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Field Trip 1:

Givetian and Frasnian of Southern Belgium

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Rugose corals – Tabulate corals – Stromatoporoids – reefs – mounds – biostromes – carbonate platform – Givetian – Frasnian – Late Frasnian extinctions – classical sites Givet and Frasnes

ABSTRACT. This three-day field trip in Southern Belgium illustrates Givetian and Frasnian sections and outcrops. The first day will give an overview of the proximal facies of the Upper Frasnian Aisemont Fm, with a particular insight of the Late Frasnian crisis and extinction events. The second day will focus on Givetian and Frasnian reef mounds and platform limestone, including off-shore mounds, reef barrier, lagoon and fore-reef facies belts. The last field trip day is dedicated to the Couvin-Philippeville area. The Late Frasnian reef mounds will be examined in several quarries located near the historical stratotype of the stage.

The Givetian carbonate platform initiation coincided with a reduction of detrital supply. High accommodation allowed the development of a thick carbonate platform with various environments. Location of facies belts was related to major sea level changes, shifting reef barriers North and South of Givet. During the Middle Frasnian, reef mounds grew offshore of a less developed platform. They are large flattened buildups showing limited vertical differentiation, large-scale progradation features, extensive exportation of material towards off-reef environment and development of inner lagoon facies. Middle Frasnian sea level fluctuations were relatively

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mild, and sedimentation was able to keep-up with sea level rise. At the opposite end of this spectrum, during the Late Frasnian, severe eustatic rises together with rising oceanic hypoxic conditions were responsible for collapse of the carbonate factory, drowning of the Frasnian carbonate platform and development of buildups with relatively limited lateral extension, vertical facies differentiation, low potential for material exportation and high content in microaerophilic iron bacteria.

CONTENT

INTRODUCTION

This three-day field trip in southern Belgium illustrates Givetian and Frasnian sections and outcrops, among which, the classical sites of Frasnes and Givet. Quality and accuracy of available data differs from one section to the other but the collection of fossils is mostly possible. The program may change a little due to changing exposure quality or weather but the trip will be organized as follow:

The first day is dedicated to the Late Frasnian Aisemont Formation, a proximal time equivalent of the well-known Petit-Mont carbonate mounds, with a particular insight of the Late Frasnian crisis and extinctions events. Another stop concerns the Eifelian-Givetian transition in Marenne, an unusual Lower Givetian succession (including reef) in a context of a high siliciclastic input. A last stop in Givet will give the opportunity to see the stratotype sections.

The second day will focus on Givetian and Frasnian reef mounds and platform limestone, including off-shore mounds, reef barrier, lagoon and fore-reef facies belts. After a first stop near the Lesse River where Givetian limestone show a well-developed barrier-lagoon system, and a quick look at the Givetian-Frasnian boundary, a very long section in the Middle Frasnian reef mound complex will be examined in detail. A time-equivalent section in Middle Frasnian platform limestone near the Meuse River will be the last outcrop of the day.

The third and last field trip day is dedicated to the Couvin-Philippeville area. The Late Frasnian Petit-Mont Member reef mounds will be examined in detail in several quarries located near the historical stratotype of the stage. Attention will be given to mounds development relatively to sea level changes.

1. HISTORICAL BACKGROUND

Southern Belgium is a classical area for the study of the Givetian and Frasnian geology and palaeontology. According to GOSSELET (1876), the Givetian corresponds to the "Calcaire de Givet" cropping out along the Meuse River near Givet. However, since MAILLIEUX (1910), the term Givetian was used in a more restricted way, excluding the upper Fromelennes Formation, which was assigned to the Frasnian. SARTENAER & ERRERA (1972) proposed that the Givetian stage should approximately represent the time period corresponding to the deposition of the Givet Limestone, composed of the Trois-Fontaines, Mont d'Haurs and Fromelennes formations. Later, PRÉAT & TOURNEUR (1991) proposed the Terres d'Haurs Formation for the more argillaceous top of the Trois-Fontaines – base of the Mont d'Haurs interval. As in the Ardenne, the Givetian is mainly represented by shallow water platform limestone with relatively poor conodont fauna, the global stratotype section and point (GSSP) for the base of the Givetian stage is now located in Morocco and refers to the first occurrence of *Polygnathus hemiansatus*. However, BULTYNCK & HOLLEVOET (1999) demonstrated that another conodont, *Icriodus obliquimarginateus*, appearing at the same level as *P. hemiansatus* is present in the Hanonet Formation, below the Givet Group.

The term Frasnian introduced by GOSSELET in 1879 is clearly related to the "*Système du calcaire de Frasne*" mentioned for the first time by D'OMALIUS D'HALLOY (1862) and described among others by GOSSELET (1874) under the heading "*schistes et calcaire de Frasne à Rhynchonella cuboides*". So the area for the naming of the stage is the locality of Frasnes near Couvin. In 1982, it was proposed that the Givetian-Frasnian boundary should coincide with the base of the Lower *Polygnathus asymmetricus* Zone defined by the first occurrence of an early morphotype of *Ancyrodella rotundiloba*. This species appears slightly above the base of the Nismes Formation in the Ardennes sections. The GSSP for the base of the Frasnian is now in the Montagne Noire, southern France. The detailed stratigraphic distribution of conodonts, rugose corals, brachiopods and ostracods throughout the Frasnian from different areas of Belgium is provided by BOULVAIN et al. (1999). Further interesting information can be found in COEN-AUBERT (2000), BULTYNCK et al. (2000) and COEN-AUBERT & BOULVAIN (2006).

The Ardenne, in Southern Belgium has long provided a lot of "top-quality" outcrops among which, many are exceptionaly rich in fossils. The study of the Devonian rugose and tabulate corals has begun with the works of G. Dewalque, E. Maillieux, E. Dupont and H. Forir, who were involved in the geological mapping survey of Belgium at the end of the 19th century and collected a huge amount of specimens. Several taxa were also described by GOLDFUSS (1826) and DE KONINCK (1878). The major contribution to the study of the Devonian corals and stromatoporoids was made by M. Lecompte during the first part of the 20th century. LECOMPTE published several monographs on the Tabulata (1939) and stromatoporoids (1951, 1952). Lecompte's collection was re-investigated by SORAUF (1967) and by H.H. Tsien who is one of the most important contributor to the palaeocology of Devonian corals and reefs (TSIEN 1967, 1971, 1976b, 1977a, 1977b, 1978, 1979, 1980), and to the systematic of several genera (TSIEN 1969, 1970, 1974, 1976a, 1977b). J. Pel collected during the 1970' new material from the Belgian Givetian that allowed the decription of new genera (DETHIER & PEL 1971, PEL & LEJEUNE 1971, 1972). After these studies, the reseaches on tabulate declined, until the contribution of TOURNEUR (1985). The Middle Devonian and Frasnian rugose corals are still worked by M. Coen-Aubert that constituted and studied new collections form Belgium and surrounding areas (COEN-AUBERT, 1974, 1980c, 1980b, 1987a, 1987b, 1988, 1990a, 1990b, 1992, 1994, 1995, 1996, 1997, 1998, 1999, 2002, 2004, 2008, 2009, COEN-AUBERT & LACROIX, 1978, BOULVAIN et al. 1987, BOULVAIN & COEN-AUBERT 1997b).

2. GEOLOGICAL SETTINGS

2.1. General sedimentological settings

The Devonian Period shows long-term patterns in reef development. During the Lower and early Middle Devonian, sea level was still relatively low and reefs were characterized by poor diversity and provinciality. Their growth was reduced, probably related to the low accommodation space. Detrital supply, originating from the erosion of the Caledonian mountain belt hindered reef development in a number of coastal area (BURCHETTE 1981).

Lower to early Middle Devonian reefs are of limited extension and thickness. Mounds and banks are the dominant morphologies. In the Emsian-Givetian, a "super greenhouse" time span, reefs developed in abnormally high latitudes (KIESSLING et al. 1999). Reef morphologies include barriers, platform reefs, fringing reefs, atolls and mounds, as already noticed by TSIEN (1971, 1976, 1977c). Frasnian reefs are characterized by loss of diversity, cosmopolitanism and collapse of the carbonate factory at the end of the stage (COPPER 2002).

Frasnian eustatic fluctuations were severe and sea level variations controlled the reef development. Early Frasnian shows reduced episodes of reef building, while Middle Frasnian represents an acme in reef development: nearly all reef morphologies are represented: platform reefs, barriers, atolls and mounds, as already noticed by TSIEN (1971). Late Frasnian reefs are smaller and more restricted and were progressively replaced by mounds. After the Frasnian extinction, representing the end of the Silurian-Devonian reef ecosystem, Famennian was characterized by post extinction reefs, in a context of sea level lowstand and major loss of reef habitats.

Southern Belgium belongs to the northern part of the Rhenohercynian fold and thrust belt. Givetian and Frasnian carbonates and shales are exposed along the borders of the Dinant, Vesdre and Namur Synclinoria and in the Philippeville Anticline.

2.2. Sedimentary history and lithostratigraphy

2.2.1. GIVETIAN

The Givetian belongs to the second Devonian transgression starting during the Eifelian. In Belgium, the sea reached the northern border of the Namur Syncline. Reduced terrigenous supply, coming from the North, indicates that the Old Red Continent (and more specifically, the Brabant peninsula) was already deeply eroded and/or that the climate was relatively dry (Fig. 1).

In the Ardenne area, the Givetian forms a continuous calcareous belt, from Glageon in the West (French Avesnois) to Liège in the East. The classical Givet sections are located in the middle (Fig. 2). Several sedimentological studies demonstrated the high lateral continuity of the different sedimentary units (reefs, lagoonal complexes…) all along this calcareous belt (TSIEN 1971, 1976; Pel 1975; PRÉAT & MAMET 1989).

Lithostratigraphically, the Givetian from the southern border of the Dinant Syncline covers five formations: the upper part of the Hanonet, Trois-Fontaines, Terres d'Haurs, Mont d'Haurs and Fromelennes formations (Fig. 3). These five formations pass laterally into two units, the Nèvremont and Le Roux formations in more proximal settings (northern border of the Dinant Syncline and southern border of the Namur Syncline) and to one single unit, the Bois de Bordeaux Formation in the vicinity of the Brabant Massif.

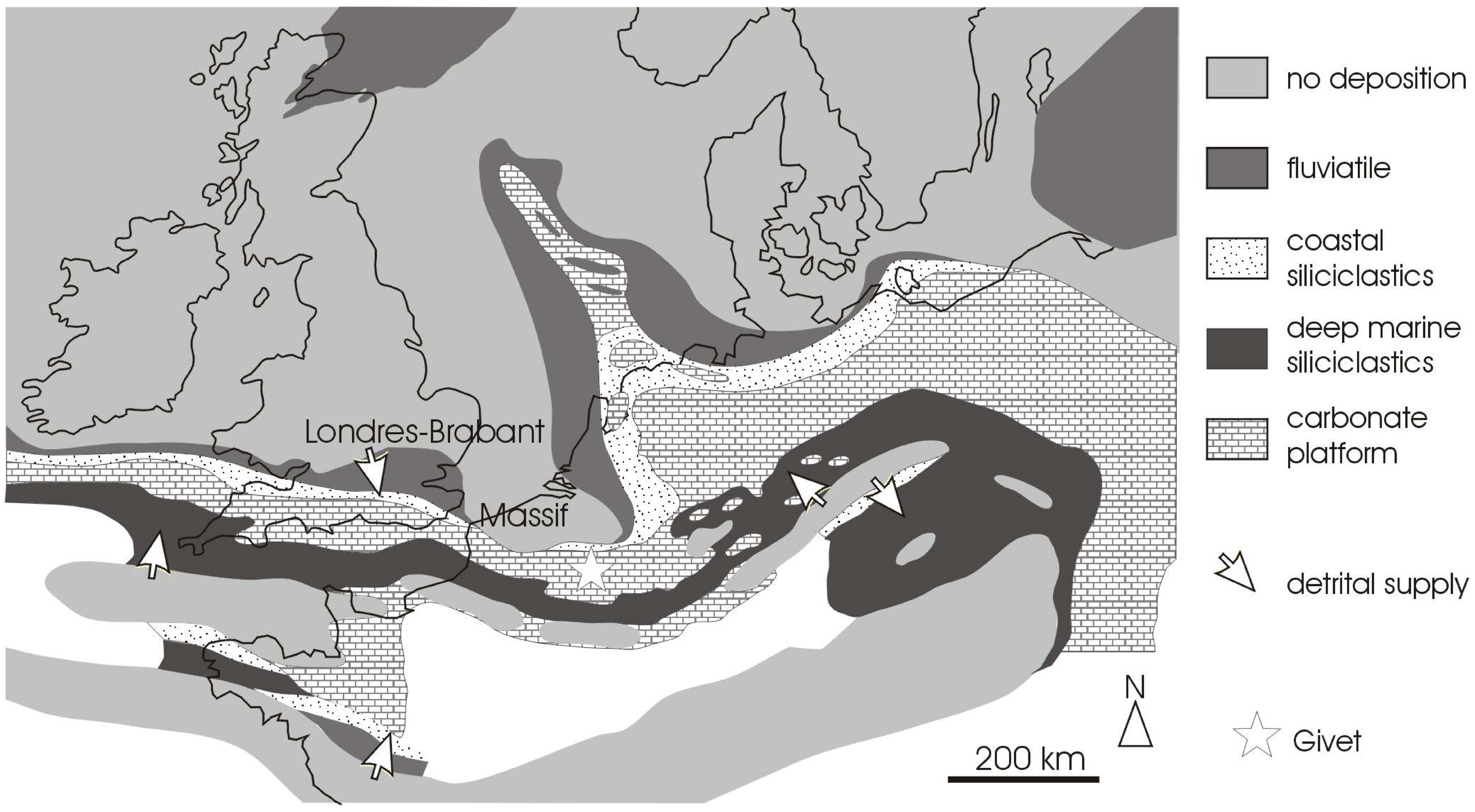

Fig. 1: Simplified palaeogeographical map of the Middle Devonian in Western Europe. Modified after ZIEGLER (1982).

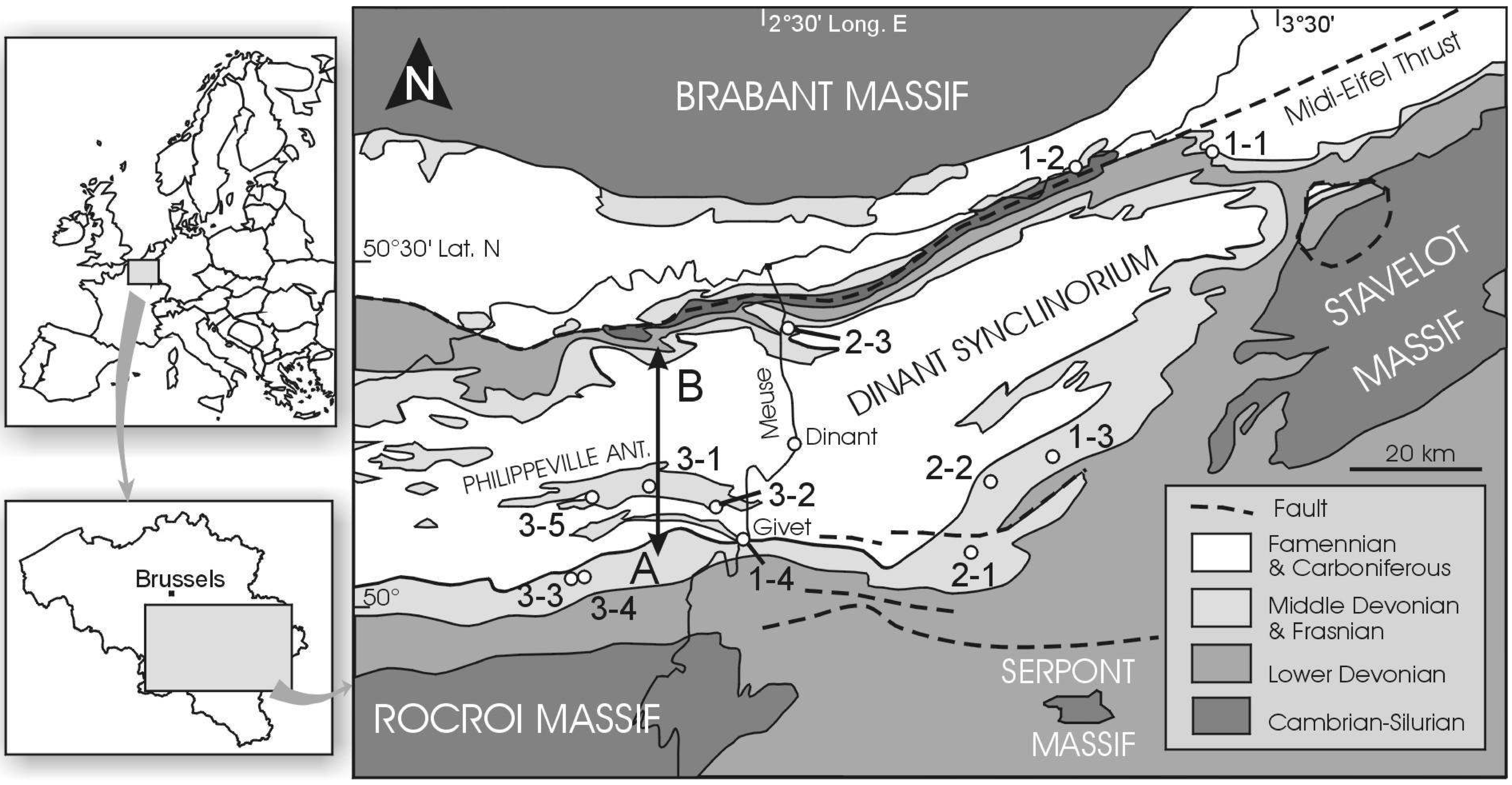

Fig. 2: Simplified geological map of Southern Belgium with location of stops (1-1 to 3-5).

This last unit is characterized by fluvial conglomerates, bioclastic limestones and detrital sediments with paleosols. This fieldtrip will be focused on the marine formations from the southern border of the Dinant Syncline, corresponding to the Givetian stratotype.
The Eifelian sedimentation in the Ardenne corresponds to a mixed regime, with both detrital supply (Jemelle Fm) and carbonate production (Couvin Fm). The Hanonet Formation makes the transition between the shales and siltstones from the Upper Eifelian and the first Givetian reef complex. In most sections, the boundary between the Hanonet and Trois-Fontaines formations is sharp: the argillaceous limestone from the Hanonet Formation passes upwards into purer limestones, forming the base of the Trois-Fontaines Formation. This limit represents the base of the Givetian carbonate platform. In most sections exposing the base of the Trois-Fontaines Formation, the first metres correspond to relatively coarse grained dm-thick beds (grainstones and packstones) with crinoids and lithoclasts, separated by argillaceous seams. Frequent hummocky cross stratification and erosion seams lead to an interpretation of this facies as tempestites.

The crinoidal accumulations acted as a sole for reef initiation, and the second characteristic unit of the Trois-Fontaines Formation is a barrier reef ("premier biostrome" *auctores*). This reef runs laterally over nearly 150 km. Although very constant, its thickness and sedimentological characteristics vary locally and are of great interest for the understanding of the working of the Givetian reef system (BOULVAIN et al. 2009).

This reef-complex (Fig. 4) is nearly 10 to 20 metres thick. Its total width is unknown but certainly higher than several hundreds of metres according to its high lateral continuity. Detailed study of the Resteigne, Glageon and Baileux sections allowed reconstruction of the different development stages of the reef (PRÉAT et al. 1984; BOULVAIN et al. 1995; MABILLE & BOULVAIN 2008, BOULVAIN et al. 2009). Over the crinoidal sole, grew lenses rich in lamellar and tabular stromatoporoids, solitary and fasciculate rugose corals, branching and massive tabulate corals. Progressively, massive stromatoporoids became more abundant, associated with some rugose and tabulate corals and brachiopods. Multiple coatings associating stromatoporoids, corals, cyanobacteria (*Girvanella, Bevocastria, Sphaerocodium*) attest to a strong competition for life space. The community became richer in calcareous algae as palaeosiphonocladales (mainly *Issinella*), phylloids (*Resteignella*) and dasycladales (*Givetianella*) (MAMET & PRÉAT 1986). Peloids are abundant. All the organisms, greater than several tens of cm in size, are broken and overturned; this being a common feature in shallow reefs, even in present day

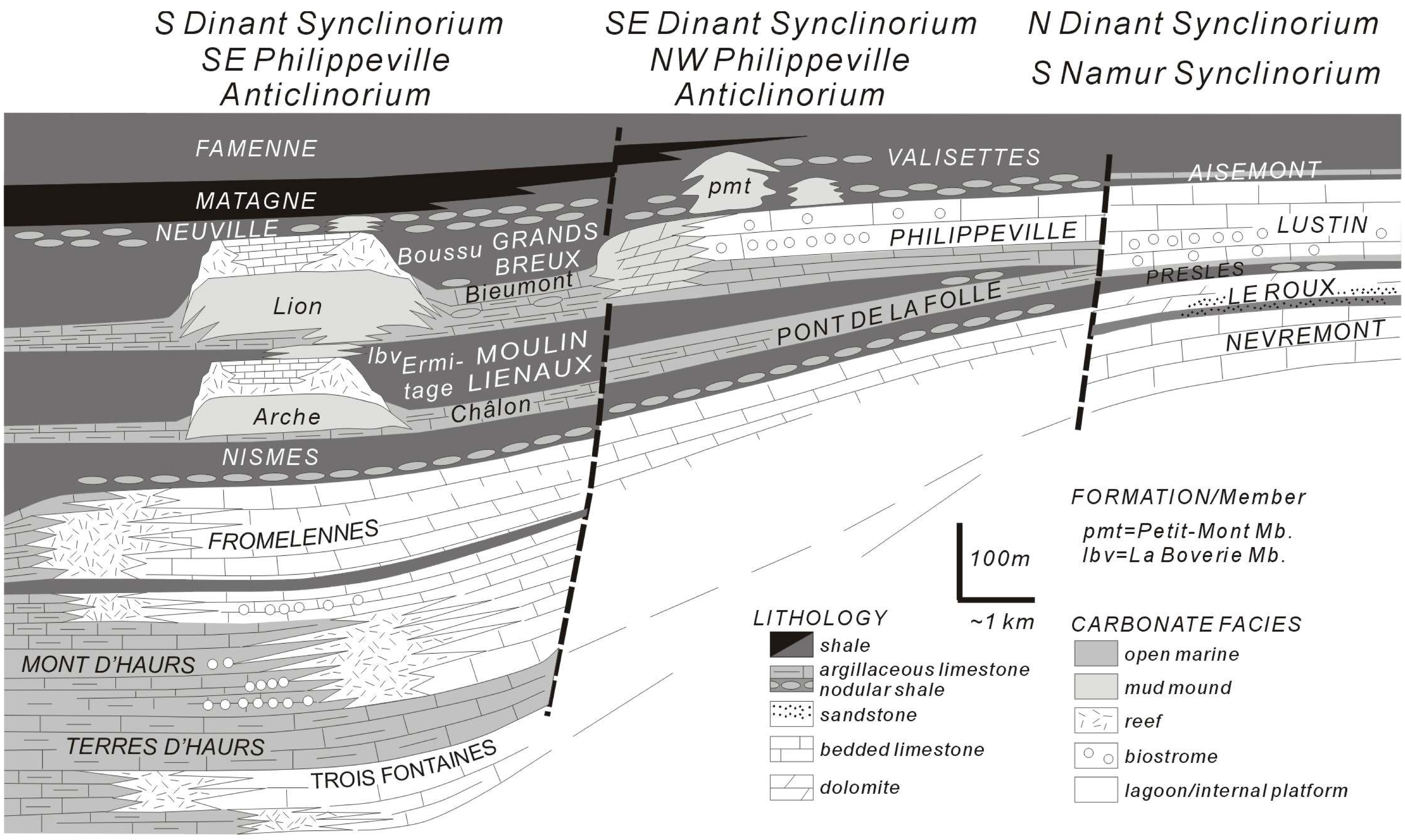

Fig. 3: The Givetian-Frasnian sedimentation basin before Variscan tectonism. This section corresponds to the A-B arrow on Fig. 2. (BOULVAIN et al. 2009).

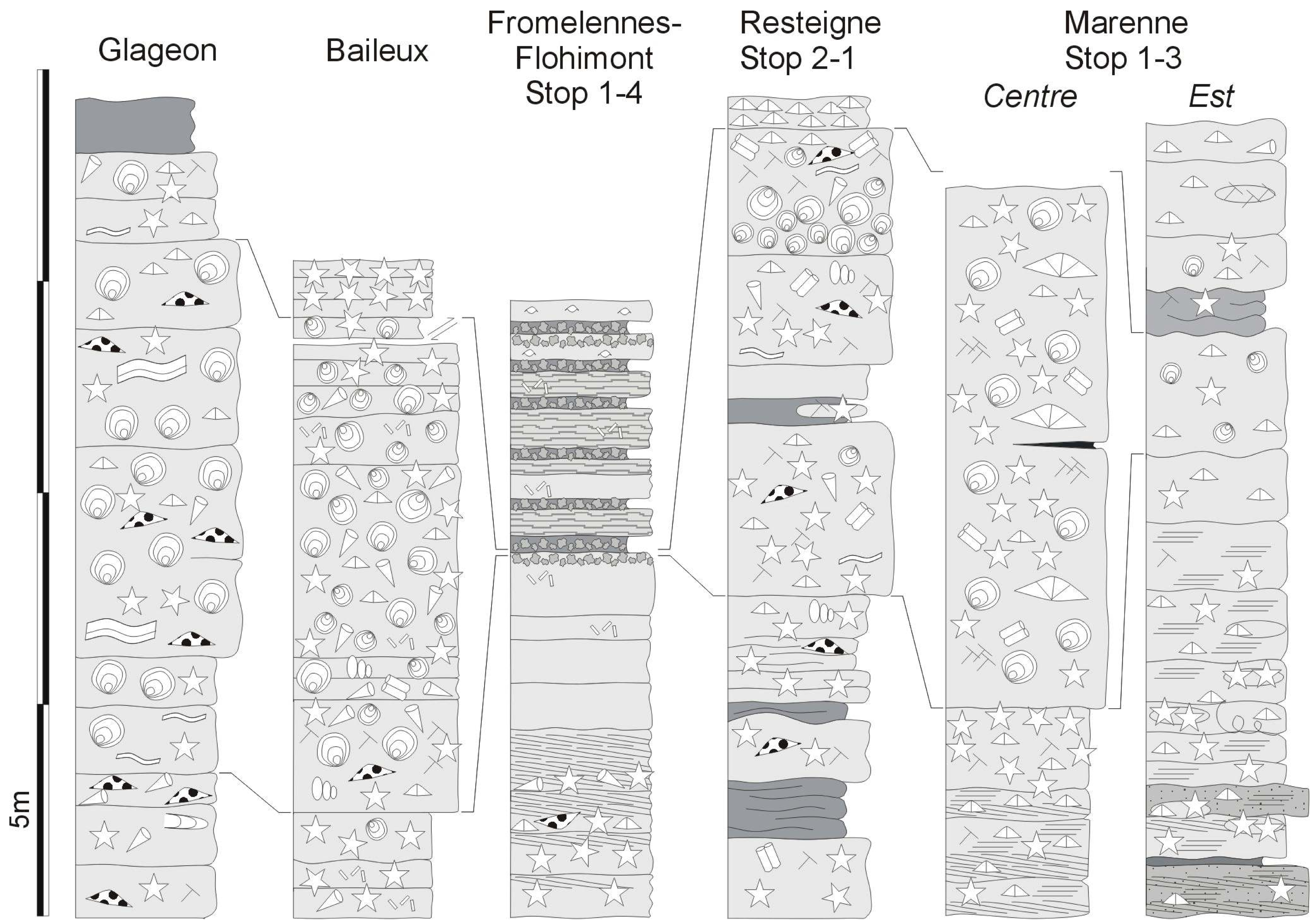

Fig. 4: Lateral variations in the base of the Trois-Fontaines Formation. The correlation lines mark the reef base and top. Location of sections, see Fig. 2. Legend of symbols, see Fig. 32. (BOULVAIN et al. 2009).

barriers (RIEGL & PILLER 1997). It corresponds to periods of reef development, alternating with high energy events like tsunamis or major storms, responsible for breaking and reworking of reef building organisms. In Marenne, in a context of continuous detrital supply, the reef is poorly developed, but the constituents remain the same (MABILLE et al. 2008).

Above the reef, dm-thick accumulations of brachiopods or gastropods ("coquina beds") are frequently observed. These beds are storm deposits left on the shore. Most sections in this Givetian barrier show probably what could be interpreted as proximal back reef deposits, resulting from accumulation in quieter water of material reworked by storms or tsunamis.

Besides own reef development, a sea level drop must be supposed to explain the final emersion of the reef top. This sea level drop is attested in the Flohimont section at Givet by several paleosols (Fig. 14) developed directly on the top of bioclastic limestones deposited below the fair weather wave base (BOULVAIN et al. 2009)

After reef emersion, mainly related to a sea level fall, the loss of accommodation induced a basinward shift of reef building communities (HANDFORD & LOUCKS 1993). The exact location of the new reef is impossible to determine by lack of outcrops, but it seems logical that the new barrier was situated some kilometres to the south of present day Givetian outcrops (BOULVAIN et al. 2009).

The development of a new barrier southward from the former is responsible for the deposition of the lagoonal complex constituting the upper half of the Trois-Fontaines Formation (BOULVAIN et al. 2009). The lagoonal complex is characterized by fine grained sediments with a relatively low diversified fauna: leperditids ostracods (CASIER & PRÉAT 1991), gastropods, burrowing organisms, and a flora dominated by calcispherids and palaosiphonocladales (PRÉAT & BOULVAIN 1982). This facies suggests that the lagoonal complex was restricted. Locally, monospecific coral populations of *Hillaepora* developed in the lagoon (PRÉAT et al. 1984, TOURNEUR 1987) or storm events reworked material coming from the barrier, deposited as rudstone beds interrupting the lagoonal deposits.

The constant accumulation of lagoonal deposits over several tens of metres was the consequence of a new sea level rise, allowing a vertical aggradation of the reef barrier (BOULVAIN et al.

2009). At the end of this period, a sea level stabilisation favoured the filling of the lagoon and development of extensive tidal flats. The tidal flats were dominated by algal-microbial mats, covering the intertidal and supratidal area of the carbonate platform (PRÉAT & BOULVAIN 1987). Similar sediment types are observed today, for example in the Bahamas (PURSER 1983). Several sections however differ from this model: the Marenne section for example shows open marine beds within the lagoonal complex (MABILLE et al. 2008).

After lagoon filling and final development of tidal flat complexes corresponding to the top of the Trois-Fontaines Formation, the sedimentation started again during a new marine transgression. The Terres d'Haurs is characterized by argillaceous limestone with horizontal burrows, locally rich in crinoids, brachiopods (often concentrated in coquina beds by storms), gastropods and coral patch reefs. The base of the formation is underlined by a metre-thick uninterrupted or lenticular reef with massive rugose (*Argutastrea*) or tabulate corals (*Thamnopora*, *Pachyfavosites*,…) (PRÉAT et al. 1984; COEN-AUBERT 1977, 2003; COEN-AUBERT et al. 1986). Near the top of the formation, several metres of crinoidal limestone appear in most sections. All these facies point to an open environment, below the wave base. However, the sporadic occurrence of oolitic beds or of calcareous algae suggests an easy communication with shallower zones, as is the case on a ramp profile (BOULVAIN et al. 1995, MABILLE & BOULVAIN 2008).

The base of the Mont d'Haurs Formation corresponds to the first massive bed with stromatoporoids and corals (BULTYNCK et al. 1991). This formation is divided in two parts (Fig. 13); the lower unit shows relatively monotonous argillaceous limestone with crinoids, brachiopods, issinellids and gastropods, locally interrupted by metre-thick stromatoporoid- and coral-rich beds (Fig. 15). The upper part is characterized by purer limestones with peloids, oolithes, calcispherids and palaeosiphonocladales (BOULVAIN et al. 1995). Some beds rich in massive and dendroid stromatoporoids, branching tabulate and solitary or massive rugose corals are observed in the upper unit (COEN-AUBERT 1999).

The lower unit shows several characteristics of an open environment, located below the wave base, such as the facies observed in the Terre d'Haurs Formation. The sporadic occurrence of beds rich in building organisms is not easily explained, as these beds do not show any crinoidal sole, nor ecological development sequence like that observed in the Trois-Fontaines barrier reef (Fig. 4). Moreover, the relatively rich and diversified fauna (COEN-AUBERT 1999, 2002) does not correspond to a coral carpet, generally characterized by poorer assemblages (RIEGL & PILLER 2000). This paradox disappears when closely examining these beds: they are in fact debris flow reworking material coming from a reef barrier located northwards from the outcrop zone (BOULVAIN et al. 2009). These debris flows were deposited during major storms or tsunamis.

The upper part of the Mont d'Haurs Formation shows more protected, restricted environments, alternatively quiet or more agitated, located behind a reef barrier. Periodic destruction of the barrier provided material for the coarser beds. Small local patch reefs with dendroid stromatoporoids and branching tabulate corals also developed in this lagoon. Near the top of the Mont d'Haurs Formation, the environment became progressively more open marine, as coral fauna is observed to become richer and more diversified (COEN-AUBERT 1999). This can be correlated with the marine transgression that characterizes the base of the Fromelennes Formation.

The Fromelennes Formation includes three members which are from base to top (BULTYNCK et al. 1991): the Flohimont Member, consisting of argillaceous limestone beds with brachiopods separated by clay seams; the Moulin Boreux Member characterized by fine-grained limestones with dendroid stromatoporoids and finally, the Fort Hulobiet Member which shows argillaceous limestones and shales (Fig. 13).

The Flohimont Membre is a transgressive unit, deposited during sea level rise. The most calcareous part of the Fromelennes Formation, the Moulin Boreux Member, shows typical cyclic facies successions. These cycles show that some coral-stromatoporoid carpets were periodically growing in a relatively protected environment (delicate forms are often preserved). The carpets were followed by lagoonal and intertidal algal-microbial sediments following accommodation decrease. The presence of characeae and dominance of amphiporids suggest frequent salinity fluctuations (MAMET & PRÉAT 1986). In addition to information collected from fossil associations, two other important elements have to be taken into account: the occurrence of evaporite pseudomorphs (BOULVAIN & COEN-AUBERT 1997a) and the relatively high abundance of primary dolomite. These observations, suggest a highly periodical salinity indicating a restricted, partially evaporitic character for the Fromelennes platform. Biological communities were dominated by specialized organisms (dendroid stromatoporoids, cyanobacteria), developing carpets and mats in the subtidal environment.

After this long period of stability, the top of the Fromelennes Formation (Fort Hulobiet Member) shows an opening of the platform, attested by a faunal diversification and more specifically, the return of corals and crinoids. This announces the large marine transgression characterizing the base of the Frasnian.

2.2.2. FRASNIAN

After the deposition of the Lower Frasnian Nismes transgressive shale unit, a complex carbonate platform developed in Belgium, showing environments ranging from restricted shallow-water lagoons and supratidal areas to a relatively deep outboard ramp with reef mounds. This Frasnian carbonate platform is especially instructive because of a combination of extraordinary outcrops ("marble" quarries with large sawn sections) and a long history of paleontological study which has led to a refined stratigraphic framework (BOULVAIN et al. 1999). Carbonate mounds have been the subject of intense investigation carried out by generations of geologists (Lecompte, Tsien, Coen-Aubert, Boulvain - see Historical background) but a few of these studies focused on the shallow-water part of the platform (TSIEN 1971, 1975, 1976, 1977, DA SILVA & BOULVAIN 2004).

The platform can be divided in three main depositional areas characterized by a different facies association, carbonate production rate and sedimentary evolution (Fig. 5). During the Middle Frasnian, the most distal part of the platform ("southern belt") is located along the southern border of the Dinant Synclinorium (Fig. 2), the "intermediate belt" corresponds mainly to the Philippeville Anticline and the "northern belt" - the shallower- crops out in the northern part of the Dinant Synclinorium, the Namur Synclinorium and the Vesdre area.

- The southern belt is characterized by carbonate mound sedimentation with associated flank and off-mound facies. Since the classical studies of MAILLEUX (1913) and TSIEN (1971, 1976), three levels of carbonate mounds were known. These are in ascending order the Arche, Lion and Petit-Mont Members belonging respectively to the Moulin Liénaux, Grands Breux and Neuville Formations (Fig. 3). The famous Arche and Lion buildups are located in the vicinity of Frasnes, historical stratotype of the Frasnian. Recently, BOULVAIN et al. (2005) gave information about a set of outcrops located some distance from Frasnes: the La Boverie quarry, close to Rochefort, and the Moulin Bayot sections, close to Vodelée. At both locations, it was possible to study a series of buildups starting near the base of the Arche Member and ending within the Lion Member. Moreover, at both locations, an additional buildup was recognized between the Arche and Lion Members. The regional presence of this additional buildup along all the south side of the Dinant Synclinorium is now supported by its occurrence in boreholes drilled in the Nord quarry at Frasnes. The name of La Boverie Member was introduced by BOULVAIN & COEN-AUBERT (2006), as a subdivision of the Moulin Liénaux Formation, for the carbonate deposits lying between the Arche and Bieumont Members.

- The intermediate belt. In the Philippeville Anticline, the carbonate mound-bearing levels were replaced by shales and argillaceous limestones

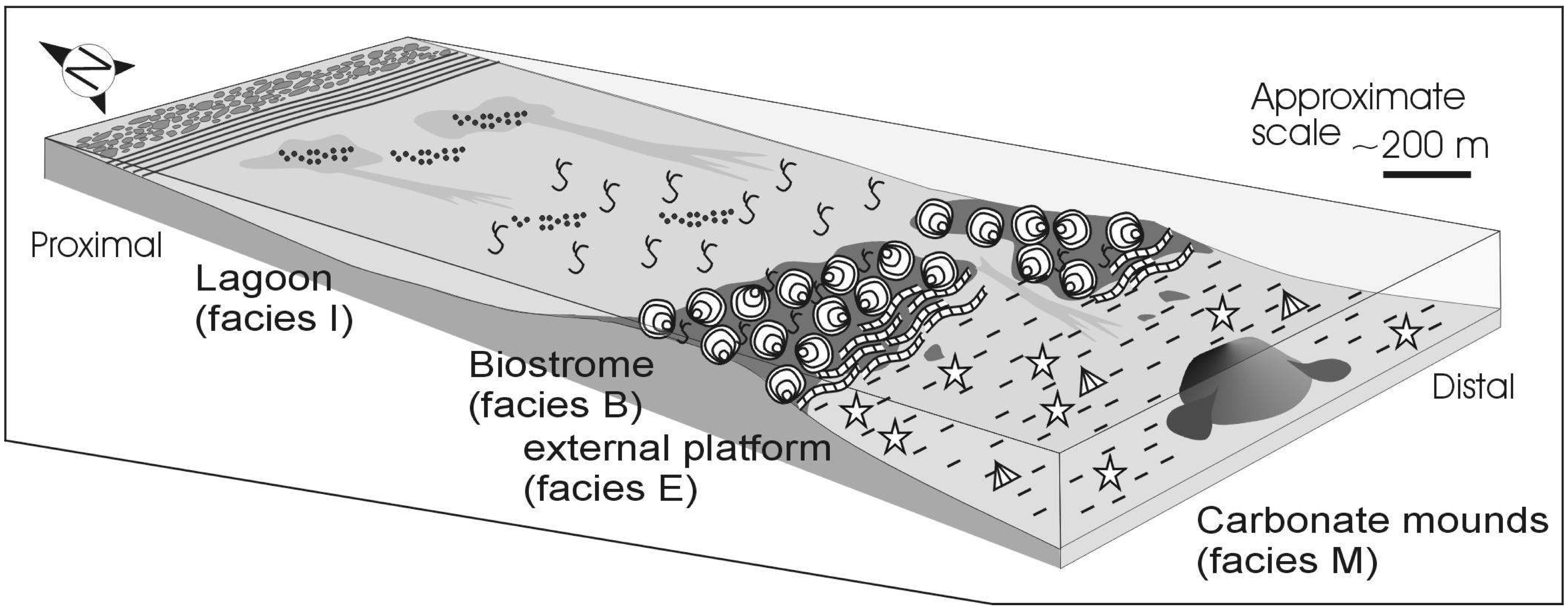

Fig. 5: General organization of Middle Frasnian sedimentation domains (DA SILVA et al. 2009).

(Pont de la Folle Formation) followed by bedded limestone consisting of open-marine facies and biostromes (Philippeville Formation).

- The northern belt. Along the northern border of the Dinant Synclinorium ("northern belt"), the Middle Frasnian consists of bedded limestones, exhibiting a distinct proximal aspect with biostromes alternating with lagoonal facies followed by palaeosoils and lagoonal deposits (DA SILVA & BOULVAIN, 2002).

During the Upper Frasnian, a general northern shift or retrogradation of the platform is observed: the southern belt extends into the Philippeville Anticline with spectacular development of Petit Mont Member mounds and the intermediate belt shifts to the Northern border of the Dinant Synclinorium.

Microfacies are ordered from the most distal to the most proximal, or from the deeper to the shallower. However, this order is not always effective, due to lateral variations, especially in the more proximal parts of the platform. Microfacies are grouped in 4 main facies belts: carbonate mounds and flank deposits (M), external platform or ramp (E), biostromes (B) and internal platform (I) (Fig. 5).

- Carbonate atolls and mounds (M, southern and intermediate belts, Figs 6 & 7). Eight facies were recognized in the buildups, each characterized by a specific range of textures and assemblage of organisms (BOULVAIN 2007): spiculitic wackestone with stromatactis (facies M1), which becomes progressively enriched in crinoids and corals (M2); grey or pinkish limestone with stromatactis, corals, and stromatoporoids (M3); grey limestone with corals, peloids and dasycladales (M4); grey, microbial limestone (M5); grey limestone with dendroid stromatoporoids (M6); grey, laminar fenestral limestone, (M7); grey, bioturbated limestone (M8).

Laterally to the buildup facies, thin-bedded bioclastic and intraclastic facies are observed, most elements of which underwent a certain transport. Frequent sorting and rounding of their elements characterize these facies. They are ordered according to their content and grain-size: microbioclastic, often argillaceous packstones with ostracodes, trilobites and cricoconarids (M9); bioclastic packstones, grainstones and rudstones with intraclasts (M10) and packstones, grainstones and rudstones with peloids and intraclasts (M11).

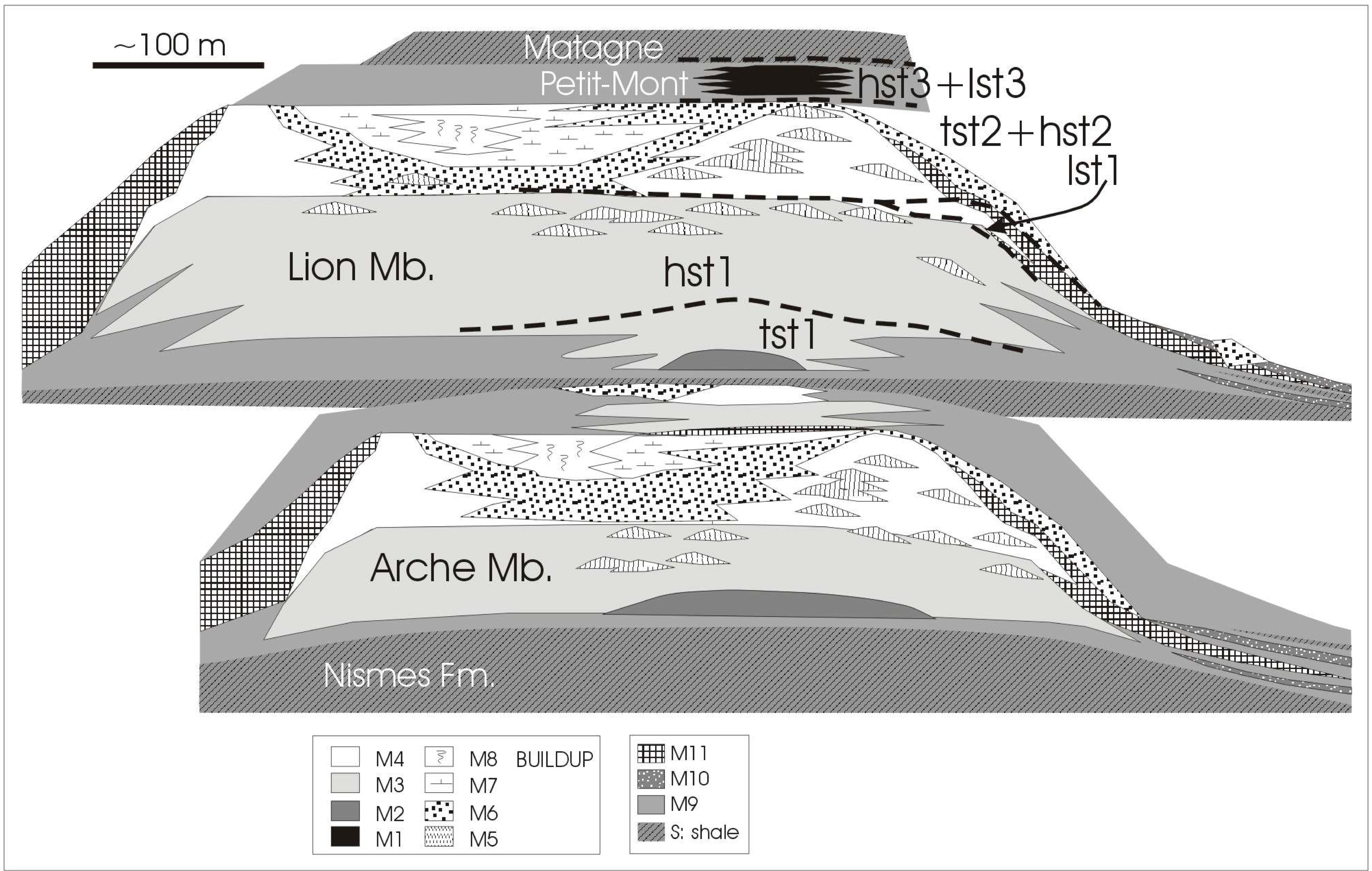

Fig. 6: Sedimentary models of Middle to Upper Frasnian mounds along the Southern border of the Dinant Synclinorium (BOULVAIN 2007).

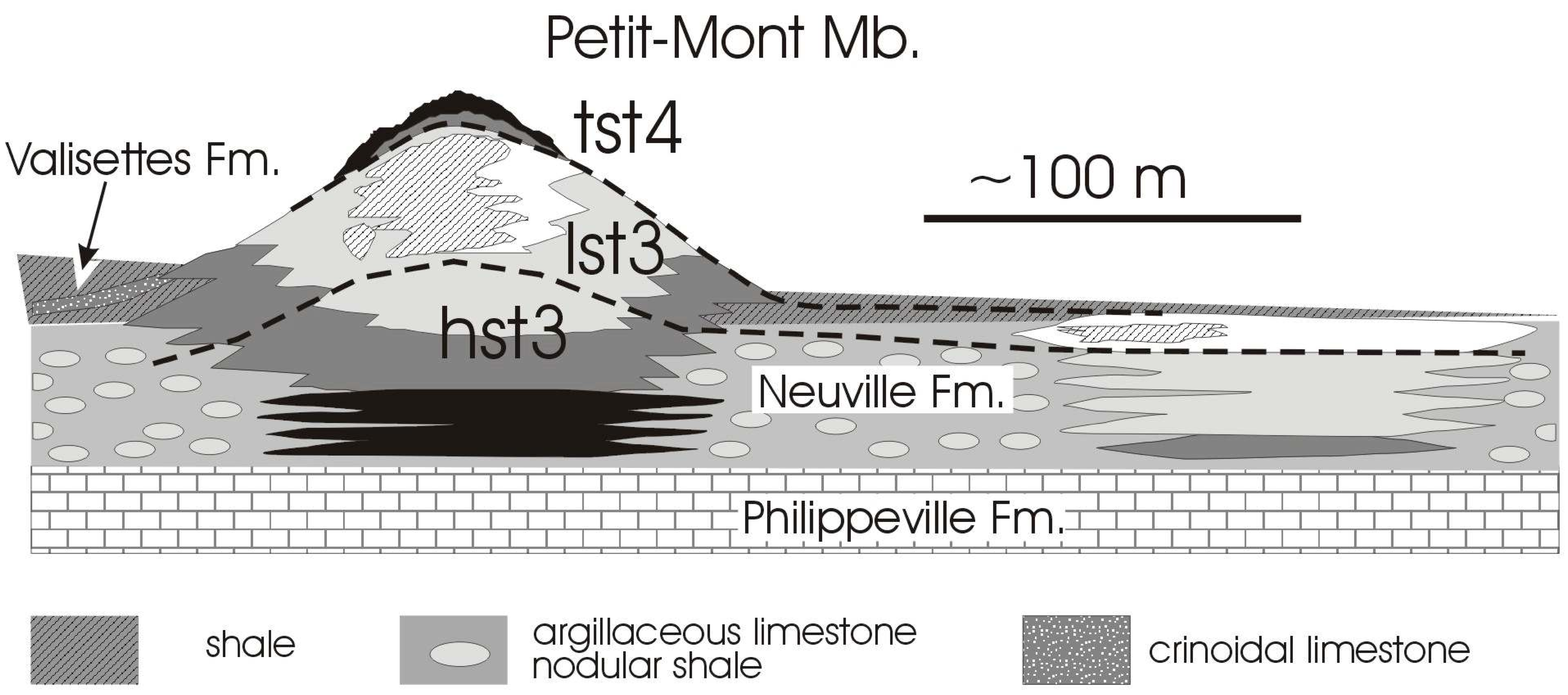

Fig. 7: Sedimentary model of Late Frasnian Petit-Mont Member mounds in the Philippeville Anticline. Explanation of microfacies, see Fig. 6 (BOULVAIN 2007).

Sedimentological evidence suggests that facies M1 and M2 correspond to iron bacteria-sponge-dominated communities, developing in a quiet aphotic and hypoxic environment (BOULVAIN et al. 2001). M3 developed between storm wavebase and fairweather wavebase, in an oligophotic environment. Facies M5 developed close to fairweather wavebase. Facies M6 and the fenestral limestone M7 correspond to an environment with slightly restricted water circulation. Facies M8 developed at subtidal depths in a quiet, lagoonal environment. Microbioclastic packstones (M9) are characterized by an open-marine facies with brachiopods, bryozoans and crinoids, whereas bioclastic rudstones (M10) and intraclastic packstones or grainstones (M11) show a clear mound influence as most of the bioclastic and intraclastic material is derived from these buildups (HUMBLET & BOULVAIN 2001).

The main differences between the Middle and Late Frasnian mounds concern facies architecture and are a consequence of different palaeoceanographic settings. The large flattened middle Frasnian Arche and Lion buildups show limited vertical differentiation, large-scale progradation features, extensive exportation of material towards off-reef environment and development of inner lagoonal facies. They grew offshore from a well-developed carbonate platform with a healthy carbonate factory. Middle Frasnian sea level fluctuations were relatively mild, and sedimentation was able to keep-up with sea level rise (BOULVAIN 2007). Reef initiation occurs during a transgression with the development of mud or skeletal mound facies (M2-3). During the subsequent lowstand, reef growth was restricted to a downslope position, resulting in the development of a circular reef margin (atoll crown). During the following transgressive stage, algal and microbial mound facies with stromatoporoids, corals and peloids were deposited (M4-6). The occurrence of relatively restricted facies (M7-8) inside this crown is possibly the result of a balance between sea-level rise and reef growth. During the regression which causes the emersion of the top of the reef and the displacement of the facies downslope, some flank deposits are developed corresponding to the dismantling of the top of the mounds (M10-11).

At the opposite extreme, during the Late Frasnian, severe eustatic rises, together with rising oceanic hypoxic conditions were responsible for frequent collapses of the carbonate factory, drowning of the middle Frasnian carbonate platform, and development of buildups with relatively limited lateral extension, high vertical facies differentiation, low potential for material exportation and high content in microaerophilic iron bacteria (BOULVAIN 2001). In this context, the main part of the Petit-Mont mounds developped as a catch-up sequence (M1-3) during a highstand while the shallowest algal-microbial facies (M4-5) were the consequence of a sea-level drop.

- carbonate platform (E, B, I, intermediate and northern belts, Fig. 5). The ideal shallowing-upward facies succession starts with open-marine deposits corresponding to crinoidal packstones (E1). They are followed by biostromes with laminar stromatoporoids (B1), overturned and broken massive stromatoporoids (B2) and then dendroid stromatoporoids (B3). Then, biostromes are overlain by subtidal lagoonal facies with *Amphipora*, paleosiphonocladales and peloids (I1), followed by mudstone (I3) and laminated pelloidal facies (I4) in the intertidal zone. The subtidal and intertidal zones were cutted by channels filled by *Umbella* and intraclasts (I2). The supratidal zone was characterized by paleosoils (I5) (DA SILVA & BOULVAIN 2004). An important sedimentological observation concerning platform evolution (intermediate and southern belts) is the apparent division seen in all the sections between an upper and a lower unit (DA SILVA & BOULVAIN 2002) (Fig. 23). The lower unit is dominated in the intermediate belt by ramp facies with some biostromal interruptions, and in the northern belt by biostromes with lagoonal interruptions. The upper unit (lagoon) consists of an alternation of biostromes and lagoonal facies in the intermediate belt and of lagoonal facies (with paleosoils) in the northern belt.

Within these sedimentological units, facies are stacked into metre-scale cycles, showing mainly shallowing-upward trends. Such cyclicity is common in Devonian shallow-water carbonates. Different kinds of cycles however, are identified here.

In the intermediate belt, sedimentation during the deposition of the biostromal unit is mainly acyclic with the stacking of 10 cm-thick crinoidal beds, probably due to the deeper environment being less sensitive to minor relative sea-level variations. In the lagoonal unit, the cycles are characterized by biostromes followed by lagoonal deposits and capped by intertidal laminites. In the northern belt, the biostromal unit shows one or few metres-thick cycles, with crinoid beds (the colonization stage) followed by massive biostromes and lagoonal deposits and capped by intertidal laminites. The lagoonal unit is characterized by restricted subtidal and intertidal facies covered by, or transformed into paleosoils. These cycles are not always complete.

In the proximal zone of the ramp, the Upper Frasnian Aisemont Formation recorded a trangressive-regressive cycle corresponding to a single third order sequence (POTY & CHEVALIER 2007) that coincides with the first part of the IId cycle of JOHNSON et al. (1985) but also with the "*semichatovae* trangression" (ALEKSEEV et al. 1996). POTY & CHEVALIER (2007) interpreted it as an erosion transgressive surface (disconformity) reflecting an emersion of the shelf. The lower member of the Aisemont Fm, constitutes locally a phillipsastreid-stromatoporioid biostrome (see STOP D1-1 and D1-2) The middle member is made of shale, and the upper member is constituted of oncoidal bioclastic limestone and dolostone with phillipstastreid and alveolitids. The lower and middle members of the Aisemont Fm set up the transgressive systems tract of the "Aisemont sequence" (POTY & CHEVALIER 2007). The maximum flooding surface is reached in the dysoxic shale of the middle member. The highstand systems tract corresponds to the upper part of the middle member and the lower part of the upper one. A falling stage systems tract is recognized by the presence of erosion surfaces in the upper part of the upper member of the Aisemont Formation (DENAYER & POTY 2010). This member is topped by a last erosion transgressive surface corresponding to the sequence boundary on which the shale of the Lambermont, Falisole and Franc-Waret formations (lateral equivalents) deposited, witnessing a definitive switch in the sedimentation type toward the predominant argillaceous deposits of the latest Frasnian and earliest Famennian times.

In the Namur-Dinant Basin (both in shallow-water and deeper facies), the Kellwasser events are clearly separated and their intensity depends on their position along the ramp (MOTTEQUIN 2008). GOUWY & BULTYNCK (2000) recognized the Lower Kellwasser Event in the upper *Palmatolepsis rhenana* conodont Biozone, in the lower part of the Matagne Formation (southern part of Dinant Synclinorium), at the base of the Les Valisettes Formation (Philippeville Anticlinorium) and in the middle member of the Aisemont Formation (northern part of the Namur-Dinant Basin). The Upper Kellwasser Event corresponds to the upper part of the Matagne Formation, and is located at the top of the Les Valisettes and Lambermont formations, in the *P. linguiformis* Biozone (MOTTEQUIN 2008, POTY & CHEVALIER 2007, DENAYER & POTY 2010). The onset of the Late Frasnian Crisis starts before the Lower Kellwasser Event, within the Early *rhenana* conodont Biozone but has no significant effect on the diversity of corals (POTY & CHEVALIER 2007) and few on brachiopods (MOTTEQUIN 2008) but is an evidence of the degradation of the global environment during the Late Frasnian, as several changes of facies witness it in the Namur-Dinant Basin (POTY & CHEVALIER 2007, DENAYER & POTY 2010).

3. BIOSTRATIGRAPHY

3.1. Givetian

For the Givetian, the general framework for the conodonts and the rugose corals is given by Figs 8 and 9. The conodont zonation is based on the papers of BULTYNCK & DEJONGHE (2002) and GOUWY & BULTYNCK (2003). These microfossils have been revised recently by NARKIEWICZ & BULTYNCK (2010) in the upper part of the Fromelennes Formation.

As shown by TSIEN (1970, 1974, 1976a) and especially COEN-AUBERT (1988, 1992, 1990b, 1996, 1997b, 1998, 2000 and 2008), the rugose coral faunas of the Hanonet Formation and the base of the Trois-Fontaines Formation are closely related. Another interesting component of the Hanonet formation is the occurrence of *Calceola sandalina* as mentioned by WRIGHT et al. (2010). *Argutastrea quadrigemina* is characteristic for the lower part of the Terres d'Haurs Formation, but it appears already at the top of the Trois-Fontaines Formation (Fig. 8). The fauna from the lower part of the Mont d'Haurs Formation investigated by COEN-AUBERT (1999, 2002, 2004) is highly diversified though several species are already present at the top of the Terres d'Haurs Formation. *Wapitiphyllum laxum* is typical for the upper part of the Mont d'Haurs Formation and the base of the Moulin Boreux Member from the Fromelennes Formation where it is associated with the last stringocephalids according to COEN-AUBERT (2004). Finally, *Disphyllum virgatum* is frequent at the top of the Fromelennes Formation (Fig. 9).

The tabulate coral faunas of the Hanonet Formation and of the base of the Trois-Fontaines Formation show a high diversity, in the continuation of the Eifelian faunas (HUBERT 2009). Colonies of favositids, of the *Favosites goldfussi* group, are frequent, with growth forms and dimensions rather variable – as internal characters like thickness of the walls and development of the septal spines. Alveolitids and coenitids (in erected or creeping lamellae) are locally abundant, as well as heliolitids and chaetetids (including forms like *Pachytheca* with strongly thickened skeletons). Thamnoporids are present as branches with strong peripheral thickening of the walls (*Thamnopora nicholsoni* group) or as large bushes of thin branches with moderate thickening of skeleton (*Thamnopora reticulata* group). These last thamnoporids are still abundant in the crinoidal part of the base of Trois-Fontaines Formation, as well as favositids and alveolitids, with some rare coenitids. In some localities, numerous large colonies of *Mariusilites chaetetoides* can be observed, and rare small branches of *Hillaepora circulipora* (with encrusting stromatoporoid) or very small branches of *Dendropora circulipora*. In the upper beds of the biostrome at the base of Trois-

Fontaines appeared colonies of *Pachyfavosites polymorphus* and many fragments of *Hillaepora spicata*. This last species is the most frequent in the upper part of Trois-Fontaines Formation, with sporadic colonies of *Pachyfavosites* and branches of

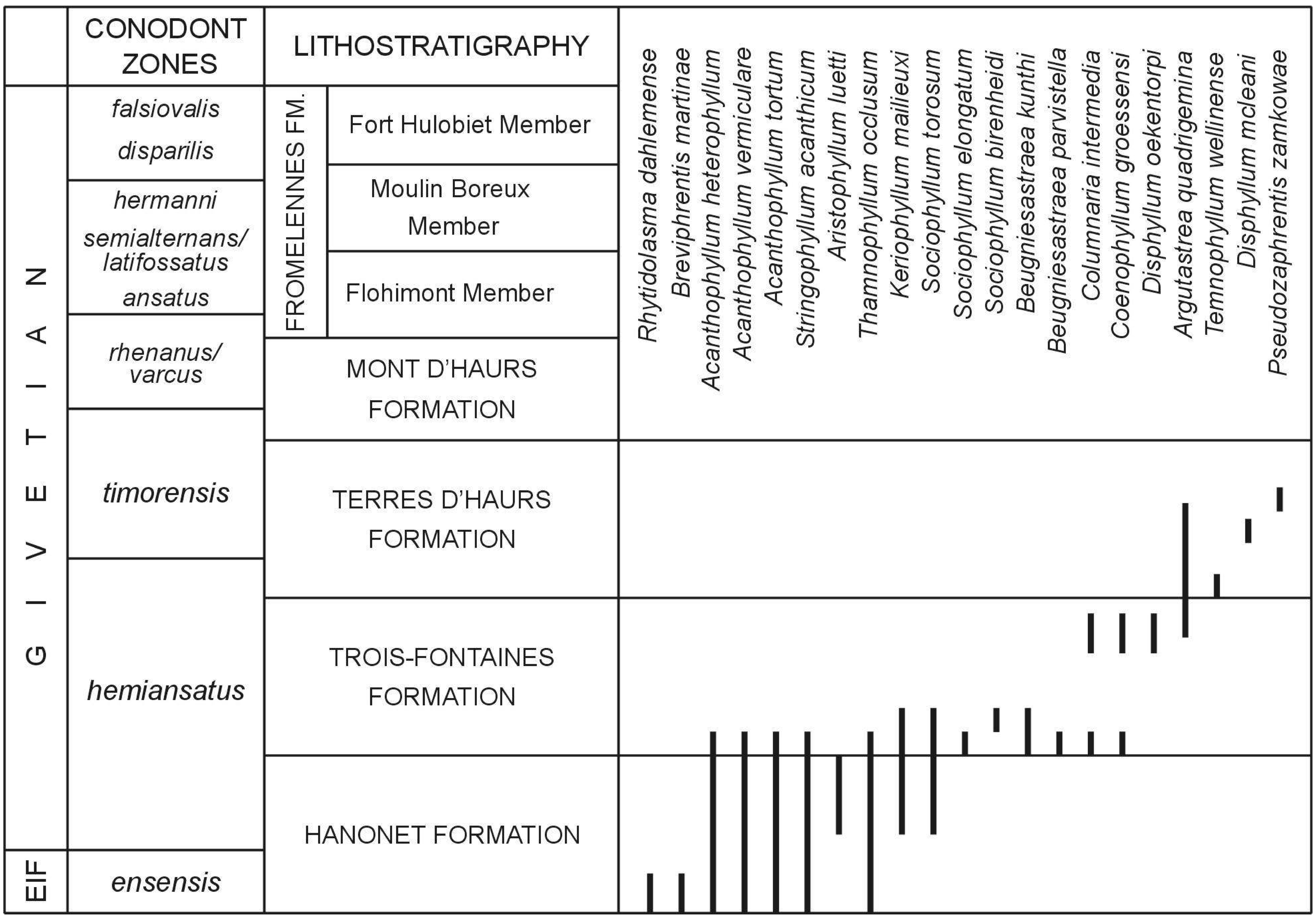

Fig. 8: Stratigraphic distribution of the Early Givetian rugose corals from the south side of the Dinant Synclinorium.

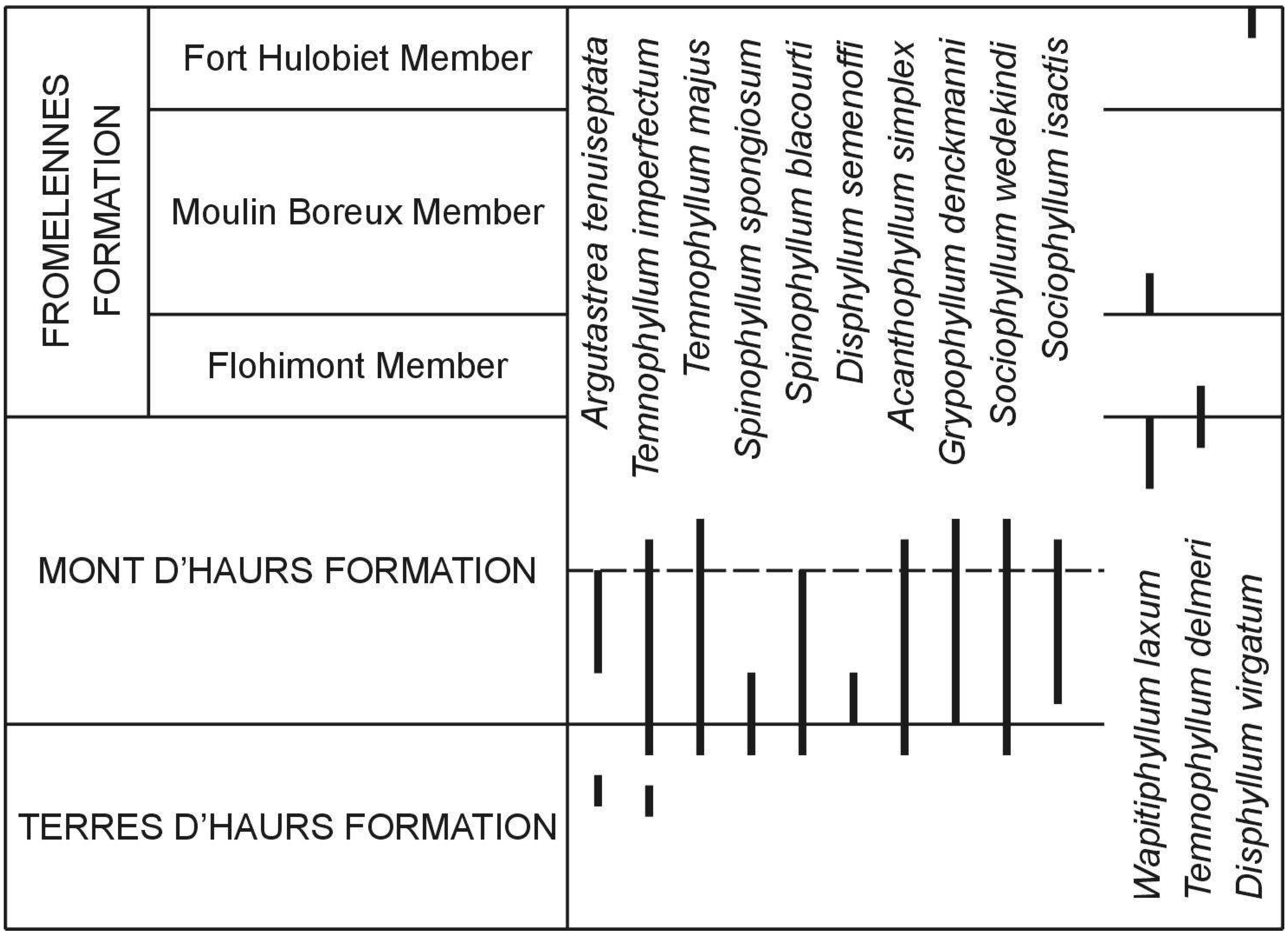

Fig. 9: Stratigraphic distribution of the Givetian rugose corals from the upper part of the Terres d'Haurs Formation to the top of the Fromelennes Formation, for the south side of the Dinant Synclinorium.

Thamnopora with well-developed squamulae (*Thamnopora germanica* group). The small patch reefs at the base of the Terres d'Haurs Formation are composed of numerous *Pachyfavosites polymorphus*, large bushes of *Thamnopora cervicornis* and branches of *Hillaepora spicata*, around the large massive colonies of *Argutastrea quadrigemina*.

After, the diversity quickly decreased, with the last occurrences of favositids, rare thamnoporids and alveolitids, but the first colonies of typical *Caliapora battersbyi* appeared. This species is abundant in the Mont d'Haurs Formation, with frequent alveolitids and rare squamulate large thamnoporids, and the last heliolitids. *Caliapora* occurs also in the lower part of Fromelennes Formation, with the last stringocephalids, and disappeared in the same time. Higher, scolioporids and rare thamnoporids (*Thamnopora polyforata* group) can be observed.

3.2. Frasnian

The biostratigraphy of the is better known due to many studies on conodont and corals (e.g. BOULVAIN et al. 1999, GOUWY & BULTYNCK 2000 and BULTYNCK & DEJONGHE 2002).

The Early and Middle Frasnian rugose coral faunas from the south side of the Dinant Synclinorium have been recently revised by BOULVAIN & COEN-AUBERT (2006) and COEN-AUBERT (2000, 2009), whereas older studies mainly focussed on the Bieumont and Boussu-en-Fagne members (COEN-AUBERT 1982, 1994) and the upper Frasnian (COEN et al. 1976, COEN-AUBERT 2000).

The tabulate coral faunas of the Frasnian, described in detail for the last time by LECOMPTE (1939), are in great need of systematic revision. They show a rather low diversity, compared with the Middle Devonian faunas. Two groups largely dominated; alveolitids (different growth forms, lamellar or massive to branching ones, with small corallites like *Alveolites tenuissimus*, or with larger ones, like *Alveolites suborbicularis*) and branching species of scolioporids and thamnoporids. These last ones can be described as forms with large corallites (*Thamnopora boloniensis* / *Thamnopora cristata* group) and forms with smaller ones (*Thamnopora micropora*). Studies of some outcrops revealed the existence of special taxa like the thin *Senceliaepora tenuiramosa*, small branches called by Lecompte "*Cladopora gracilis*" or some strange forms of auloporids sensu lato (including layered colonies of *Thecostegites*). Their stratigraphic interest has to be checked by new collections.

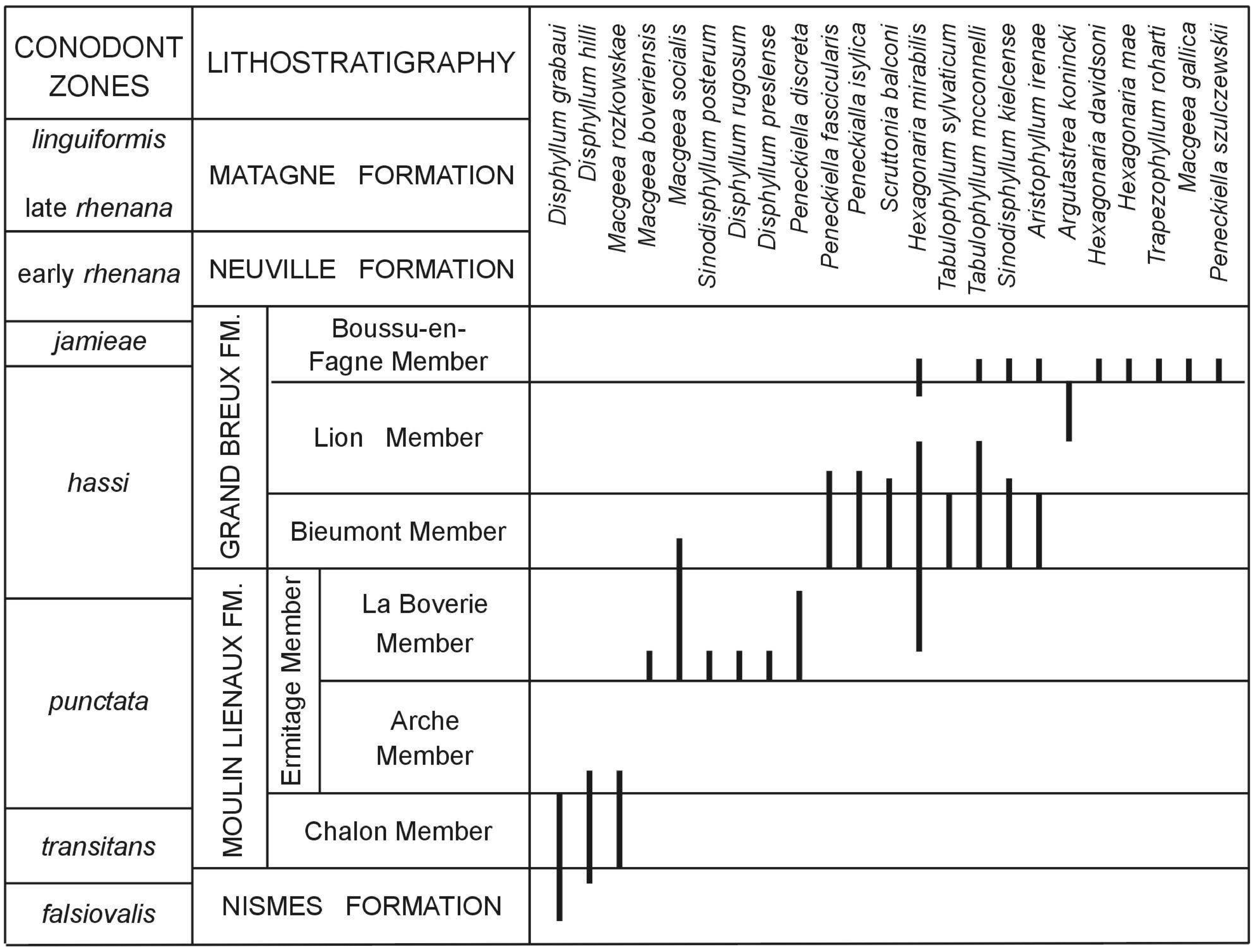

Fig. 10: Stratigraphic distribution of the Early and Middle Frasnian rugose corals from the south side of the Dinant Synclinorium.

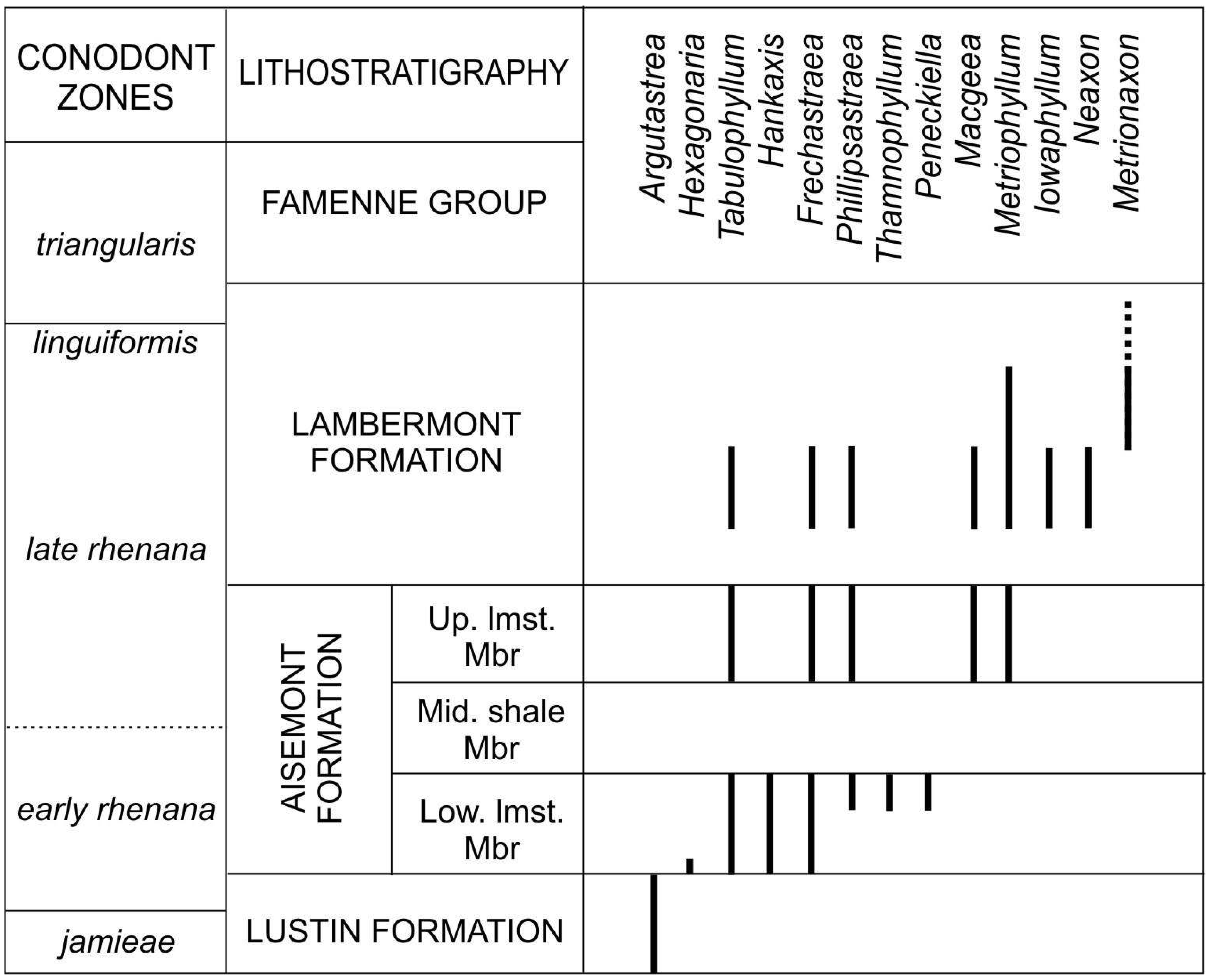

Fig. 11: Stratigraphic distribution of the Late Frasnian rugose corals from the northern side of the Dinant Synclinorium, the Namur Synclinorium and the Vesdre Area. Data from COEN-AUBERT (1974, 1982), COEN et al. (1976), CHEVALIER (1994), PAQUAY (2002), POTY & CHEVALIER (2007), DENAYER & POTY (2010) and COEN-AUBERT (in press).

4. FIELD TRIP ITINERARY

FRIDAY 19TH AUGUST 2011

9:00 Depart from Liège and drive to Trooz
9:30 STOP D1-1 – Prayon outcrop (Middle-Late Frasnian transition, Upper Frasnian biostrome)
10:30 STOP D1-2 - Engis (Upper Frasnian rugose coral biostrome)
13:00 Lunch near Marche-en-Famenne
14:30 STOP D1-3 - Marenne quarry (Eifelian-Givetian platform limestone)
16:00 STOP D1-4 – Fromelennes-Flohimont road section (Givetian platform limestone)
17:30 STOP D1-5 – Givet, landscape
18:30 Diner and overnight in Castel Les Sorbiers, Heer-sur-Meuse.

SATURDAY 20TH AUGUST 2011

9:00 Depart from Heer-sur-Meuse and drive to the Lesse valley
9:30 STOP D2-1 – Resteigne quarry (Eifelian-Givetian platform limestone)
12:30 Lunch in Han-sur-Lesse
14:00 STOP D2-2 – La Boverie quarry (Frasnian reef mounds)
16:30 STOP D2-3 – Tailfer quarry and road section (Frasnian platform limestone)
18:30 Diner and overnight in Castel Les Sorbiers, Heer-sur-Meuse.

SUNDAY 21TH AUGUST 2011

9:00 Depart from Heer-sur-Meuse and drive to the Philippeville-Couvin area
9:30 STOP D3-1 – Les Wayons quarry (Frasnian reef mound)
10:30 STOP D3-2 – Hautmont quarry (Frasnian reef mound)
12:30 Lunch in Couvin
14:00 STOP D3-3 - Arche quarry (Frasnian reef mound)
15:30 STOP D3-4 – Lion quarry (Frasnian reef mound)
16:30 STOP D3-5 – Beauchâteau quarry (Frasnian reef mound)
17:30 end of the field trip FT1, stop possible at the Namur railway station with easy connection to Paris and Brussels or way back to Liège (arriving in the evening).

STOP D1-1 – PRAYON SECTION (VESDRE AREA)

References

LALOUX ET AL. (1996)
RENSONNET (2005)
POTY & CHEVALIER (2007)

Location and access

Disused quarry and outcrops on the corner of the northern flank of the small river Magne and the eastern flank of the Vesdre valley, at Prayon (Trooz). Vesdre tectonic unit. A neighbouring zinc ore processing facility caused an intense alteration of the limestones, leading to a great contrast between fossils and matrix. The ground pollution impacted the biotope where a particular metallophyte flora settled (e.g. *Viola calaminaria*).

Stratigraphical units and age

Lustin Fm and lower part of Aisemont Fm (uppermost middle Frasnian and lowermost upper Frasnian).

Highlights

In the Prayon area, the Lustin Formation is about 45 m thick; it overlies directly the Pepinster Formation (Givetian). The 15 m exposed in the section are composed of limestones showing metre to plurimetre-thick succession of shallowing-upward parasequences. A typical cycle starts with a transgressive stage characterised by rudstone with dense accumulation of reef-builders (bulbous stromatoporoids, fasciculate, massive, and solitary rugosa, along with branched tabulate corals) shifting to a succession of more proximal (mudstone/wackestone with lagoonal fauna and flora) to supratidal facies. A variant interrupts this stacking pattern towards the top where the cycles are characterised by a succession of floatstone/rudstone with *Amphipora* shifting to bioturbated mudstone and thin-bedded limestone with planar laminations interpreted as stromatolites. The subtidal facies were developed under the fair-weather wave base within a shallow carbonate platform occasionally affected by tropical storms. The overall succession evidences a clear shallowing-upward trend

The rudstones consist of parabiostromes that indicate a storm-prone platform. The section contains two autobiostromes. The first one crops out spectacularly along the hillside (35 m^2 plan view), depicting a seafloor dominated by *Disphyllum* sp. and *Alveolites suborbicularis*

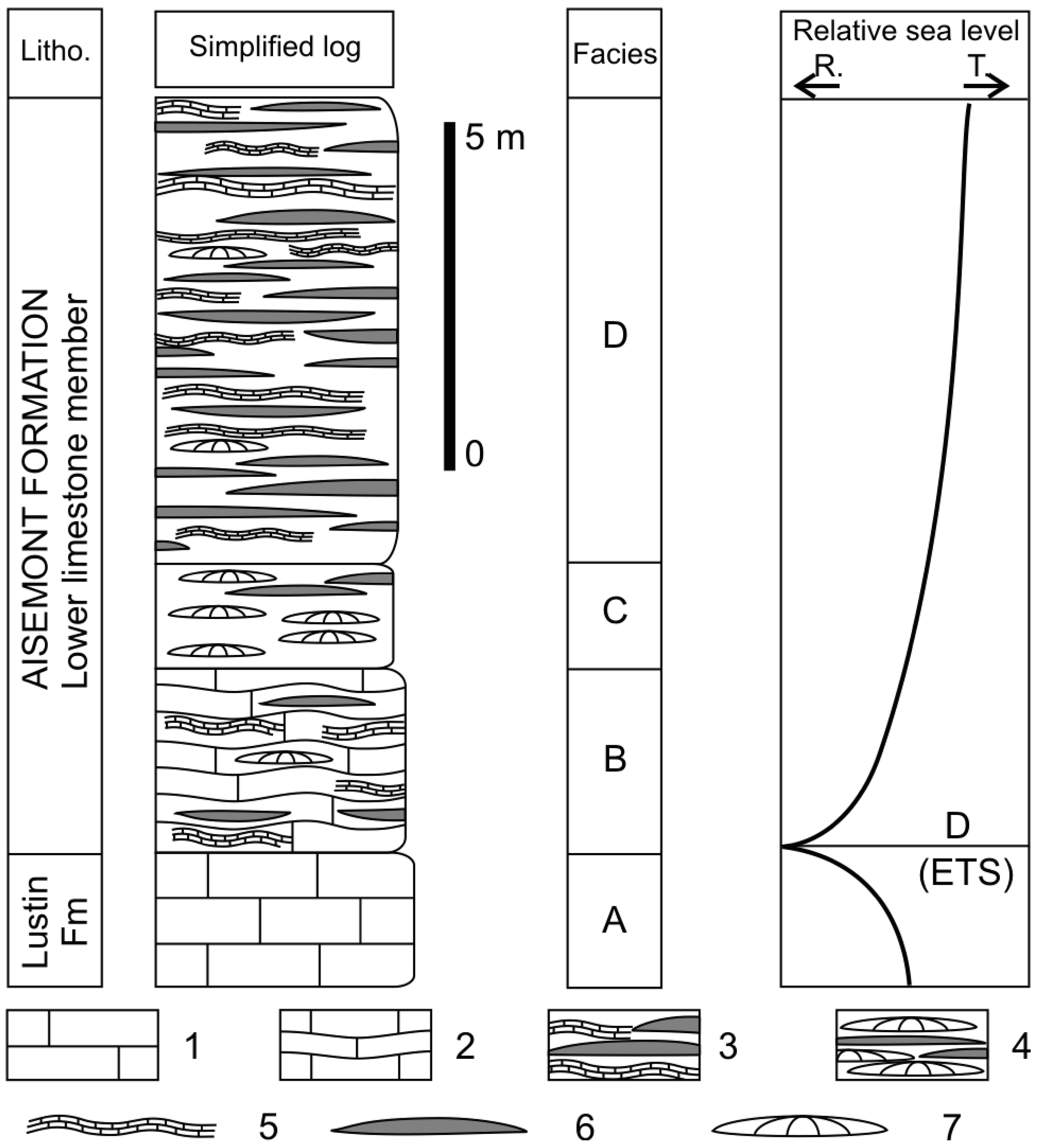

Fig. 12: Log and facies evolution of the lower member of Aisemont at Prayon. A, open-marine coral-stromatoporoid limestone; B, laminar stromatoporoid-coral biostrome; C, *Frechastraea-Alveolites* biostrome; D, laminar *Alveolites*-stromatoporoid biostrome. R and T, regressive and transgressive relative sea level; D (ETS), disconformity (transgressive erosion surface); Litho, lithostratigraphy; Fm, Formation; 1, limestone; 2, slightly nodular limestone with stromatoporoids and corals; 3, *Alveolites*-stromatoporoid biostrome; 4, limestone with corals; 5, laminar stromatoporoid; 6, laminar *Alveolites*; 7, phillipsastreid. (from POTY & CHEVALIER 2007)

colonies. The overturning rate is low with 85% of these colonies being in living position. The exceptional level of conservation is due to a draping 40 cm-thick argillaceous deposit with carbonate nodules. This layer represents a cinerite subsequently transformed in a calcrete-type palaeosoil. Large carbonate nodules found in troughs of the autobiostrome top surface may result from the presence of an arborescent palaeoforest. The second autobiostrome terminates the section and consists of a bindstone made of laminar and tabular stromatoporoids. This latter bed may represent the transition to the "Lagoonal Unit" referenced by COEN-AUBERT & LACROIX (1978).

Some massive laminite bearing beds crop out 20 m further to the north-east, without any connection with the above-described section. This is likely due to transverse faulting and it is reasonable to assume that these beds belong to the "Lagoonal Unit". The upper part of the Lustin Formation with its typical lagoon-type limestones and the Aisemont Formation (Late Frasnian) crop out 250 m further in the same direction along a footpass. The section exposes 3 m of bioclastic limestones rich in corals and stromatoporoids of the top of the Lustin Formation, and the lower limestone member of the Aisemont Formation (10.94 m thick). As in other sections, the Aisemont Formation rests in disconformity on an erosional transgressive surface capping the Lustin Formation. The lower member can be divided into three lithological units which are more or less dolomitized (Fig. 12):

1) The lower unit comprises 2.7 m of decimetre to pluridecimetre-thick bedded limestone (packstone), locally bioturbed and slightly argillaceous, with numerous laminar stromatoporoids and common laminar to tabular *Alveolites* and *Frechastraea*. The latter may be reworked and overturned, but the stromatoporoids and *Alveolites* are in living position, encrusting and stabilizing the substrate. Other components comprise crinoids, fragments of brachiopods, siliceous sponge spicules (pseudomorphosed in calcite), bryozoa and gastropods. The base of the unit is sandy.

2) The middle unit is composed of 1.54 m of massive limestone (packstone), bioturbated, with numerous laminar to tabular *Frechastraea* and common laminar *Alveolites* (both from 20 up to 60 % of the volume of the rock). The latter often bind the sediment. Some *Phillipsastrea* are present. Laminar stromatoporoids are uncommon and only present at the base of this unit. Corals are partly reworked and overturned. The composition of the packstone is similar to that of the lower unit.

3) The upper unit is a 6.7 m-thick biostrome composed of laminar *Alveolites*-stromatoporoid bindstone with some *Frechastraea*. The matrix varies from packstone to mudstone-wackestone, sometimes slightly argillaceous (Fig. 12).

The first unit was deposited in a shallow-water environment, under a moderate influence of the fair-weather wave zone, but subjected to storm waves, as indicated by the reworked fossils. The argillaceous input was low, allowing the growth of stromatoporoids, *Alveolites* and sponges, which stabilized the substrate.

The second unit was deposited in an

environment similar to, but possibly slightly deeper than the previous one as suggested by the general evolution of the section, still subjected to storm waves. *Frechastraea* and *Alveolites* formed a coral meadow. A high sedimentation rate could have prevented the growth of stromatoporoids.

The third biostrome unit formed under or near the storm-wave base and was subjected to input of limestone sediments, maybe triggered by storms.

Therefore the section shows a deepening upwards in the lower member.

Biostratigraphy

The uppermost part of the Lustin Fm is by correlation situated in the Lower *rhenana* conodont zone, as the lower member of the Aisemont Fm (BULTYNCK et al. 2000: GOUWY & BULTYNCK 2000). The lower member corresponds to the first coral assemblage of COEN et al. (1976; "faune 1").

Main faunal component

Lustin Formation:

Corals and stromatoporoids were not precisely determined. *Disphyllum* sp., *Arguastrea* sp., *Tabulophyllum* sp., alveolitids and thamnoporids. Stromatoporoids include massive forms and *Amphipora*.

Lower member of Aisemont Formation:

Numerous *Alveolites tenuissimus*, *A. suborbicularis*, and laminar stromatoporoids. Some *Frechastraea limitata*, *F. pentagona*, and *Phillipsastrea ananas*.

STOP D1-2 – ENGIS "TCHAFORNIS" PARK

References

CHEVALIER (1994)

POTY & CHEVALIER (2007).

Location and access

Disused quarry near the center of Engis, redeveloped as a public park (Tchafornis park). South-Eastern border of the Namur Synclinorium.

Stratigraphical units and age

Lustin Fm and lower part of Aisemont Fm (uppermost middle Frasnian and lowermost upper Frasnian).

Highlights

The quarry exposes the upper part of the Lustin Formation, the lower limestone member and the base of the middle shale member of the Aisemont Formation.

The upper part of Lustin Fm (16,5 m thick) is composed of plurimetre-thick shallowing-upwards parasequences comprising typically from the base to top (Fig. 13): (1) bioclastic limestones (wackestone, packstone) rich in tabulate corals, rugosa and stromatoporoids, and (2) mudstone and stromatolitic boundstone. The latter dominating in the upper part of the section. There are some nodular argillaceous beds corresponding to palaeosols developed from cineritic levels. One of them, 75 cm thick, could be the same than the one observed in the Prayon section. Limestones are more or less dolomitized in the upper half.

The lower member of Aisemont rests in disconformity on an erosional transgressive surface capping the Lustin Fm. It can be divided in four units, from base to top (Fig. 12).

1) A 40 cm-thick unit of more or less argillaceous wackestone to grainstone, strongly bioturbated, rich in siliceous sponge spicules and crinoids, including some layers of calcareous shales. It contains numerous colonies of *Frechastraea* and *Alveolites*, in living position or more or less disturbed.

2) A 3.7 m-thick coral autobiostrome composed mainly by *Frechastraea* and *Alveolites* (Fig. 13). *Frechastraea* colonies are laminar and discoid, from a few centimetres to 70-80 cm in diameter, and from some millimetres to 6-7 cm thick. Most are between 10 and 20 cm in diameter and from 1 to 3 cm in height. It is remarkable that there were not firmly attached to the substrate (a dead colony), but they hug tightly it and rest intimately on it to resist to the turbulence. *Alveolites* are laminar to conical, encrusting the substrate. *Phillipsastrea* colonies are also present, taking the same shape and strategy than *Frechastraea*. There are some laminar stromatoporoids and *Sphaerocodium*.

Colonies of rugose corals are often overturned, being used as substrate for other ones. The density of the frame builder can reach 90% of the rock. The matrix is a shale or a slightly argillaceous packstone.

3) A 1.5 m-thick, more or less dolomitized, argillaceous limestone passing to calcareous shale, with numerous *Frechastraea*, *Alveolites* and *Hankaxis*, and some *Phillipsastrea*, often tipped or overturned. The shape of the colonial rugosa varies from tabular to domal, with margins more or less ragged. Some of the ragged domal colonies show a deflected growth indicating a response to an unidirectional current. *Alveolites* are domal to columnar, from some cm up to 12-15 cm in height.

4) A 35 cm-thick argillaceous diagenetic dolomite with some rugose and tabulate corals. This unit is overlain by the shales of the middle member of the Formation.

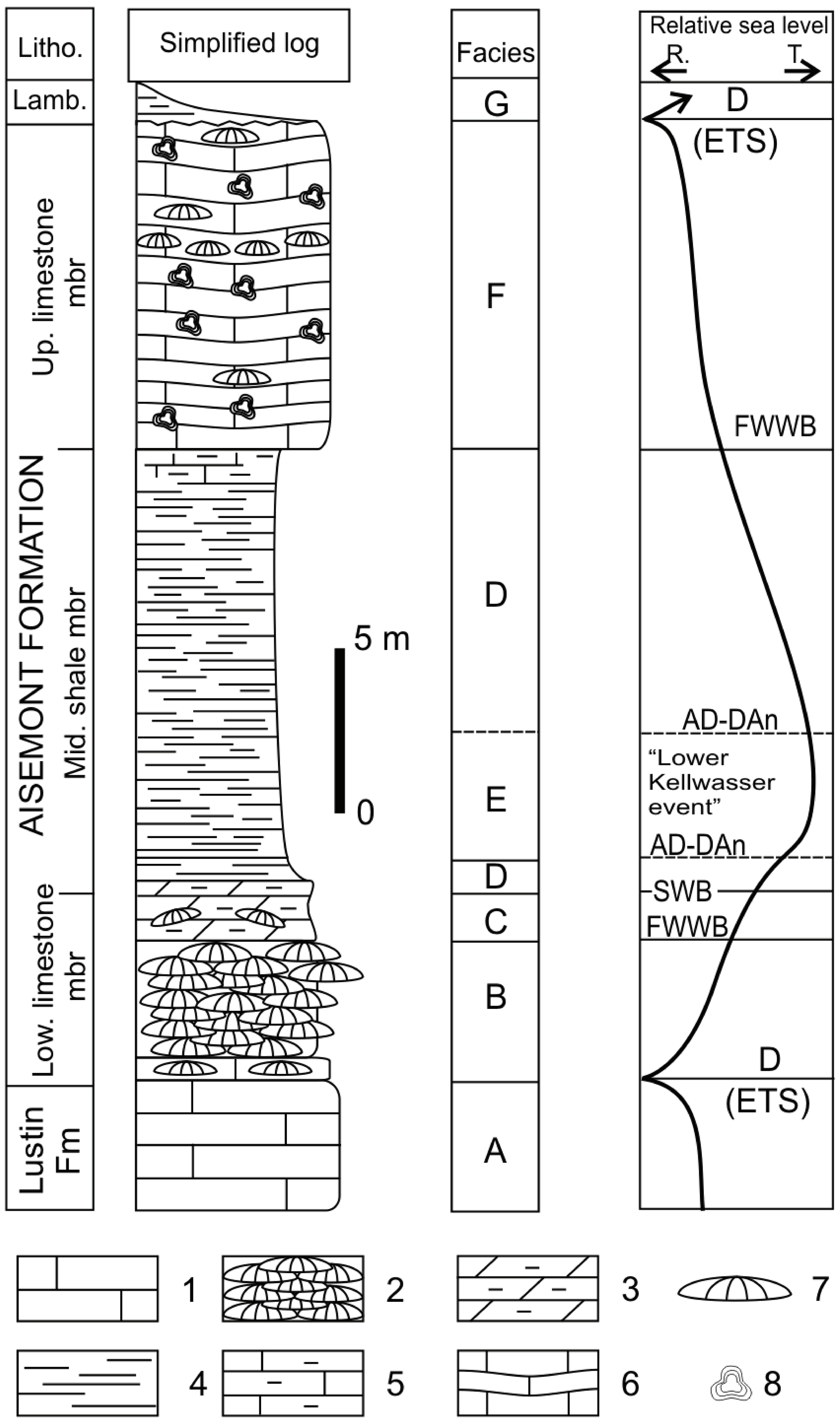

Fig 13: Log of the Aisemont Fm in Engis and La Malieue sections. A, limestone with corals and stromatoporoids (including *Amphipora*) or with stromatolithes, of open marine to restricted environments; B, *Frechastraea-Alveolites* biostrome in the fair-weather wave zone with argillaceous input; C, coral meadow on soft carbonated argillaceous substrate in the storm wave zone; D, brachiopod association in an aerobic-dysaerobic argillaceous environment under the storm wave base; E, dysaerobic-anaerobic argillaceous facies; F, coral-oncolites oipen-marine limestone facies; G, carbonated argillaceous environment; R and T, regressive and transgressive relative sea level; D (ETS), disconformity (erosion transgressive surface); FWWB, fair-weather wave base; AD-DAn, aerobic to dysaerobic-anoxic transition; SWB, storm wave base; 1, limestone; 2, biostrome; 3, dolomitic shale; 4, shale; 5, calcareous shale; 6, argillaceous limestone; 7, colonial coral; 8, oncolite; Litho, lithostratigraphy; Lamb, Lambermont Formation. (from POTY & CHEVALIER, 2007)

The first unit is considered as being deposited within the fair-weather wave zone, with episodes of clay deposition. The second, biostromal unit developed in an argillaceous environment with uncommon limestone inputs, in the fair-weather wave zone and commonly disturbed by storm waves. That environment usually does not allow the growth of stromatoporoids. The third unit deposited in an environment probably below the fair-weather wave zone, but subjected to bottom currents and affected by storm waves. The relatively high rate of carbonated argillaceous sedimentation affected the coral growth and prevented the growth of stromatoporoids and bryozoans. The last unit corresponds to a similar, but slightly deeper than the previous one. Therefore, the evolution of the four units corresponds to a deepening upwards, as in the Prayon section, but more proximal.

Fig. 14: Photography of the *Frechastraea* autobisotrome (unit B on Fig. 13) of the lower member of the Aisemont Fm in the Engis "Les Tchafornis" park.

Biostratigraphy

Both the upper part of the Lustin Fm and the lower member of the Aisemont Fm are situated in the Lower *rhenana* conodont zone (BULTYNCK et al. 2000: GOUWY & BULTYNCK 2000). The lower member corresponds to the first coral assemblage of COEN et al. (1976; "first biostrome with *Phillipsastrea*").

Main faunal component

Lustin Formation:

Corals and stromatoporoids were not precisely determined. *Disphyllum* sp., *Arguastrea* sp. and *Alveolites suborbicularis*. Stromatoporoids include massive forms and *Amphipora*.

Lower member of Aisemont Formation:

Frechastraea limitata (the most common), *F. pentagon*a, *Phillipsastrea ananas*, *Hankaxis insignis*, uncommon *Tabulophyllum* sp. and *Peneckiella* sp., *Alveolites tenuissimus*, *A. suborbicularis*, *Aulopora serpens*, *A. repens*, uncommon fragments of *Thamnopora* sp., *Scoliopora* sp. and laminar stromatoporoids.

STOP D1-3 – MARENNE QUARRY

References
BARCHY et al. (2004)
GODEFROID & MOTTEQUIN (2005)
MABILLE et al. (2008

Location and access
Quarry near Marche-en-Famenne, South-Eastern border of the Dinant Synclinorium.

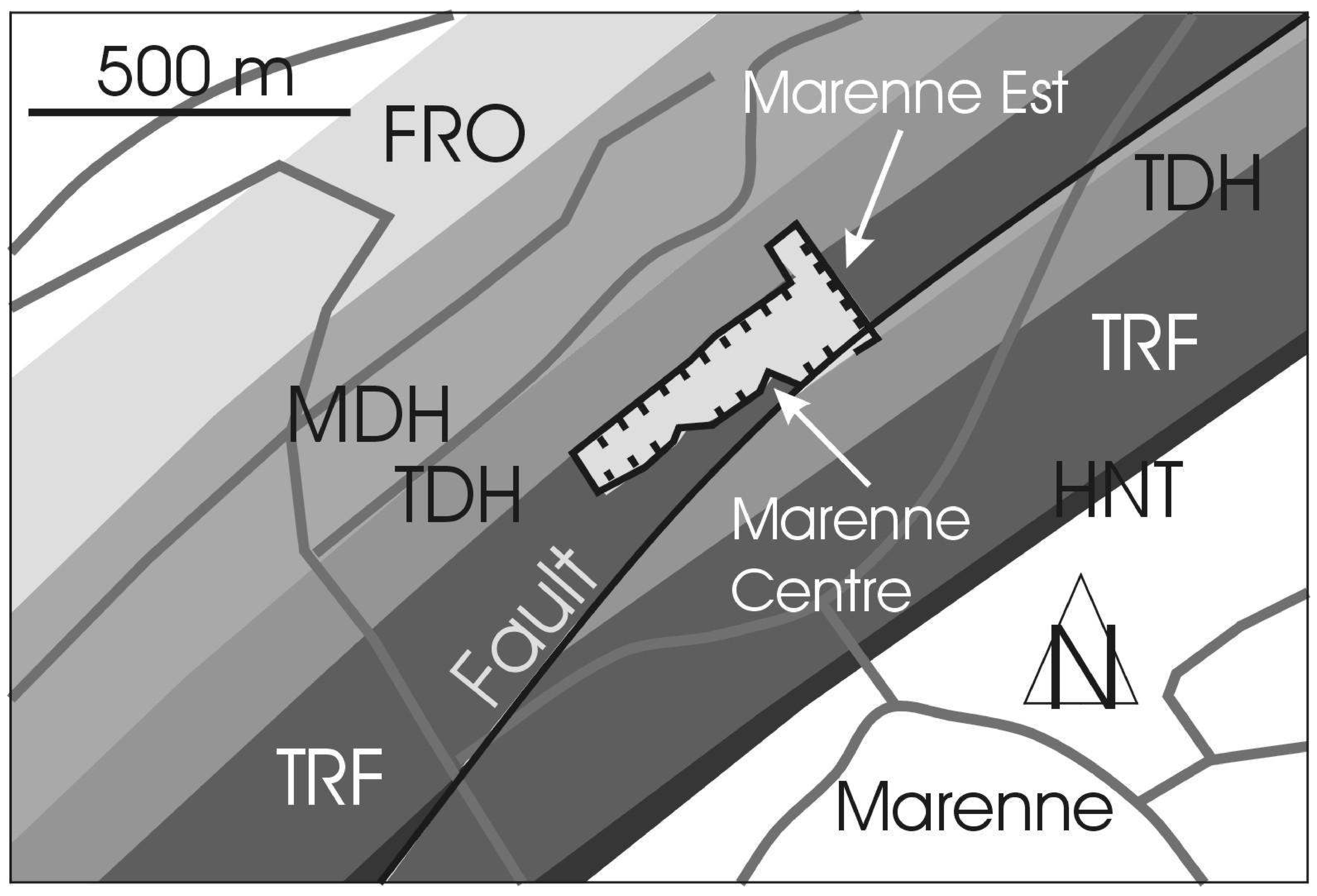

Fig. 15: Schematic geological map from the Marenne area and location of sections (modified from BARCHY et al 2004).

Stratigraphical units and age
Hanonet, Trois-Fontaines and Terres d'Haurs formations. (Givetian).

Highlights
This quarry exposes a remarkable succession of strata from the upper Hanonet, Trois-Fontaines and base of the Terres d'Haurs formations that were investigated by BARCHY et al. (2004), MABILLE et al. (2008) and GODEFROID & MOTTEQUIN (2005). The section situated in the eastern part of the quarry (Marenne Est on Fig. 15) exposes a mixed carbonate-siliciclastic succession replacing the classical base of the Trois-Fontaines Formation. Whereas the section situated in the middle part of the quarry (Marenne Centre on Fig. 15) exposes a reefal lens. The sedimentological model proposed for the Hanonet-Trois-Fontaines transition strata is a ramp. In this area, terrigenous inputs were particularly important. The mid-ramp is more or less influenced by storm events. The inner ramp is characterized by the development of the reefal lens and by peloidal limestone. The upper part of Trois-Fontaines Formation is depicted by a back-reef model which is mainly dominated by lagoons. However, intermittent agitation and non-restricted settings allow the local development and the reworking of branching organisms. The last model proposed concerns the Terres d'Haurs Formation and corresponds to a ramp profile with the development of shoals. Those shoals locally protect semi-restricted lagoons. Algal mats are also observed.

Biostratigraphy
Early Givetian. Different species of conodonts have been found by COEN et al. (1974) in the more or less silty limestones from the lower part of the Trois-Fontaines Formation. Among them, *Icriodus obliquimarginatus* and *Bipennatus bipennatus* morphotype alpha indicate a rather low position in the Givetian.

Main faunal component
The rugose coral fauna has been investigated in detail in the Trois-Fontaines, Terres d'Haurs and Mont d'Haurs Formations exposed to the north of the Marenne Fault. However, some specimens come also from the Terres d'Haurs and Mont d'Haurs Formations occurring to the south of the Marenne Fault.

Trois-Fontaines Formation: In the lower part of the lithostratigraphic unit, *Columnaria intermedia*, *Beugniesastraea kunthi* and *Sociophyllum elongatum* are present in a reefal lens cropping out along the southwest wall of the quarry, laterally to the upper part of more or less silty limestones. *Disphyllum oekentorpi* can be found in a bed rich in bushes of *Scoliopora*, lying 26 m below the top of the Trois-Fontaines Formation.

Terres d'Haurs Formation: The lithostratigraphic unit is about 90 m thick. It starts with coarsely crinoidal or argillaceous limestones often rich in tabulate corals, colonies of *Argutastrea quadrigemina* and solitary coralla of *Temnophyllum wellinense*. A bed with *Disphyllum mcleani* occurs about 30 m above the base of the Terres d'Haurs Formation and there are several levels with *Argutastrea quadrigemina* up to 43 m above the same boundary. The last of these colonies are accompanied by a few specimens of *Pseudozaphrentis zamkowae* and *Temnophyllum imperfectum*. In the upper 9 m of the Terres d'Haurs Formation, the rugose coral fauna is similar to that present in the overlying Mont d'Haurs Formation and is represented by *T. imperfectum*, *T. majus*, *Spinophyllum spongiosum* and *S. blacourti*.

Mont d'Haurs Formation: To the north of the Marenne Fault, the lower part of the Mont d'Haurs Formation is represented by 34 m of more or less argillaceous and bioclastic limestones. These deposits are exposed in the upper excavation and often contain rugose and tabulate corals as well as massive and laminar stromatoporoids. At 8 m above the base of the Mont d'Haurs Formation, there is a remarkable level which is composed of about 7 m of shales and argillaceous limestones full of cylindrical corallites of *Disphyllum semenoffi* and *Thamnophyllum*, large specimens of *Cystiphylloides* and smaller solitary coralla of *Spinophyllum blacourti* and *S. spongiosum*. This marker level crops also out to the south of the Marenne Fault and allows to validate the correlation between the two sides of the Marenne Fault recognized by BARCHY et al. (2004). The additional fauna of the Mont d'Haurs Formation consists of *Sociophyllum isactis*, *S. wedekindi*, *Temnophyllum imperfectum*, *Acanthophyllum simplex* and *Grypophyllum denckmanni*.

STOP D1-4 – FROMELENNES–FLOHIMONT ROAD SECTION

References

COEN & COEN-AUBERT (1971)
TSIEN (1967, 1970, 1971, 1974, 1977b, 1979)
BOULVAIN ET AL. (2009)
HUBERT (2009)

Location and access

Section along the road from Fromelennes to Flohimont, near Givet.

Stratigraphical units and age

Trois-Fontaines Fm (Givetian), Terres d'Haurs Fm. (Givetian), Mont d'Haurs Fm. (Givetian), Fromelennes Fm. (Givetian), Nismes Fm. (Frasnian).

Highlights

This road section encompasses the entire Givet group, from the base of the Trois-Fontaines Formation up to the top of the Fromelennes Fm. (Fig. 17). The base of the Trois-Fontaines Fm. shows proximal tempestites with lithoclasts, directly topped by several paleosols (Fig. 18), indicating a sea-level drop (this drop was responsible for reef progradation, for example in Resteigne –see STOP D2-1). No Trois-Fontaines basal reef developed in this section. After the paleosols episode, lagoonal deposits end the Trois-Fontaines Fm.

After lagoon filling, the sedimentation started again during a new marine transgression. The Terres d'Haurs Fm. is characterized by argillaceous limestone deposited below the storm wave zone. The base of the Mont d'Haurs Formation corresponds then to the first massive bed with stromatoporoids and corals (Fig. 16). It is interpreted as a debris flow reworking material coming from a reef barrier located northwards from the outcrop zone. The Mont d'Haurs Fm. is divided in two parts (Fig. 17); the lower unit shows relatively monotonous argillaceous limestone with crinoids, brachiopods, issinellids and gastropods locally interrupted by debris flows. The upper part is characterized by purer limestones with peloids, oolithes, calcispherids and palaeosiphonocladales (BOULVAIN et al. 1995). Some beds rich in massive and dendroid stromatoporoids, branching tabulate and solitary or massive rugose corals are observed in the upper unit.

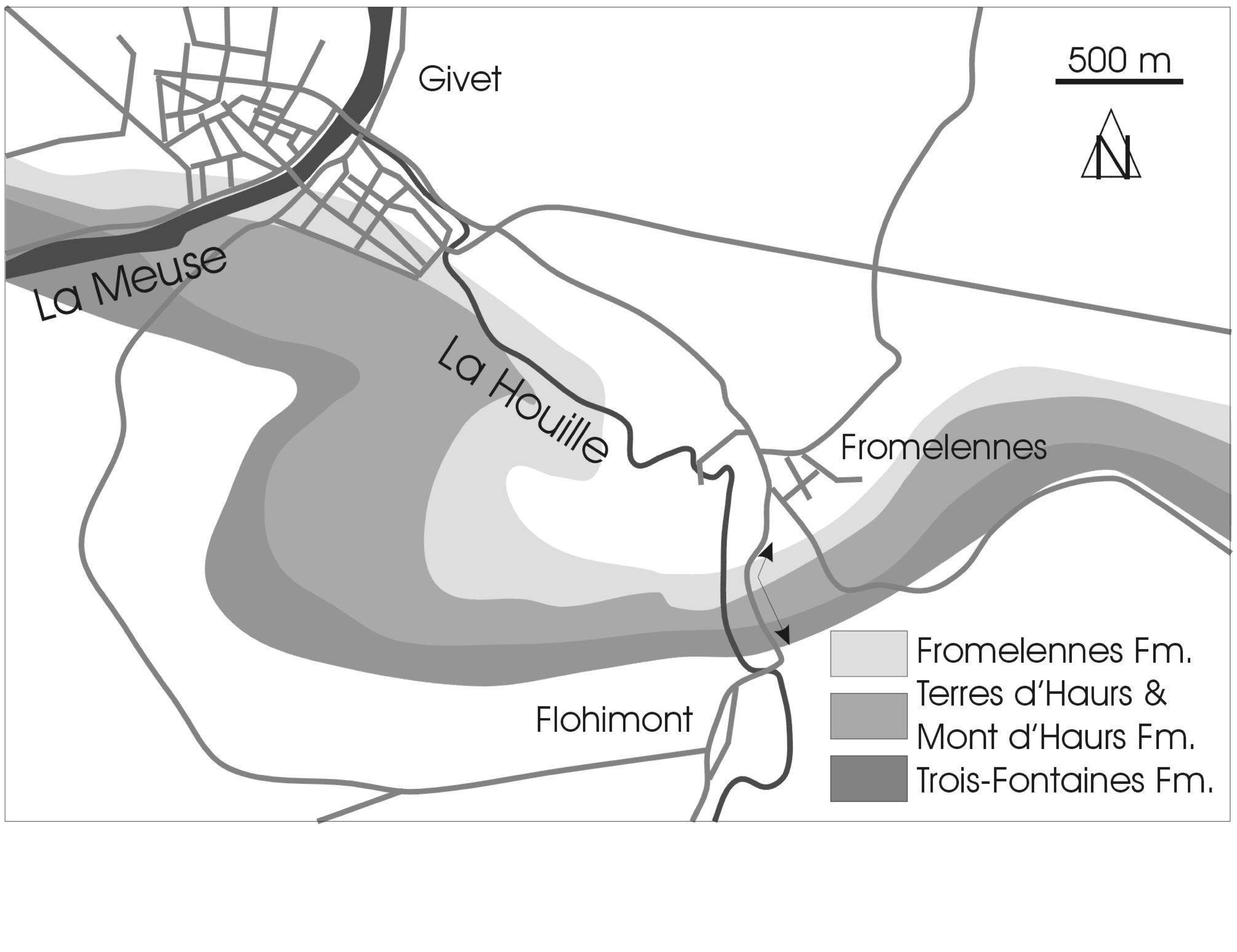

Fig. 16: Schematic geological map of the Givet area. Arrowed: the Fromelennes-Flohimont road section (modified from MANSY et al 2003).

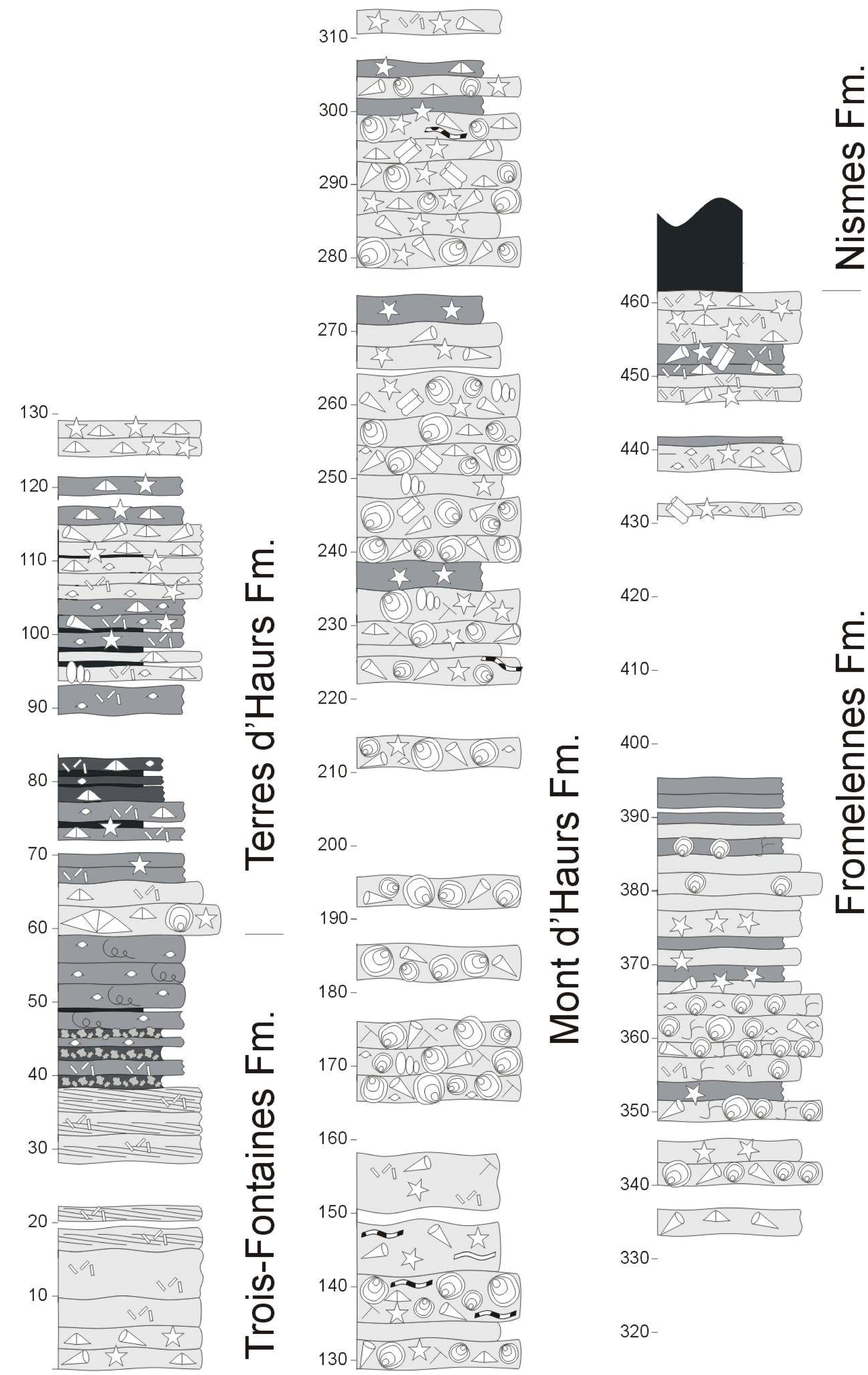

Fig. 17: Logs from the Givetian in Givet (Fromelennes-Flohimont) road section. Explanation of symbols, see Fig. 32. (Boulvain et al 2009).

The Fromelennes Fm. starts with the Flohimont Member, consisting in argillaceous limestone beds with brachiopods. Then the Moulin Boreux Member is characterized by fine-grained limestones with dendroid stromatoporoids and finally, the Fort Hulobiet Member shows argillaceous limestones and shales (Fig. 17). The most calcareous part of the Fromelennes

Formation, the Moulin Boreux Member, shows typical cyclic facies successions:

- a basal unit with dendroid stromatoporoids (*Amphipora, Stachyodes*), bulbous stromatoporoids, branching tabulate corals and sporadic rugose corals; all these organisms being often coated by codiaceae (*Bevocastria*);
- a thinner middle unit comprised of bioturbated limestones, with poor macrofauna but abundant ostracods (leperditids), palaeosiphonocladales (*Kamaena* and *Triangulinella*), characeae (*Umbella*), calcispherids, gastropods, peloids and fragments of cyanobacterial coatings;
- an upper unit showing algal-microbial mats, and locally paleosols.

Fig. 18: Paleosol in the Trois-Fontaines Formation in Givet (Fromelennes-Flohimont road section).

The shales and nodular shales of the Nismes Formation have a sharp contact with the top of the Givetian limestone in nearly all the sedimentation area. This shale, rich in atrypids and spiriferids brachiopods was deposited below the wave base.

Biostratigraphy

Givetian and base of the Frasnian. The conodonts of the Fromelennes section have been revised by BULTYNCK et al. (2001), close to the boundary between the Mont d'Haurs and Fromelennes Formations. The uppermost part of the Mont d'Haurs Formation belongs to the *Polygnathus timorensis* Zone whereas the lowest part of the Fromelennes Formation is assigned to the *P. rhenanus/P. varcus* Zone. Rare specimens of *P. ansatus* occur 9 m above the base of the lithostratigraphic unit indicating the *P. ansatus* Zone. Recently, the base of the *P. rhenanus/P. varcus* Zone has been selected as the base of the Middle Givetian. But according to the graphic correlations made by GOUWY & BULTYNCK (2003), the base of the *P. rhenanus/P. varcus* Zone is projected 50 m above the base of the Mont d'Haurs Formation.

At the base of the Nismes Formation, COEN & COEN-AUBERT (1971) and BULTYNCK et al. (1988) mentioned the successive occurrence of *Ancyrodella binodosa* and *A. rotundiloba* which is characteristic for the base of the Frasnian.

Fig. 19: Coral- and stromatoporoid-rich bed in the Mont d'Haurs Formation. It is interpreted as a debris flow coming from a reef barrier located northwards. Fromelennes-Flohimont road section.

Main faunal component

Top of the Mont d'Haurs Formation:
Wapitiphyllum laxum and fragmentary coralla of *Temnophyllum delmeri*.
Base of the Flohimont Member:
T. delmeri.

STOP D1-5 – GIVET LANDSCAPE

Location and access

Landscape from the right bench of the Meuse River.

Stratigraphical units and age

Givet Group (Givetian)

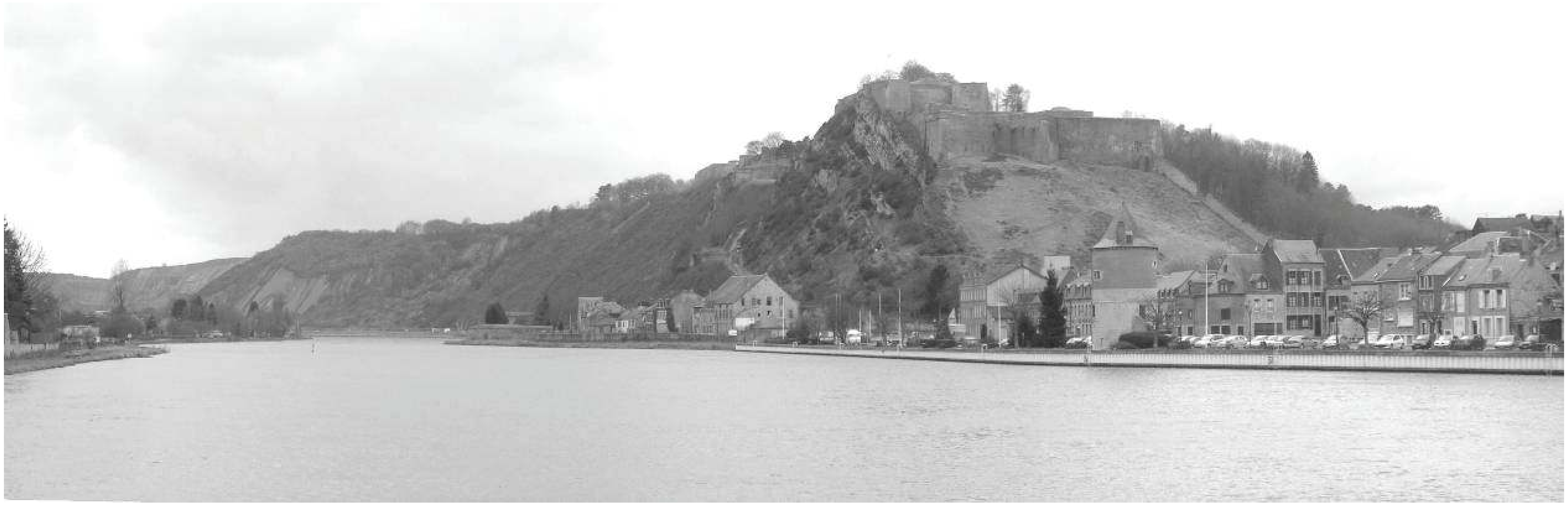

Fig. 20: View of the Givet Group from the right bench of the Meuse River.

STOP D2-1– RESTEIGNE QUARRY

References

COEN-AUBERT (1977, 2003)
PREAT et al. (1984)
COEN-AUBERT et al. (1986)
CASIER & PREAT (1990, 1991)
BOULVAIN et al. (2009)

Location and access

Disused quarry near the Lesse River in Resteigne. Southern border of the Dinant Synclinorium.

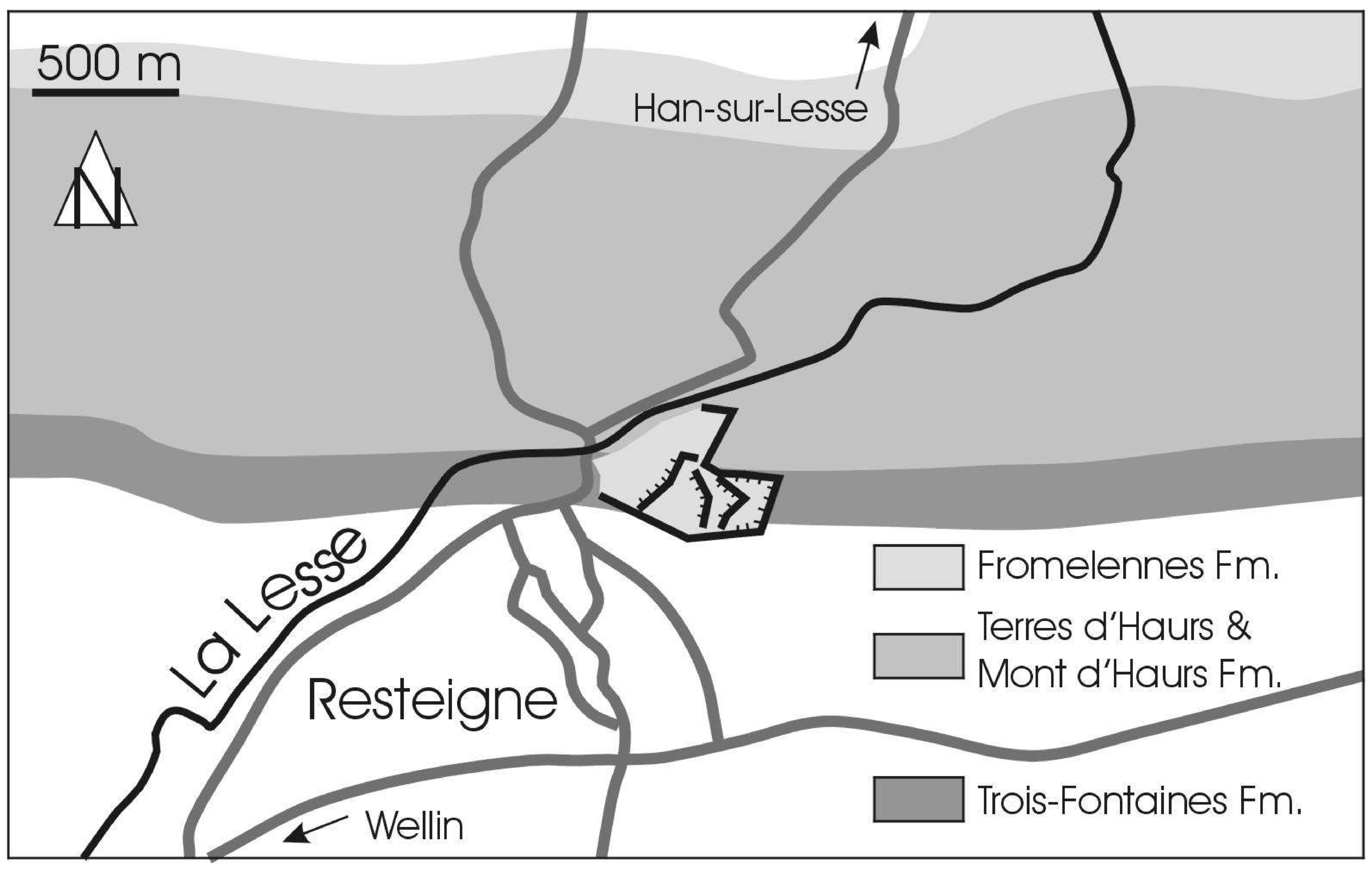

Fig. 21: Schematic geological map of Resteigne.

Stratigraphical units and age

Hanonet Fm. (Givetian), Tois-Fontaines Fm (Givetian), Terres d'Haurs Fm. (Givetian).

Highlights

This quarry shows the upper part of the Hanonet Fm, the Trois-Fontaines Fm. and the lower part of the Terre d'Haurs Fm. (Figs 22 & 24). The argillaceous limestone from the Hanonet Formation passes upwards into purer limestones, forming the base of the Trois-Fontaines Formation (Fig. 23).

Fig. 22: Base of the Terres d'Haurs Formation in Resteigne. Isolated colonies of massive rugose corals (*A. quadrigemina*).

Fig. 23: The base of the Trois-Fontaines Formation (arrowed) in the Resteigne quarry.

The first meters of the Trois-Fontaines Fm. are storm deposits rich in crinoids, acting as a sole for reef initiation. Over the crinoidal sole grew lenses rich in lamellar and tabular stromatoporoids, solitary and fasciculate rugose corals, branching and massive tabulate corals. Progressively, massive stromatoporoids became more abundant, associated with some rugose and tabulate corals and brachiopods. Multiple coatings associating stromatoporoids, corals, cyanobacteria (*Girvanella, Bevocastria, Sphaerocodium*) are observed. The community became richer in calcareous algae as palaeosiphonocladales (mainly *Issinella*), phylloids (*Resteignella*) and dasycladales (*Givetianella*) (MAMET & PRÉAT 1986). Peloids are abundant. Above the reef, dm-thick accumulations of brachiopods or gastropods ("coquina beds") with early marine cement are observed. These beds are storm deposits left on the shore.

After progradation of the reef barrier southward, a lagoonal complex developed: it constitutes the upper half of the Trois-Fontaines Formation. This lagoonal complex is characterized by fine grained sediments with a relatively low diversified fauna: leperditid ostracods (CASIER & PRÉAT 1991), gastropods, burrowing organisms, and a flora dominated by calcispherids and palaeosiphonocladales (PRÉAT & BOULVAIN, 1982).

After lagoon filling and final development of tidal flat complexes with algal-microbial mats, corresponding to the top of the Trois-Fontaines Fm., the sedimentation started again during a new marine transgression. The Terres d'Haurs Fm. is characterized by argillaceous limestone with horizontal burrows, locally rich in crinoids, brachiopods, gastropods and coral patch reefs. The base of the formation is underlined by a metre-thick lenticular reef with massive rugose (*Argutastrea*) or tabulate corals (*Thamnopora, Pachyfavosites*, …) (PREAT et al. 1984; COEN-AUBERT 1977, 2003; COEN-AUBERT et al. 1986) (Fig. 22).

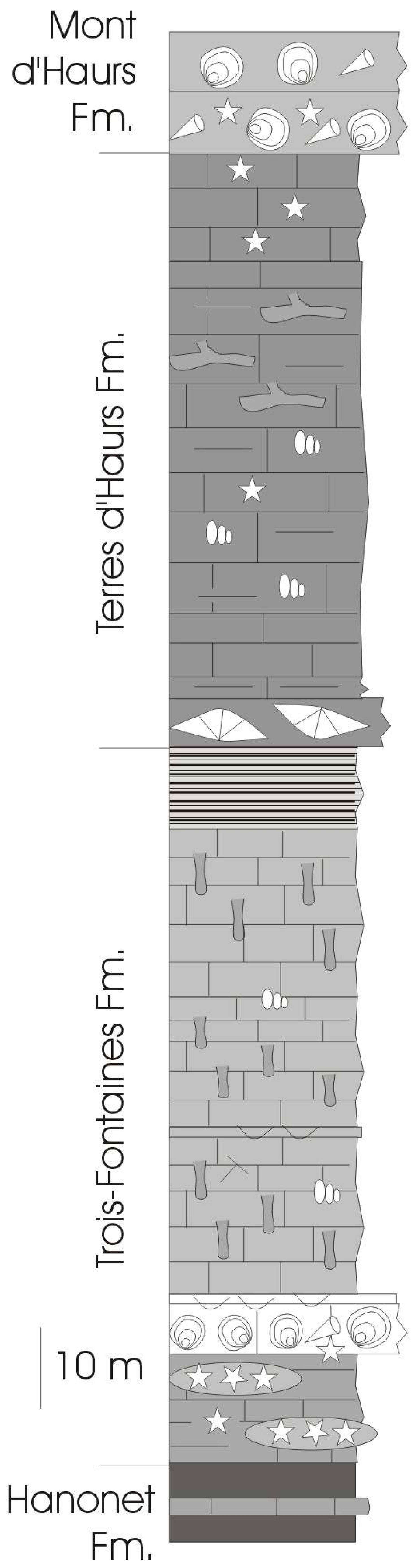

Fig. 24: Schematic log of the Resteigne quarry. Explanation of symbols, see Fig. 32.

Biostratigraphy
Top of the Eifelian and Lower Givetian.

Main faunal components

From the top of the Jemelle Fm. to the base of the Mont d'Haurs Fm., there is a succession of different rugose coral faunas in the Resteigne quarry which is also the type locality for *Sociophyllum birenheidi*, *Columnaria intermedia* and *Breviphrentis martinae*.

Hanonet Formation: At the base of the lithostratigraphic unit occur *Breviphrentis martinae* and *Rhytidolasma dahlemense* in association with *Acanthophyllum heterophyllum*, *A. vermiculare* and *A. tortum*. The latter two species of *Acanthophyllum* are also present in the middle part of the Hanonet Fm. together with *Aristophyllum luetti* and *Stringophyllum acanthicum*.

The tabulate corals have not been studied in detail but show the same assemblage as usual in these argillaceous limestones: alveolitids and coenitids in lamellae (some of them with calices on both sides of the colony, of *Platyaxum* type), globular irregular colonies of *Favosites goldfussi*, in place numerous fragments of branching *Thamnopora*, auloporids like *Remesia crispa*, etc.

Trois-Fontaines Formation: At the base of the lithostratigraphic unit, there are coarsely crinoidal limestones with reefal lenses rich in corals and stromatoporoids. The colonial forms of this level are represented by *Columnaria intermedia*, *Beugniesastraea kunthi*, *B. parvistella*, *Sociophyllum elongatum*, *S. torosum* and *Thamnophyllum occlusum* with a few small corallites of *Coenophyllum* *groessensi*. The overlying biostrome with massive stromatoporoids below the stringocephalid coquina contains *Sociophyllum birenheidi* with a few specimens of *S. torosum*, *Beugniesastraea kunthi*, *Keriophyllum maillieuxi* and *Lyrielasma* sp. A described by COEN-AUBERT (1990). In the upper part of the lagoonal limestones of the Trois-Fontaines Fm. are observed locally *Disphyllum oekentorpi* and *Argutastrea quadrigemina*.

In the crinoidal limestones of the lower part of the Formation, the same forms as in the underlying strata can be observed, including branchs of *Thamnopora reticulata*. The levels rich in stringocephalids contain also new forms like squamulate thamnoporids (of the *Thamnopora germanica* type) and fragments of *Hillaepora spicata* – both species occur frequently in the overlying lagoonal limestones, with strata very rich in *Hillaepora spicata*. Colonies of *Pachyfavosites polymorphus*, already present in the first biostrome, are more frequent in the upper part of the unit, and abundant in the biostrome marking the boundary with the Terres d'Haurs Formation.

Terres d'Haurs Formation: The lithostratigraphic unit starts with a coralliferous biostrome with numerous colonies of *A. quadrigemina* associated with a few coralla of *Temnophyllum wellinense*. A bed rich in *Disphyllum mcleani* is present 22.5 m above the base of the Terres d'Haurs Fm. Higher are still found first a few specimens of *Argutastrea quadrigemina* and then several coralla of *Pseudozaphrentis zamkowae*. At the top of the Terres d'Haurs Fm. appear *Spinophyllum spongiosum* and *Acanthophyllum simplex*.

In the biostrome of the base, around the massive colonies of *Argutastrea quadrigemina*, many specimens of *Pachyfavosites polymorphus* with branches of *Thamnopora cervicornis* and *Hillaepora spicata*. The same forms can be observed sporadically in the overlying beds, with some alveolitids and scolioporids.

Base of the Mont d'Haurs Formation: *A. simplex*, *Grypophyllum denckmanni* and *Sociophyllum wedekindi*.

The tabulate coral fauna shows rather higher diversity, with thamnoporids (with large squamulate corallites), alveolitids, scolioporids, heliolitids, etc.

STOP D2-2 – LA BOVERIE QUARRY

References

LECOMPTE (1956)
TSIEN (1970, 1978)
BOULVAIN et al. (2005)
BOULVAIN & COEN-AUBERT (2006)
BOULVAIN (2007)
DA SILVA et al. (in press b)

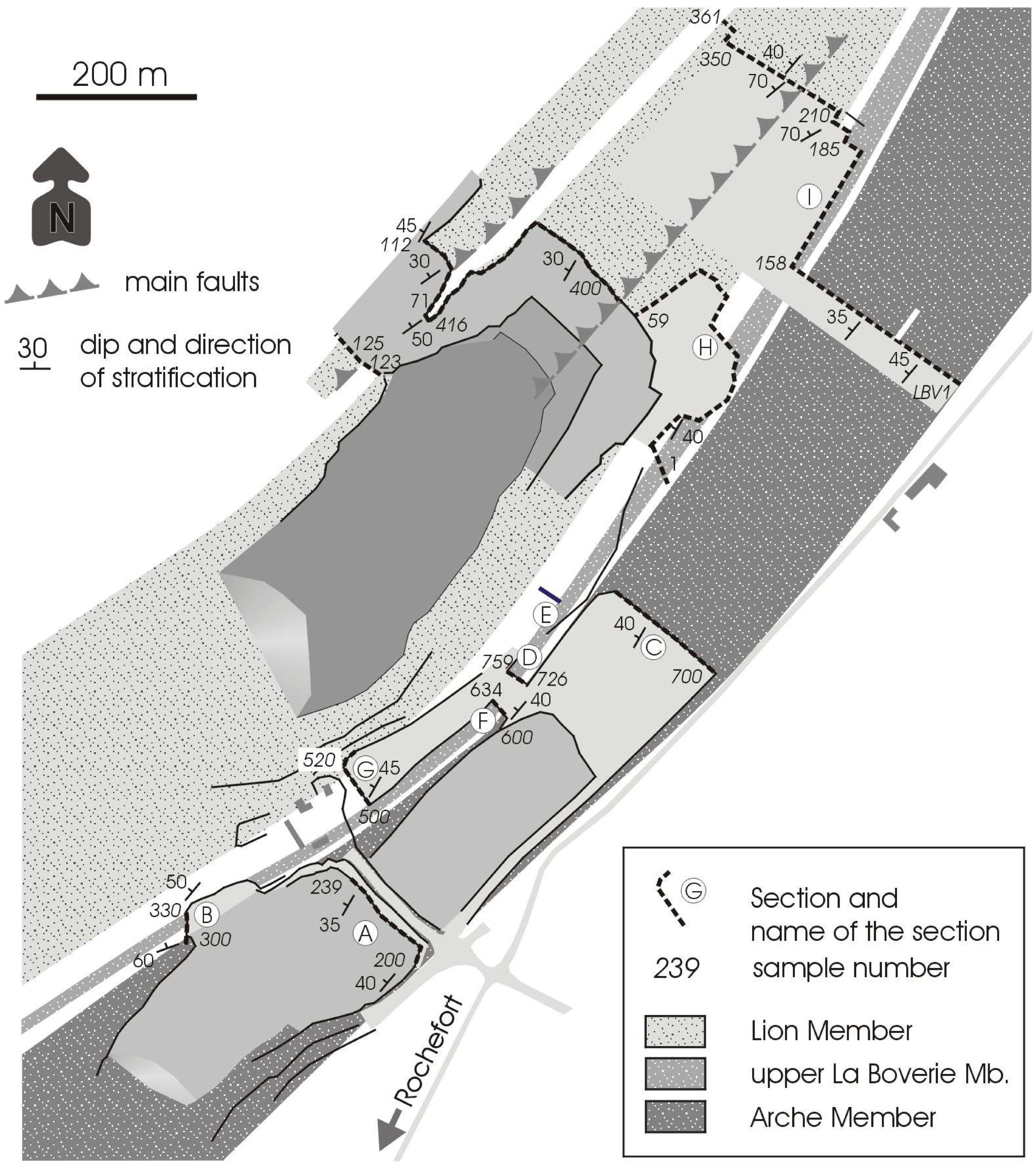

Fig. 25: Geology of the La Boverie quarry and studied sections (A-I).

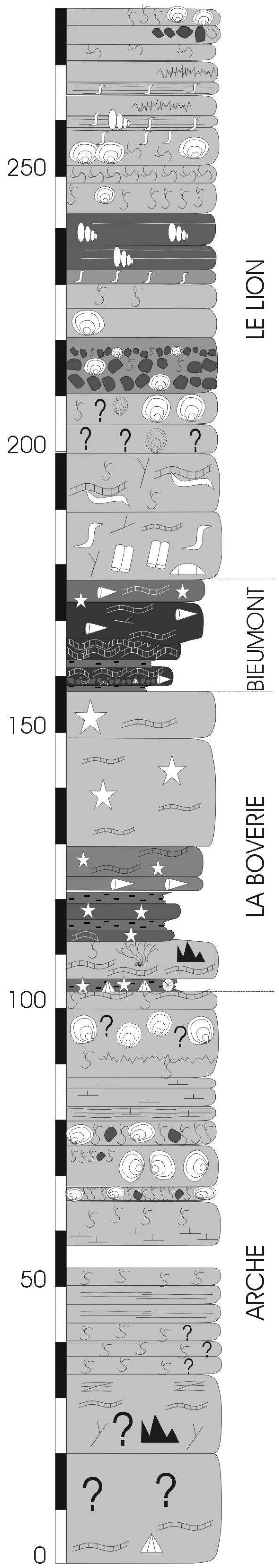

Fig. 26: Log of section I (see Fig. 25 for location) from the La Boverie quarry (DA SILVA et al. in press, b).

Location and access
Active quarry along the road from Marche to Rochefort, near Jemelle. Southern border of the Dinant Synclinorium.

Stratigraphical units and age
Moulin Liénaux Fm., Grands Breux Fm., Neuville Fm. (Frasnian).

Highlights
La Boverie quarry is located at the south-eastern edge of the Dinant Synclinorium, on the Gerni plateau. From the ~3,5 km large Arche and Lion mounds, the La Boverie quarry intersects about 1.1 km sediment, mainly corresponding to the central part of the buildups The series of buildups exposed in the quarry is nearly 220 m thick (Figs 24 & 25).

Roughly, the two generations of buildup began with grey or pinkish floatstone containing stromatactis, corals and stromatoporoids (M3). After about 40 to 70 m of this facies forming the bulk of the mounds, the grey algal M4 facies began to develop, including microbial bindstone or bafflestone lenses (M5), which tend to coalesce upwards. More restricted facies (M6-7) developed in the central part of the buildups. Microbioclastic packstones (M9) mainly occur in off-mound facies. In this facies, the influence of reefs on the sediment budget remains relatively low. On the other hand, the lithoclastic grainstones and bioclastic rudstones are facies where extensive supply of reefal debris is significant (M10-11). This reefal input consists of bioclastic-lithoclastic sediment reworked from the mound and deposited by debris flows showing decimetre-deep basal erosion structures (HUMBLET & BOULVAIN 2001).

The top of the Arche Member is particularly well-exposed in this quarry. It consists of grey massive limestone with microbial mats and/or dendroid stromatoporoids (M5-6). This shallow facies forms usually the upper part of the Arche and Lion Members. Above this and with a sharp contact, there is dark shale including bioclastic lenses or beds (lower part of the La Boverie Member). This implies the collapse of the Arche mound carbonate factory with the deposition of relatively deep argillaceous sediments. Very locally, carbonate production is maintained, but shows a severe facies retrogradation and the replacement of a microbial mat-dendroid stromatoporoid assemblage by a sponge-coral-crinoid assemblage locally red colored by iron bacteria. Later, the carbonate accumulation increases and the shale is replaced upwards by argillaceous bioclastic limestones. Growing centres remain localized. This unit corresponds to the lower part of the intermediate buildup. The next unit is laterally homogeneous. It consists of a massive, generally light grey limestone rich in dendroid or massive stromatoporoid, tabulate corals and microbial mats. This is a shallow facies, close to that from the top of the Arche Member. This rapid transition and the lateral progradation of a relatively shallow facies over deeper bioclastic sediments or mound facies are obvious in all sections. It suggests a sudden restart of the shallow-water carbonate factory, probably related to a sea-level fall. This second unit corresponds to the upper part of the La Boverie Member. Hardgrounds are locally developed on the top of the buildup.

The transition to the Bieumont and Lion Members resembles that between the Arche and La Boverie Members. It is mainly characterized by the collapse of the carbonate factory with widespread deposition of shale and bioclastic limestone lenses, except in some local areas where buildup development keeps on. These isolated "survival" mounds show again a return to the deeper sponge-coral-crinoid assemblage (M2).

The more argillaceous facies which follow are ascribed to the Bieumont Member. The relatively thick Lion Member overlies these argillaceous-bioclastic facies. Above this mound, there are more or less nodular calcareous shale belonging to the Boussu-en-Fagne Member, which is succeeded by the Neuville Formation.

Biostratigraphy
Mainly Middle Frasnian.

Main faunal component

The rugose coral fauna is very rich and highly diversified in the La Boverie quarry which is also the type locality for *Macgeea boveriensis* and *Peneckiella discreta*.

Chalon Member and base of the Arche Member: *Macgeea rozkowskae*, *Disphyllum hilli* and *D. grabaui*.

La Boverie Member: Solitary coralla of *Macgeea boveriensis*, *M. socialis* and *Sinodisphyllum posterum* are present at the base of the lithostratigraphic unit together with a few colonies of *Disphyllum rugosum*, *D. preslense* and *Peneckiella discreta*. *Hexagonaria mirabilis* appears rather low in the member. Accumulations of thickets of *Peneckiella discreta* are locally much developed just below the small mound which characterizes the top of La Boverie Member.

Bieumont Member: *Hexagonaria mirabilis*, *Scruttonia balconi*, *Peneckiella fascicularis*, *P. isylica*, *Tabulophyllum mcconnelli*, *T. sylvaticum*, *Sinodisphyllum kielcense*, *Aristophyllum irenae and Macgeea socialis*.

Lion Member: *Hexagonaria mirabilis* at the base and occasionally *Argutastrea konincki* higher in the lithostratigraphic unit.

Boussu-en-Fagne Member: *Hexagonaria mirabilis*, *H. davidsoni*, *H. mae*, *Trapezophyllum roharti*, *Macgeea gallica* and *Tabulophyllum mcconnelli*.

STOP D2-3– TAILFER ROAD SECTION AND QUARRY

References
LECOMPTE (1960)
TSIEN (1971, 1975, 1976a, 1976b, 1977a, 1978, 1979)
TSIEN et al. (1973)
COEN-AUBERT & COEN (1974)
DA SILVA & BOULVAIN (2002)
DA SILVA et al. (in press a)

Location and access
The Tailfer outcrop, located along the Meuse River right bench, corresponds to the northern flank of an E-W syncline and the direction and dip of strata is N100°E/50°S.

Stratigraphical units and age
Presles Fm. and Lustin Fm. (Frasnian).

Highlights
The Tailfer section is the most remarkable outcrop of the Lustin Formation. The main facies are characteristic of a shallow water platform (Fig. 5):

- External facies: decimetre-thick dark calcareous beds, with some argillaceous intercalations, composed of packstone or wackestone with crinoids and ostracods (E1). This facies is interpreted as being deposited below the fair-weather wave base (FWWB) but within storm weather wave base (SWWB).

- Biostromal facies: The biostromes are mainly constructed by stromatoporoids with different morphologies: laminar stromatoporoid biostromes (B1), rudstone with high domical stromatoporoids and rugose and tabulate corals (B2) and floatstone composed of dendroid stromatoporoid biostromes (B3). These microfacies correspond to a biostromal belt, with low to strong wave energy, close to FWWB where the sediment was episodically reworked by storms.

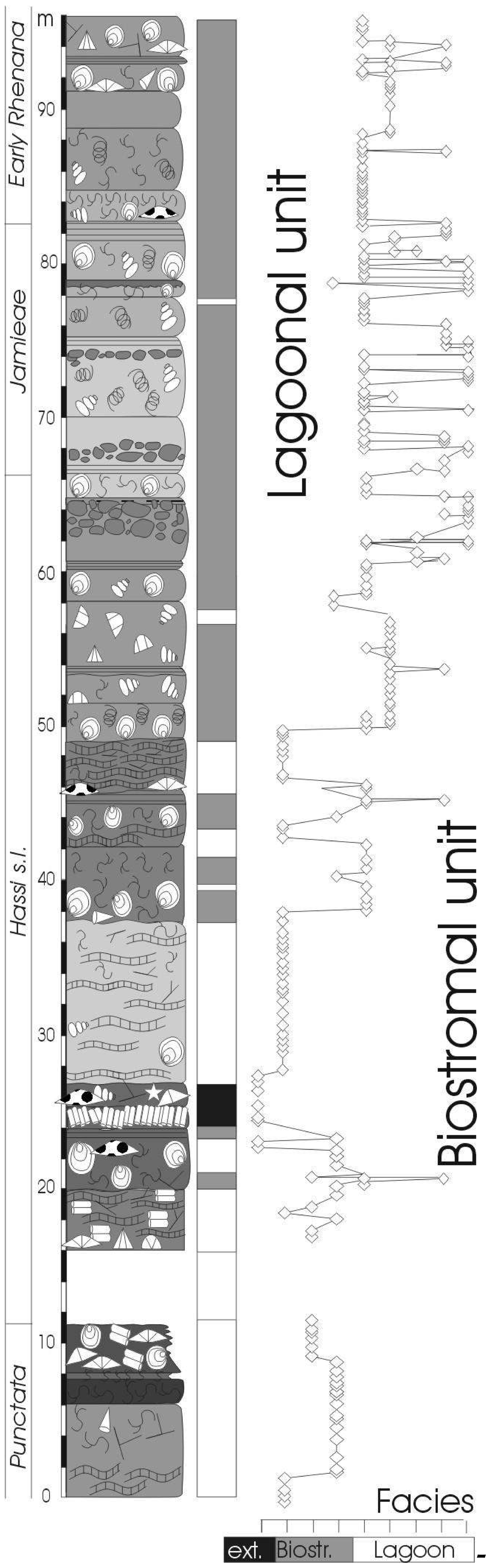

Fig. 27: Lithogical column and sedimentological evolution through time, with the separation of the Tailfer section in two units, a lower one dominated by biostromal facies and a upper one dominated by lagoonal facies (DA SILVA & BOULVAIN 2002).

Internal facies: The subtidal facies are characterized by floatstone with *Amphipora*, packstone with palaeosiphonocladales and packstone with peloids (I1). The intertidal facies consists of wackestone or packstone with *Umbella*, mudstone with ostracods and laminated grainstone with peloids (I3, I4). The supratidal zone is characterized by strongly brecciated decimetre- to metre-thick intervals cut by desiccation cracks showing typical features of pedogenesis (I5).

The ideal shallowing-upward facies succession starts with open-marine deposits corresponding to crinoidal packstones (E1). They are followed by biostromes with laminar stromatoporoids (B1), overturned and broken massive stromatoporoids (B2) and then dendroid stromatoporoids (B3). Then, biostromes are overlain by subtidal lagoonal facies with *Amphipora*, paleosiphonocladales and peloids (I1), followed by mudstone and laminated pelloidal facies (I3-4) in the intertidal zone. The subtidal and intertidal zones were cutted by channels filled by *Umbella* and intraclasts (I2). The supratidal zone was characterized by paleosols (I5) (DA SILVA & BOULVAIN, 2004).

An important sedimentological observation concerning the environmental evolution is the apparent division of the section between an upper and a lower unit (DA SILVA & BOULVAIN, 2002) (Fig. 27). The lower unit (biostromal unit) is dominated by biostromes growing on external facies, and capped by lagoonal facies. The upper unit (lagoonal unit) consists of lagoonal facies (with paleosols).

They are different type of biostromes considering the setting and different kind of stromatoporoids are observed (DA SILVA et al., in press a):

- In the lagoonal facies, the most common stromatoporoid, in terms of numbers of specimens is clearly the branching *Amphipora* (which can reach 100% of the stromatoporoid fauna, but note that these are presumed delicate forms found only as fragments), followed by branching *Stachyodes*, encrusting *Clathrocoilona*, domical *Actinostroma* and *Stictostroma*. The stromatoporoids are commonly overturned and sometimes broken. Encrustations, mostly by *Clathrocoilona*, are very common and affect almost all species and are always better developed on one side. Intergrown tubes and borings commonly affect all species.

- In the biostromal facies: as said before, 3 types of biostromes are recognisable: laminar stromatoporoid biostromes (B1), rudstone with high domical stromatoporoids and rugose and tabulate corals (B2) and floatstone composed of dendroid stromatoporoid biostromes (B3). The laminar stromatoporoid biostromes are showing the most spectacular exposure and are the most abundant; so we will focus on these. Low profile stromatoporoids would have presented advantages in deeper zones or more turbid zone in case of soft sediment to avoid sinking (KERSHAW 1998), for substrate stabilisation, stability during time of higher energy and low sedimentation rate (KERSHAW 1990). Three main types of laminar stromatoporoid biostromes are observed, characterized by different faunal assemblage and sedimentary features:

Biostrome type 1. Automicrite in which stromatoporoids are uncommon, with very thin laminar *S. australe* and *Stictostroma* (2 to 5 mm thick, with a few *Stictostroma* reaching cm-thick size). All specimens of *S. australe* are in growth orientation, with no evidence that any have been overturned; therefore they are considered to be in place. A depositional succession occurs repeatedly in this facies: (1) brachiopod shells packstone to grainstone; (2) stromatoporoids, *S. australe* and *Stictostroma* level; (3) mud dominated facies, characterized by a high proportion of automicrite, clotted structures, diffuse peloids, mud encrustations and fine micrite. In some case, clotted laminated peloids and micrites have built centimetre-thick mound shapes. The fact that stromatoporoids remain very thin (millimetre-thick) indicates a quiet water environment interrupted by rare events of sedimentation. Furthermore, evidence of growth interruptions like anastomosed growth forms and raggedness are observed, which may be explained by a mixture of sedimentation events interrupting growth, and formation of primary cavities (KERSHAW et al. 2006) as well as (presumably) frequent higher energy events revealed by alternation of tempestite and mud-*Stachyodes australe* levels, which could explain the cessation of stromatoporoid growth.

Biostrome type 2. Micrite and laminar and tabular stromatoporoid dominated biostromes: in these biostromes, the proportion of micrite and stromatoporoids is more or less equal. The matrix is generally light grey and rich in small bioclasts or shows a clotted, finely laminated and locally peloidal fabric. Some micritic encrustations are observed (0.2 mm-thick irregular encrustations, mostly around brachiopods). The stromatoporoids are mostly *Stictostroma* and branching *Stachyodes* with a few *Amphipora* and *Clathrocoilona*. Laminar and tabular *Stictostroma* commonly have well developed astrorhizal mamelons and can present some more irregular wavy shape; they can also present a ragged outline, irregular shape and interruptions of growth with internal sediment and/or cement. The maximum thickness of these low profile stromatoporoids is around 10 cm. In these biostromes, stromatoporoids are thicker with more ragged boundaries, with also wavy shapes and very well-developed mamelons, compared to biostrome 1. These could indicate a higher sedimentary rate and also a quieter environment, with less storm events (because grainstones and reworked levels are not common in comparison with the two other biostrome types), allowing stromatoporoids to reach greater thicknesses. Stromatoporoids were probably quickly buried as they are very often in place (or at least overturned but not broken) and are not commonly affected by bioerosion. The presence of automicrite in some layers may have created a more lithified sea floor.

Biostrome type 3. Stromatoporoid (40 to 50 % of the rock and mm- to cm- thick) floatstone associated with a few tabulate corals. Stromatoporoids are almost entirely laminar (98% of specimen numbers) with rare encrusting growth shapes. *Stictostroma* is the most abundant (82% by number of specimens). Astrorhizal mamelons are frequent and face upwards as well as downward, corresponding to in life-position and overturned stromatoporoids. A decimetre-thick alternation is observed, of mostly in place structures (facing the right way up laminar stromatoporoids, with clotted mud) alternating with reworked structures (facing upward and downward stromatoporoids, with stromatoporoids and tabulate corals debris) (Fig. 28). Some laminar stromatoporoids show interruptions of growth with sediment layers and ragged margins. The alternation of upright and overturned stromatoporoids corresponds to an alternation of lower and higher energy events. Upright stromatoporoids are surrounded by micritic matrix and overturned stromatoporoids are surrounded by micritic matrix, together with tabulate corals and stromatoporoid debris. This biostrome developed in a quiet environment that was subject to episodic storms which disrupted the biota and overturned the stromatoporoids.

- In the external facies: Stromatoporoid-dominated autoparabiostromes to allobiostromes, several tens of cm-thick, are observed intercalated in the dark crinoidal beds. The most abundant (in terms of numbers of specimens) stromatoporoid growth forms are branching *Stachyodes* (cm-thick) followed by tabular and laminar (2 to 5 cm thick), domical (max. 30 cm in diameter), with some encrusters. The stromatoporoid fauna of this outer zone is in decreasing order of numerical abundance: branching *Stachyodes*, followed by low profile *Stictostroma*, *Salairella* and *S. australe*, high profile *Actinostroma*, branching *Amphipora* and encrusting *Clathrocoilona*. These stromatoporoids are mostly broken and/or overturned and the branching profiles are always lying on their side and are commonly strongly damaged.

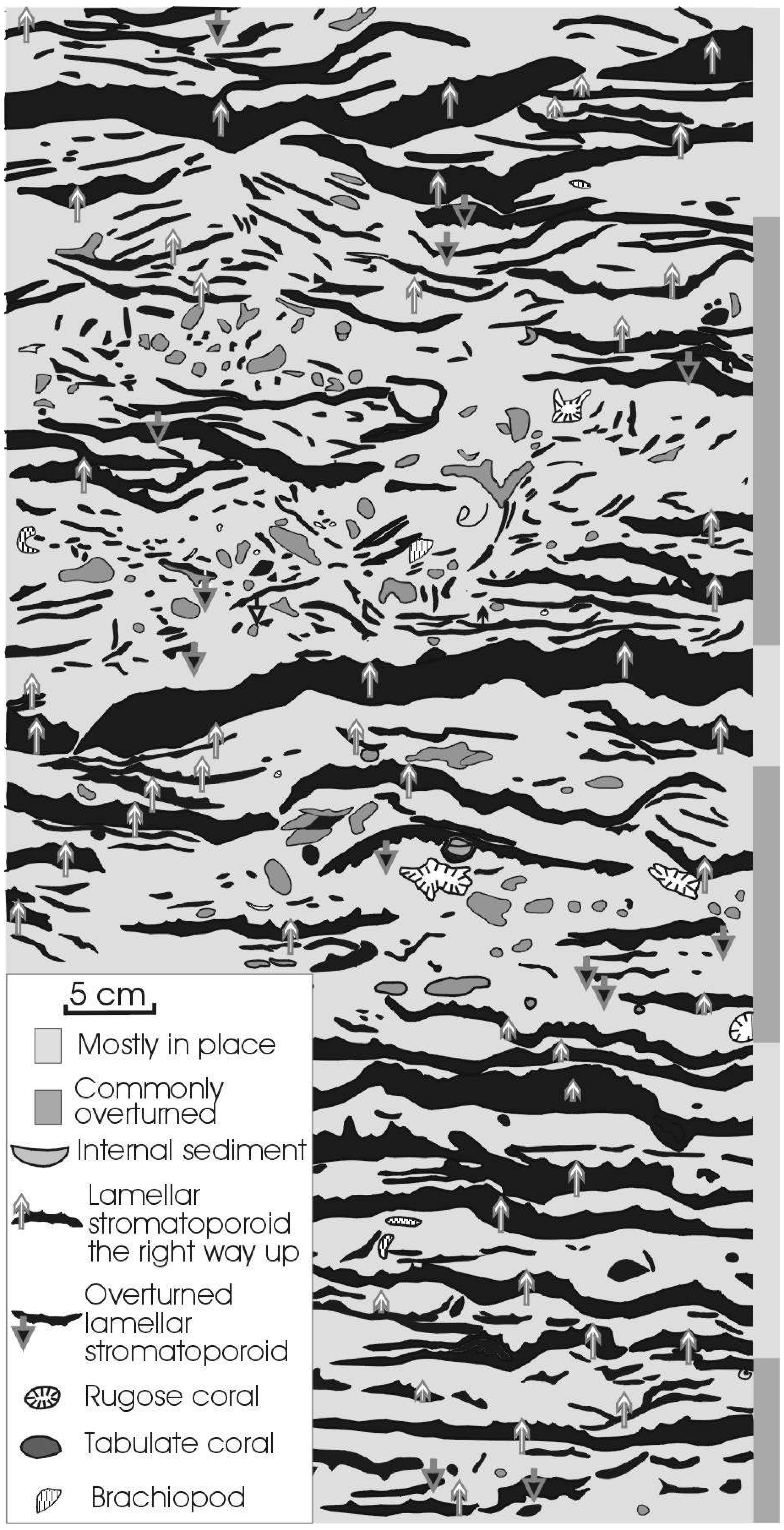

Fig. 28: Sketch from the Tailfer section, middle part of the biostrome, showing the alternation of mostly in place structures and overturned stromatoporoids (DA SILVA & BOULVAIN 2002).

In conclusion of the palaeoecological study, we can say that stromatoporoids are the most abundant large skeletal organisms in the facies studied, with principal occurrence in biostromes. Stromatoporoid assemblages tend to have one species that is more abundant than the other, which is consistent with other detailed studies of stromatoporoid faunas. Diversity is minimal in the biostromes themselves, but the faunas there are the most abundant, indicating that this is the most favourable environment for stromatoporoids in the Frasnian of Belgium. A strong relationship between palaeoenvironments and growth forms is observed (DA SILVA et al. 2011): tabular growth forms are mostly observed in outer, outer intermediate, and inner intermediate zone environments, laminar growth forms are dominant in the outer intermediate zone but are also observed in the inner intermediate zone; domical are mostly observed in the inner zone as well as the branching, encrusting and irregular growth forms. High profile forms are almost never observed associated with low profile tabular / laminar growth forms. However, taxonomic control is also obviously important and some genera are only observed in one or two growth forms. *Amphipora* is observed as only branching skeletons and *Clathrocoilona* as only an encruster and *Stachyodes* is always branching except in the case of the laminar *Stachyodes australe* (these are well-established relationships between growth form and taxa; STEARN et al. 1999). *Stictostroma* is mostly low profile but can also occur as domical growth forms; and *Actinostroma* developed thick tabular growth forms or high profile mostly domal shapes. The first stromatoporoids to form in the sequence (at the transition between argillaceous and carbonated environments) are characterized by low profile growth forms, which may have played an important role in stabilizing and colonising the substrate, and therefore promoting the carbonate factory development.

Biostratigraphy

Early to Middle Frasnian. The conodont *Ancyrodella rotundiloba* characteristic of the base of the Frasnian occurs in the Presles Fm. whereas the Lustin Fm. ends just below the base of the Late Frasnian.

Main faunal component

The following genera have been identified (DA SILVA et al. in press a): *Actinostroma, Amphipora, Atelodictyon, Clathrocoilona, Salairella, Stachyodes* (*Stachyodes australe* is identified as a separate taxon within this genus, owing to its consistent laminar growth form), *Stictostroma, Stromatopora and Trupetostroma*.

Among the rugose corals, the Tailfer roadsection and quarry is mostly known for its colonial forms. More particularly, it is the type locality for *Wapitiphyllum tenue* (COEN-AUBERT 1980) and *Argutastrea lecomptei* (TSIEN 1978).

A few coralla of *Macgeea lacroixi* have been found in the lower part of the biostromal unit from the Lustin Fm., above the first level of massive limestone belonging to the Sainte-Anne Marble. Then occur the beautiful thickets of *Disphyllum preslense* COEN-AUBERT 2009 which are not exposed in Tailfer, but which can be seen southwards, in the section of the Rochers de Frênes at Lustin. At

Stromatoporoid	Morphology	Size	Substrate	'Reefal structure'	Environmental zone
Amphipora	Thinly branched	mm to cm	Never observed in place associated with peloids and algae	Patches, always broken	Inner
Stachyodes	Thick branches	cm	Never observed in place associated with almost all sediments	Patches, always broken	Inner intermediate Outer
	Thinly laminated to anastomosed	mm thick dm large	On mud, shells or encrusting other strom (*Sti. or StA.)*	"Microbial biostromes" Colonization phase	Outer intermediate
Actinostroma	Domical - Bulbous or DM ragged or smooth	few cm to 50cm	Growing mostly on mud Sometimes on *Actinostroma*	Biostromes - patches	Inner Outer
	Tabular	few cm to 5m	Growing mostly on mud Sometimes on *Actinostroma*	Biostromes - patches	Inner intermediate
Stictostroma	Laminar - Tabular Ragged margins mamelons	cm to dm thick / dm to m large	Growing mostly on mud	"Microbial biostromes"	Outer intermediate
	Domical - Bulbous ragged or smooth	cm to dm large	Never observed in place. Associated with peloids and algae	Biostromes - patches	Inner
Clathrocoilona	Encrusting	mm to dm thick	Growing always on hard debris stromatoporoids, tabulate, ...	Biostromes - patches	Inner interm. Inner
Trupetostroma	Bulbous - DM ragged or smooth	cm - dm	Mostly not in place, associated with peloids and algae	Biostromes - patches	Inner
	Tabular - laminar	cm thick, dm large often broken	Mostly not in place, associated with mud	Biostromes - patches	Inner intermediate
Salairella	Tabular	cm thick, dm large often broken	Crinoidal substrate	Biostromes - patches	Outer

Fig. 29: Description of the main stromatoporoid morphologies and their distribution on the platform in relation to the substrate, biostrome and environment (Da Silva et al. in press, a)

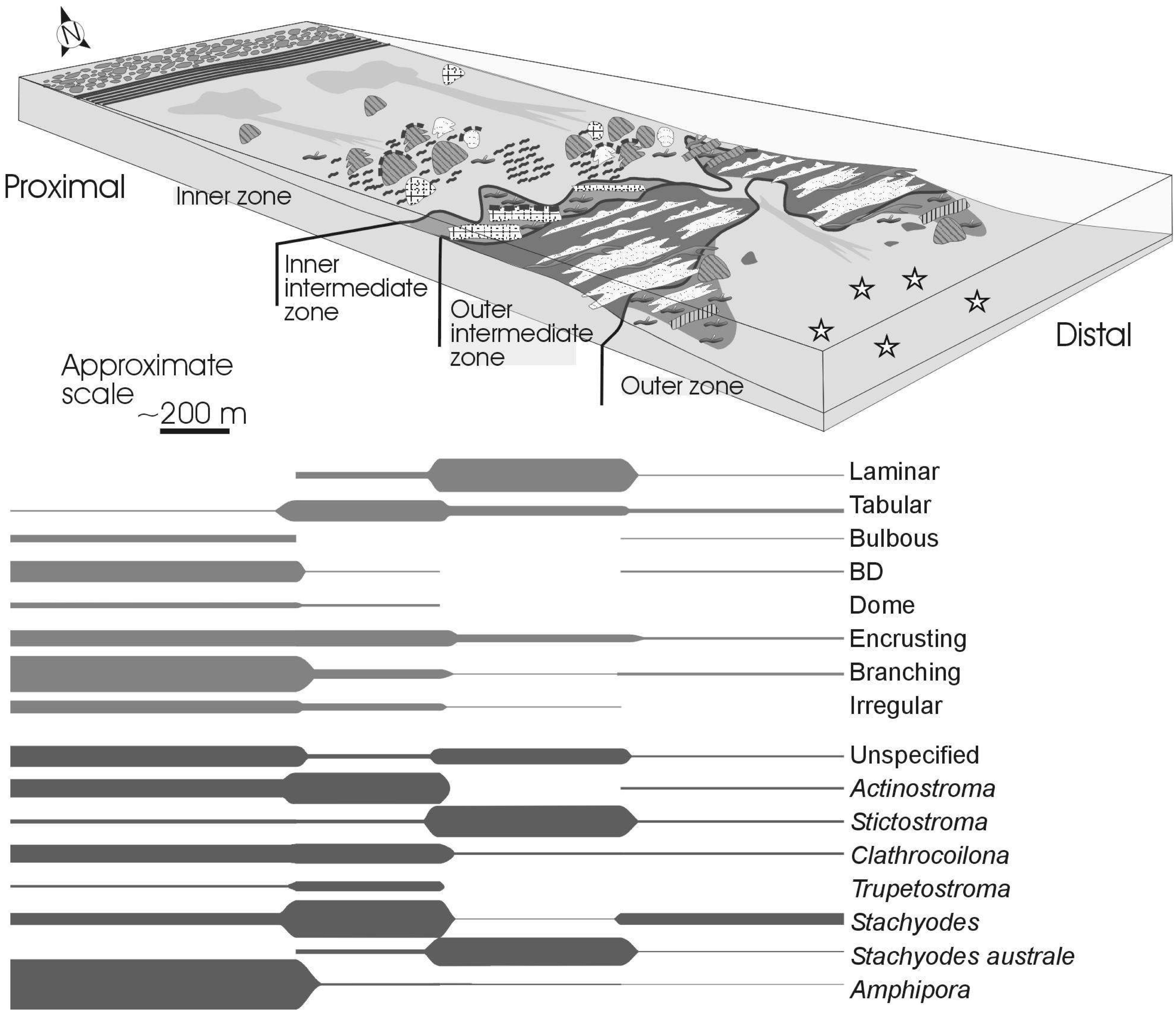

Fig. 30: Synthesis of the distribution of stromatoporoids and stromatoporoid growth form along the platform model. The key to stromatoporoids is shown on Fig. 32 (Da Silva et al. in press, a).

Tailfer, there is a bed with *D. preslense* followed by another one with large colonies of *Wapitiphyllum tenue*, just below the second level of massive limestone from the biostromal unit of the Lustin Fm. At the top of these reefal limestones, the bedded limestones rich in laminar stromatoporoids contain also *Hexagonaria mirabilis* and *Tabulophyllum mcconnelli*.

Argutastrea konincki is present at the base of the overlying lagoonal unit whereas *A. lecomptei* is abundant at the top of the Lustin Fm.

The tabulate coral fauna of Tailfer has not been studied until now in detail. Alveolitids with different growth forms and thamnoporids seems to dominate, together with discreet auloporids.

Uses as ornamental stones

The limestones of Tailfer, easily polished as "marbles", have been intensively exploited from the end of 19th century until the last World War. Many different varieties were then distinguished – the classical "Sainte-Anne", blueish grey with white spots of calcite / the "Grand Antique de Meuse" or "Rubané de Tailfer" with lamellar stromatoporoids, beds with fossils somewhat darker than the light matrix, usually called "Florence", here with some greenish shades ("Vert de Tailfer") or slightly violet ones ("Lilas").

STOP D3-1 – LES WATONS QUARRY

References

BOULVAIN (1993, 2001, 2007)

Location and access

Disused quarry near Merlemont. Philippeville Anticlinorium.

Stratigraphical units and age

Neuville Fm., Petit-Mont Member (Frasnian).

Highlights

The small village of Merlemont is located in the southern part of the Philippeville Anticline (Fig. 31). In this area, more than sixty Petit-Mont Member mounds are known. Some have been actively quarried since Roman time, giving the famous red ("*griotte*"), pinkish ("*royal*") and grey marbles. Old houses from the Merlemont and Vodelée villages are made from these marbles.

The abandoned marble quarry of Les Wayons, now used as a training area for speleology, exposes the lower part of a Late Frasnian mound. Stratification is nearly vertical and the base of the mound, in tectonic contact with shale, is visible in the NW part of the quarry.

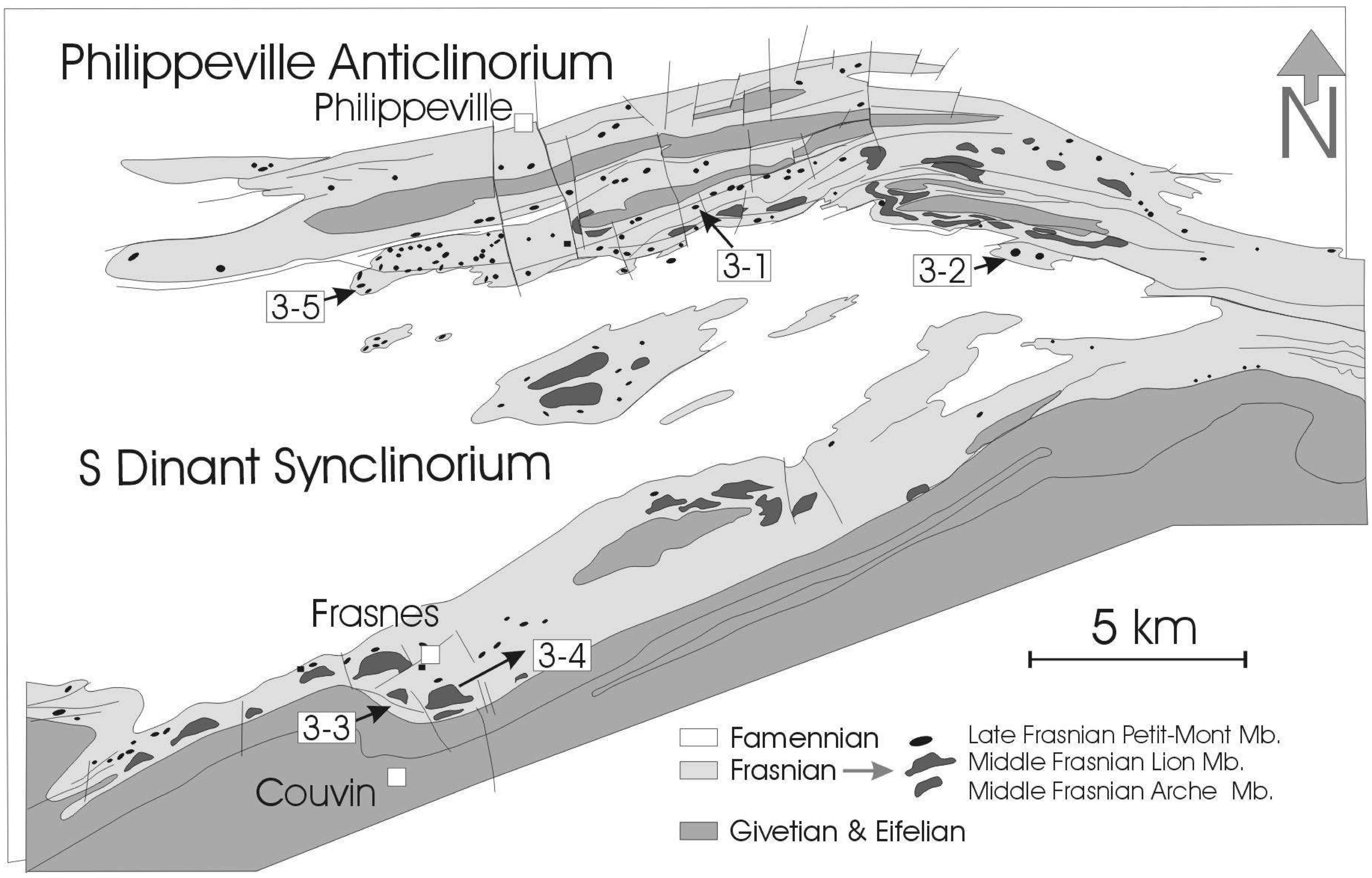

Fig. 31: Geological map of the Philippeville-Couvin area (BOULVAIN 2007).

Some 20 m of red stromatactis limestone (M1) forms the lower part of the mound (Fig. 32). Red colour is related to high amounts of microaerophilic iron bacteria in the sediment (Fig. 33) (BOULVAIN et al. 2001). Stromatactis are derived from collapse of sponges whose spicules are very abundant in this facies (BOURQUE & BOULVAIN, 1993). The upper part of the mound shows a shallowing upward sequence, with replacement of the sponge-bacteria community by crinoids, corals, stromatoporoids (M2 & 3) and finally by green algae and cyanobacteria (M4 & 5).

Biostratigraphy
Late Frasnian.

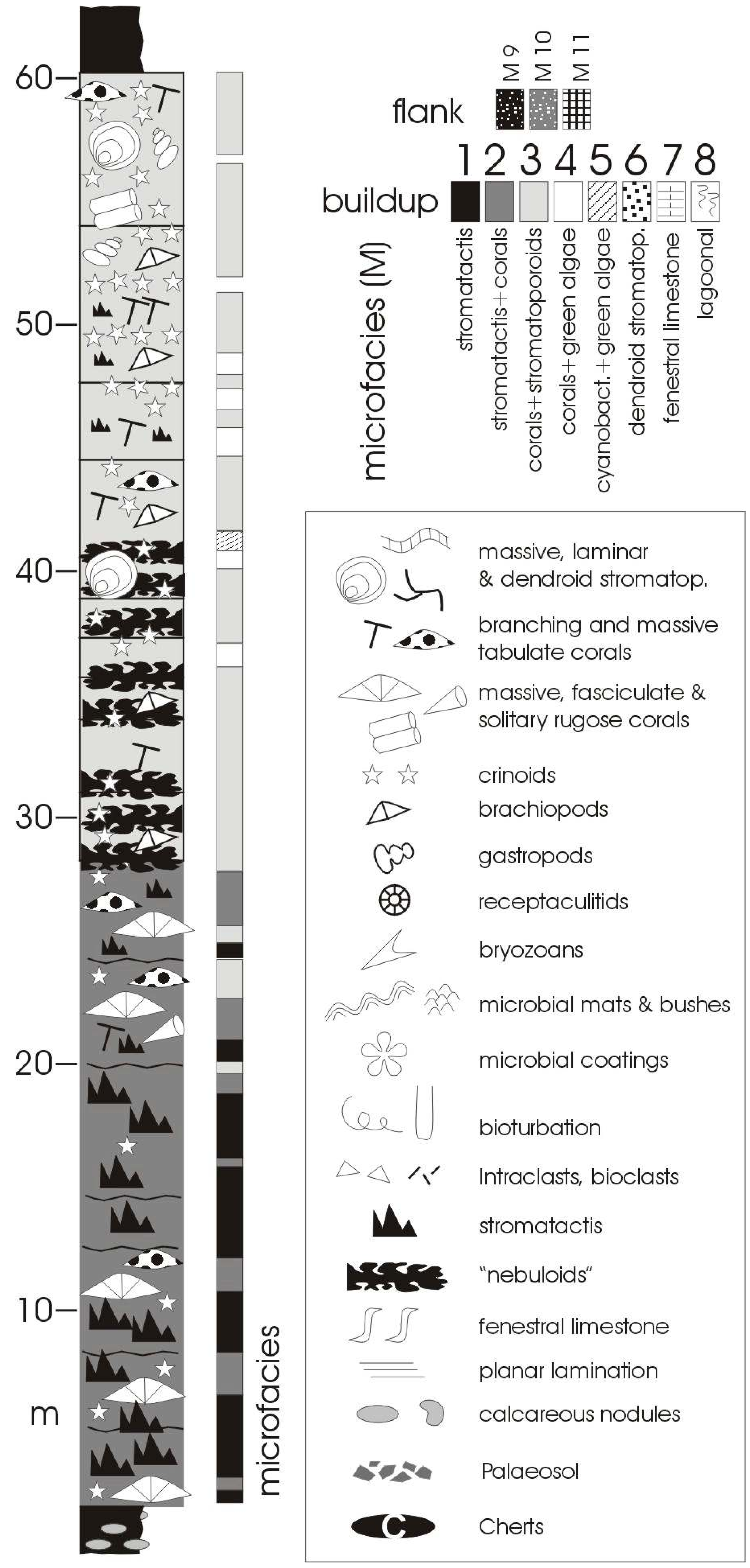

Fig. 32: Log of Les Wayons mound. Explanation of symbols for all logs (BOULVAIN, 2007).

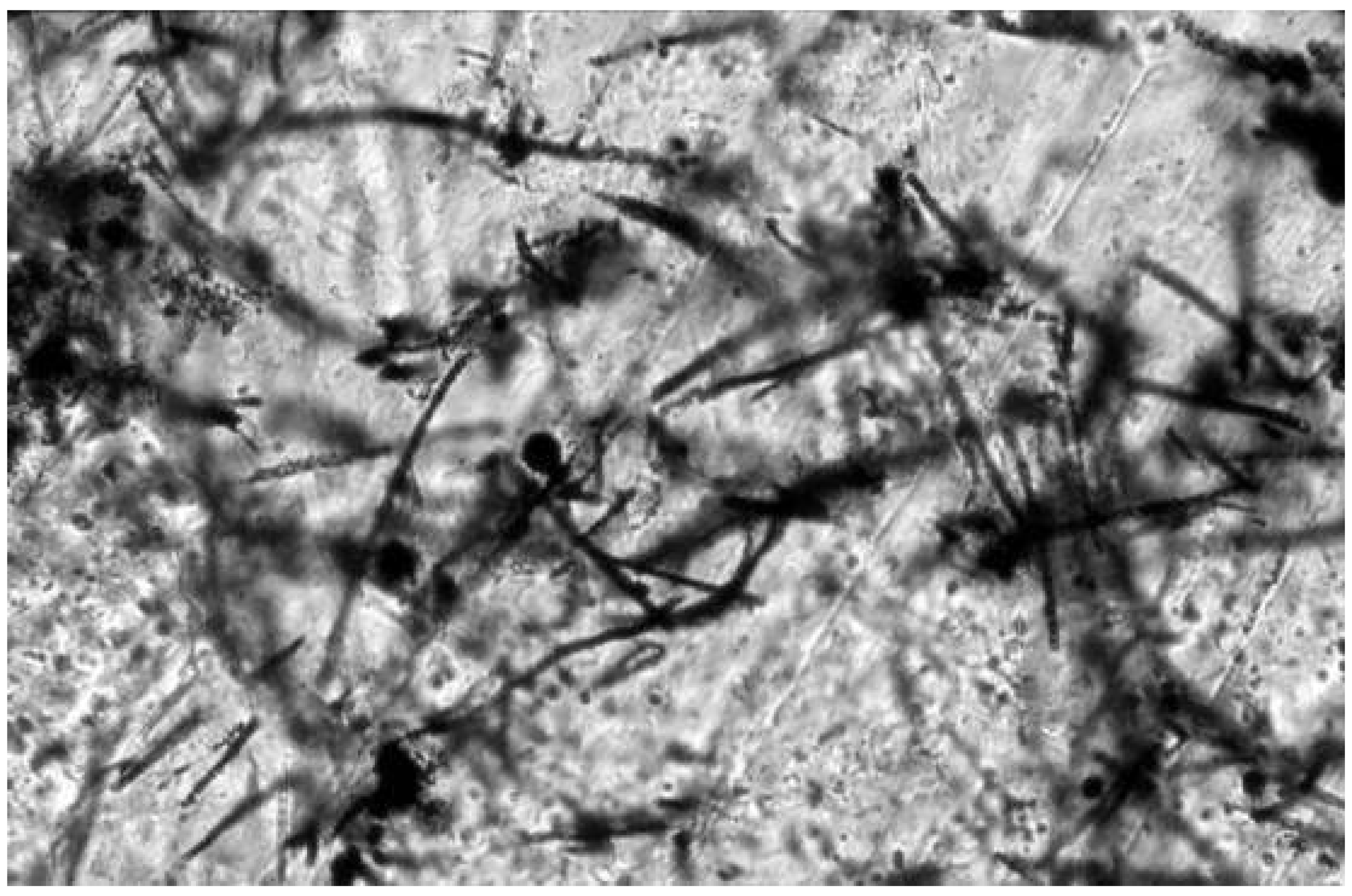

Fig. 33: Microaerophilic iron bacteria from the Petit-Mont Membre (Rochefontaine quarry). The diameter of coccoids is 2 µm.

STOP D3-2 – HAUTMONT QUARRY

References
DUMON (1957)
TSIEN (1984)
COEN et al. (1977)
BOULVAIN (1993, 2001, 2007)

Location and access
Active quarry near Vodelée. Philippeville Anticlinorium.

Stratigraphical units and age
Neuville Fm., Valisettes Fm., Petit-Mont Member (Frasnian).

Highlights
This stop is dedicated to a very spectacular Late Frasnian carbonate mound (Petit-Mont Member): the Hautmont mound near Vodelée. This active quarry is located on the SE end of the Philippeville Anticline.

The central part of the mound is in nearly horizontal position (Fig. 34). The top of the mound is well accessible and all stages of mound drowning are visible (Fig. 35). The upper central part of the mound shows a core of grey microbial, coral stromatoporoid limestone (M5). This facies forms massive limestone with stylolites. Decimetre- to metre-scale growth cavities cemented by granular spar are abundant. Breccia is locally present. The fauna is dominated by subspherical coral colonies (*Hankaxis, Phillipsastrea, Alveolites*), *Thamnopora*, brachiopods and subordinate dendroid stromatoporoids (*Amphipora*). *Renalcis* is locally abundant. Thrombolitic structures and microbial mats are present. Within thrombolites, *Renalcis* is associated with *Palaeomicrocodium*.

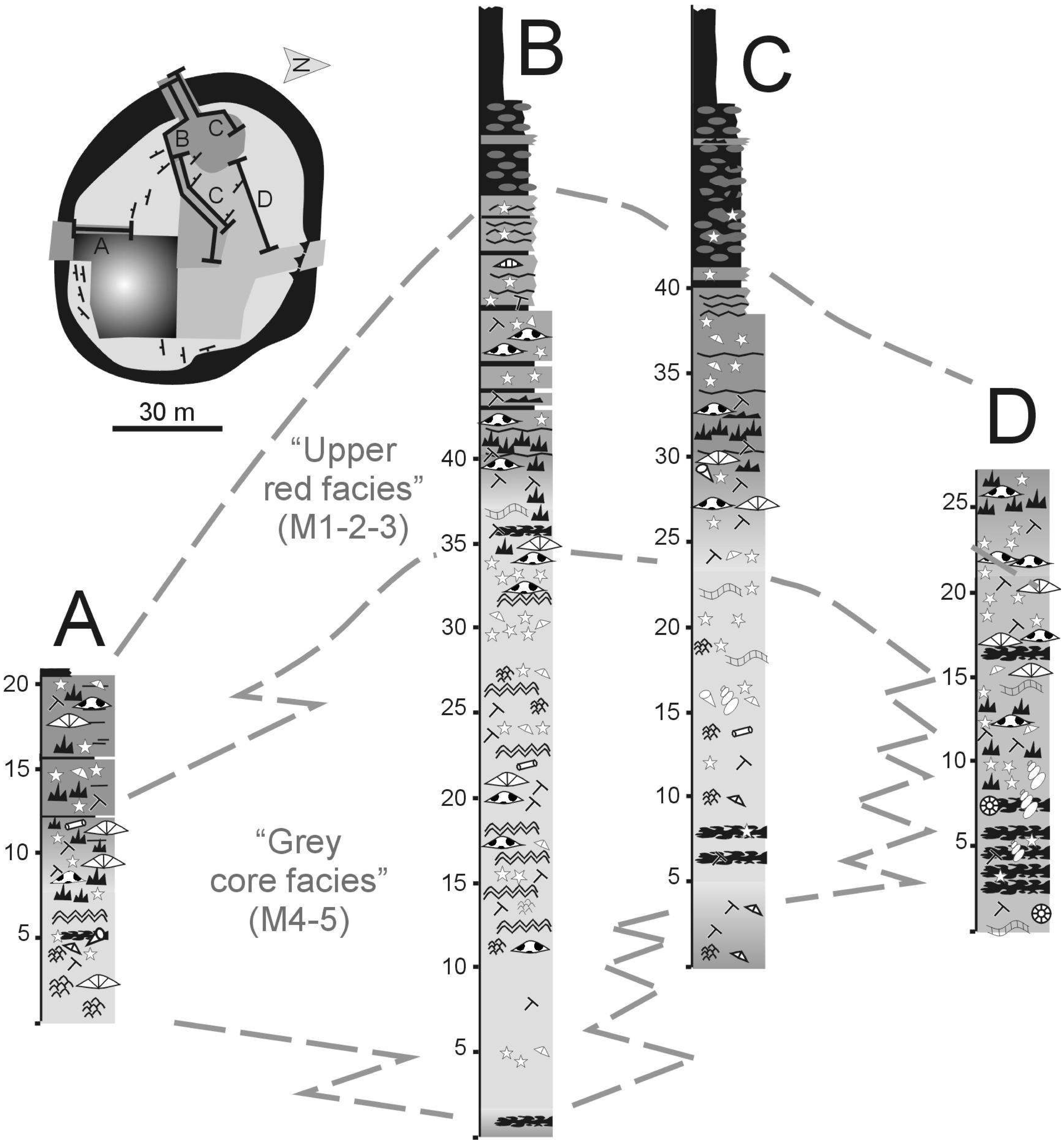

Fig. 34: Logs of the Hautmont quarry. Location of the logs on a horizontal sketch of the quarry. Explanation of symbols, see Fig. 32.

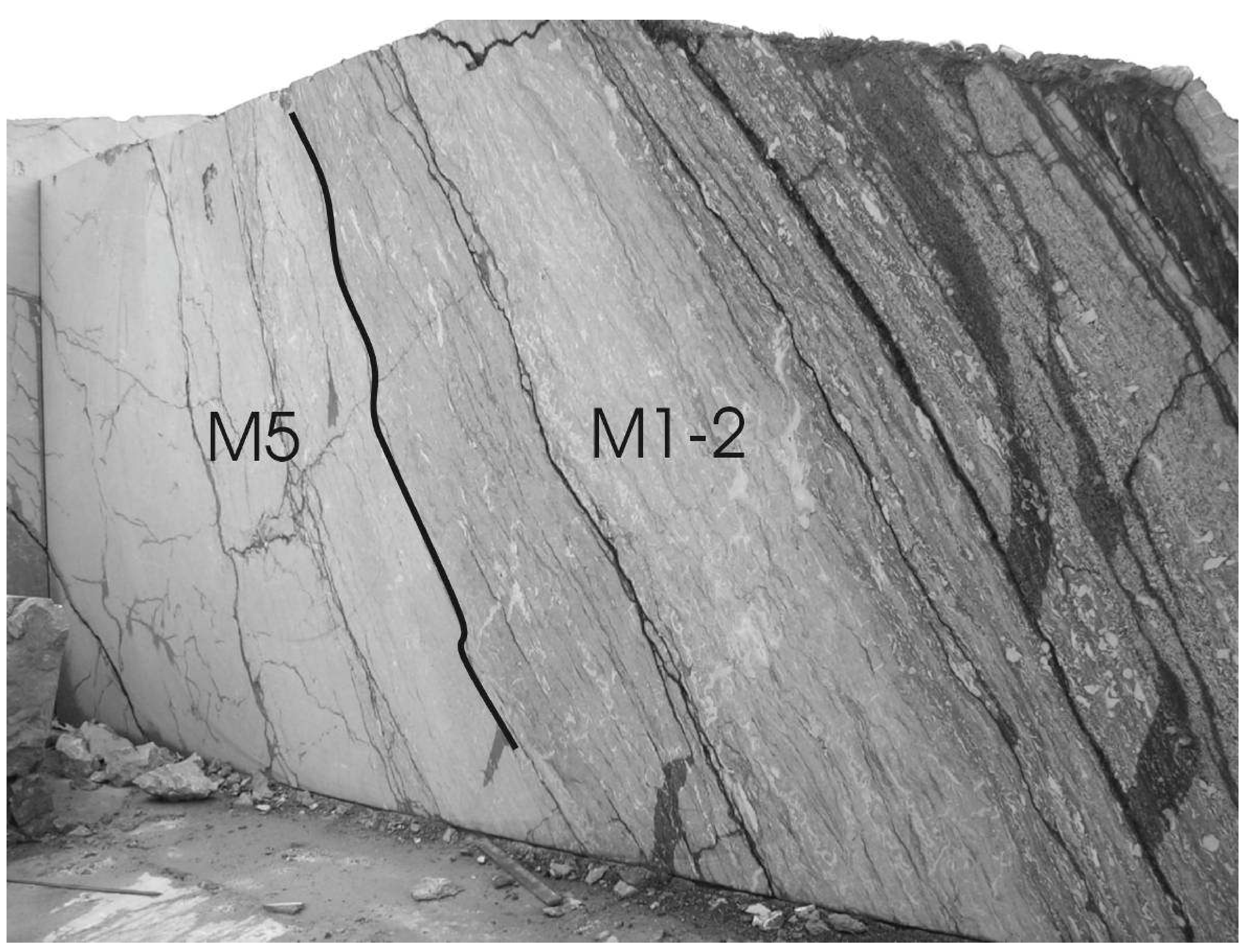

Fig. 35: Drowning sequence of the Hautmont mound. Vodelée, Petit-Mont Member.

Biostratigraphy
Late Frasnian.

Main faunal component

In the core of grey limestone from the mound have been sampled very fragmentary coralla of *Hankaxis mirabilis* accompanied by a few specimens of *Frechastraea micrastraea*. This species together with *Phillipsastrea ananas* is abundant in the pinkish limestones of section D. The transition between the second and third faunas of Late Frasnian rugose corals described by COEN et al. (1976) is observed in the red limestones from the top of the bioherm. Indeed, this level contains rare fragments of *Frechastraea micrastraea*, transition forms between *F. micrastraea* and *F. pentagona* or *F. minima* and typical representatives of the third fauna with *F. pentagona*, *F. minima* and *Phillipsastrea veserensis*. Very thin colonies of *Frechastraea minima* are also present in the red shales with beds of limestone overlying the mound.

The tabulate corals of Hautmont have not been studied in details and the assemblages are rather different in the different "colours" of the limestones (dark "*griotte*" to the light "*gris Saint-Edouard*"). Thamnoporids have been observed as numerous small fragments of branches or as large bushes, without doubt important for their baffling function – the species is *Thamnopora micropora,* established for specimens from the Tapoumont quarry, close to the Beauchâteau quarry (STOP D3-5). Alveolitids are present under diverse growth forms, lamellar to branching ("*Alveolites subaequalis*" group sensu LECOMPTE, 1939). Many "tubes"can be observed, especially in the "dark" facies, including probably auloporids and syringoporids, but also cladochonids.

Uses as ornamental stones

The massive outcrops of red to grey limestones have been intensively exploited for the marble industry – the quarries of Vodelée, as Beauchâteau, were already active in the XVIII[th] century, as can be observed in the famous Ferraris Maps, realized during the Austrian time. Each of the different coloured facies received a spacial name – "*griotte*" for the dark red limestones in the lower or upper part of the reef, "*royal*" for the bright red part, "*byzantin*" with greyish or black shades, "*gris Saint-Edouard*" or even "*gris Versailles*" for the grey veined limestones of the core of the reef. Among very numerous references around the world (Castle of Versailles, Saint-Pieters in Rome, the harem of Topkapı in Istanbul…), the famous Galeries royales Saint-Hubert in Brussels were decorated with coloroured marbles from the Hautmont quarry in the middle 19[th] century.

STOP D3-3 – ARCHE QUARRY

References

LECOMPTE (1954, 1960)
TSIEN (1970, 1971, 1975, 1977b, 1978, 1979, 1980)
CORNET (1975)
BOULVAIN et al. (2004)
BOULVAIN (2007)

Location and access

Disused quarry near Frasnes. Southern border of the Dinant Synclinorium.

Stratigraphical units and age

Moulin Liénaux Fm., Arche and Chalon members (Frasnian).

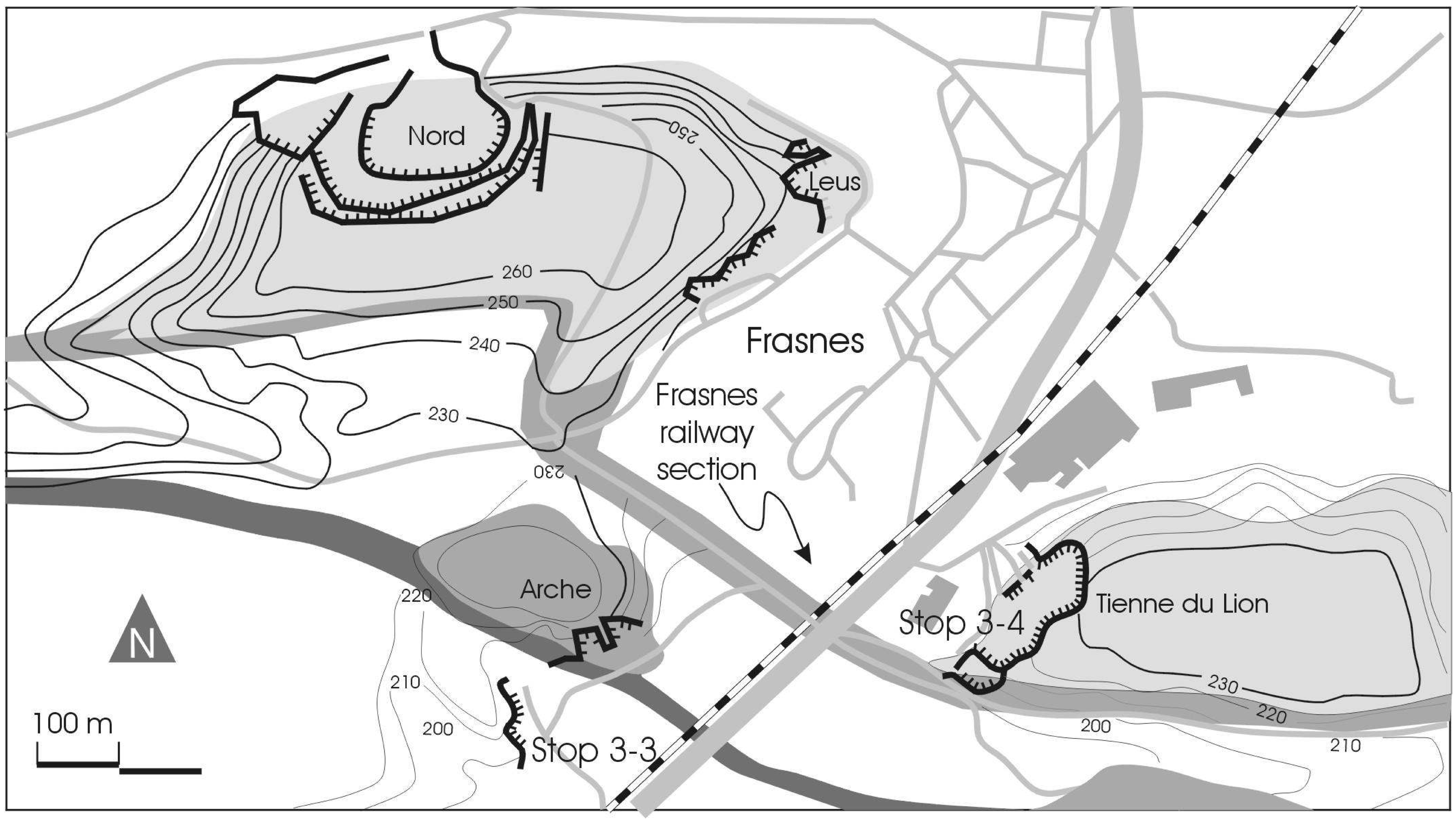

Fig. 36: Simplified geological map (modified from BARCHY & MARION 1999) of the Frasnes area with location of stops and of Arche and Lion Members mounds (BOULVAIN et al. 2004).

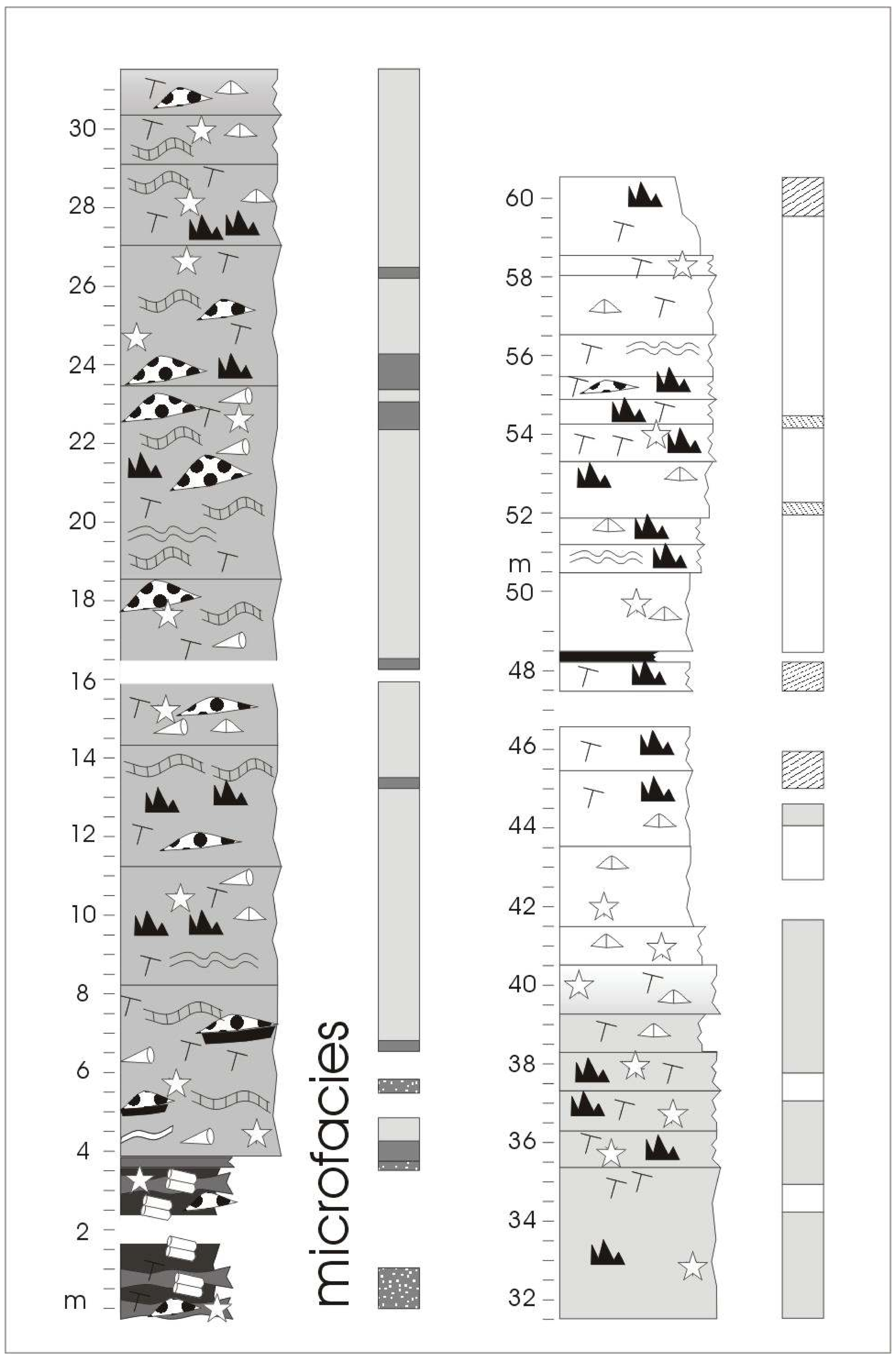

Fig. 37: Log of the Arche quarry, Frasnes, Arche Member. Explanation of symbols, see Fig. 32 (BOULVAIN et al. 2004).

Highlights

The disused Arche quarry is located close to the village of Frasnes (Fig. 36) and is cut into a 450 x 250 m limestone buildup belonging to the Arche Member (Fig. 37). Some stratified beds located just below the base of the mound show a strike of N145°E with a dip of 30°N. The thickness of the mound is estimated to 120 m.

The exposed base of the buildup consists of nodular shales and lenses of argillaceous limestone containing large amounts of broken and aligned *Disphyllum* corallites accompanied by crinoids, brachiopods, platy tabulate corals and solitary corallites of *Macgeea rozkowskae*. The last bed below the mound is very rich in vermiform structures attributed to sponges. The buildup starts sharply with pink floatstone showing abundant zebra, shelter fenestrae and stromatactis. The fauna includes *Alveolites, Thamnopora*, laminar stromatoporoids, crinoids, brachiopods, bryozoans and solitary rugose corals (M3). This facies continues to a height of 31 m, where the colour of the sediment becomes progressively lighter and M4 facies alternates with M3. In this unit, the macrofauna is composed of crinoids, brachiopods and branching tabulate corals. Peloids and microbial coatings become progressively more abundant upwards. From 42 m to the top of the section, the limestone (grainstone, bindstone) fades into grey with alternating M4 and M5 facies. The macrofauna includes dendroid and laminar stromatoporoids, gastropods, brachiopods, crinoids and branching tabulate corals. Petrographically, this last unit is rich in microbial laminites, peloids and dasycladaceens.

Biostratigraphy

Early to Middle Frasnian. The conodonts of the Arche quarry have been investigated in detail by VANDELAER et al. (1989). The top of the Nismes Fm. and the main part of the Chalon Member are situated in the *Palmatolepis transitans* Zone. The top of the Chalon Member and the Arche Member belong to the *P. punctata* Zone.

Main faunal component

The Arche quarry is the type locality for *Disphyllum hilli* and *D. grabaui*. These two species associated with a few coralla of *Macgeea rozkowskae* form large accumulations of numerous corallites in the Chalon Member just below the Arche Member. At the base of this lithostratigraphic unit, *M. rozkowskae* and *D. hilli* are still present.

STOP D3-4 – LION QUARRY

References

LECOMPTE (1960)
TSIEN (1971, 1975, 1977A, 1978, 1979, 1980)
CORNET (1975)
BOULVAIN ET AL. (2004)
BOULVAIN (2007)

Location and access

Disused quarry near Frasnes. Southern border of the Dinant Synclinorium.

Stratigraphical units and age

Grands Breux Fm., Lion and Boussu-en-Fagne members (Frasnian).

Highlights

This large old quarry lies 750 m SE of Frasnes, close to the Rocroi-Charleroi main road (Fig. 36). Bioclastic beds situated near the south end of the quarry show a strike of N90°E with a dip of 35°N. The Lion hill is nearly 800 x 400 m in area and the suggested thickness of the buildup reaches 150 m.

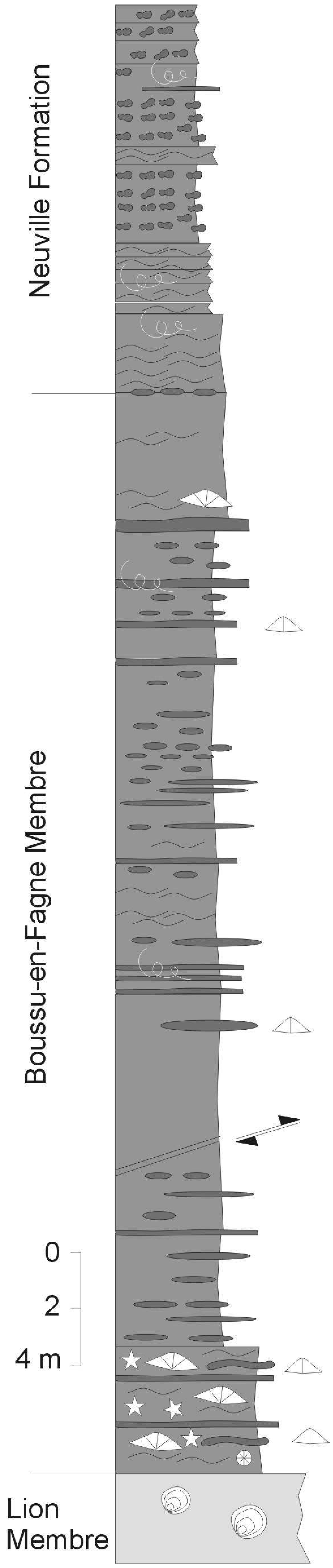

Fig. 38: Log of the Boussu-en-Fagne Mb. and Neuville Fm. In the Lion quarry, Frasnes.

The front wall of the quarry is about 280 m wide and 50 m high, giving a spectacular SW-NE section of the buildup (Fig. 38). Knowing the general palaeogeography of the Frasnian platform, this SW-NE section corresponds roughly to a fore-mound/ mound core transect.

The geometry of the bedding planes shows a very clear progradation in the form of 50 m high sigmoidal beds in the southern part of the quarry and nearly horizontal bedding in the northern area. These well-bedded zones are separated by a more massive zone in the central part of the quarry.

The base of the mound is not visible in the quarry and the bulk of the buildup consists of grey floatstone with stromatactis, branching tabulate corals, brachiopods, crinoids, bulbous or tabular (rarely dendroid) stromatoporoids and fasciculate rugose corals (M3). The north-east end of the Lion quarry, corresponding to the highest part of the mound, shows a transition between facies M3 and the algal facies M4, with lenses of microbial facies M5. These facies are capped in the northernmost part of the quarry by fenestral peloidal limestone (M7). The southern sections show alternations of bioconstructed facies M3 and reworked bioclastic material (M10). The upper south-west flank of Lion quarry is characterized by debris flows of lithoclastic material and sediment rich in dendroid stromatoporoids (M11). This material is thought to have been eroded from the central part of the mound.

A small wire-cut section close to the entrance of the quarry shows lenses of grey limestone with dendroid stromatoporoids (M6) and microbial bafflestones (M5). A metre-thick neptunian dyke with parietal encrustations of iron-bacteria cuts this unit. The main access trenches to the quarry expose a very interesting section in the Boussu-en-Fagne Member shale, deposited during the drowning of the mound.

Biostratigraphy

Middle to Late Frasnian. The conodonts of the Lion quarry have been investigated in detail by SANDBERG et al. (1992). The main part of the outcrop belongs to the *Palmatolepis hassi* Zone. In the upper part of the Boussu-en-Fagne Member succeed the *P. jamiae* Zone and the base of the Early *P. rhenana* Zone. In the latter zone, *P. semichatovae* appears close to the base of the Neuville Fm., indicating the base of the Late Frasnian.

Main faunal component

The rugose coral fauna has been studied by COEN-AUBERT (1994) close to the top of the Lion Member

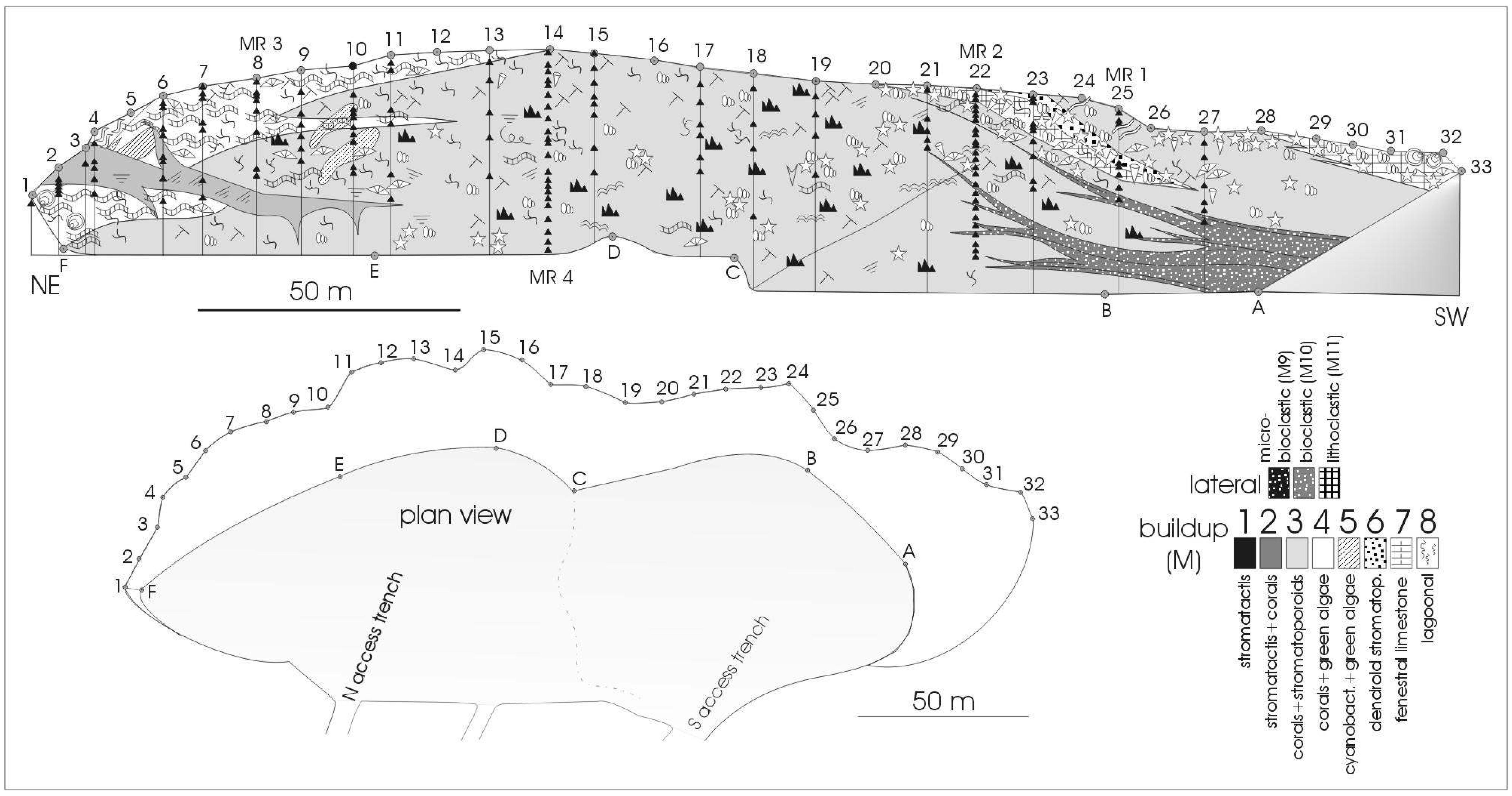

Fig. 39: NE-SE section in the Lion mound. Frasnes, Lion Member. Explanation of symbols, see Fig. 32 (BOULVAIN et al. 2004).

and in the Boussu-en-Fagne Member. *Hexagonaria mirabilis* is already present at the top of the Lion Member. Corals are mostly abundant at the base of the Boussu-en-Fagne Member, in contact with the mound. They are represented by *H. mirabilis*, *H. mae*, *Peneckiella szulczewskii* and *Macgeea gallica*. Rare coralla of *Tabulophyllum m*cconnelli have been found higher in the lithostratigraphic unit. No rugose corals have been observed in the overlying Neuville Formation.

STOP D3-5 – BEAUCHATEAU QUARRY

References

TSIEN (1971, 1976a, 1976b, 1976c, 1977a, 1978, 1979, 1980, 1984)
TOURNEUR (1982)
BOULVAIN & COEN-AUBERT (1992)
BOULVAIN (1993, 2001, 2007)

Location and access

Disused quarry near Senzeilles. Philippeville Anticlinorium.

Stratigraphical units and age

Neuville Fm., Petit-Mont Member (Frasnian).

Highlights

This abandoned marble quarry, located near the village of Senzeille in the SW part of the Philippeville Anticline, is the most spectacular outcrop of a Late Frasnian carbonate mound in Belgium (Figs. 40 & 41). The mound is standing in subhorizontal position and large sawn sections expose facies ranging from the middle part of the mound (M3) to its top (M 4 and 5). The upper central panel shows interfingering between grey massive microbial facies and pink bedded bioclastic flank sediments: The left part of the quarry shows crinoid-rich argillaceous flank sediments.

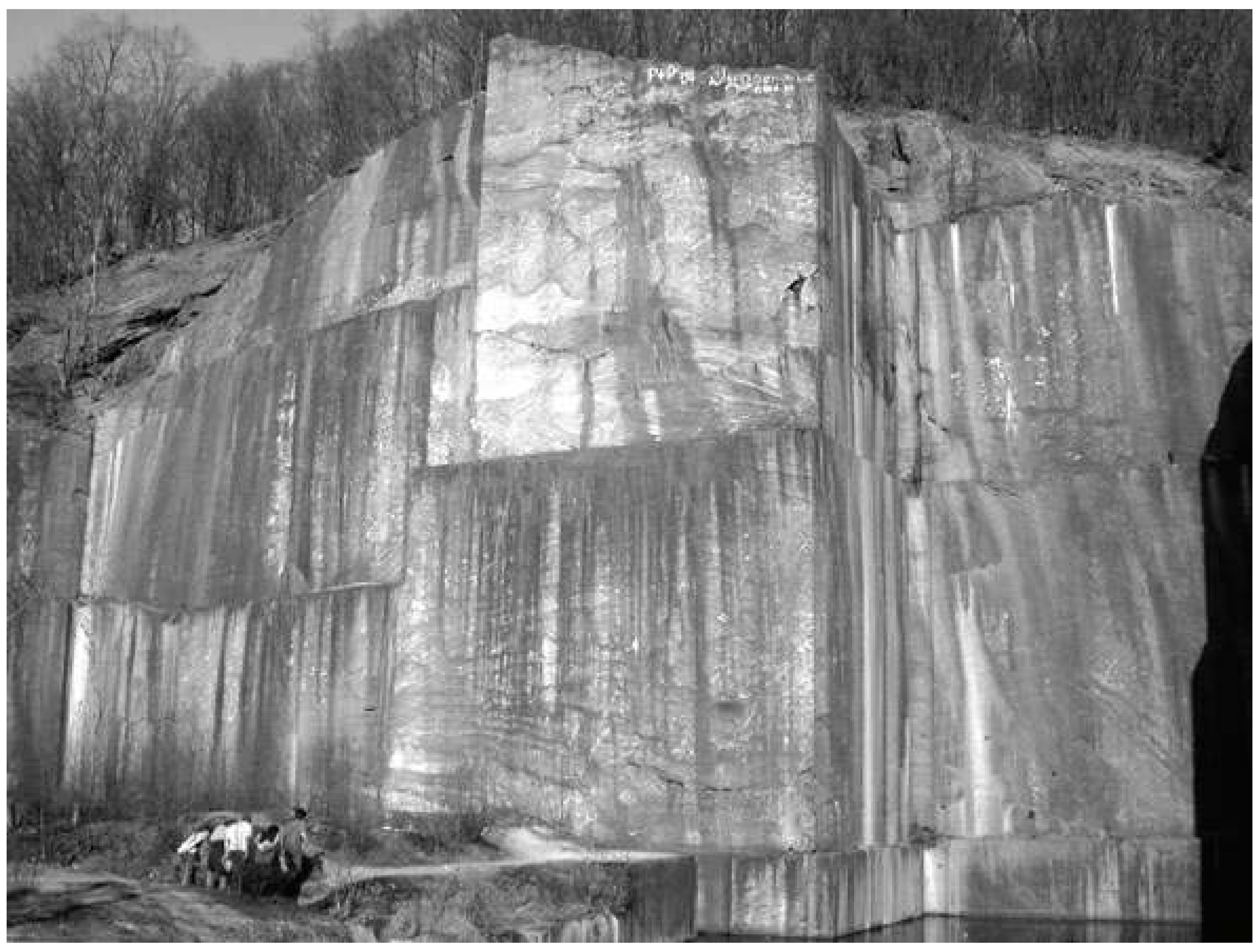

Fig. 40: The Beauchâteau quarry, Petit-Mont Member, Senzeille.

Contradictory inferences about the initial mechanical state of carbonate mound mud appear to derive from field observations. The persistence of dips as high as 35° on the flanks of several mounds, the presence of lithoclasts in the grey limestone (M5) and the sharp distinct character of some fractures indicate early lithification. Conversely, plastic deformation of the sediment, presence of overturned coral colonies (very spectacular in the lower central panel of the quarry), formation of zebra structures by lateral compression, scarcity of hardgrounds and of sediment borings, and the irregular character of some synsedimentary fractures indicate an absence of early lithification. It appears that the sediment was initially sufficiently ductile to permit synsedimentary deformation, yet sufficiently coherent to have maintained open cavities (stromatactis) and significant relief. It is likely that the sediment had a gel-like consistency, probably related to the presence of significant quantities of organic matter.

Biostratigraphy

Late Frasnian. Early? to Late *Palmatolepis rhenana* Zone. The conodonts of Beauchâteau quarry have been investigated in detail by TOURNEUR (1982) and Sandberg et al. *in* BULTYNCK et al. (1988).

Main faunal component

The Beauchâteau quarry is the type locality for *Tabulophyllum implicatum*, *Iowaphyllum mutabile*, *Thecostegites dumoni*, *Phillipsastrea falsa* and *Senceliaepora tenuiramosa*.

In the red marble bioherm, the rugose corals are represented by *Frechastraea micrastraea*, *Phillipsastrea ananas*, *Thamnophyllum hollardi*, *Macgeea pauciseptata* and *Tabulophyllum implicatum* with rare *F. limitata*. However, a large colony of Iowaphyllum rhenanum has been sampled in the grey part from the top of the mound. The same coral fauna occurs in the bedded crinoidal limestones forming slope deposits in the lower part of the flanks of the mound. Higher up, these sediments are capped by red and green shales (southeast) or nodular limestones (northwest) belonging to the Les Valisettes Formation and containing a different fauna with *Frechastraea pentagona*, *F. minima*, *Phillipsastrea falsa*, *Iowaphyllum rhenanum* and *I. mutabile*.

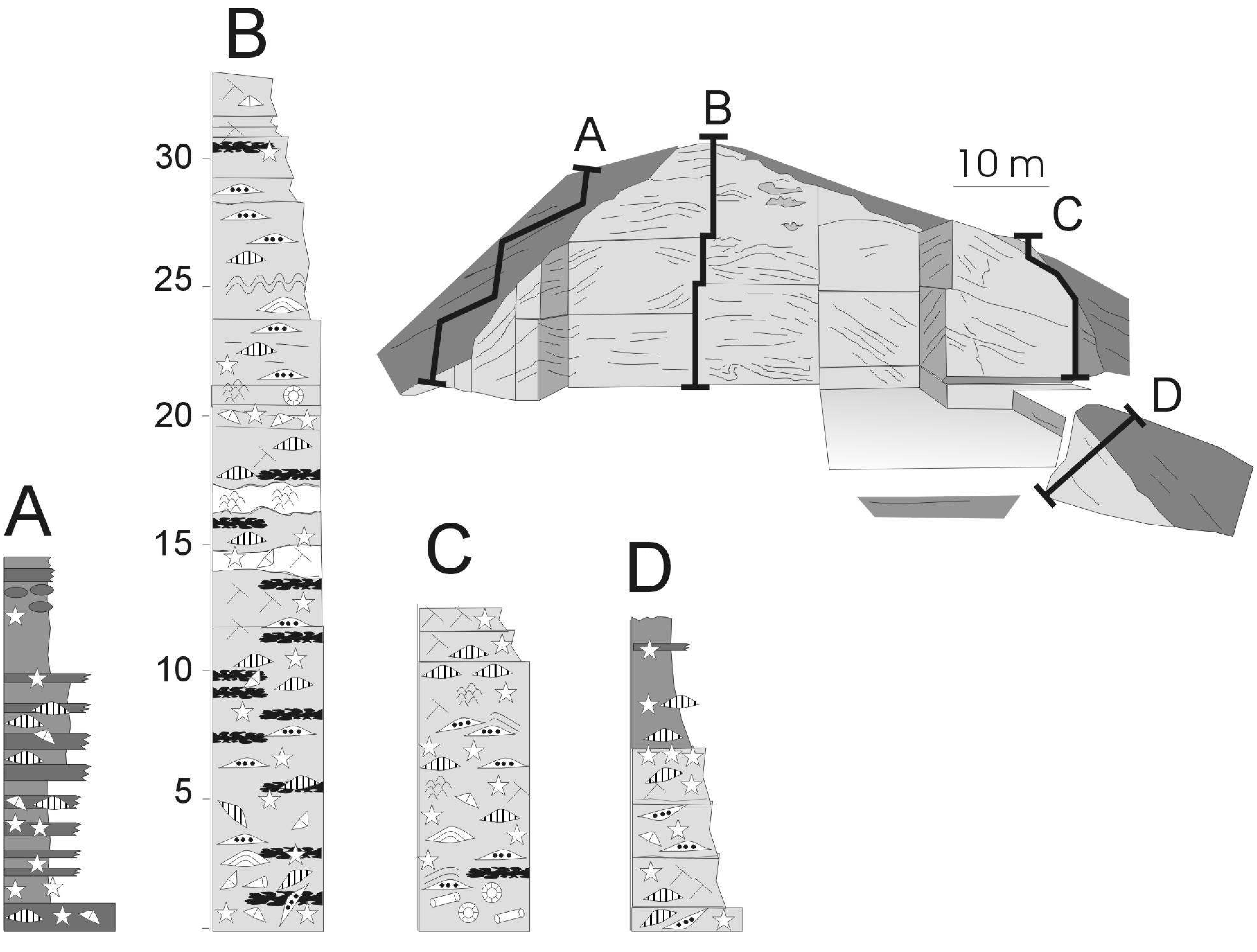

Fig. 41: Logs of the Beauchâteau quarry, Petit-Mont Mb. Senzeille (BOULVAIN 2001).

As in other "red reefs", the tabulate coral faunas have not been revised since the fundamental work of LECOMPTE (1939), which described (too) many species of alveolitids and some other forms – *Thamnopora micropora* (distinct from the classical *Th. boloniensis / cristata* by its smaller corallites) and thin branches of "*Cladopora gracilis*", usually attributed to the genus Egosiella. In Beauchâteau can be studied good exposures of lateral shaly facies, which contain interesting faunas. With numerous fragments of echinoderms (microcrinoids), bryozoans and small rugose corals, very thin branches of Senceliaepora tenuiramosa (described in this locality for the first time) can be collected – their special growth form, with oval calices in decussate disposition, connected by superficial canals, is very characteristic.

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