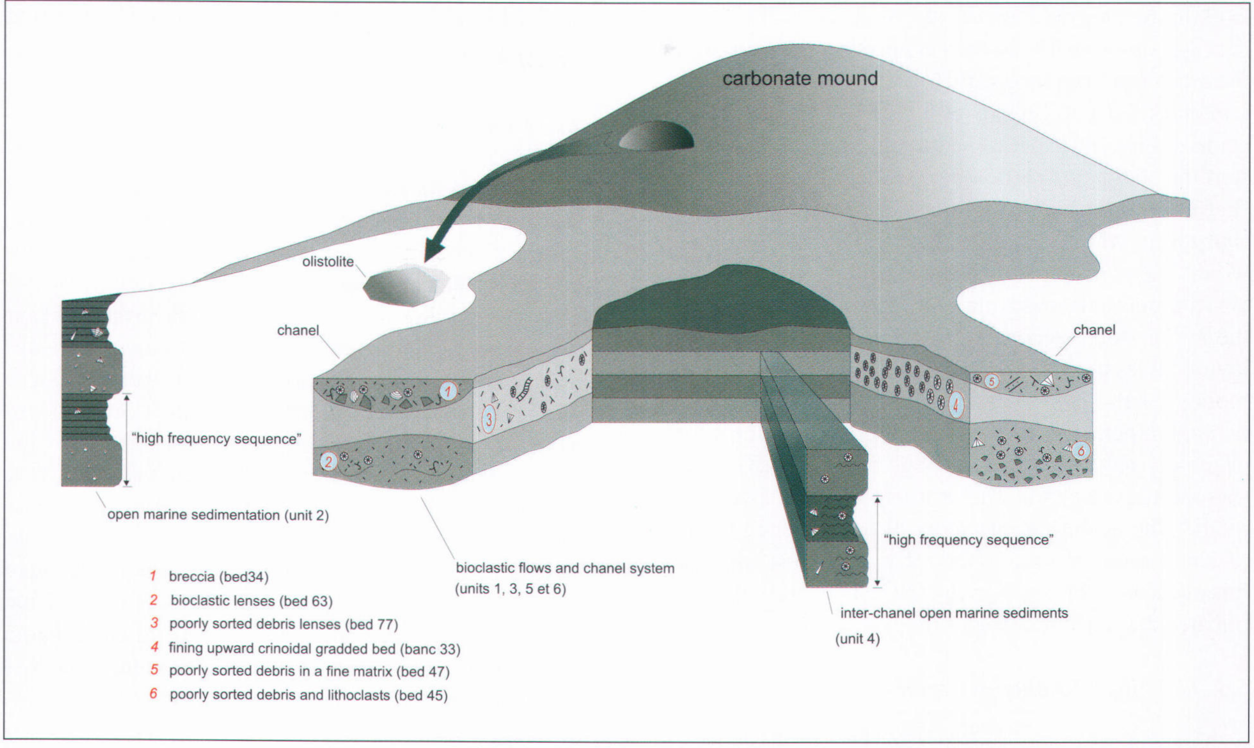

Figure 6. Schematic reconstruction of the sedimentary environments in the vicinity of a Lion Member carbonate mound. For the meaning of symbols, see legend of Figure 5.

- at the scale of the whole section, a rhythmicity is also observed ("low frequency"). It results from the installation of a argilo-carbonated unit (second unit) on a bioclastic substrate (first unit), the progradation of reef-influenced facies (bioclastic limestone in a channel system), the development of a boundstone (bed 60 of the fifth unit), and the recurrence of bioclastic limestone (second half of the fifth unit and sixth unit).

5.2. The "low frequency" cycle

At this scale, the sedimentation records the progradation and retrogradation of the reef (reached with bed 60). From the base of the section, debris of reef-building organisms are present and point to sporadic impulses of sediments coming from a growing reef. Apparently, the build-up was already well developed, as shown by the presence of branching stromatoporoids in the first beds. After that, the argilo-carbonated unit (second unit) does not show any trace of a reefal contribution. This abrupt passage towards a pronounced distality, characterized by a very argillaceous sedimentation in an open environment, represents a reefal retrogradation. The installation of a collecting channels system with bioclastic infilling marks the return of reefal contribution and the progradation of the build-up. Boundstone with large cavities of bed 60 represents the apogee of the reefal extension. This reefal unit is overlain by a channelized system which decreases appreciably towards the top of the section (sixth unit) where low scale debris flows form thin beds without true incision of the previous deposits (deposits of distal fore-reef slope).

Several causes are proposed to explain the reefal development cycles. One opposes the external factors (allocyclicity) to the internal factors (autocyclicity). Among the first, fluctuations of sea level can be dominating in controlling reef development. Following this hypothesis and assuming that sea level variations were responsible for the facies succession observed in Lompret, it's possible to attempt a sequence stratigraphy interpretation and to try to define the successive system tracts. The second unit, consisting of schist and argillaceous limestone, would correspond to the transgressive system tract. The installation of this unit, which accompanies the abrupt retrogradation of bioclastic facies, can be explained by a reefal "give up". The reefal growth is not rapid enough to balance the rise of sea level, which involves the decline of the reefal development, accelerated, in some cases, by an environmental stress such as temperature fluctuation or turbidity (Neumann & Macintyre, 1985). The appearance of light grey massive limestone in the section would mark the beginning of the high system tract. It indeed seems that high sea level favours carbonate production. The combined effect of reef growth and sea level stabilization involves a decrease of accommodation. This reduction in available space would explain the progradation of the reefal facies. This tendency is quite visible in the Lompret section, through the evolution from bioclastic limestone to channel system and finally to boundstone. The fourth unit, characterized by argillaceous sedimentation, could represent the sediments settled between the channels. The first unit could be part of the low system tract. The sharp limit which separates it from the following unit would then correspond to the flooding surface. The environment inferred from unit 1 could be the base of the reefal slope, according to the nature of the overlaying facies (unit 2) and by comparison with Wilson's model (SFB 3). In addition to extrinsic factors like depth, temperature, turbidity or oxygenation, it is also necessary to consider the action of reef-specific factors (autocyclicity). These intrinsic factors could modify the accretion rate more or less independently of environmental parameters. It is then possible that this cycle superimposes on the sea level cycle and complicates the interpretation of the sedimentary record.

5.3. The "high frequency" cycle

With the retrogradation of reefal facies and decrease of supply of reef-derived material, the environment was able to record a basin high-frequency rhythmic sedimentation (second unit). Such a rhythmicity is represented by the stacking of limestone and argillaceous limestone or schist. Ferry (1991) described similar facies in the Mesozoic basin of south-east France. Associated with hemipelagic (slope) and subpelagic (basin) environments, these marl-limestone rhythms would find their origin in the variations of the earth orbital parameters (Milankovitch cycles) and would be related to glacio-eustatic or other mechanisms (see Mörner (1994), for a discussion of non glacio-eustatic mechanisms responsible for high frequency cycles). This kind of elementary sequence was observed in many series in the world, which shows the universality of this cycle and supports the assumption of the astronomical cause. It is much less easy to demonstrate the "high frequency" sequences within the massive limestone constituting units 1, 3, 5 and 6. However, the succession of beds 45, 46, 47, 48, 49 and 50 could correspond to a "high frequency" sequence (4th or 5th order). The low sea level would be represented by the succession of decreasing intensity debris flows. The high sea level would be characterized by a fine-grained bioclastic sedimentation, or even by argilo-carbonated facies (bed 50). The nature of the sedimentary recording of high and low levels depends on the amplitude of the fluctuations and the position of the section compared to the reef (distality, proximality). That explains the variations of the sedimentary response to high frequency fluctuations, and even the absence of recording.

6. Lateral facies variations of the Bieumont Member

6.1. Comparison of the four sections

Each of the four sections which were the subjects of this sedimentological study present particular characteristics. They all are associated with different environments. The Leus section shows a particular monotonous facies whose interpretation will be proposed later in this text. The three other sections can be distinguished on the basis of relative abundance of reef-building organisms debris which is an evaluation of the intensity of reefal influence. The southern end of the Lion quarry exposes an environment which was constantly subjected to bioclastic flows. This well-bedded limestone, approximately 19 m thick, passes laterally to the boundstones of the Lion Member. Among the three sections considered, the southern section of the Lion quarry occupies the more proximal position compared to the mound. The good outcrop of the mound makes it possible to locate this section in fore-reef environment.

The railway trench of Frasnes cuts nodular shales and 37 m of argillaceous limestone with scarce debris originating from the mounds. This low reefal influence is totally unexpected when considering the location of the section compared to the Lion Member mounds. It is indeed situated less than 250 m from the western end of the Lion Member, whose lateral extension is approximately 1 km with a thickness of 350 m (Marion & Barchy, Geological map Chimay-Couvain, 1999). The geological map indicates the presence of a N325°E fault which passes just between the Lion mound and the railway trench. Nevertheless, it is improbable that this accident could justify the lack of reefal supply in the railway section because its throw is too weak. There is a difference in direction and dip of the strata in the railway trench (N318°E, 32°N-E) and the access trench to the Lion quarry (N231°E, 40°N), but the stratification is probably influenced by the presence of the mound. Another possible explanation is the hypothesis of a reefal export directed towards the south. Moreover, let us note that the progradation of the Lion mound occurred in this direction. The Lion and Nord mounds would then delimit a kind of deep key or channel characterized by significant argillaceous sedimentation and low reefal supply.

The Lompret section is located in an intermediate position. As mentioned above, this situation enables it to record the growth cycle of the mound as well as the "high frequency" sequences constituting the most argillaceous units. In Frasnes, the stratotype does not show well defined marl-limestone sequences. Either the high input of argilo-carbonated fine-grained sediments prevents the recording of high-frequency sequences, or marl-limestone sequences observed in Lompret depend only on a local mechanism, in which case the hypothesis of an astronomical control is no longer valid. Only the base of the Lompret section (unit 1) is characterized by facies close to Frasnes railway trench ones. Just like in Frasnes, the base of the Lompret section is characterized by argillaceous-carbonated mud sedimentation containing small fragments of crinoids, trilobites, ostracods, bryozoans, gastropods and brachiopods, together with algal debris such as calcispherids, *Renalcis, Girvanella, Sphaerocodium*. The major difference lies in the abundance of reefal debris. Whereas in Frasnes, reef building organisms are exceptional, the first unit of the Lompret section shows local concentrations of cm-scale reef-derived bioclasts. The other characteristic of the Frasnes section is the importance of bioturbation. The second unit of the Lompret section precedes the massive bioclastic limestone of units 3, 5 and 6. Considering the argillaceous character of the second unit, it must be asked whether this unit would already belong to the Boussu Member, in which case the base of the Lompret section would correspond to the top of the Bieumont Member. However, this hypothesis does not seem correct considering the more significant proportion of shales in the Boussu Member compared to unit 2 of Lompret. Moreover, the upper part of the section clearly shows the limit between the massive limestone of the sixth unit and shales undoubtedly belonging to the Boussu Member. The lithological limit between Boussu and Bieumont Members can thus only be located at the top of the sixth unit. The bioclastic limestone of units 3, 5 and 6 are very different from the dark grey argillaceous limestone of the Bieumont Member stratotype and are closer to the southern Lion section, or even to the boundstones of the Lion Member. The Bieumont Member is very thick in Lompret. Indeed, excepting two 10 m observation hiatus, 48 m of strata were described without reaching the base of the member.

The Leus section is 20 m thick. Boulvain & Coen-Aubert (1997b) interpreted these calcispherids-containing peloidal packstones and grainstones like Harris (1994) did for similar sediments on the flanks of the Latemar build-up (Triassic from Dolomites). The latter interpreted this type of sediments as bioclastic flows reworking lagoonal sediments. Limestone of the Leus quarry indeed show a significant fraction of sediments whose origin is undoubtedly a restricted environment (calcispherids, peloids, palaeosiphonocladal algae), while the remaining fraction corresponds to an open environment (crinoids, fenestellids, brachiopods). The progressive increase of granulometry towards the top of the section could be explained by a progradation of the reef. Consequently, bioclastic flows near the top of the section would be closer to the mound than those located at the base.

6.2. Other examples of lateral variations

The Grands Breux Formation, including the Bieumont, Lion, and Boussu-en-Fagne Members, may be followed throughout the southern border of the Dinant Synclinorium. It was studied by Coen (1977) in the Han-sur-Lesse area. The Bieumont Member was also studied in the Focant borehole by Coen-Aubert (1994) and Boulvain & Coen-Aubert (1997a), and in Barvaux by Coen (1974).

The Focant borehole drilled on the southern border of the Dinant Synclinorium, in the Famenne depression, between Givet and Han-sur-Lesse. It cuts through the Famenne, Matagne, Neuville, Grands Breux, Moulin Liénaux and Nismes Formations several times and ends in the Fromelennes Formation. The thickness of the Bieumont Member varies from 23 to 46 m and the facies is close to those described in the area of Han-sur-Lesse by Coen (1977). The lower part consists of a crinoidic sole on which alveolitids-rugose corals developed. This unit is overlain by an argillaceous episode with low diversity (brachiopods, crinoids, solitary rugose corals). The upper part is constituted by microbioclastic limestone, locally richer in crinoids, with some alveolitids and rugose corals. The thickness of the Bieumont Member in the Han-sur-Lesse area varies from 18 to 20 m. In the Focant borehole, its thickness may strongly increase with the development of a light grey biohermal facies, locally rich in fibrous cement. Thickness also varies according to the importance of the argillaceous episode compared to the bioclastic limestone. Although the base of the Bieumont Member is missing in the Lompret section, similarities with Focant and Han-sur-Lesse sections are observed. The argillaceous episode preceding bioclastic limestone could correspond to unit 2 in Lompret. As in Lompret, progradation of reefal facies would explain the appearance of bioclastic limestone. The presence of boundstones, mentioned in the Focant borehole, is also observed in the Lompret section (bed 60).

Farther to the east, the Barvaux area offers the possibility of studying the lateral facies variations of the Bieumont Member. Frasnian is primarily schistous there and its thickness increases towards the south. Thus, Coen (1974) proposed two stratigraphic scales: that of Barvaux-north (immediate neighbourhood of Barvaux) and that of Barvaux-south (Biron). Near Barvaux (more exactly south of Hotemme), the Bieumont Member consists of thin-bedded fine-grained limestone, locally nodular, even argillaceous, with corals near the base of the unit. Near the top of the unit, a small bioherm, 4 to 5 m thick is observed. Closer to Barvaux, approximately 600 meters south-south-east of the church, in an old quarry, 12 m of massive limestone overlays small coral lenses (1,5 to 2 m thick). In Biron, the Bieumont Member consists of black thinly-bedded fine-grained limestone, locally nodular and very poor in fossils. In the two localities, the thickness of the thinly-bedded fine-grained limestone is 22 m. Lompret also shows some similarities with the facies described in the Eastern border of the Dinant Synclinorium, specially the plausible presence of a small biohermal lens and of massive limestone, also observed in the old quarry south of Barvaux.

7. Conclusions

The study of the Lompret section led us to define six lithological units. Unit 1, consisting of fine-grained argillaceous limestone, is close to the stratotype of the Bieumont Member. Units 2 and 4 show a very marked rhythmic character with m-scale argilo-carbonated sequences. Units 3, 5 and 6 are composed of more or less grainy bioclastic limestone representing debris flows collected by underwater channels. A reefal facies is present within the fifth unit. The study of thin sections allowed to distinguish 16 microfacies. Their high number is explained by the bioclastic nature of sedimentation and the high environmental variability of the Lompret section. This is clearly highlighted by the lithological curve, carried out after having sorted microfacies according to their respective position compared to the mound.

A reconstruction of the spatial distribution of facies from Lompret was carried out. The model illustrates the five principal facies observed in this section: the external platform sediments and those settled between the channels, the bioclastic debris flows, the allochton reefal block and the autochton reefal facies.

Two orders of rhythmicity were defined. The first is observed at the scale of the sequences constituting units 2 and 4; the second at the scale of the whole section. We discussed the mechanisms at the origin of the "high frequency" sequences. Other mechanisms than glacioeustatism may be involved. Nevertheless, each would be related to effects of variations of earth orbital parameters. Concerning the second order of rhythmicity, the progradation of massive limestone is not necessarily related to sea level fluctuation. Allocyclic factors such as sea-level, temperature or turbidity variation, and autocyclic factors like changing reefal accretion rate must be considered. However, admitting the variation of relative sea level as the main parameter, it's possible to associate the reefal development cycle of Lompret with a third order eustatic cycle. In this case, the second lithological unit would correspond to the transgressive system tract and the massive limestone of the third unit would represent the highstand system tract.

Comparison with other sections reveals manifest lateral facies variations, mainly related to their variable position compared to the mounds, which represent a significant bioclastic source. Thus reefal influence was very low in the railway section of Frasnes, whereas the southern section of the Lion quarry represents an environment constantly subjected to sediments exported from the reef. The Lompret section was located in an intermediate situation since it shows an argillaceous facies devoid of reef-building organisms alternating with reef-derived debris flows. The Leus section represents an environment continuously subjected to sediment supply originating from the back part of the Nord reef.

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