

A MICROBE-BRYOZOAN REEF FROM THE MIDDLE VISEAN OF THE NAMUR SYNCLINE (ENGIHOUL QUARRY)

Emmanuel CHEVALIER¹ & Markus ARETZ²

1. Université de Liège, Unité de Paléontologie Animale, Allée du 6 Août, 4000 Liège, Belgium; E.Chevalier@ulg.ac.be

2. Universität zu Köln, Geologisches Institut, Zùlpicher Str. 49a, 50674 Köln, Germany; markus.aretz@uni-koeln.de

(7 figures)

ABSTRACT. A microbe-bryozoan patch-reef was temporarily exposed in the Lives Formation (middle Visean) at the Engihoul Quarry, southern limb of the Namur syncline. It developed within the Corphalie Member during the transition from bioclastic to stromatolitic facies.

Reef formation is the result of a complex meshwork of calcified microbes, which formed complex layers which resemble “*Osagia*”-biocenose and individual columnar aggregates, fenestellid bryozoans, and early cements. Reef growth began on a hard-substrate provided by brachiopods and microbial crusts. Brachiopods (*Composita* sp.) are locally abundant in the reef facies, and contributed substantial firm ground for encrustation. Reef growth was controlled mainly by the abundance of fenestellid bryozoans. Their presence indicates reef formation during normal marine conditions. The reef developed in a high-energy area of the inner shelf. Reef growth probably stopped with the establishment of a peloidal mudstone facies, eventually indicating hypersaline conditions.

The Engihoul reef is similar to Bomel reefs (also in the Lives Formation). All are the same age and developed in the transitional phase of the Corphalie Member, but minor differences in the individual reef fauna occur. The transitional phase of the Corphalie Member is an important horizon for reef formation with clear independence from other reef forming episodes within the Belgian Dinantian succession.

Keywords: microbes, bryozoans, brachiopods, reef, middle Visean, Lives Formation, Namur syncline.

1. Introduction

The Dinantian succession of Belgium is relatively poor in buildups of shallow marine environments, compared to the widespread distribution of Eifelian to Frasnian reefs. Waulsortian mounds or banks (Lees & Miller, 1995) of late Tournaisian deeper ramp settings (Hance *et al.*, 2001) are commonly regarded to be the only significant bioconstructions within the Dinantian succession of Belgium. Such is the case in regards to the volumetrical abundance, but several smaller, non-Waulsortian buildups have been reported in the Visean. Lauwers (1992) described one large and several small cryptalgal-bryozoan buildups within the Lives Formation (Middle Visean, Livian) of Bomel (Namur sedimentation area; Poty, 1997). *Siphonodendron* dominated biostromes from the middle and upper Visean successions of the Namur and Dinant basins partly represent initial pavements of failed reef development (Aretz, 2001, 2002). The late Visean succession of the Campine Basin comprises patchy microbial facies interpreted as microbe-dominated reefs (Muechez & Peeters, 1986; Muechez *et al.*, 1987, 1990).

The aims of this paper are: (i) to describe a second shallow-water reef locality within the Lives Formation, (ii) to elucidate the internal development of the reef and factors controlling its development, (iii) to discuss the framework of the reef and the rigidity of microbial dominated

facies, and (iv) to integrate the reef into the spectrum of Dinantian shallow-water buildups.

A consensus on reef terminology does not exist. Herein, buildup and bioconstruction are used as general terms for varied mostly rigid, biological-induced and biological-controlled structures with topographic relief. Reefs are rigid build-ups; frame reefs are reefs in which essentially in place skeletons or calcified microbes are in contact (Riding, 2002). Framework is the meshwork of a bioconstruction that leads to rigidity. It is due to skeletal organisms as well as to a broad range of non-skeletal organisms and processes (Webb, 1996). The absence of skeletal organisms does not imply the lack of rigidity and vice versa.

2. Setting

The operating Engihoul Quarry or Carrière du Lion (Carmeuse S.A.) is situated ~10 km west of Liège on the right bank of the Meuse River, immediately upstream of the Engis bridge (Fig. 1). The quarry is located directly north of the Faille du Midi on the southern limb of the Namur Syncline. It exposes an almost complete succession of Dinantian strata on the southern margin of the central part of the Namur sedimentation area (NSA, Poty, 1997) (Fig. 2).

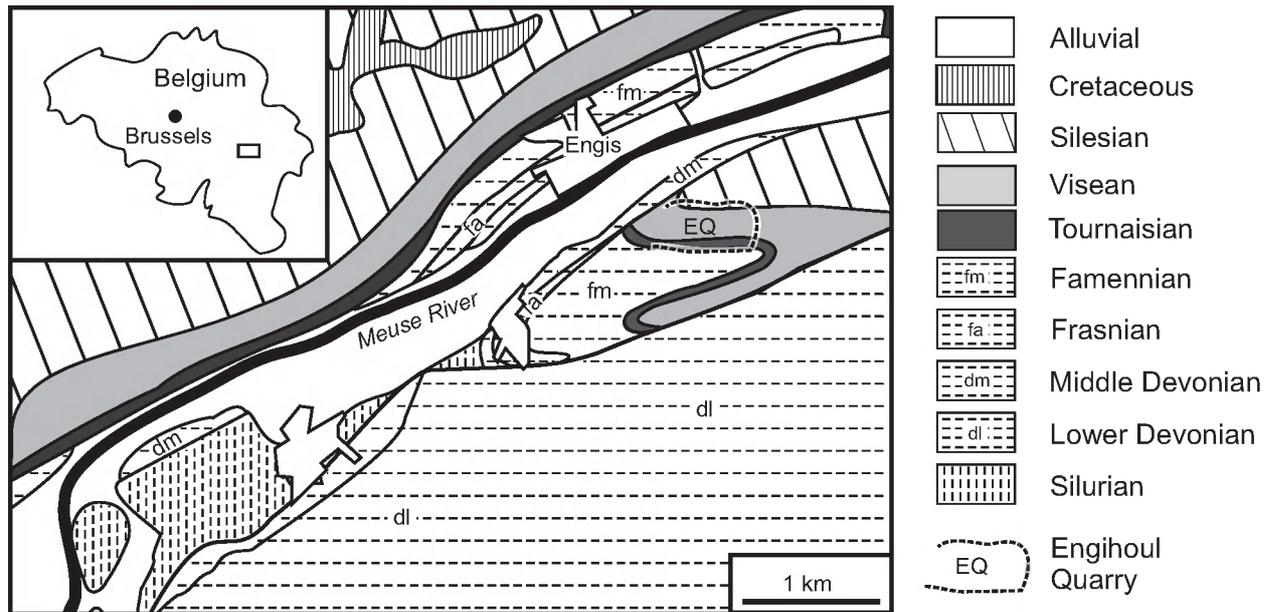
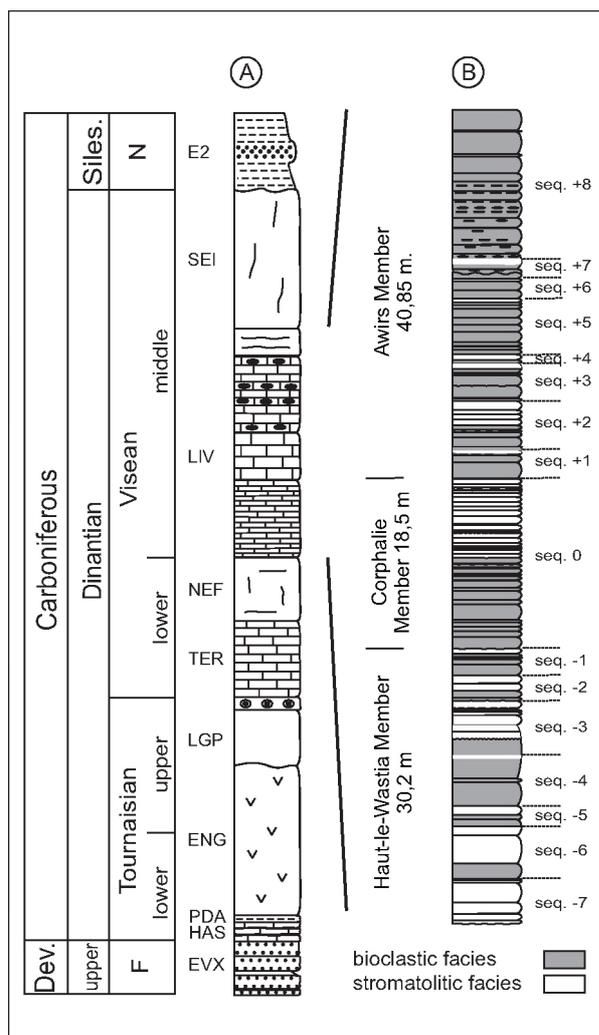


Figure 1. Location of the Engihoul Quarry (eastern Namur Syncline, Belgium) on a simplified geological map.



The studied section comprises the middle part of the Lives Formation (V2b_ of previous authors) (Paproth *et al.*, 1983; Poty *et al.*, 2002). Parasequences (Gerards, 1955; Gerards & Michot, 1963) characterise the entire Lives Formation (Fig. 2). Sedimentologically, each parasequence (1-18 m thick) shallows upward. Basal subtidal marine bioclastic packstones/grainstones pass into stromatolitic boundstones or mudstones with peloids and algae representing intertidal to supratidal environments. A paleosol is developed on top of some sequences. The origin of the cyclicity is unknown. Glacio-eustatic sea-level fluctuations triggering younger Warnantian parasequences (Wright & Vanstone, 2001) may be involved, since isotope data indicated cooling episodes starting in the Tournaisian (Bruckschen & Veizer, 1997).

The Lives Formation is subdivided on the basis of lithological criteria and the parasequences, into three members: a lower Haut-le-Wastia Member, a middle Corphalie Member and an upper Awirs Member (Laloux *et al.*, 1996). The entire formation belongs to the Cf5 foraminifera biozone of Conil *et al.* (1991). The limit of the rugose coral biozones RC5/RC 6 coincides with the limit between the Haut-le-Wastia and Corphalie members. According to Hance *et al.* (2001) the entire formation forms the TST of the 7th third order sedimentary sequence of the Belgian Dinantian.

Figure 2. Stratigraphic overview of the Engihoul quarry succession (A) and simplified log of the Lives Formation (B). Siles.: Silesian, F: Famennian, N: Namurian; Formations: EVX: Evieux, HAS: Hastière, PDA: Pont d'Arcole, ENG: Engihoul, LGP: Longpré, TER: Terwagne, NEF: Neffe, LIV: Lives, SEI, Seilles, E2: Namurian shales, *Eumorphoceras* goniatite biozonation.

3. Succession

3.1. Lithology

The Corphalie Member comprises a single parasequence (= Sequence 0 of Gerard & Michot, 1963). It is 18,5 m thick in the Engihoul Quarry. Thick-bedded, blue-grey bioclastic limestones dominate the lower part of the member (= 10 m thick), whereas thin-bedded, dark lime mudstones form the upper part (= 8,5 m thick). A characteristic bright colour due to weathering is partly seen in the upper part of the member and reveals lamination. A bed rich in brachiopods (*Composita* sp.) forms a relatively distinctive boundary between the two units in the field.

3.2. Sedimentology

The sedimentological development and distribution of allochems in the Corphalie Member in the Engihoul Quarry is shown in a semi-quantitative petrological log in Fig. 3.

The first 6,75 meters (beds 118A to 124) are characterized by grainstones and more rarely rudstones rich in marine bioclasts that are commonly micritized. Palaeobereselleae dominate; other algal fragments (mainly *Koninckopora*, less commonly *Girvanella*, aougjaliid indet., and a few *Aphralysia*) and various foraminifers are also abundant. Fragmented echinoids, corals, gastropods and brachiopods are invariably present but are less abundant. Ostracods and rhabdomesid bryozoans are rare.

The central part of the member (beds 125 to 132) has a very heterogeneous facies distribution. It is also marked by an important decrease in the abundance of skeletal grains and an increase in sponges, algal peloids and Porostromata levels (in some cases present only as rounded clasts). This part corresponds to a shift from subtidal conditions to a more restricted environment that was occasionally reopened or submitted to tempest inputs.

The upper 5,75 meters (beds 134 to 143c) comprise stromatolitic boundstones and mudstones-wackestones, that were deposited in a very shallow intertidal to supratidal environment.

The stromatolitic boundstones consists of thin micritic laminae intercalated by peloidal grainstone with many cavities. Porostromata fragments and sponge spicule aggregates are common, whereas other bioclasts are rare (ostracods, fragmented brachiopods and echinoids). The boundstones are in some cases brecciated. Uncommon anhydrite and gypsum pseudomorphs also occur.

The mudstones-wackestones contain sponge spicules and rare other bioclasts (ostracods, fragmented brachiopods and echinoids). Small cavities and anhydrite-gypsum pseudomorphs are present.

4. The reef and its surrounding facies

Although well developed bedding is characteristic for the Corphalie Member, a massive lens (2 m high, 5 m across) was observed in the wall of the second lowest quarry level at ~10 m height (Fig. 4). The lens was temporarily exposed in 2002, and had been mined by the spring of 2003. To evaluate the nature, geometry and facies of the lens, eight sections have logged, named A-H from top to the bottom of the quarry wall (Fig. 4). In section A and H at least one sample per bed was taken, sampling in the other sections was more random in consequence of limitations due to the massive character of the lens and the fresh exposure of the sections. However, 50 samples were taken from the critical interval and ~60 thin sections (most 7x10 cm in size) were prepared. The results obtained from the eight sections have been compared to an additional log of the entire Lives Formation at this quarry.

4.1. Description of the reef and its surrounding facies

The lens is situated immediately above the brachiopod level that macroscopically separates the lower bioclastic part from the upper stromatolitic part of the Corphalie Member. The thickness and geometry of the surrounding beds were highly influenced and the normal, regular bedding pattern is disturbed. Beds below the lens are deflected downwards, and overlying beds over it. The regular bedding of the lateral equivalent strata deflects near the lens margins, and the beds pass into massive facies. The brachiopod bed is only 50% of its typical thickness under the lens. Less drastic reductions of the thickness of the overlying beds were observed, but quantification is hampered by the thin-bedded nature of the limestones and a more heterogeneous composition of the beds in the stromatolitic facies.

A heterogeneous facies distribution occurs in the bed below the lens. It is dominated by brachiopods (*Composita* sp.) and oncoids (Fig. 6, C). The texture ranges from bioclastic grainstone to oncolitic packstone with a majority of samples being intermediates of these end-members. This bed is the first bed of the Corphalie Member in which coatings of allochems and extraclasts became abundant, and the formation of oncoids occurred widely.

Macroscopically, the lens is composed of massive, dark grey limestone. The macrofossil content is restricted to brachiopods and a few bryozoans. Microscopically, the central part of the lens consists of microbe-bryozoan boundstones. Long, almost intact fenestellid bryozoan sheets (Fig. 5, B) are encrusted by up to 4.5 mm thick, dark micritic layers. The internal organisation of such layers is complex and heterogeneous, and much micrite may be the result of the precipitation of carbonate around non-calcifying microbes. Abundant micritisation prevents identification of many clasts, but scattered *Aphralysia* and other calcifying microbes (irregular tubes; Porostromata?)

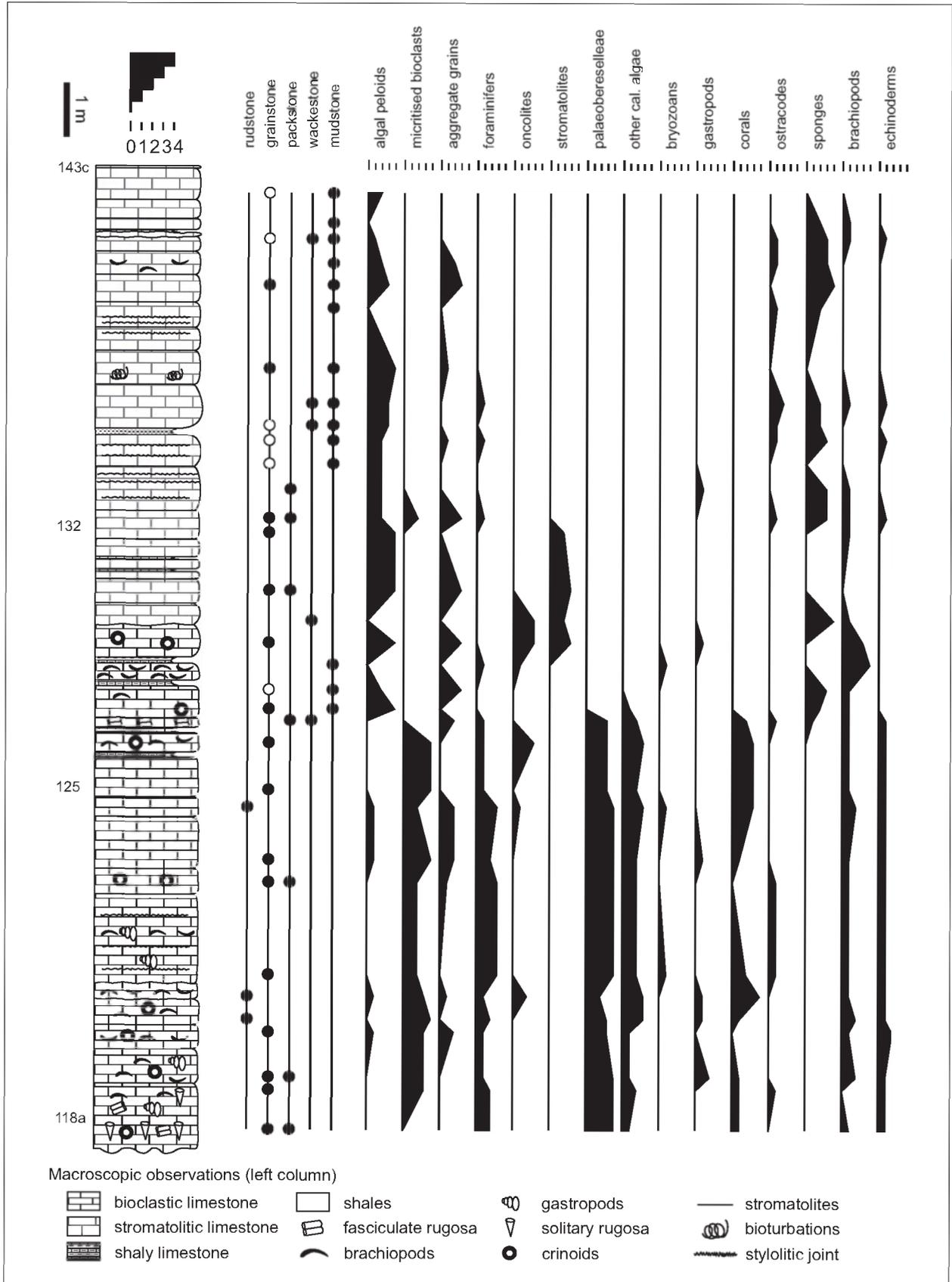


Figure 3. Petrographic log of the Corphalie Member in the Engihoul Quarry showing the vertical variations in microfacies and allochems. The allochems are semi-quantitatively ranked from absent (0) to dominant (4). Numbers on the left indicate the bed numbers.

can be identified. Within the layers, small single carbonate grains and possible intra- and extraclasts are incorporated (Fig. 5, F). These dark micritic layers resemble in their complex structure and constituents the crusts of “*Osagia*” biocenose described by Mamet *et al.* (1987). However, some authors consider *Osagia* as a crust of attached porcelaneous foraminifera (order Miliolida), for instance *Calcitornella* or *Calcivertella* (Vachard, comm. pers.). Therefore, the microbial encrustations we describe as “*Osagia*”-like biocenose are microecosystem that were constituted by very different, and independent processes (i. e., biofilms and cyanobacteria). These dark micritic layers become irregularly much thicker and formed independently from bryozoan sheets. Calcified microbes are not only restricted to the dark layers. They form larger, columnar crusts or, in some cases, aggregates (?) (Figs 5, A, G), which are randomly distributed, but most commonly attached to the layers, or directly on the fenestellids and brachiopod shells (Figs 5, F, G). Growth direction is random, but a significant number of columnar microbial crusts initiated their growth on cavity roofs and grew oblique towards a supposed cavity centre.

The macrofauna consists of brachiopods (*Composita* sp.) (Figs 5, D, E, G, H), fenestellid (Figs 5, B, E, F, G, H) and rhabdomesid bryozoans (Figs 5, C, H), vermetid gastropods or annelid worm tubes, and rare chaetetid sponges, corals and paleoberesellid algae (Fig. 5, D). Only few of the thin brachiopod shells are bored and this is mostly connected to microbial coatings on inner shell surfaces. The shape of the fenestellid bryozoans may partly differ from the normal cup-shape form and become more horizontal (Fig. 5 G), possibly like in some modern fenestrate bryozoans (see Hayward, 2000: 120).

The dark micritic layers form an open meshwork, which is supported by the macro-organisms (Figs 5, G, H). The primary pore space of this meshwork is considerably reduced through the infill of carbonate mud and peloidal silt. Additionally, allochems, mostly oncoids and larger peloids, may be abundant in some cavities (Fig. 5, B). Concentrations of sponge spicules (Fig. 5, E) occur locally within the internal carbonate sediment. In later phases, the meshes were completely filled by cement. Cementation started with edges of brown microcrystalline cements, which were succeeded by bright, blocky sparitic cements. The shells of brachiopods are commonly filled

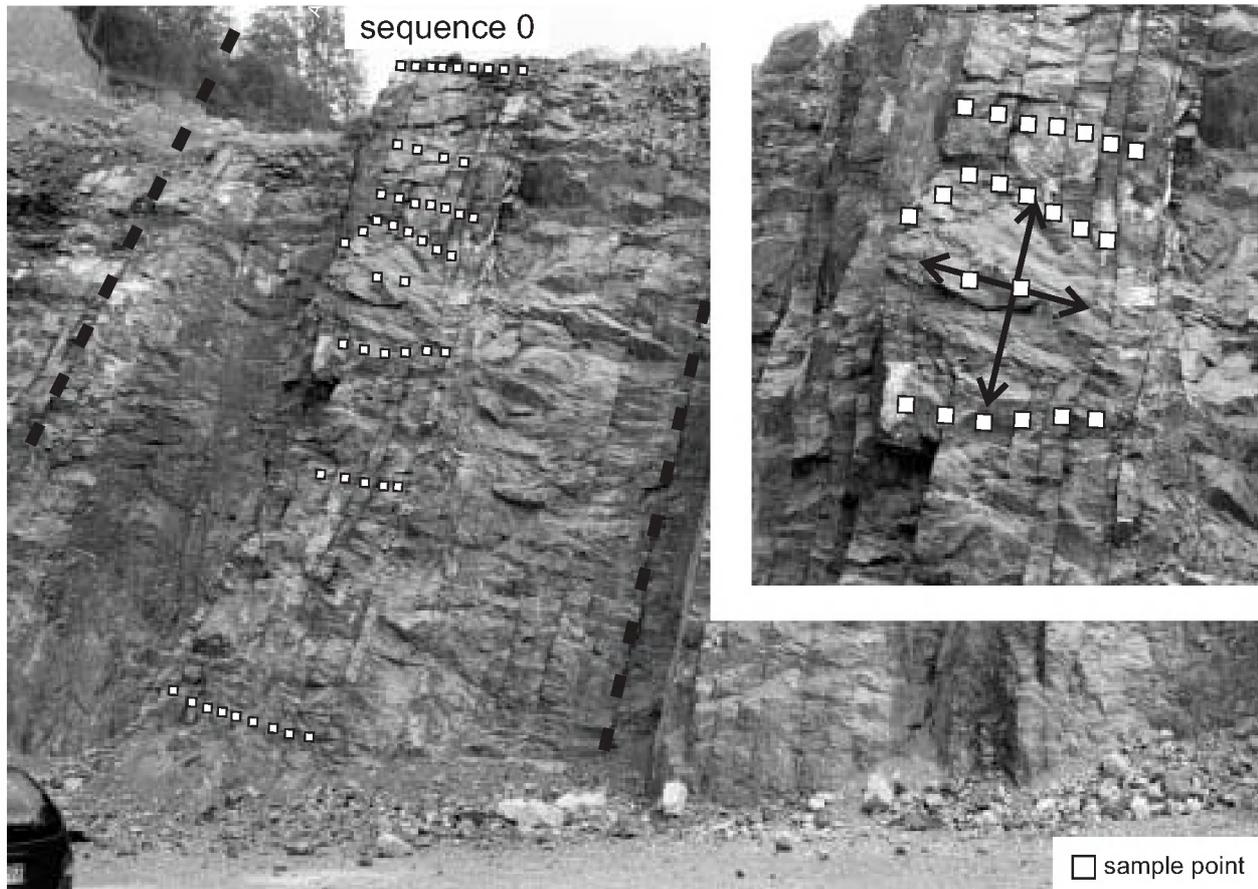


Figure 4. Reef within the Lives Formation in the wall of the second lowest bench (height ~20m), and position of the samples. Engihoul Quarry (photo: July 2002) .

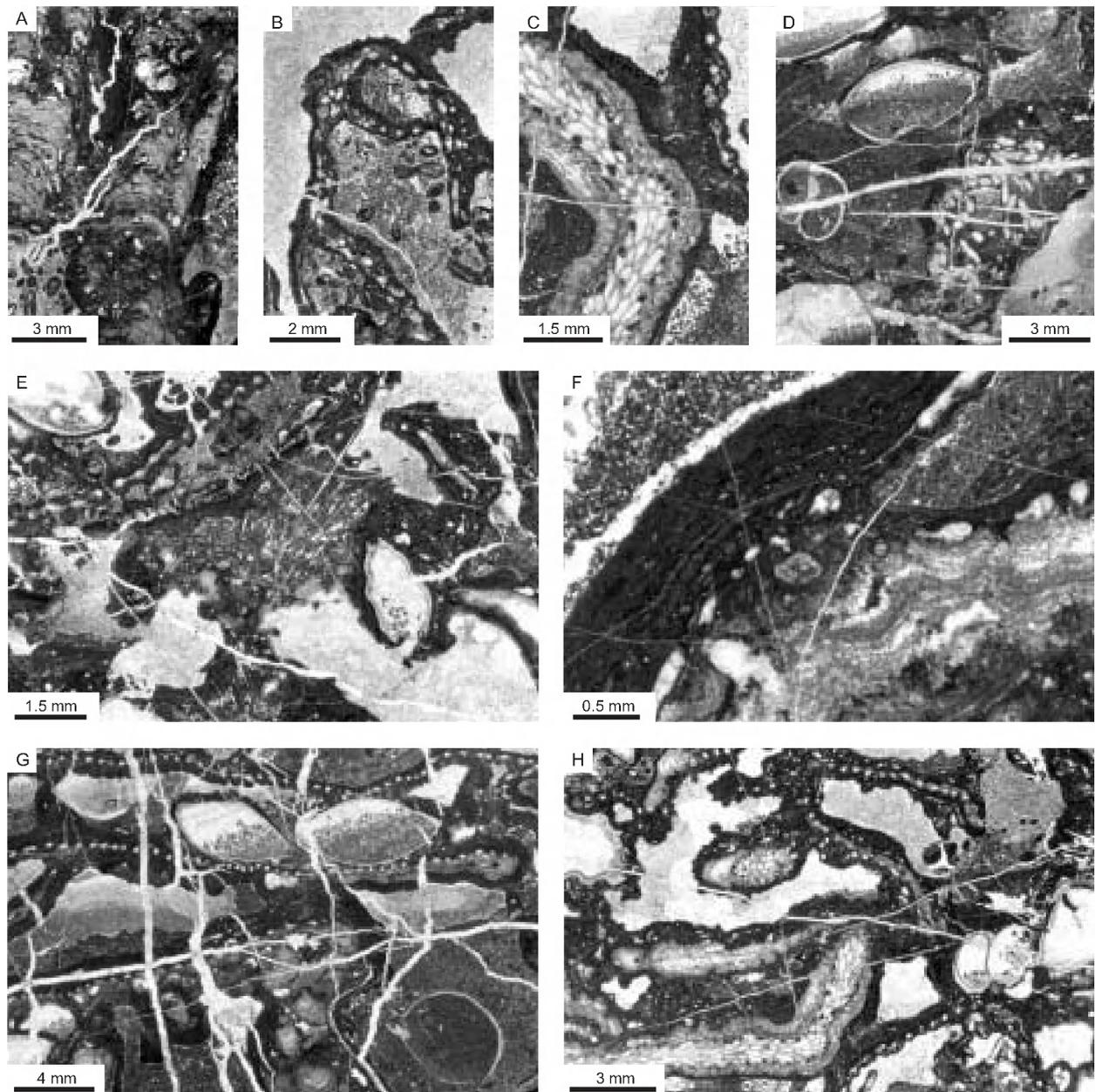


Figure 5. Reef facies. A: columnar calcimicrobe crust; B: fenestellid bryozoans with encrustation of a “*Osagia*”-like layer, C: rhabdomesid bryozoan with thin encrustation of a calcimicrobe (*Aphralysia* ?), D: brachiopods with geopetal sediments, calcareous algae and gastropod; E: sponge spicule concentration within a cavity of the reef framework of fenestellids and “*Osagia*”-like layers. The cavity is partly filled by peloidal sediment. F: A fenestellid bryozoan sheet is encrusted on its upper side by a dark micritic layer of the “*Osagia*”-like type, showing its complex composition, and on the lower side by a calcimicrobe (*Aphralysia* ?).; G-H: general reef fabrics and organic network. G: primary pore space is largely reduced through peloidal sediments, H.: primary pore space of the organic network is mostly cemented.

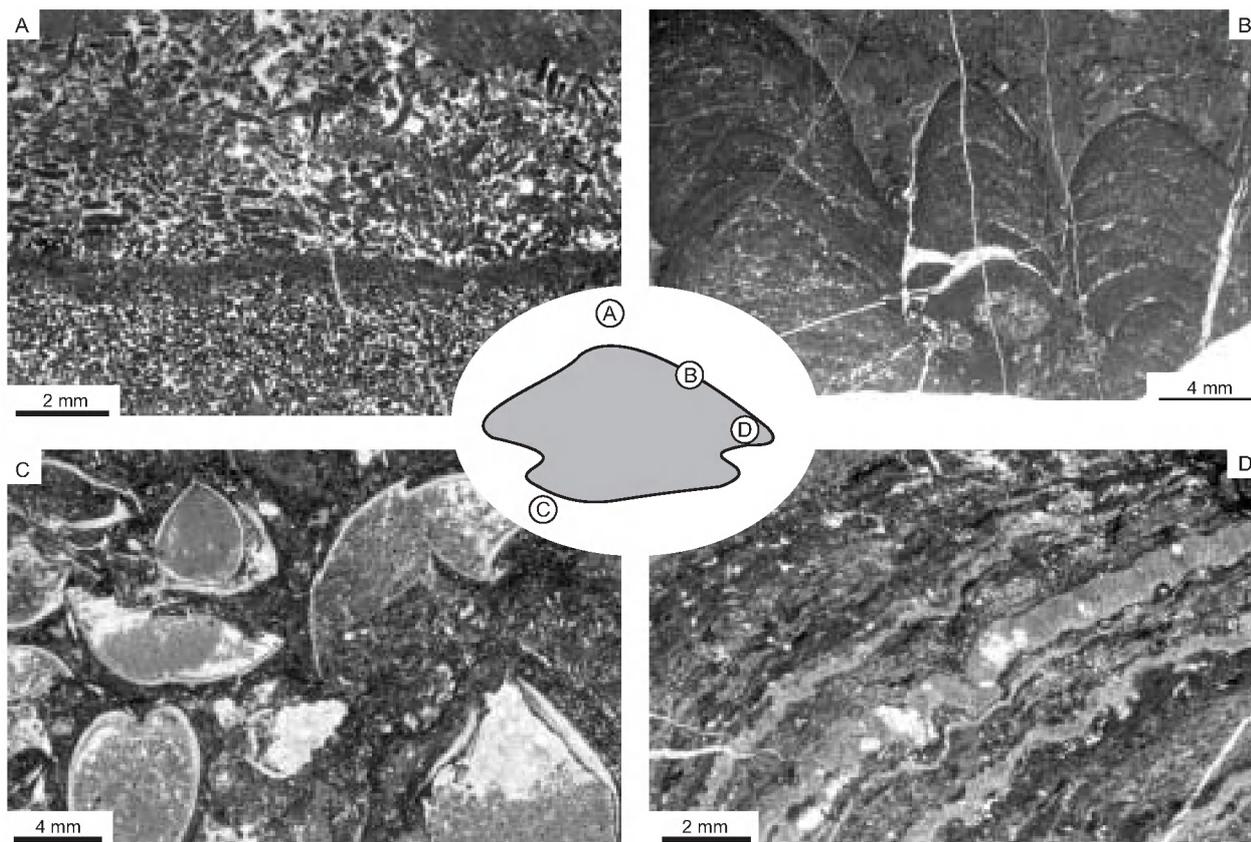


Figure 6. Marginal reef facies: A: Microbial coatings and mats interbedded with brownish calcite cement layers form a stacked aggregate of calcifying microbes (often *Aphralysia*) and cements. B-D Off-reef facies at the margins of the reef: B: underlying brachiopod bed; C: individualised stromatolites from the upper part of the flanking beds; D: peloidal, partly layered mudstone which caps the reef top.

with geopetal sediment, which become finer towards the top. Different generations of cavity filling sediments are relatively scarce. In some cases, an early cement was followed by a filling of geopetal sediment.

Locally, fine carbonate sediment is sufficiently abundant that mudstone or wackestone texture developed and cavity formation was highly suppressed (Fig. 5, G lower half). A second generation of cavities developed independently from the organic meshwork, and commonly destroyed it. It is relatively common at the outer margins of the lens and may be due to subsequent dissolution phenomena. The bryozoan rich core facies of the lens consists to 40-55% of the organic meshwork and 5-15 % of spar filled cavities. Due to parts with much carbonate mud and silt, the fine sediments comprise 30-55% of the counted surfaces. These calculations are based on measured surfaces of the three categories in digitalised thin sections.

Towards the outer margins of the lens, the abundance of fenestellid bryozoans decreases and the complex "*Osagia*"-like layers become less abundant. Therefore, the relatively dense meshwork of fenestellids and "*Osagia*"-like layers is locally restricted and was mainly replaced by mud-dominated stromatolitic facies. That development

resulted in a significant decrease in the abundance of spar-filled cavities, which is related to the large increase in the amount of carbonate sediment. Peloidal mudstones commonly with laminated textures, became abundant, and individualised stromatolites (1,2 mm width, 2,5 mm high) developed in places (Fig. 6, B). However, calcimicrobes contributed significantly to the formation of microbialites (often smaller patches). Microbial coatings and mats are interbedded with brownish calcite cement layers, which "mirror" the outer shape of the microbes (Fig. 6, D), thus forming stacked aggregates of calcified microbes (commonly *Aphralysia*) and cements. The development of these aggregates seems to be independent from macrofossils, however some shells of vermetid gastropods or annelid worm tubes, brachiopods and very few corals are incorporated. Skeletal grains are diverse, but their abundance is relatively low. Oncoids occur in local concentrations.

More distal surrounding sediments display a heterogeneous distribution (Fig. 7) of dominating peloidal mudstones, partly layered, and minor bioclastic or oncolitic pack/grainstones. Individual stromatolites occur rarely. The lens is directly overlain by peloidal mudstone facies (Fig. 6, A).

4.2. Interpretation

The massive lens is interpreted as a patch-reef. According to the usage of Webb (2002), the lens can be considered as a shallow-water reef, that consist of three framework types: biocementstone, microbialite, and skeletal frame. The proportions mentioned in 4.1. for the three principal sedimentary components, are characteristic of a domical filled microframe reef (Riding, 2002)

A primary meshwork of bryozoans (mainly fenestellids) and complex microbial “*Osagia*”-like layers is mainly supported by brachiopods and minor by vermetid gastropods, chaetetid sponges, calcareous algae, and few corals. This support is of a passive nature and is restricted to the provision of hard substrate. However, incrustation of these skeletons by the primary reef builder seems not to have been essential, but substantially facilitated reef growth. The primary reef builder formed an open meshwork, which must have been rigid. Abundant cavities in this open meshwork were colonised by other organisms (such as calcimicrobes in Fig. 5, G). Therefore, the roof of these cavities must have been rigid before it could be colonised by other organisms. Also the downward growth orientation of those organisms indicates a rigid cavity roof. The cryptic habitats in the reef were colonised by calcimicrobes and siliceous sponges, the later known only from cavity fillings.

Additional processes to increase rigidity were the incorporation of macrofossil shells and early marine cementation. The aggregates of layered calcite cement and calcimicrobes indicate alternating intervals of cementation and microbial precipitation. The onset of cementation before the start of geopetal sedimentation is a further strong indication for the important early cementation processes. Infill of geopetal sediments resulted in the reduction of open pore space, and further strengthened the framework. Therefore, the reef formation is mainly due to three groups: microbes, which formed complex “*Osagia*”-like layers and individual aggregates, fenestellid bryozoans,

and early cements. Other organisms contributed only passively towards reef formation, but through their abundance, brachiopods are locally an important part of the reef fauna.

An estimation of the reef geometry and its relief is rather difficult. The onlap of the surrounding beds indicates gentle relief on the reef. Relief may have been not more than 0.5 m. Also the differences in bed thickness above the reef indicates relief and its influence on the sedimentation on surrounding areas. However, reef debris is so far not surely identified in the off-reef facies, but reworked microbial material may be incorporated in the peloidal mudstones of the off-reef facies. The deflection of the brachiopod bed under the reef may indicate differences in the compaction rate during burial due to the early lithified reef body.

The reef formed in a highly unstable shallow-water environment during the overall change from bioclastic- to stromatolitic-dominated facies. Although field observations show an abrupt change, the petrographic analyses indicate several shifts between the two facies on a 2.5 m thick interval (figs. 3, 7). The flourishing development of brachiopods and microbial coatings in the basal brachiopod bed furnished a hard substrate suitable for the growth of the reefal community. The reduced thickness of the brachiopod bed below the reef indicates that reef formation initiated during the sedimentation of this bed. Reef initiation was linked to the local abundance of fenestellid bryozoans, since this abundance is the only major compositional change of the brachiopod bed in the eastern Namur Sedimentation Area (unpub. obser. of the authors). Once the initial framework of fenestellids and calcifying microbes established, reef growth and stabilisation began. The critical importance of the fenestellids is seen at the lateral reef margins, where bryozoans are still present, but the drastic decrease of fenestellids resulted in the interruption of the meshwork, and therefore the reef growth did not continue. However, a differentiation into flank and core facies is not supported by the data

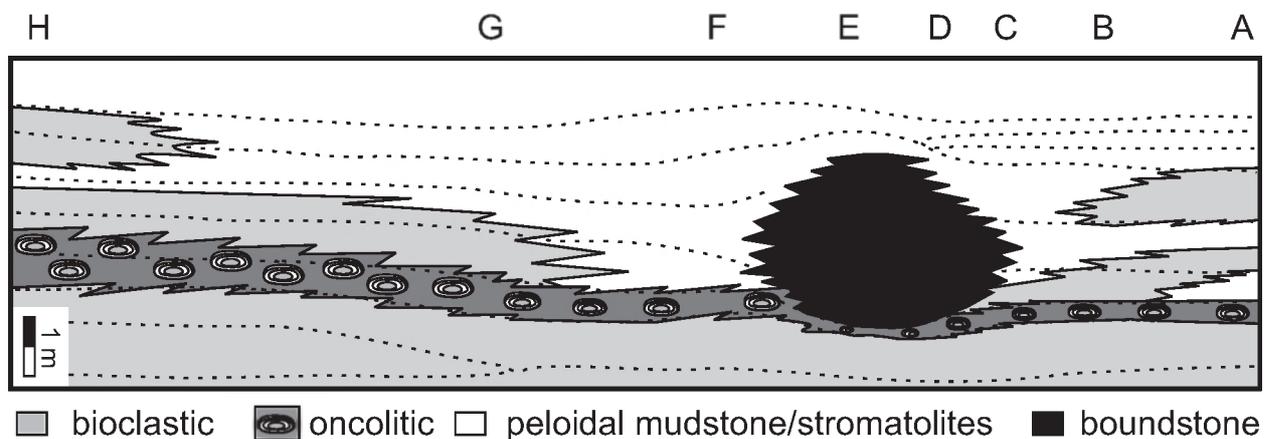


Figure 7: Facies map: distribution of four dominating facies types in beds 126-133.

obtained here. The reason for the stratigraphic termination of reef development is not clear. As with the lateral margins, the absence of fenestellids may be critical. In a later step, the reef was covered by shallow-water peloidal limestone, and finally the relief was levelled out about half a meter above the reef top.

5. Discussion

5.1. Controlling factors

It is critical to evaluate the paleoecological setting of the reef. Reef formation initiated during a time of high-energy as indicated by the amount of broken shells and thick-shelled gastropods in the basal brachiopod bed. The reduced thickness of the brachiopod bed below the reef suggests that reef formation started during sedimentation of the upper part of this bed. Later, the environment may have been stressed through the shoaling-up facies shifts towards intratidal and supratidal conditions due to a relative sea level fall but equally changes in salinity may have been important.

As already mentioned, the presence and abundance of fenestellid bryozoans is critical for the reef formation. Therefore the paleoecological factors controlling the fenestellid bryozoans are major controlling factors for the reef development. Since most bryozoans are adapted to normal marine salinity, a change in salinity is possible at the top of the reef. A change in salinity at this time interval may be supported by the overall change in the allochem spectrum (Fig. 3). Organisms adapted to normal marine conditions as echinoderms and calcareous algae almost disappeared in the mudstone facies, other groups as brachiopods and foraminifers occurred only locally and are mostly concentrated in tempestit layers.

A second major controlling factor in shallow-water reefs is the origin of the rigidity. In the Engihoul reef, most reef-builders do not form a rigid, heavily calcified skeleton. This functional disadvantage was overcome by the interaction of several organisms (e.g. "*Osagia*"-like layers) and a relative quick reduction of primary pore space. Possibly not only fenestellid bryozoans were "scaffold constructors" (Webb, 1996), but also the "*Osagia*"-like layers. Additionally, early cementation and possible lithification further enhanced the rigidity of the reef. Therefore, all factors controlling these early diagenetic processes must be considered.

5.2. Comparison

The reef in the Engihoul Quarry can be easily correlated with the reefs that appear exactly in the same stratigraphic position (transitional level of the Corphalie Member) in the Bomel quarry, especially the so-called smaller reefs (Lauwers, 1992). The framework is basically the same. However, fenestellid bryozoans and individualised columnar calcimicrobes play a more important role in Engihoul.

Another striking difference is the general poverty of *Siphonodendron martini* (colonial rugosa) in the Engihoul section at this stratigraphic interval. Neither concentrations in the basal beds nor occurrences within the reef or as capping beds, which are known from Bomel (Lauwers, 1992; Aretz, 2002), have been observed here.

The larger dimensions of the reef at the quarry entrance at Bomel lead to some differences in interpretation of internal sediments and cements. The smaller reefs including the Engihoul reef have not been subaerially exposed, and therefore have a less complicated diagenetic history.

The reefs of the Lives Formation are very different in respect to the "classical Dinantian buildup type" Waulsortian banks. They are younger and originated in a single sedimentary sequence. Lives reefs have an organic framework, which consists of skeletal organisms, calcimicrobes and non-calcified microbes. This contrasts with mud-dominated textures of the Waulsortian banks. Another obvious difference is the reef size. Lives reefs are very small compared to Waulsortian banks, which could form very large complexes (Lees & Miller, 1995). The depositional environment of the Lives reefs was a somewhat stressed, shallow-water environment, whereas Waulsortian banks developed from subphotic depths into shallow conditions of the photic zone. Therefore, the faunal constituents of the higher Waulsortian phases (C+D) may match with the fauna found in and around the Lives reefs, but that does not imply any constructional similarities. It just emphasises the deposition in shallow water. Waulsortian banks are typical for ramp settings (Hance *et al.*, 2001), whereas the Lives reefs formed in an inner platform setting.

Non-Waulsortian buildups from the late Visean succession of the Campine Basin (Muechez & Peeters, 1986; Muechez *et al.*, 1987, 1990) also consist of microbial framework fabrics. However, unlike in the Engihoul reef, neither fenestellid bryozoan nor "*Osagia*"-like layers contributed to reef formation. Reef sizes are also apparently different, with Campine reefs being somewhat larger.

Western European reefs of early and middle Visean age also have been described from the British Isles (Adams, 1984; Bancroft *et al.*, 1988; Kelly & Somerville, 1992; Somerville *et al.*, 1992). The Nant-y-Gamar buildup (Bancroft *et al.*, 1988) is very rich in bryozoans, but microbial fabrics are lacking. This pattern is contrasted by the Furness reef, in which microbial fabrics are important, but the spectrum of bioconstructors does not include abundant bryozoans. None of the British reefs is exactly similar with the Engihoul reef. A partial overlap of bioconstructors, depositional setting, size, and abundance of microbial fabrics is observed, but each British reef represents an individual reef type, which is not copied elsewhere. The overlap is the result of reef formation in shallow-water and the ubiquitous occurrence of shallow water organisms in most shallow-water environments.

On a global scale, the Engihoul reef is most similar to cryptalgal (=microbes) -bryozoan reefs from Nova

Scotia (Dix & James, 1987). The stratigraphic position is the same, but the dating of the Canadian reefs as Holkerian is not as precise as the Engihoul reef. The Canadian reefs have a very similar framework, but slight differences are observed in the bioconstructors. Fenestellid bryozoans, important in the Belgian reef, are not observed in Canadian reefs. Common to reefs in both regions is the importance of early cements. In both regions reefs formed in stressed environments, in Canada within narrow palaeokarst valleys, in Belgium in a time of highly unstable ecological conditions. However, the main differences include: (a) the dimensions of the reefs, Canadian reefs being somewhat larger, (b) the different types of bryozoans and layers, (c) the stacked pattern of the Canadian reefs, which contrasts with the Belgian occurrence on a single horizon, and (d) the absence of quartz in the Belgian reef.

Although different types of shallow water reefs have been reported in upper Visean strata of Europe (see Aretz, 2002), none of the reefs shows similar framework fabrics to the Engihoul reef. However, the Engihoul reef confirms the globally observed importance of microbial fabrics for reef construction and stabilisation in the Mississippian (Aretz, 2002, Bourque *et al.*, 1995, Mundy, 1994, Webb, 1994, 2002).

Microbial fabrics, fenestellid bryozoans, and early cements were also important contributors to buildup formation in Pennsylvanian and early Permian time (Minwegen, 2001, Wahlman, 2002). Those buildups formed mostly in somewhat deeper water. Therefore, detailed comparisons with the Engihoul reef reveal significant differences.

6. Conclusions

A microbe-bryozoan patch-reef was temporarily exposed in 2002 in the Corphalie Member at the Engihoul Quarry. Reef formation is mainly due to three groups: calcified microbes, which formed complex "Osagia"-like layers and individual aggregates, fenestellid bryozoans, and early cements. Rigidity of the reef is due to the complex meshwork of these groups. This meshwork combines several of the framework types of Webb (1996): skeletal, microbialite, and biocementstone.

Brachiopods and microbial coatings were important in the initial stage of reef development in contributing an initial hard-substrate. Later, brachiopods were included in places and formed substantial firm ground for encrustation.

The reef formed in a shallow-water environment of the inner shelf, and numerous bioclastic fragments indicate its formation in a higher-energy setting. Reef development was largely controlled by the presence of fenestellid bryozoans, which indicates that the reef formed in normal marine conditions. However, the reef is embedded in a succession of highly variable and unstable facies.

The reef is topped by peloidal mudstones probably of intra-/supratidal origin, which may indicate hypersaline conditions.

The Engihoul Quarry is the second known reef locality for the Lives Formation, with all reefs appearing in the transitional phase of the Corphalie Member. The new locality shows that reefs are more common than previously thought. The comparison of reef fauna may indicate some differences in the composition and abundance within individual reefs. The Engihoul reef is well incorporated into the range of Visean shallow-water reefs. Although some superficial similarities exist to the Waulsortian facies, it is clearly not genetically linked to those buildups.

Acknowledgements. Carmeuse S.A is thanked for the permission to work in the Engihoul quarry, and the quarry workers are thanked for their support and assistance during the excavation of the samples. E. Poty (Liège) provided additional information on the succession and added numerous valuable comments. H.-G. Herbig (Köln) and G.E. Webb (Brisbane) are acknowledged for stimulating discussions on Carboniferous reefs. R. Bäuml (Köln) prepared the thin sections. D. Vachard (Lille) and G.E. Webb (Brisbane) are thanked for their constructive reviews.

7. References

- ADAMS, A., 1984. Development of algal-foraminiferal-coral reefs in the Lower Carboniferous of Furness, northwest England. *Lethaia*, 17: 233-249.
- ARETZ, M., 2001. The upper Visean coral-horizons of Royseux – The development of an unusual facies in Belgian Early Carboniferous. *Tohoku University Museum, Bulletin*, 1: 86-95.
- ARETZ, M., 2002. Habitatanalyse und Riffbildungspotential kolonialer rugoser Korallen aus dem Unterkarbon (Mississippium) von Westeuropa. *Kölner Forum für Geologie und Paläontologie*, 9: 1-155.
- BANCROFT, A.J., SOMERVILLE, I.D. & STRANK, A.R.E., 1988. A bryozoan buildup from the Lower Carboniferous of North Wales. *Lethaia*, 21: 51-65.
- BOURQUE, P.-A., MADI, A. & MAMET, B., 1995. Waulsortian-type bioherm development and response to sea-level fluctuations: upper Visean of Bechar Basin, Western Algeria. *Journal Sedimentary Research*, B65: 80-95.
- BRUCKSCHEN, P. & VEIZER, J., 1997. Oxygen and carbon isotopic composition of Dinantian brachiopods: paleoenvironmental implications for the Lower Carboniferous of Europe. - *Paleogeography, Paleoclimatology, Palaeoecology*, 132: 243-264.
- CONIL, R., GROESSENS, E., LALOUX, M., POTY, E. & TOURNEUR, F., 1991. Carboniferous guide foraminifera, corals and conodonts in the Franco-Belgian and Campine basins: their potential for widespread correlation. *Courier Forschungsinstitut Senckenberg*, 130: 15-30.
- DIX, G.R. & James, N.P., 1987. Late Mississippian bryozoan/microbial build-ups on a drowned karst ter-

- rain; Port au Port Peninsula, western Newfoundland. *Sedimentology*, 34: 779-793.
- GERARDS, J., 1955. Sédimentation rythmique des calcaires V2b du Bassin de Namur. Mém. Lic., ULg, 96 p, unpublished.
- GÉRARDS, J. & MICHOT, P., 1963. Le Viséen moyen, partie supérieur: V2b. in: Michot, P., Gérard, J., Monty, C. & Pirlet, H., (eds.), *Sédimentologie des formations viséennes du Synclinorium de Namur, dans la Vallée de la Meuse. 6^e Congrès international de Sédimentologie, Belgique et Pays-Bas, Livret-Guide, Exc. G-1*: 10-12.
- HANCE L., POTY, E. & DEVUYST, F.X., 2001. Stratigraphie séquentielle du Dinantien type (Belgique) et corrélation avec le Nord de la France (Boulonnais, Avesnois). *Bulletin de la Société géologique de France*, 172: 411-426.
- HAYWARD, P.J., 2000. Lace corals (Bryozoa: Phidoloporidae) from Australia and the tropical south-west Pacific. *Journal of Zoology*, 252: 109-136.
- KELLY, J.G. & SOMERVILLE, I.D., 1992. Arundian (Dinantian) carbonate mudbanks in north-west Ireland. *Geological Journal*, 27: 221-241.
- LALOUX, M., DEJONGHE, L., GEUKENS, F., GHYSEL, P. & HANCE, L., 1996. *Carte géologique de Wallonie à 1/25.000. Fléron-Verviers 42/7-8 (+ notice explicative)*. Ministère de la Région Wallonne, Namur.
- LAUWERS, A.S., 1992. Growth and diagenesis of cryptalgal-bryozoan buildups within a mid-Visean (Dinantian) cyclic sequence, Belgium. *Annales de la Société géologique de Belgique*, 115: 187-213.
- LEES, A. & MILLER, J., 1995. Waulsortian Banks. In: Monty C.L.V., Bosence, D.W.J., Bridges, P.H. & Pratt, B.R. (Eds.), *Carbonate mud-mounds, their origin and evolution. International Association of Sedimentologists, Special Publications 23*: 191-271.
- MAMET, B.L., ROUX, A., NASSICHUK W.W., 1987. Algues carbonifères et permiennes de l'Arctique canadien. *Bulletin of the Geological Survey of Canada*, 342: 1-143.
- MINWEGEN, E., 2001. Die Biokonstruktionen im Pennsylvanien des Kantabrischen Gebirges (Nordspanien). *Kölner Forum für Geologie und Paläontologie*, 9: 1-139.
- MUCHEZ, P., CONIL, R., VIAENE, W., BOUCKAERT, J. & POTY, E., 1987. Sedimentology and biostratigraphy of the Visean carbonates of the Heibaart (DzH1) borehole (Northern Belgium). *Annales de la Société Géologique de Belgique*, 110: 199-208.
- MUCHEZ, P. & PEETERS, C., 1986. The occurrence of a cryptalgal reef structure in the upper Visean of the Visé area. *Annales de la Société Géologique de Belgique*, 109: 573-577.
- MUCHEZ, P., VIAENE, W., BOUCKAERT, J., CONIL, R., DUSAR, M., POTY, E., SOILLE, P. & VANDENBERGHE, N., 1990. The occurrence of a microbial buildup at Poederlee (Campine Basin, Belgium): biostratigraphy, sedimentology, early diagenesis and significance for early Warnantian paleogeography. *Annales de la Société Géologique de Belgique*, 113: 329-339.
- MUNDY, D.J.C., 1994. Microbialite-sponge-bryozoan-coral framestones in Lower Carboniferous (Late Visean) buildups of Northern England (UK). *Memoir of Canada Society of Petroleum Geologists*, 17: 713-729.
- PAPROTH, E., CONIL, R., BLESS, M.J.M., BOONEN, P., BOUCKAERT, J., CARPENTIER, N., COEN, M., DELCAMBRE, B., DEPRIJCK, C., DEUZON, S., DREESEN, R., GROESSENS, E., HANCE, L., HENNEBERT, M., HIBO, D., HAHN, G. & R., HISLAIRE, O., KASIG, W., LALOUX, M., LAUWERS, A., LEES, A., LYS, M., OP DE BEEK, K., OVERLAU, P., PIRLET, H., POTY, E., RAMSBOTTOM, W., STREEL, M., SWENNEN, R., THOREZ, J., VANGUESTAINE, M., VAN STEENWINKEL, M. & VIESLET, J.L., 1983. Bio- and lithostratigraphic subdivisions of the Dinantian in Belgium, a review. *Annales de la Société Géologique de Belgique*, 106: 185-239.
- POTY, E., 1997. Devonian and Carboniferous tectonics in the eastern and southeastern part of the Brabant Massif (Belgium). *Aardkundige Mededelingen, Leuven University Press*, 8: 143-144.
- POTY, E., HANCE, L., LEES, A. & HENNEBERT, M., 2002. Dinantian lithostratigraphic units (Belgium). *Geologica Belgica*, 4: 69-93.
- RIDING, R., 2002. Structure and composition of organic reefs and carbonate mud mounds: concepts and categories. *Earth-Science Reviews*, 58: 163-231.
- SOMERVILLE, I.D., PICKARD, N.A.H., STROGEN, P. & JONES, G.L., 1992. Early to mid-Visean shallow water platform buildups, north Co. Dublin, Ireland. *Geological Journal*, 27: 151-172.
- WAHLMAN, G.P., 2002. Upper Carboniferous - Lower Permian (Bashkirian-Kungurian) mounds and reefs. In: Kiessling, W., Flügel, E. & Golonka, J. (eds), *Phanerozoic Reef Patterns. SEPM Special Publications*, 72: 271-338.
- WEBB, G.E., 1994. Non-Waulsortian Mississippian bioherms: a comparative analysis. *Memoir of Canada Society of Petroleum Geologists*, 17: 701-712.
- WEBB, G.E., 1996. Was Phanerozoic reef history controlled by the distribution of non-enzymatically secreted reef carbonates (microbial carbonate and biologically induced cement)? *Sedimentology*, 43: 947-971.
- WEBB, G.E., 2002. Latest Devonian and Early Carboniferous reefs: depressed reef building after the Middle Paleozoic collapse. In: Kiessling, W., Flügel, E. & Golonka, J. (eds), *Phanerozoic Reef Patterns. SEPM Special Publications*, 72: 239-269.
- WRIGHT, V.P. & VANSTONE, S.D., 2001. Onset of Late Paleozoic glacio-eustasy and evolving climates of low latitude areas: a synthesis of current understanding. *Journal of the Geological Society*, 158: 579-582.