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The Devonian and Carboniferous of southern Belgium

14th - 16th July 2023

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Notes :

4th International Congress on Stratigraphy –Lille – 14th-16th July 2023, Post-excursion 1

The Devonian and Carboniferous of southern Belgium

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Field-trip programme

Note that the programme may change depending on the weather and the efficiency of the excursionists!

Friday July 14th

1-1 Beauchâteau quarry: upper Frasnian mud-mound
1-2 Cimetière de Boussu-en-Fagne quarry: middle and upper Frasnian buildups
1-3 Couvin cliff: stratotype of the former Couvinian stage (Eifelian)
1-4 Fondry des Chiens: Eifelian-Givetian boundary in stromatoporoid reef
1-5 Givet: landscape on the Givetian stratotype section
1-6 Waulsort: type locality of the Waulsortian mounds (Tournaisian)
1-7 Dinant: landscape on the type-locality of the Dinantian (lower Carboniferous)
1-8 Bayard Rock in Dinant: peri-Waulsortian succession (Tournaisian)

Saturday July 15th

2-1 Triffoy quarry: Famennian alluvio-lagoonal succession
2-2 Royseux section: Devonian-Carboniferous boundary and lower Tournaisian succession
2-3 Chabôfosse trenches: upper Viséan coral biostromes
2-4 Marche-en-Famenne sections: type area of the Famennian stage, upper Frasnian shales
2-5 Jemelle section: Eifelian shaly succession
2-6 Sourd d'Ave section: Givetian-Frasnian boundary
2-7 Resteigne quarry: upper Eifelian to Givetian carbonate succession

Sunday July 16th

3-1 Lives quarry: middle Viséan shelf sequences
3-2 Jambes Rock: Viséan-Namurian unconformity
3-3 Namur Citadelle: stratotype of the Namurian regional stage
3-4 Walgrappe: scenic view on Famennian sandstone in the Walgrappe Syncline
3-5 Salet road section and quarry: Tournaisian-Viséan transition, Denée 'black marble' Lagerstätte
3-6 Centre Gregoire Fournier Museum in the Maredsous Abbey: Denée 'black marble' fossils

1. Introduction

Four Devonian and Carboniferous stages recognised by the IUGS were originally defined in Belgium: Frasnian and Famennian (Upper Devonian), and Tournaisian and Viséan (lower Carboniferous). The Gedinnian and Couvinian were initially used as international stages but were replaced in the 1970-80s respectively by the Lochkhovian p.p. and the Eifelian p.p., respectively, whereas the Namurian (lower Carboniferous) is now considered as a regional stage. The Givetian stage is defined in the French locality of Givet, very close to Belgium and most of the interesting sections are visible in nearby Belgium.

The Devonian and Carboniferous successions are particularly well exposed in the Dinant Synclinorium. Several localities, especially in its southern limb are classical sites (e.g. Couvin, Givet, Frasnes, Marche-en-Famenne, Dinant) for stratigraphical and palaeontological purposes. We chose to introduce several lesser-known localities besides the ‘grand classics’ that have already been thoroughly discussed. However, some of them are poorly exposed (Couvin) or protected (Givet) nowadays, hampering good observations.

The aim of this excursion is to give a brief overview of the main sedimentary and palaeoenvironmental settings of the Belgian Devonian and Carboniferous and to give some insights on their global scientific potential.

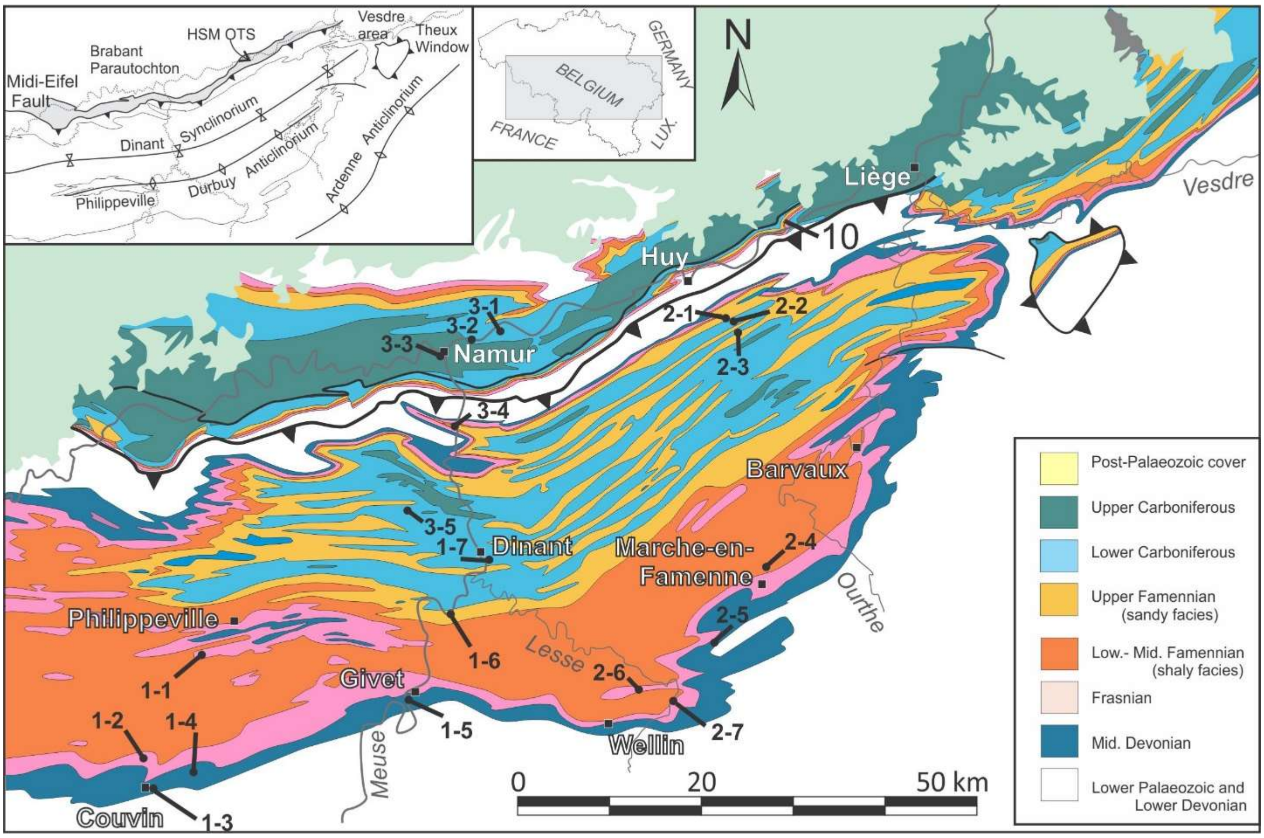

Figure 1: Simplified geological map of Belgium and surrounding areas (modified after de Béthune, 1954), with position of the visited outcrops and sections. Legend: 1-1 Beauchâteau quarry, 1-2 Cimetière de Boussu-en-Fagne quarry, 1-3 Couvin Cliff, 1-4 Fondry des Chiens, 1-5 Givet, 1-6 Waulsort, 1-7 Dinant and Bayard Rock, 2-1 Triffoy quarry, 2-2 Royseux section, 2-3 Chabôfosse trenches, 2-4 Marche-en-Famenne, 2-5 Jemelle section, 2-6 Sourd d’Ave section, 2-7 Resteigne quarry, 3-1 Lives quarry and rock, 3-2 Jambes Rock, 3-3 Citadelle de Namur, 3-4 Walgrappe, 3-5 Salet section and quarry. Abbreviation: HSM OTS, Haine-Sambre-Meuse Overturned Thrust Sheets.

2. Geological settings

Southern Belgium is part of the Rhenohercynian Fold Belt, which extends across Europe from Portugal through southern England, northern France, Belgium, and Germany, into Poland and resulting of the Variscan orogeny that took place during the Late Carboniferous. During this time slice, the Namur-Dinant Basin was situated along the south-eastern margin of Laurussia on the Rhenohercynian Ocean at an estimated latitude of 25°S. It recorded proximal facies in its northern part whereas its southern part acted as a shallow basin with deeper facies. However, deeper water environments are not known in Belgium.

The Devonian and Carboniferous strata crop out in several Variscan structural units, such as the Dinant Synclinorium, the Haine-Sambre-Meuse overturned trust sheets (former 'southern limb of the Namur Synclinorium), the Brabant Parautochthon (former 'northern limb of the Namur Synclinorium', continuing westwards to the Boulonnais area of northern France), the Philippeville-Durbuy Anticlinorium and the Vesdre area (Fig. 1).

As soon as the Early Devonian, the Dinant-Namur Basin functioned as a shelf divided in several sedimentation areas corresponding to several blocks that display distinct characters of subsidence and accommodation. The Early Devonian is largely dominated by siliciclastic facies of the 'Old Red Sandstone' witnessing the weathering and erosion of the Caledonian Chain located to the north. Each transgression pushed the coastline northwards as the littoral facies reached the northern part of the Dinant Synclinorium during the Lochkhovian-Praguian but reached the Namur area only by the Givetian-Frasnian.

The Middle Devonian Period recorded the onset of the 'carbonate factory' and the development of many metazoan and microbialite reefs, among which large Eifelian bioherms and extensive Givetian stromatoporoid and tabulate coral biostromes.

The Frasnian succession (Upper Devonian) reflects a ramp setting with several breaks of slope. The distal part of the Namur–Dinant Basin recorded the development of several carbonate mound levels separated by argillaceous episodes. The Famennian strata witnesses of a large-scale regression. This change is marked by a transition to thick argillaceous deposition during the Late Frasnian and Early Famennian. During the rest of the Famennian, alluvial to offshore siliciclastics dominated.

The Devonian-Carboniferous transition is characterised by the reinstallation of carbonate facies that suggest a change in regional climate, from cold to hot.

The Tournaisian is typically dominated by crinoidal limestones forming thick and widely extended units on the shelf. In the deeper part of the Namur-Dinant Basin (*Auge dinantaise* in the old literature), large accumupulation of mud-dominated Waulsortian mounds and banks strongly influenced the topography. At least three generations of mounds are superimposed on top of each other and separated by fine-grained, often cherty, limestone grouped under the term 'peri-Waulsortian facies'. In the beginning of the Viséan, the depositional settings changed again, with the filling of the depressions between the inner shelf and the Waulsortian mounds and the final smoothing of the relief. The platform displays an increasing restricted character during the Viséan, culminating with the deposition of stromatolitic limestone and evaporites. The upper Viséan however displays several biologically induced constructions, including the mounds of the Visé stratotype as well as isolated zones of marine influence surrounded by very-shallow platform where stromatolites continued to form. Following the Viséan-Serpukhovian sea-level drop that ended the Viséan carbonate factory, the Namurian to Westaphalian siliciclastics reflect the forthcoming Variscan orogeny.

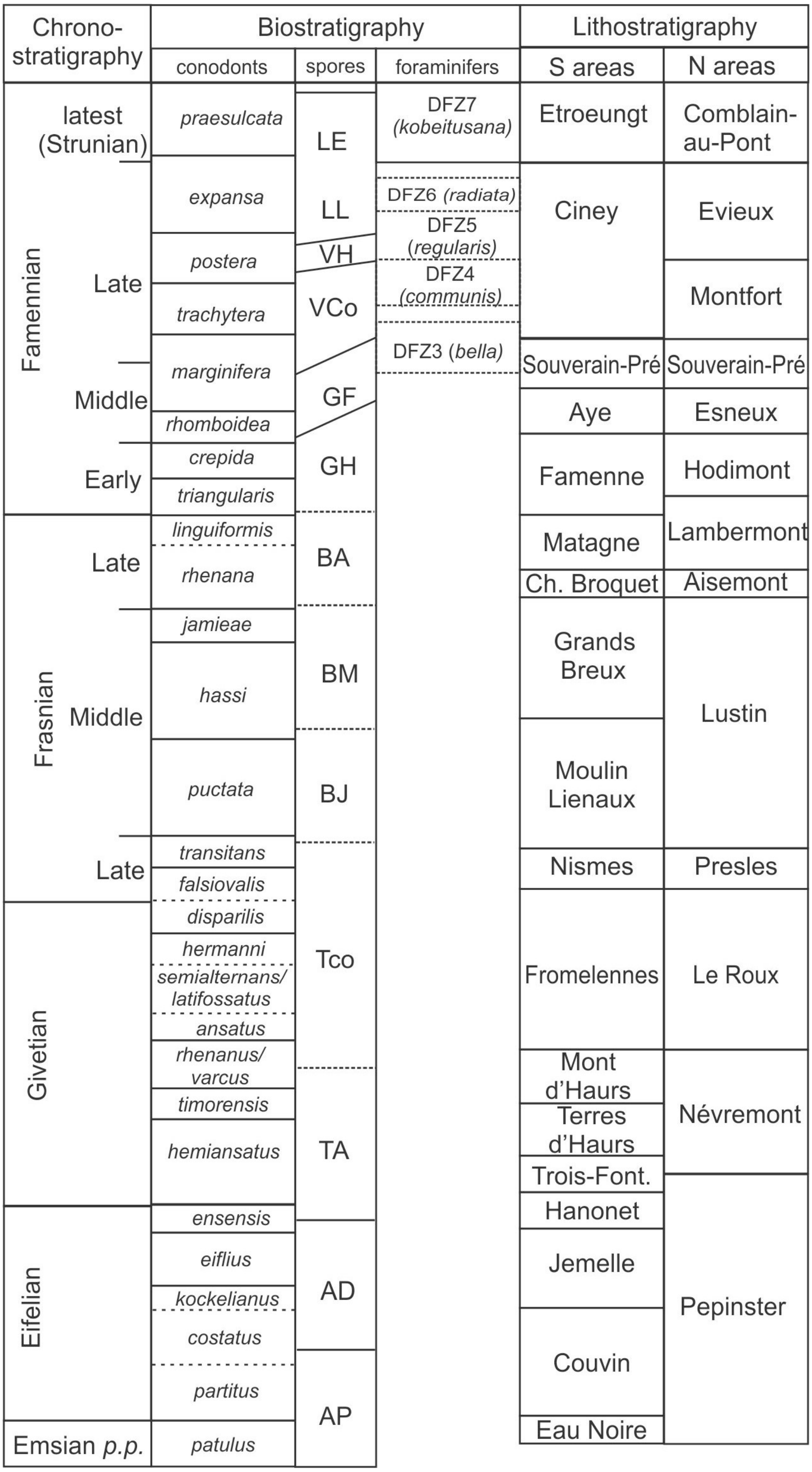

Figure 2: Biostratgraphic chart of the Middle and Upper Devonian of S Belgium. Standart conodont zones after (Ziegler & Sandberg, 1990, Belka et al., 1997 and Walliser and Bultynck, 2011); spores zones after Streel et al. (1987, 2021); foraminifer biozones after Conil et al. (1977) emended by Poty et al. (2006).

3. Lithostratigraphy and depositional evolution

3.1. Middle Devonian – Eifelian

The Eifelian depositional history effectively started in the Upper Emsian ('lower Couvinian') in the distal part of the Namur-Dinant Basin with a second-order transgression that led to a change from siliciclastic-dominated to carbonate-dominated depositional environment. Icriodid conodonts are very abundant in these facies and the first appearance datum (FAD) of *Icriodus retrodepressus* is commonly used for an approximate positioning of the Emsian-Eifelian boundary as the guide taxa *Polygnathus costatus partitus* is rare (Fig. 2). The boundary falls near the top of the Eau Noire Formation (Fm) in its stratotype (Bultynck & Godefroid, 1974).

Strong variations in lithological composition occurs along the southern limb of the Dinant Synclinorium (see Dumoulin & Blockmans, 2008; Denayer, 2019) (Fig. 3). The typical succession is known from Nismes to the French border westwards. The Saint-Joseph and Eau Noire formations correspond to bioclastic calcareous siltstone and shale. The c. 380 m-thick Couvin Fm is rather homogenous in this area (Marion & Barchy, 1999). It starts with the Villers-la-Tour Member (Mbr) typically made of stromatoporoid parabiostromes arranged in sequences. The Petigny Mbr recorded the maximum flooding of the eustatic sequence and the development of slightly dysoxic facies of the Choteč event (Denayer, 2019). The overlying Cul d'Efer Mbr saw the development of stromatoporoid-tabulate corals parabiostromes, capped by an emersion surface. The Abîme Mbr (160 m-thick) is dominated by massive biostromal beds alternating with fine-grained more restricted limestone. The Couvin Fm is capped by the Jemelle Fm (c. 300 m) composed of shale, calcareous shale and siltstone with some biohermal lenses in its upper part (Tienne Sainte-Anne Mbr). The uppermost part of the formation is silty or sandy. The Hanonet Fm is dominated by argillaceous limestone alternating with calcareous shale and laterally including stromatoporoid banks.

East of Nismes towards Givet, the lower three members of the Couvin Fm as well as the lower part of the Abîme Mbr are not recorded and are replaced by the Vieux Moulin Mbr of the Jemelle Fm, represented by siltstone and calcareous shale (Fig. 3). Only the uppermost 70 m of the Couvin Fm can be traced eastwards. The Chavées Mbr (upper member of Jemelle Fm) also covers the Couvin limestone. Between Givet and the Beauraing area (Figs 1, 3). It is however not the case in the Wancennes area where large bioherms are recorded (Wancennes Fm). In Wellin, dolostone with stromatoporoids (equivalent to the Abîme Mbr) is covered with a biohermal complex (Wellin Mbr, laterally passing to the Hanonet Fm; Coen-Aubert et al., 1991) (Fig. 3). In the Jemelle area and eastwards, the Saint-Joseph and Eau Noire formations are not distinguished anymore (Barchy & Marion, 2014). The Jemelle Fm is divided into three members (Bultynck et al., 1991): the Station Mbr (c. 40 m-thick, sandy shale), the Cimetière Mbr (c. 110 m, shale with limestone nodules) and Chavées Mbr (c. 40 m, shale and limestone beds). This last member is overlain with the 110 m-thick sandy Lomme Fm and with the argillaceous limestone of the Hanonet Fm. Northeastwards, the Saint-Joseph, Eau Noire and Jemelle formations progressively pass to the red siliciclastics of the Pepinster Fm. Westwards it passes to the Rivière Fm composed of the Rouillon (shale, sandstone, conglomerate) and Claminforge (calcareous shale and sandstone) members.

In conclusion, the Eifelian succession should be regarded as a transgressive deposit showing proximal siliciclastic facies in the northern part of the basin and purely marine argillaceous, mixed and carbonate facies in the southern part. Four third-order eustatic sequences are recorded between the uppermost Emsian and the lowermost Givetian. The first one – MD1 – started in the Saint-Joseph Fm and ended in the Cul d'Efer Mbr, MD2 covers the Abîme Mbr, MD3 is recorded in the Chavées Mbr, MD4 started in the Lomme Fm and ended in the lower part of the Givetian Trois-Fontaines Fm (Denayer, 2019).

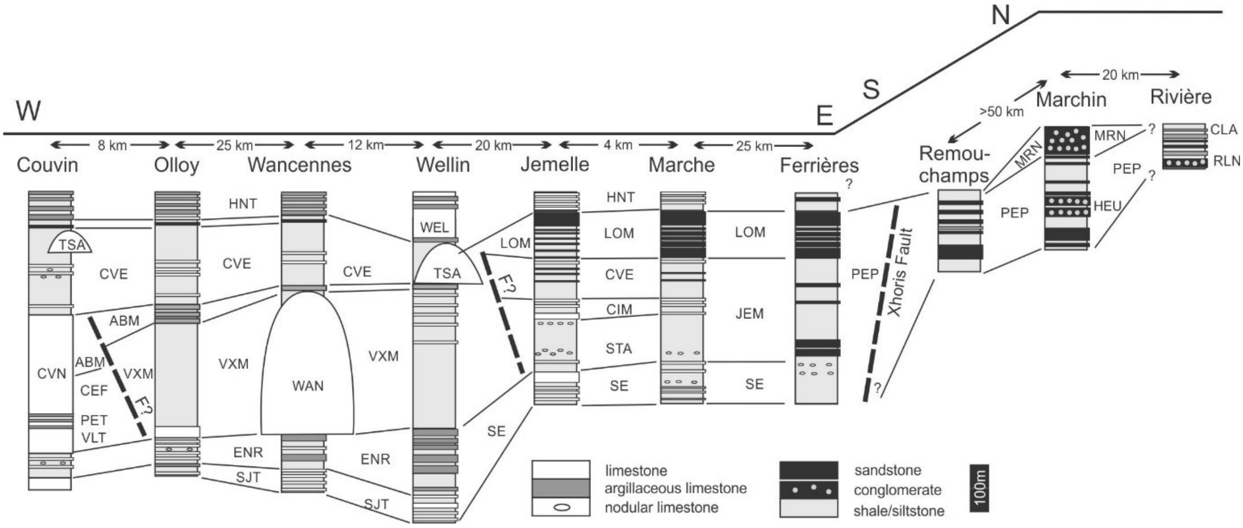

Figure 3: Lateral variation of lithostratigraphic units between the Couvin area (West), Ferrières (East) and Rivière area (North). Modified from Dumoulin & Blockmans (2008) with data from Barchy & Marion (2014 and in press), Marion & Barchy (in press) and Bultynck et al., 1991, 2000). Abbreviations: ABM: Abîme Mbr, CEF: Cul d'Efer Mbr, CIM: Cimetière Mbr, CLA: Claminforge Mbr, CVE: Chavées Mbr, CVN: Couvin Fm, ENR: Eau Noire Fm, HEU: Heusy Mbr, HNT: Hanonet Fm, JEM: Jemelle Fm, LOM: Lomme Fm, MRN: Marchin Mbr, RLN: Rouillon Mbr, PEP: Pepinster Fm, PET: Petigny Mbr, STJ: Saint-Joseph Fm, SE: Saint-Joseph–Eau Noire Gp, STA: Station Mbr, TSA: Tienne Sainte-Anne Mbr, VLT: Vilers-la-Tour Mbr, VXM: Vieux Moulin Mbr, WAN: Wancennes Fm, WEL: Wellin Fm, F: fault.

3.2. Middle Devonian – Givetian

Due to facies unsuitable for the polygnathid guides taxa across the Eifelian-Givetian boundary, the use of *Icriodus obliquimarginatus* as a marker for the boundary in southern Belgium was recommended by Bultynck et al. (2000) (Fig. 2). The FAD of *I. obliquimarginatus* falls within the Hanonet Fm, c. 42 m above the base of the formation in the Couvin area (Bultynck et al., 2000) in a darkish argillaceous limestone unit (Bultynck & Hollevoet, 1999). In proximal areas, the boundary is approximately located near the top of the Claminforge Mbr of the Rivière Fm (Bultynck & Boonen, 1977). The typical Givetian brachiopod taxa *Gerolsteinites givefex* and *Stringocephalus burtini* both appear in the lower part of the Trois-Fontaines Fm (Godefroid, 1995) and allow correlation with the Givetian of the Eifel Hills (Bultynck et al., 2000).

The Givetian succession is very regular along the southern limb of the Dinant Synclinorium, with a high lateral continuity of the sedimentary units (Tsien, 1971; 1976; Préat & Mamet, 1989), suggesting a smoothing of the topographies that dictated the deposition of the Eifelian formations (Fig. 4). The Givet Limestone Group starts with the Trois-Fontaines Fm which is dominated by bioclastic limestone with a basal biostromal unit. The upper part of the formation recorded more restricted environment, notably with the deposition of stromatolitic units (Bultynck et al., 1991). The Terres d'Haurs Fm differs from the previous formation by its higher argillaceous content. Its base is marked by a coral bed with *Argutastrea quadrigemina, Pachyfavosites* ssp. and *Thamnopora* ssp. that can be traced over tens of kilometres. The Mont d'Haurs Fm is characterised by thick-bedded limestone showing an alternation of biostromal and 'lagoonal' facies (Boulvain et al., 2009). The Fromelennes Fm is divided into three members: the Flohimont Mbr is typically composed of calcareous shale with bioclastic beds, the Moulin Boreux Mbr is made of sequential limestone (bioclastic-stromatolitic), the Fort Hulobiet Mbr is composed of argillaceous limestone with an abundant macrofauna (stromatoporoids, corals, brachiopods). Northwards those formations pass to the mixed carbonate-siliciclastic Névremont and Le Roux formations (Bultynck & Dejonghe, 2002). In the

Brabant Parautochthon (e.g. Ronquières area), only the Middle-Upper Givetian is recorded by the Bois de Bordeaux Fm (red siliciclastics and mixed carbonate-siliciclastics) which rests unconformably upon the Lower Palaeozoic basement (Bultynck et al., 1991).

The Givetian can be considered as in continuity of the transgression started in the Eifelian, with the establishment of carbonate platform facies in the context of a high relative sea level. The third-order sequence MD4, starting in the Eifelian, ended in the Trois-Fontaines Fm. The sequence MD5 covers the Terres d'Haurs and Mont d'Haurs formations whereas the Fromelennes Fm recorded the entire sequence MD6 and is marked by a very sharp sequence boundary at the top, interpreted as a major subaerial erosive surface.

The Taghanic Event does not appear as a punctual event but covers the *ansatus* to *semialternans* zones and is consequently spread along the whole Fromelennes Fm with decoupled extinctions within ostracods (Maillet et al., 2013), corals (Coen-Aubert, 2004) and brachiopods (Brice et al., 2000). The brutal shift of sedimentation at the Givetian-Frasnian boundary is interpreted as the drowning of the platform with a major increase in sediment input and with a major rise in sea-level in the Frasnian (Bultynck et al., 2000; Casier et al., 2013). The Frasnes event corresponds to the development of shaly facies at the base of the Frasnian (Becker, 1993) and is associated with significant faunal turnover, notably among corals and stromatoporoids.

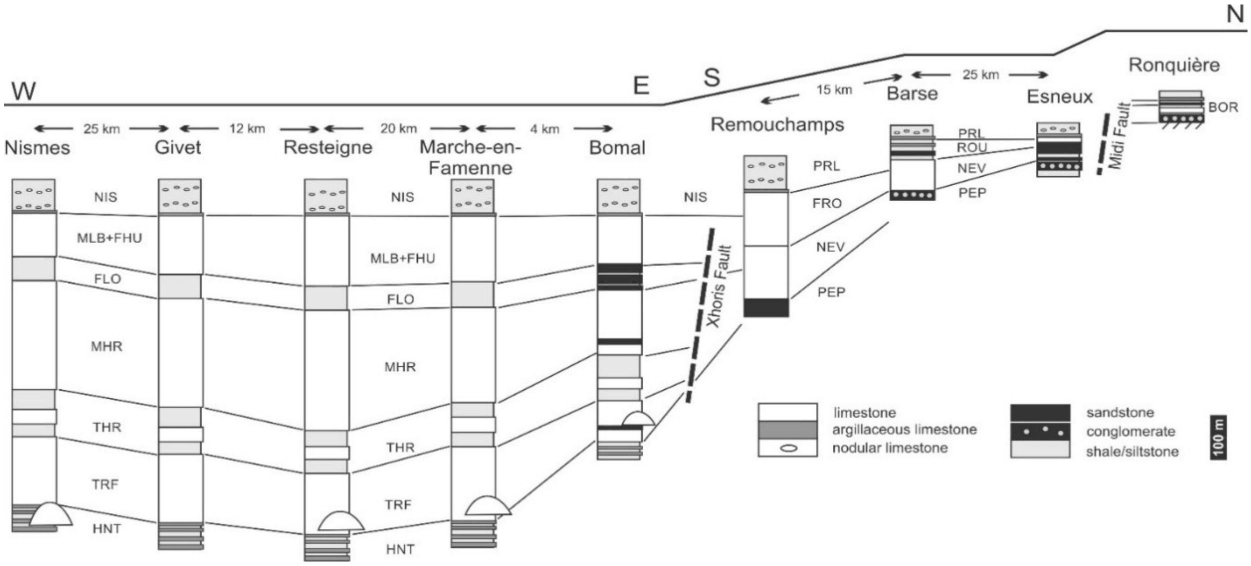

Figure 4: Lateral variation of lithostratigraphic units between the Couvin area (west), Bomal (east) and Ronquières area (north). Modified from Bultynck & Hollevoet (1999), Bultynck et al. (2000), Bultynck & Dejonghe (2002), and Mottequin et al. (2014, 2021). Abbreviations: BOR: Bois-de-Bordeaux Fm, FLO: Flohimont Mbr, FHU: Fort Hulobiet Mbr, FRO: Fromelennes Fm, HNT: Hanonet Fm, MHR: Mont d'Haurs Fm, MLB: Moulin Boreux Mbr, NEV: Névremont Fm, NIS: Nismes Fm, PEP: Pepinster Fm, PRL: Presles Fm, ROU: Le Roux Fm, THR: Terres d'Haurs Fm, TRF: Trois-Fontaines Fm.

3.3. Late Devonian – Frasnian

The Frasnian starts with the essentially shaly Nismes Fm (c. 40 m) with some carbonate beds in its lowermost part. The Givetian-Frasnian boundary is located < 1m above the base of the formation and marked by the FAD of the conodont *Ancyrodella rotundiloba* (Bultynck et al., 2000; Fig. 2). Along the southern limb of the Dinant Synclinorium, the classical succession is composed of the Moulin Liénaux Fm (*transitans* to *punctata* zones), Grands Breux Fm (*hassi* to lower *rhenana* zones), Champs Broquet Fm (*rhenana* zone) and Matagne (upper *rhenana* to lower *triangularis* zones). This package reaches 400 m in thickness.

The Moulin Liénaux Fm includes the Chalon Mbr (shale and argillaceous nodular limestone), Arche Mbr (limestone lenses rich in stromatoporoids, corals and stromatactis) and Ermitage Mbr (shale with some beds of nodular limestone) (Bultynck & Mouravieff, 1999). Locally, a fourth limestone member (La Boverie Mbr) is developed (Boulvain & Coen-Aubert, 2006) (Fig. 5). The Grands Breux Fm is composed of the Bieumont Mbr (micritic to bioclastic, argillaceous limestone), Lion Mbr (greyish massive carbonate buildup, up to 300 m-thick) and Boussu-en-Fagne Mbr (shale with some nodular levels and limestone beds) (Coen-Aubert & Boulvain, 1999). The Champs Broquet includes the Neuville Mbr (nodular limestone with shaly beds), Les Valisettes Mbr (shale) and Petit-Mont Mbr. The latter comprises of reddish carbonate buildups (30 to 80 m-thick), developed either within the Neuville or Les Valisettes Mbr (Coen-Aubert, 2015). The Matagne Formation starts with one or several beds of limestone with goniatites and bivalves followed by fine greenish to brown to black shale. It is highly diachronous (Bultynck et al., 1998) and replaced eastwards by the Barvaux Fm (purplish to green shale, Coen, 1999) (Fig. 5).

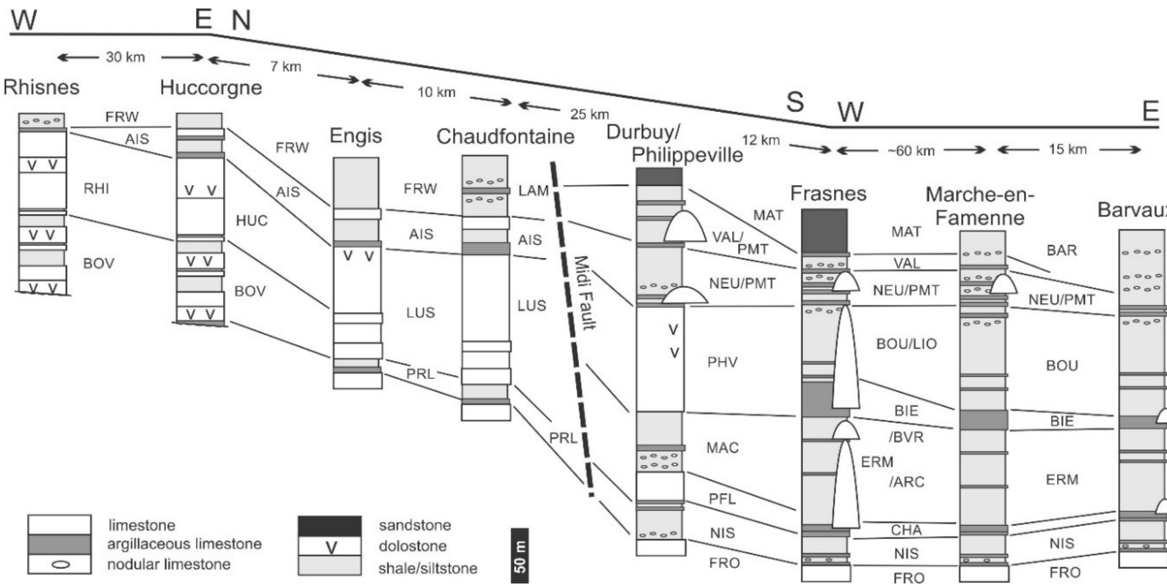

Figure 5: Lateral variation of lithostratigraphic units between the Rhisnes area (North), Durbuy (East) and Frasnes (South). Modified from Boulvain et al. (1999); Poty & Chevalier (2007) and Mottequin & Poty (2016). Abbreviations: AIS: Aisemont Fm, ARC: Arche Mbr, BAR: Barvaux Fm, BIE: Bieumont Mbr, BOU: Boussu-en-Fagne Mbr, BOV: Bovesse Fm, BVR: Boverie Mbr, CHA: Chalon Mbr, ERM: Ermitage Mbr, FRO: Fromelennes Fm, FRW: Franc-Waret Fm, HUC: Huccorgne Fm, LAM: Lambermont Fm, LIO: Lion Mbr, LUS: Lustin Fm, MAC: Machenées Mbr, MAT: Matagne Fm, NIS: Nismes Fm, PMT: Petit Mont Mbr, PFL: Pont-de-la-Folle Mbr, PRL: Presles Fm, RHI: Rhisnes Fm, VAL: Les Valisettes Mbr.

In the Philippeville–Durbuy Anticlinorium, the Moulin Liénaux passes laterally to the Pont de la Folle Fm that includes the Fontaine Samart Mbr (limestone) and the Machenées Mbr (nodular shale) members (Boulvain et al., 1999) (Fig. 5). It is overlain by the bedded, frequently dolomitized stromatoporoid limestone of the Philippeville Fm. The Neuville Mbr rests abruptly on the Philippeville Fm and is overlaid by the shaly Les Valisettes Mbr (lateral equivalent of the basal Matagne Fm). Greenish to reddish nodular limestone and shale develop in the vicinity of the buildups of the Petit-Mont Mbr (Boulvain et al., 1999). The Matagne Fm is here reduced in thickness and displays only a dark shaly facies.

In the northern areas (northern limb of the Dinant Synclinorium, HSM OTS and Vesdre area, Fig. 1), the Frasnian succession displays proximal facies starting with the Presles Fm (shale with thin limestone beds and a horizon with haematitic or chamositic oolites) belonging to the *falsiovalis* to *transitans* zones (Coen-

Aubert & Lacroix, 1985). It is overlaid by the Lustin Fm (thick-bedded limestone rich in corals and stromatoporoids (*punctata* to lower *rhenana*, Coen-Aubert & Coen, 1974) and by the Bovesse, Huccorgne and Rhisnes formations in the Brabant Parautochthon. The Aisemont Fm (lower *rhenana* to basal upper *rhenana* Zone) comprises limestone and argillaceous limestone in its lower and upper parts; the middle part consists of shale and nodular shale (Lacroix, 1999). Both limestone horizons are known in the Belgian literature as the first and second '*biostromes with Phillipsastrea'* of Coen-Aubert & Lacroix (1979) but the '*second biostrome'* is devoid of biostromal units (Denayer & Poty, 2010).

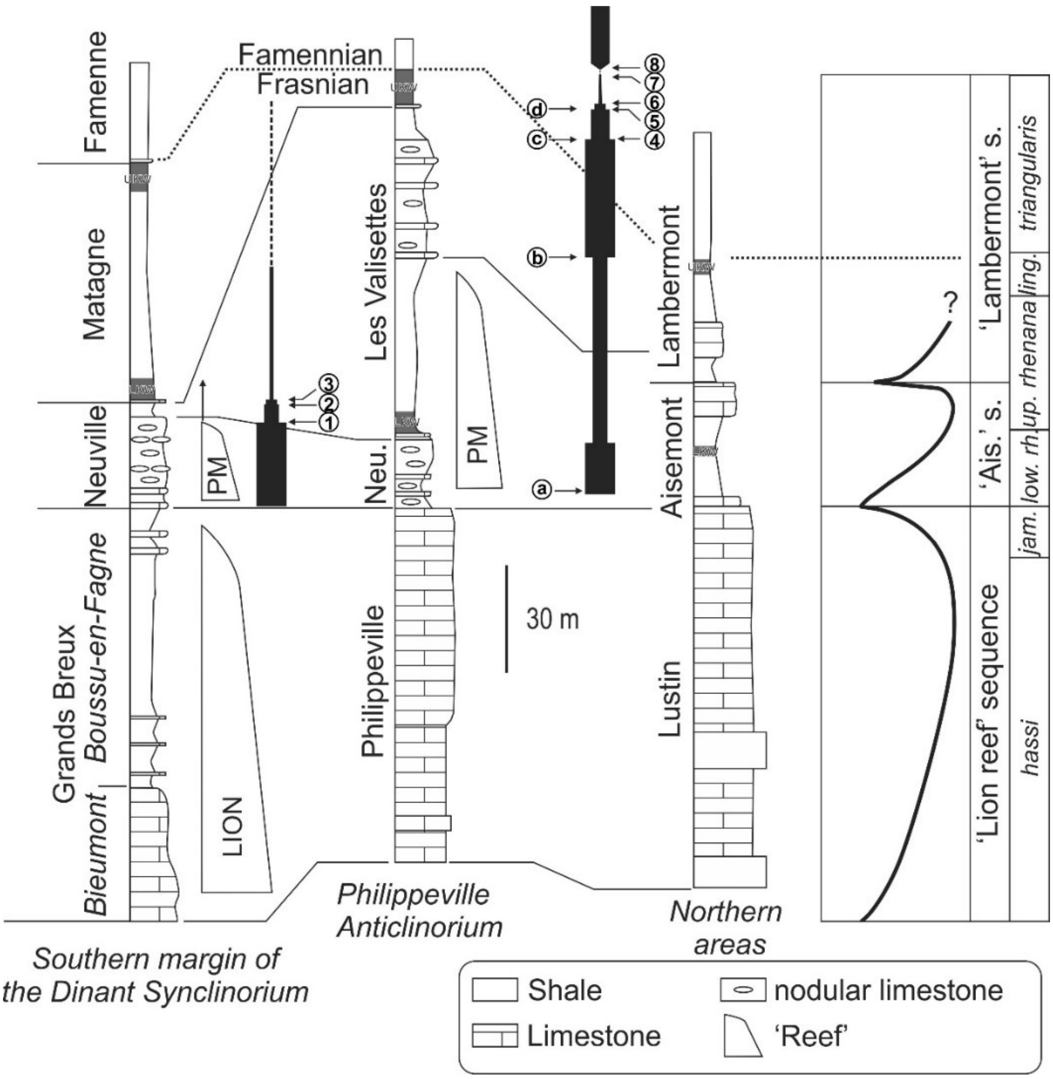

Figure 6: Mid- to Upper Frasnian lithostratigraphy of southern Belgium with sequence stratigraphy and comparison between the different extinction and recovery phases observed among the brachiopods and rugose corals from the southern margin of the Dinant Synclinorium and the Philippeville Anticlinorium (Neuville railway section) (modified from Boulvain et al., 1999a and Mottequin & Poty, 2016). Conodont data are from Bultynck et al. (1998). LKW, Lower Kellwasser; UKW, Upper Kellwasser. Brachiopods: (1) local disappearance of pentamerides; (2) local disappearance of atrypides; (3) first occurrence of Ryocharhynchus tumidus *(rhynchonellide); (4) last occurrence of pentamerides; (5) last occurrence of atrypides; (6) first occurrence of* R. tumidus *and decimation of the last Frasnian representatives of the strophomenoids (strophomenides), productides, spiriferides, athyridides and orthides, etc.; (7) disappearance of* R. tumidus*; (8) appearance of new spiriferide, athyridide and rhynchonellide species. Corals: (a) extinction of thamnoporoids and disphyllids, and replacement by phillipsastreids ('fauna 1' of Coen et al., 1977); (b) appearance of* Iowaphyllum *('fauna 3' of Coen et al., 1977); (c) extinction of all the colonial and dissepimented solitary rugose corals; and (d) extinction of the last non dissepimented solitary rugose corals. Abbreviations: Ais., Aisemont; s., sequence, LKW, Lower Kellwasser; PM: Petit Mont Member; UKW, Upper Kellwasser.*

The Lambermont Fm (upper *rhenana* to *triangularis* zones) consists of shale and nodular shale with intercalations of limestone beds (Laloux & Ghysel, 1999). Its middle part is characterised by the third *'biostrome'*, which is especially developed in the Vesdre area and consisting of argillaceous, nodular limestone with a biostromal bed with massive rugose corals. The Late Frasnian Crises started near the Middle-Upper Frasnian boundary (close to the base of the lower *rhenana* Zone, Fig. 6), at the top of the Grands Breux, Philippeville and Lustin formations where extinctions amongst macrofauna are recorded (Poty & Chevalier, 2007) (Fig. 6). The Lower Kellwasser Event has been proven to be related to a third order transgression (*semichatovae* Transgression) bringing anoxic water onto the platform but extinctions are diachronic and clearly linked to the progression of the anoxia (Mottequin & Poty, 2016). The Lower Kellwasser Event is recognised at the base of the Matagne and the Les Valisettes formations and within the middle member of the Aisemont Fm (Bultynck et al., 1998; Poty & Chevalier, 2007). The Upper Kellwasser Event covers the upper part of the Matagne and Barvaux formations and the middle part of the Lambermont Fm within the *linguiformis* Zone (Bultynck et al., 2000) (Fig. 6).

In terms of sequence stratigraphy, a third order sequence UD1 started in the Nismes and Presles formations and ended at the top of Moulin-Liénaux and Pont de la Folle formations, sequence UD2 (or 'Lion reef sequence' sensu Mottequin & Poty, 2016) covers the Grands Breux, Philippeville and Lustin formations. The sequence UD3 (or 'Aisemont sequence' sensu Mottequin & Poty, 2016, Fig. 6) covers the Champs Broquet and Aisemont formations. A last sequence UD4 is recorded in the upper Frasnian shale of the Matagne and Lambermont formation and ended in the lowermost Famennian Famenne Formation.

3.4. Late Devonian – Famennian

The conodont zonation was successfully applied on the Famennian succession (Bouckaert et al., 1965; 1968; Dusar & Dreesen, 1984; Conil et al*.,* 1986; Dreesen, 1986), together with the palynostratigraphy (Streel et al., 1987, Higgs et al., 2013, Prestianni et al., 2016) and later complemented by the study of foraminifers (Bouckaert et al., 1965), ostracods (Becker et al., 1974) (Fig. 2) and, for the lower(most) Famennian, brachiopods (Sartenaer, 1957) and acritarchs (Vanguestaine et al., 1983). These cross-biostratigraphies allowed a detailed subdivision of the Belgian Famennian and the identification of several events.

The argillaceous deposition established in the Upper Frasnian continued through a large part of the Lower Famennian with no major change of facies across the Frasnian-Famennian boundary. The Famenne Fm is a rather thick and monotonous greyish to greenish shaly unit with some bioclastic beds sometimes rich in fauna but poorly diverse. In proximal areas, the basal Famennian is marked by oolitic haematitic horizon in the Falisolle and Franc-Waret formations (levels I and II of Dreesen, 1986, Fig. 7) that is interpreted as material reworked by storm events and mark transgressive pulses (Dreesen, 1982). Another oolitic horizon (level III of Dreesen, 1986) occurs at the top of the Famenne Fm and equivalent and has been correlated eastwards to the *Cheiloceras* limestone of western Germany (Dreesen, 1982). The three oolitic haematitic horizons described by Dreesen (1982) have been correlated by Becker (1993) respectively to the Nedhen event (horizon II) and the Condroz event (horizons IIIa-b). Coarser siliciclastics deposition started with the Esneux Fm. It consists of thinly-bedded micaceous siltstone and passes laterally to the Aye shaly Fm and Watissart sandstone Mbr respectively southwards and westwards (Thorez et al., 2006). Starting with a fourth haematitic horizon (questionably correlated with the Enkenberg pulse), the Souverain-Pré Fm is a transgressive carbonate unit consisting of nodular silty limestone, commonly sandy in proximal areas and argillaceous in distal parts (Fig. 7).

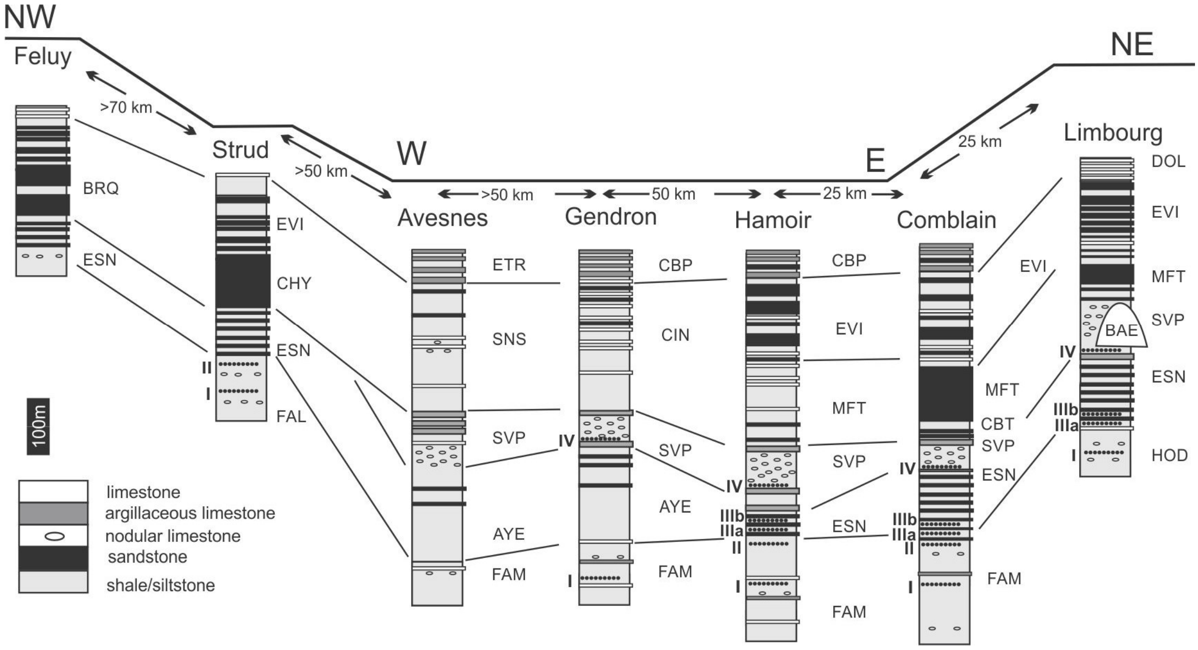

Figure 7: Lateral variation of the Famennian lithostratigraphic units between the Feluy area, Avesnes and Limbourg area. Modified from Thorez et al. (2006) and Denayer et al. (2016a). Roman numerals correspond to oolitic ironstone levels (Dreesen, 1982). Abbreviations AYE: Aye Fm, BAE: Baelen Mbr, BRQ: Bois-de-la-Rocq Fm, CHY: Citadelle de Huy Fm, CBP: Comblain-au-Pont Fm, CBT: Comblain-la-Tour Fm, ESN: Esneux Fm, ETR: Etroeungt Fm, EVI: Evieux Fm, FAL: Falisolle Fm, FAM: Famenne Group, HOD: Hodimont Fm, MFT: Monfort Fm, SAN: Sains Fm, SVP: Souverain-Pré Fm.

The limestone is a wackestone-packstone with abundant crinoid and brachiopods debris. The formation has been dated of the upper *marginifera* Zone in the southern part of the Namur-Dinant Basin and to the uppermost *marginifera* and lower *trachytera* zones in the northern part (Bultynck & Dejonghe, 2002). In the Vesdre area, the formation passes to the Baelen Mbr that constitutes one of the rare examples of Famennian reef known worldwide. The reef includes a microbialitic core with stromatactoid cavities and reddish facies. The flanks facies are mainly crinoid accumulation in a reddish, locally highly argillaceous matrix (see Dreesen et al., 2013, Vachard et al., 2017).

After this carbonate episode, the siliciclastic sedimentation returned. The Comblain-la-Tour and Monfort formations are dominated by thick-bedded arkosic sandstone deposited as a sand barrier (Thorez & Dreesen, 1986). In the proximal zones, it is replaced by the massive red sandstone of the Citadelle de Huy Fm (Thorez et al., 2006). The *annulata* Event is recorded by the shaly Bon Mariage Mbr of the Evieux Fm (Thorez et al., 2006). The overlying Evieux Fm is composed of several members all corresponding to a peculiar environment. The Royseux Mbr corresponds to rhythmic alternations of sandstone, mudstone and palaeosols (including dolcretes). The Crupet Mbr corresponds to alluvial red siliciclastics including dolcretes and channels with bone beds and plant accumulations. The latter yields abundant vertebrates (including tetrapods), arthropods and a diverse flora (see Denayer et al., 2016a). Distally, the Evieux Fm passes to the rhythmic Beverire Fm, then basinwards, to the Ciney Fm, a thick sequence of siliciclastic and carbonate alternations corresponding to a barrier system (Thorez et al., 1988). All these formations grade to the purely marine shaly units of the Sains Fm in the southwestern part of the basin (Avesnois area). The Evieux Fm and lateral equivalent witness the maximum of regression of the Famennian sequence. It is followed by a major transgression marking the return of marine settings and fauna on the internal to median ramp environment under the influence of both detrital and marine inputs (Thorez & Dreesen, 1986; Paproth et al., 1986; Van Steenwinkel, 1990). The lithostratigraphic unit composed of an alternation of carbonate and shale is named Comblain-au-Pont Formation in the northeastern part of the Namur–Dinant Basin (Condroz sedimentation area), Etroeungt Fm in the Avesnois area (Avesnois sedimentation area) and Dolhain Fm, known in the eastern part of the basin (Vesdre-Aachen sedimentation area) characterised by stromatoporoid biostromes. These three formations are lateral equivalent of each other, and their composition shows a proximal-distal gradient oriented NE-SW (Devuyst et al., 2005).

This transgression corresponds to the Epinette Transgression of Paproth et al. (1991) and to the sequence 1 of Hance et al. (2001). It also coincides with the Strunian biodiversification event of macrofauna (Poty, 1999). All these formations show a cyclic pattern interpreted by Poty (2016) as eccentricity-driven climatic oscillations (Fig. 8). The Hangenberg event and the Devonian-Carboniferous boundary, recorded at the top of these units, are not in sequence with the cycles, witnessing their complete independency of the sedimentation record (Poty, 2016). The Hangenberg Black Shale event (HBS, *praesulcata* Zone) has been recognized in the uppermost Famennian Comblain-au-Pont and Etrœungt formations with the record of several decimetre-thick dysoxic shaly units whereas the very base of the Hastière Fm is correlated with the Hangenberg Sandstone event (Poty, 2016; Denayer et al., 2021). This unit exposes at its base one bed including Devonian faunas (quasiendothyrid foraminifers, campophyllid corals, phacopid trilobites), limestone intraclasts and detrital grains. Hence this basal bed is still clearly Devonian in age but more likely indicate that these faunas were contemporaneous with the reworking due to the Hangenberg Sandstone sea-level fall (Denayer et al., 2021) (Fig. 8).

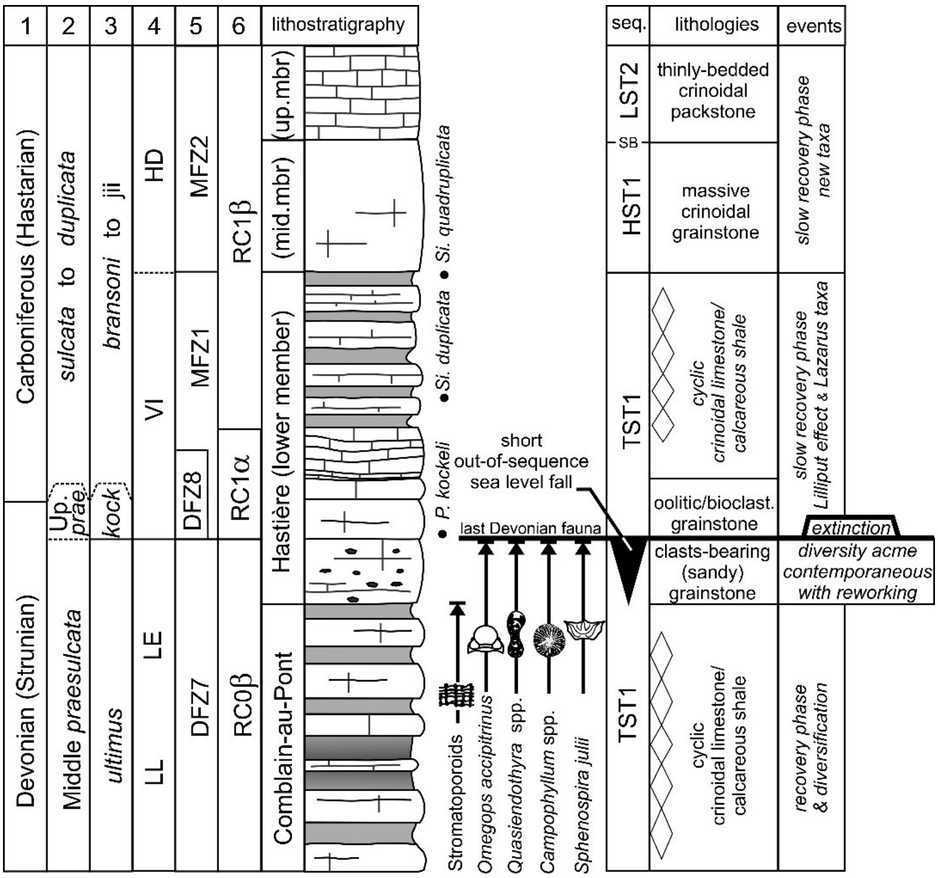

Figure 8: Bio and sedimentological events across the Devonian-Carboniferous Boundary in the Namur–Dinant Basin. 1, Chronostratigraphy. 2, Standard conodont zones of Ziegler and Sandberg (1990). 3, Revised conodont zones sensu Corradini et al. (2017). 4, Miospore palynozones from Streel et al. (1987), emended by Prestianni et al. (2016), 5, Foraminifer zones according to Poty et al. (2006), emended by Poty (2016). 6, Rugose coral zones according to Poty et al. (2006). Abbreviations: kock., kockeli; P., Protognathodus; Si., Siphonodella. *After Denayer et al. (2021).*

3.5. Early Carboniferous – Tournaisian

During the Late Devonian, the Namur-Dinant Basin displayed a strong subdivision into sedimentation areas interpreted as the result of synsedimentary block-faulting and differential subsidence (Thorez & Dreesen, 1986). This trend continues during the early Carboniferous with the individualisation of six sedimentary areas (Hance et al., 2001, emended by Poty et al., 2006 and Poty, 2016): The Namur sedimentation area (NSA) located south of the Brabant Parautochthon; the Condroz sedimentation area (CSA), which is the southern extension of the NSA and presents proximal marine facies; the Dinant sedimentation area (DSA) that is relatively deeper and influenced by the Waulsortian complex (both CSA and DSA are in the Dinant Synclinorium); the highly subsiding Hainaut sedimentation area (HSA); the Vesdre-Aachen sedimentation area (VASA) that is the lateral extension of the NSA; the Avesnois sedimentation area (ASA) which presents similar facies to CSA south of the DSA (within the western termination of the Dinant Synclinorium) (Fig. 9).

The Hastarian (lower Tournaisian) succession is rather uniform throughout all the sedimentation areas of the Namur–Dinant Basin. Towards the south, the succession becomes thicker and more complete. The inherited Late Devonian palaeotopography showing rather deeper facies in the south indicates a very slowly dipping ramp setting for the Hastarian (Hance & Poty, 2006). The Hastière Fm recorded bioclastic and crinoidal accumulation with some argillaceous interbeds arranged in cycles. The Pont d'Arcole Fm is a shaly unit corresponding to the development of dysoxic shale facies on the carbonate ramp in link with a change of accommodation and perhaps a reduction of carbonate production. The gradual changes from and to the underlying and overlying formations and the abundance of fossils in the Pont d'Arcole Fm may not fully support the idea of a disastrous black shale event as the Lower Alum Shale event well developed in the Rhenish Mountains (Amler & Herbig, 2006). However, this level corresponds to a turnover phase in the coral and foraminifer fauna. The Landelies Fm recorded the return of 'normal' carbonate sedimentation dominated by crinoidal packstone-grainstone and shows a remarkable regularity all over the Namur–Dinant Basin demonstrating its HST character. Sequence 2 starts abruptly in the DSA and CSA with the upper member of the Hastière Fm (LST?-TST) and the Pont d'Arcole Fm (TST). The medium to thick-bedded crinoidal limestones of the Landelies Fm form the HST and FSST.

All these lithostratigraphic units show a striking cyclic development, interpreted as orbitally-forced climatic sequences (greenhouse-icehouse eccentricity cycles, Poty 2016). The sequences vary from alternations of shale and calcareous shale or limestone 0.2 m to 1 m-thick.

After the deposition of the Landelies Fm, the topography of the ramp changed and a strong proximo-distal pattern develops. It is probably due to synsedimentary faulting and consequent deepening of the Dinant sedimentation area where Waulsortian complex started growing (Hance et al., 2001, 2002).

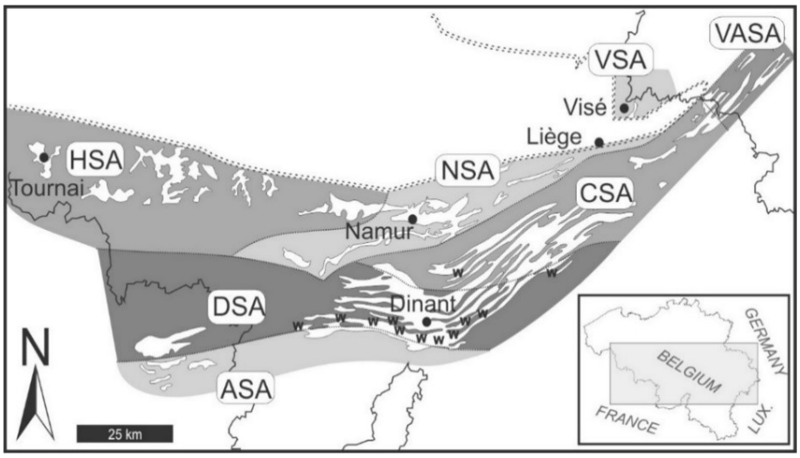

Figure 9: sedimentation areas in the Namur - Dinant Basin (modified from Poty, 2016). Abbreviations: ASA: South Avesnois sedimentation area, CSA: Condroz sedimentation area, DSA: Dinant sedimentation area, HSA: Hainaut sedimentation area, NSA: Namur sedimentation area, VASA: Vesdre-Aachen sedimentation area, VSA: Visé -Maastricht sedimentation area, W: Waulsortian mounds.

The Waulsortian complex includes the Waulsort mounds (crinoidal packstone and polymud with numerous fenestellid bryozoans and cement-filled stromatactoid cavities), passing laterally to the Bayard (crinoidal packstone-grainstone) and Leffe formations (bioclastic and peloidal wackestone, see Moniat Rock and Dinant section below).

North of the Yvoir-Ciney line, the Ivorian (upper Tournaisian) facies are typically shallower in the CSA (Yvoir, Ourthe, Martinrive and Longpré formations). Similarly, south of the Waulsortian development, the ASA shows shelf facies similar to those of the CSA (Fig. 10). In the NSA and VASA, the succession is similar but often dolomitised (Namur, Engihoul and Vesdre dolostone). The Maurenne Fm, Bayard Fm and Hun Mbr (Yvoir Fm) corresponds to the LST whereas the Yvoir and Waulsort formations form the TST respectively in the CSA and DSA. The HST are represented by the Ourthe and Waulsortian facies in the CSA and DSA. Sequence 4A is represented in the DSA by the LST-TST deposits of the lower part of the Leffe Fm and in the CSA with the TST-HST deposits of the Martinrive Fm in the CSA. The crinoidal rudstone of the Flémalle Mbr and the overlying oolitic limestone of the Avins Mbr correspond to the TST and HST-FSST of sequence 4B in the CSA and correlate with a third development of Waulsortian facies in the DSA. The latest Ivorian Avins event (Poty, 2007) is the first significant diversification event following the relatively poorly diversified Tournaisian. It is commonly recorded as oolitic limestone with an abundant fauna that suddenly became cosmopolitan. Poty (2007) interpreted it as linked to a very high sea-level period that allowed communication between basins and momentary break-down of palaeobiogeographic barriers.

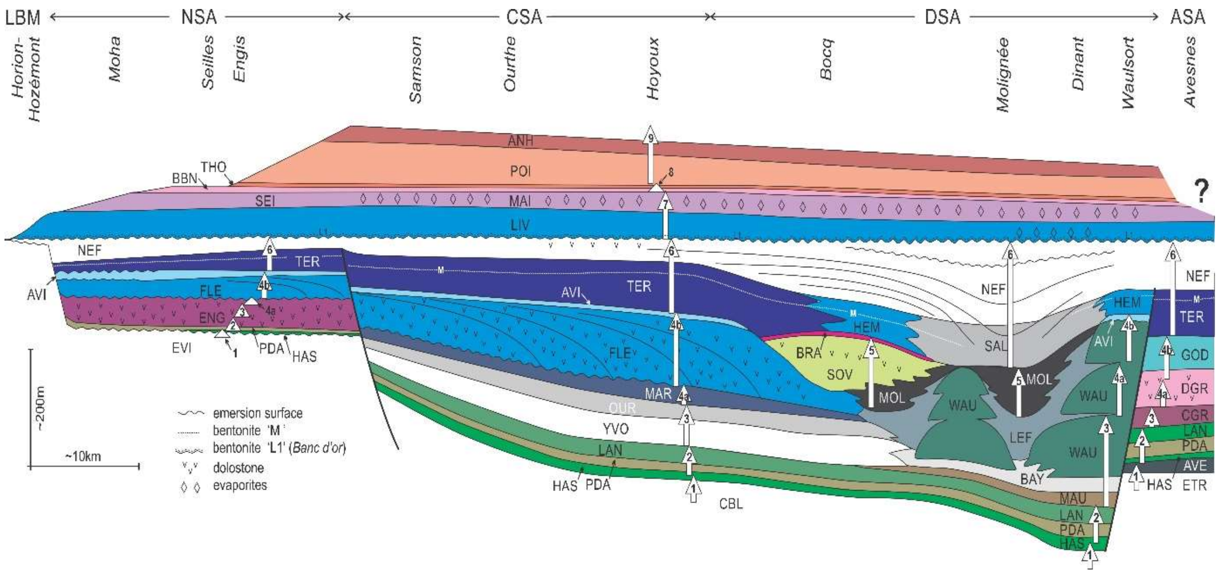

Figure 10: North-South transect through the Dinant-Namur Basin showing the spatial relationship of the lithostratigraphic units and their eustatic interpretation (modified from Hance et al., 2001 and Poty, 2016). Abbreviations: ANH: Anhée Fm, AVE: Avesnelles Fm, AVN: Avins Mbr, BAY: Bayard Fm, BBN: Bay-Bonnet Mbr, BRA: Braibant Mbr, CBL: Comblain-au-Pont Fm, CGR: Grives Limestone, CSA: Condroz sedimentation area, DGR: Grives Dolostone, DSA: Dinant sedimentation area, ENG: Engihoul Fm, ETR: Etroeungt Fm, EVI: Evieux Fm, FLE: Flémalle Mbr, GOD: Godin Fm, HAS: Hastière Fm, HEM: Hemptinne Fm, LAN: Landelies Fm, LEF: Leffe Fm, LIV: Lives Fm, MAI: Maizeret Mbr, MAR: Martinrive Fm, MAU: Maurenne Fm, MOL: Molignée Fm, NEF: Neffe Fm, NSA: Namur sedimentation area, OUR: Ourthe Fm, PDA: Pont d'Arcole Fm, POI: Poilvache Fm, SAL: Salet Fm, SEI: Seilles Mbr, SOV: Sovet Fm, TER: Terwagne Fm, THO: Thon-Samson Mbr, WAU: Waulsort Fm, YVO: Yvoir Fm. Scale indicative but not exact.

3.6. Early Carboniferous – Viséan

Straddling the Tournaisian-Viséan boundary, the Waulsortian complex still influenced the sedimentation in the DSA (Fig. 10) with the deposition of the restricted turbiditic facies (e.g. Overlau, 1966, Hance, 1988, Mottequin, 2004, 2008a) of the Molignée Fm ('black marble' facies) developed in a depression at the prograding inner-outer shelf transition (Lees, 1997). It is correlated in platform settings by a karstic surface and associated gap. It is recorded as 'black marble' facies of the Molignée Fm only in the southern DSA and as carbonate units in deep basinal settings in the basal Viséan (e.g. Faugères Fm in Montagne Noire; Aretz, 2016).

This peculiar facies records a switch in the cyclic deposition pattern from short-term climatic cycles in the Tournaisian to a parasequence-based pattern that dominates during the whole Viséan and probably witnesses the onset of the Viséan glaciation. Submarine topographic irregularities inherited from different sedimentation rates and Waulsortian buildups were smoothed out in the late Moliniacian (early Viséan) sequence 6. Evaporitic facies developed in the CSA and NSA (lower part of the Terwagne Fm) are interpreted as the LST resting disconformably upon the Avins Mbr (FSST of sequence 4B) with local karst development. In the DSA, the Salet Fm and, further south, the upper part of the black limestones of the Molignée Fm forms the LST and TST of sequence 6. In the entire Namur–Dinant Basin, the sequence 6 ends with the thick-bedded packstones and grainstones of the Neffe Fm (Figs 10, 11) as the HST and FSST (high energy oolitic, peloidal and bioclastic facies). This formation is capped by the *Banc d'Or de Bachant*, a pedogenetised bentonite (Delcambre, 1989). The *Banc d'Or de Bachant* (also known as *bentonite L1*), defines the base of the Livian regional substage, it yielded a U–Pb zircon chemical abrasion isotope dilution thermal ionisation mass spectrometry date of 341.2 Ma (Pointon et al., 2018).

During the Livian (middle Viséan) and much of the Warnantian (late Viséan), sedimentation was controlled by an aggrading shelf and glacio-eustatic sea-level fluctuations (Chevalier et al., 2006). Resulting parasequences can be correlated along the entire Belgian shelf and from the Aachen area in Germany towards the Bristol area in Britain (Hance et al., 2001).

The Livian is characterised by a change in basin geometry due to the onset of the Variscan movements, open marine facies develop to the north, whereas restricted facies and evaporites (and associated collapse breccia) developed in the south and west (HAS, cf. Saint Ghislain anhydrite). Sequence 7 includes the LST (Haut-le-Wastia Mbr), TST (Corphalie and Awirs Mbrs) and HST(-FSST?) (Seilles and Maizeret members). Sequence 8 corresponds to the stromatolitic limestones of the Bay-Bonnet Mbr (LST and TST) and to the bioclastic limestone of the Thon-Samson Mbr (HST) of the Bonne Fm. The low diversity of the Livian – though, without marked extinction – is a common phenomenon at the global scale for this time-slice. The shallow-water sedimentation continues through the Warnantian (Late Viséan) during the sequence 9 that covers the Poilvache Mbr (LST?-TST) and the Anhée Fm (HST). Except in the VSA where large bioherm developed with an abundant fauna, the Warnantian is very monotonous (Hance & Poty, 2006). Very locally in the DSA, inner platform sedimentation (sequential microbial limestone) is interrupted by the deposition of small (plurimetric) coral biostromes (Aretz, 2001). This last sequence is lacking in many parts of the NSA, VASA and ASA, due to non-deposition or subsequent erosion (Figs 10, 11). In the NSA and VSA, the lower Namurian siliciclastics fill palaeokarstic depressions reaching up to the Livian formations. The late Viséan recorded a significant sea-level fall (glaciation?) that corresponds to an emersion of the carbonate platform associated to extinctions in shallow-water communities (Hance et al., 2001).

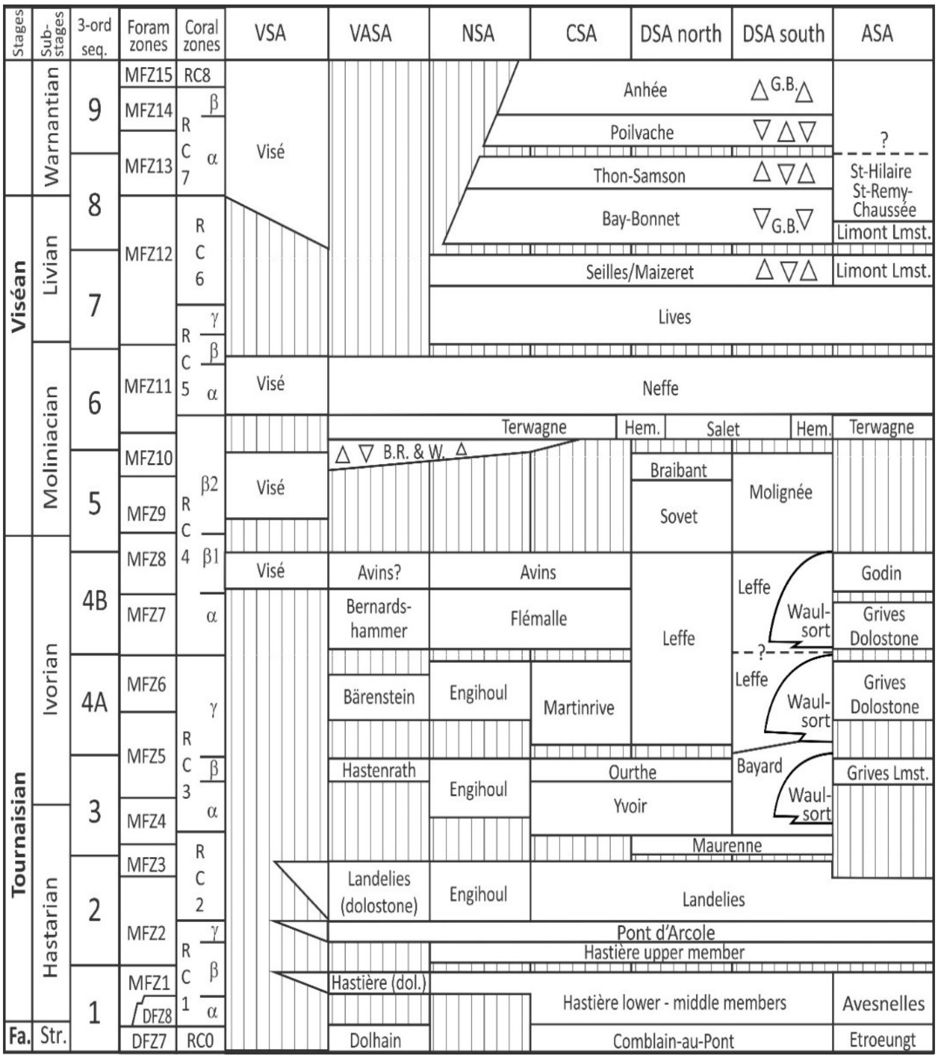

Figure 11: Biostratigraphic and lithostratigraphic chart of the lower Carboniferous of S Belgium. Emended by Poty et al. (2006) and Poty (2016).

3.7. Early and late Carboniferous: Namurian-Wesphalian (Serpukhovian-Bashkirian)

The Coal Measures corresponds to a c. 4.000 m-thick sequence of molasses sediments filling the variscan foreland basin. They result of the erosion of the first reliefs produced by the ongoing Sudetes phase of the Variscan orogenesis and progressing northwards during the Namurian (Dusar, 2006).

After the dramatic sea-level fall at the end of the Viséan, the deposition switched entirely to siliciclastics, first in a marine environment, and later in turbiditic, then deltaic and fluvial or floodplain environments with a decreasing marine influence. The gap between the top of the Viséan limestone and the first Namurian deposits extends up to the Arnsbergian E2 goniatite Zone (westwards) to the Chokierian H1 Zone (eastwards, Bouckaert, 1967).

The lithology is rather monotonous with the exception of the Chokier Fm (Chokierian, Namurian A) corresponding to dark shale and of the Andenne Fm (Alportian, Namurian B), mainly composed of sandstone. The rest of the group are organised in c. 10 m-thick cyclothems of fifth order starting with shale with marine fauna passing to proximal sandstones then fining-upwards to floodplain-type shales and coal bed.

4. Key sections

1-1 Beauchâteau quarry, Senzeille

References: Tsien (1977, 1978, 1980, 1984), Tourneur (1982), Birenheide et al. (1991), Boulvain & Coen-Aubert (1992), Boulvain (1993, 2001), Boulvain et al. (2011).

Location and access: Disused quarry 2.5 km SE of Senzeille, Philippeville Anticlinorium (Fig. 1). GPS: 50°09’36.12’N4°29’03.60’E.

Lithostratigraphy and biostratigraphy: Neuville Mbr, Petit-Mont Mbr, Upper Frasnian. Lower? to upper *Palmatolepis rhenana* Zone (Tourneur, 1982; Bultynck et al., 1988) (Figs 2, 5, 6).

Description: This disused quarry exposes a red mound in sub-horizontal position with all the ‘marble’ facies corresponding to different growth stages of the mound are nicely exposed on large sawn faces whereas flank facies can be observed laterally (Fig. 12).

On the lower central panel of the quarry, slumped structure affecting bioclastic-argillaceous alternations can be seen (Fig. 12). The abundance of large bioclastic fragments and almost intact coral colonies indicate that organisms lived in the muddy facies in the centre of the mound. The SE side of the mound is dominantly colonised by solitary rugose corals in living position whereas the NW side shows lamellar tabulate corals stabilizing coarse crinoidal accumulations. This asymmetry provides some clues about the palaeo-relief and palaeo-currents of the reef. Upwards, the red to pink facies passes to greyish facies (grey algal facies of Boulvain, 2007) which also includes laminar stromatoporoids. The top of the mound shows the reappearance of stromatactoid-bearing red facies resting on an erosive surface. Indeed, the mound recorded the third order Aisemont sequence of Poty & Chevalier (2007) (Fig. 6): the lower red and pink facies correspond to the TST and show a deepening followed by shallowing trend. The grey facies corresponds to the HST, capped by the sequence boundary (described as a karstic surface by Sandberg et al., 1992; Fig. 12) and correlated to the debris flows surrounding the mound. Hence, the uppermost red facies corresponds to the TST of the following ‘Lambermont sequence’ (Denayer & Poty, 2010; Mottequin & Poty, 2016) (Fig. 6). This succession is biostratigraphically verified because Birenheide et al. (1991) indicated that the second coral assemblage (‘*faune 2’* of Coen et al*.,* 1977), which is dominated by *Frechastraea micrastraea*, *Potyphyllum ananas*, *Thamnophyllum hollardi*, *Macgeea pauciseptata* and *Tabulophyllum implicatum*, is identified below the erosive surface whereas the third coral assemblage (‘*faune 3’*) characterises the uppermost red facies, with *Frechastraea pentagona*, *F. minima*, *Potyphyllum falsa*, *Iowaphyllum rhenanum* and *I. mutabile*.

The most common corals are small platy colonies of *F. micrastraea* and *P. ananas* and the solitary *M. pauciseptata* and *T. implicatum* (Birenheide et al., 1991). The tabulate corals are dominated by alveolitids and *Thamnopora micropora*, cladoporids, *Egosiella* sp. and *Senceliaepora tenuiramosa*. The lateral shaly facies yields a diverse brachiopod fauna mainly including atrypides and athyridides. The crinoids are rather common and calices of *Melocrinites* ssp. are not rare.

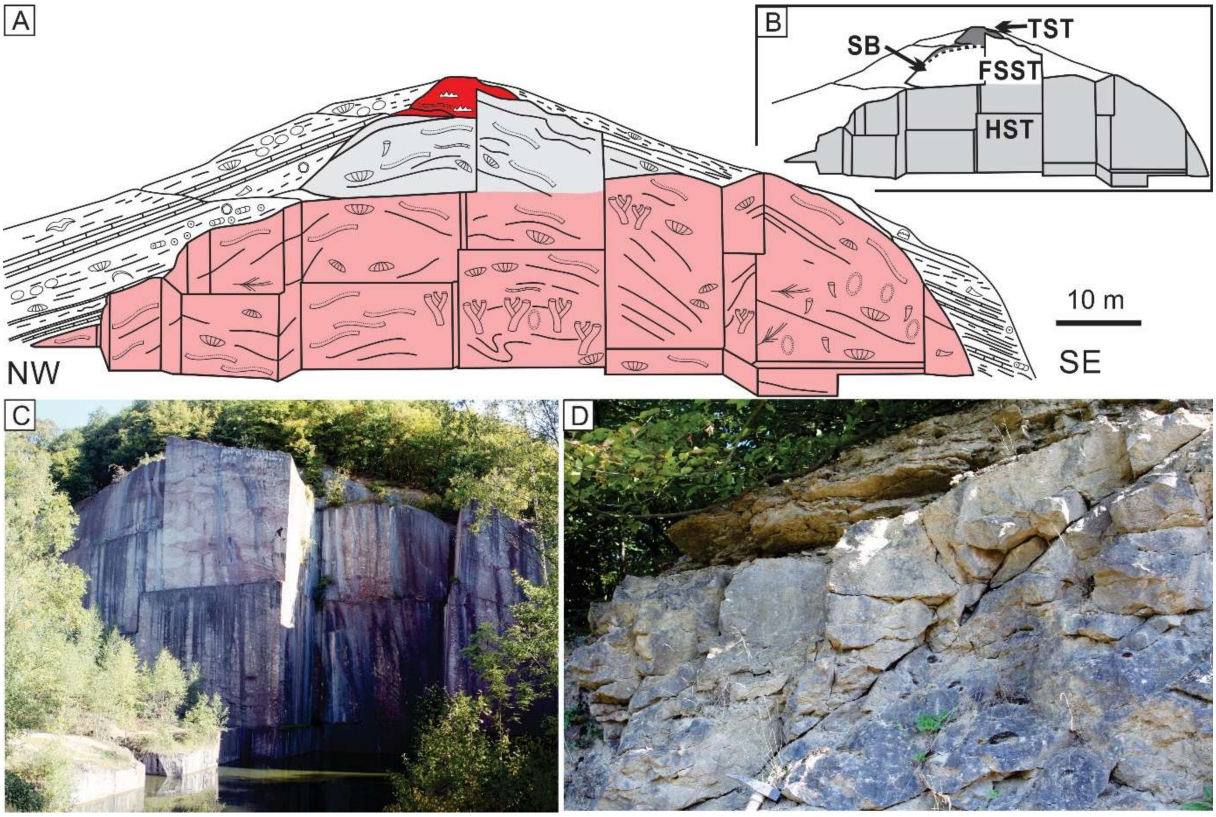

Figure 12: A. Sketch of the Beauchâteau quarry at Senzeille (Petit-Mont Mbr) with the distribution of the main facies and macrofossils (modified from Tourneur, 1982) and Birenheide et al. (1991). B. Sequential interpretation of the facies after Denayer & Poty (2010) and Mottequin & Poty (2016). C. View of the Beauchâteau quarry at Senzeille (Petit-Mont Member). D. Top of Beauchâteau mudmound: emersion–transgression surface capping the grey restricted lime mudstone with fenestrae. Legend: see Fig. 13.

1-2 Cimetière de Boussu-en-Fagne quarry

References: Lecompte (1960, 1963), Coen-Aubert (1982, 1992a, 1994), Godefroid & Helsen (1998).

Location and access: A series of small disused quarry, south of the village of Boussu-en-Fagne near Couvin, southern limb of the Dinant Synclinorium (Fig. 1). GPS: 50°04’35.02’N 4°28’34.01’E.

Lithostratigraphy and biostratigraphy: Grands Breux Fm (Lion and Boussu-en-Fagne members), Champ Broquet Fm (Neuville and Petit-Mont members); Middle-Late Frasnian (*hassi* to *rhenana* zones, Figs 2, 5, 6).

Description: This small and disused quarry exploited Middle Frasnian limestones (Lion Member) that are still visible in its southern wall (Fig. 13). About 23 m of massif, locally bioclastic, light-grey limestone, which include massive and branched stromatoporoids and tabulate corals (*Alveolites*), are exposed. They correspond to the upper part of a carbonate buildup. These limestones are sharply overlain by the essentially shaly Boussu-en-Fagne Member (c. 15 m) that can be subdivided lithologically into three successive horizons (Godefroid & Helsen, 1998). The massive limestones of the Lion Member are covered by thin beds of crinoidal limestone and shaly intercalations that are followed by shales with limestone lenses and nodules.

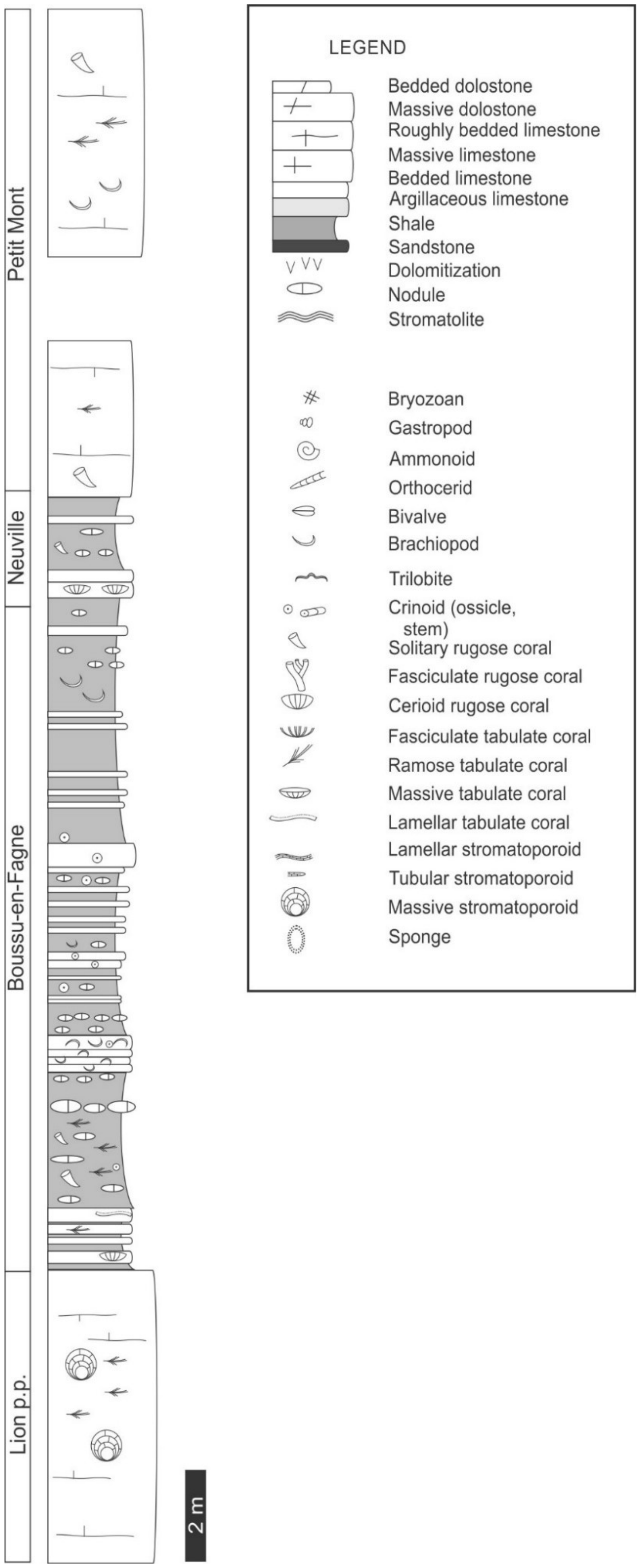

Figure 13: Schematic log of the Cimetière de Boussu-en-Fagne quarry (after Coen-Aubert, 1992b and Godefroid & Helsen, 1998).

Corals are particularly abundant in this basal interval. Besides colonies of *Hexagonaria* (*H. davidsoni*, *H. mae*), rugose corals are represented by *Disphyllum* and some solitary forms (*Macgeea* gr. *gallica*), whereas the tabulates includes lamellar and massive colonies of *Alveolites suborbicularis* and small branched colonies of *A. subaequalis* and *Thamonopora boloniensis* (Coen-Aubert, 1992b). Brachiopods are dominated by athyridides (*Athyris oehlerti*, *Dicamara plutonis*) and atrypides (*Costatrypa variablis*) (Godefroid & Helsen, 1998; Mottequin, 2008b). Then, subnodular, locally crinoidal limestone beds alternate with shales including limestone lenses and nodules. Atrypides are extremely abundant in some beds, belonging essentially to *C. variabilis*. Conversely, corals are less abundant. The lithology of the top of Boussu-en-Fagne Member is similar to that of the rest of the member but the fauna is not dominated by a particular group as corals and brachiopods are equally represented. Atrypides are still the dominant group among the latter. Some lamellar *Frechastraea* colonies are observed near the top of the member (Coen-Aubert, 1992).

The Champ Broquet Formation (c. 13 m visible) is exposed along the access path and starts with an alternation of light grey, argillaceous or crinoidal limestones with reddish coloured spots and shales that correspond to the base of the Neuville Member. These beds are overlain by fine, massif, grey and locally reddish limestones that correspond to a Petit-Mont Member buildup (Godefroid & Helsen, 1998). Corals, brachiopods and crinoids are locally present. *Ancyrognathus triangularis* is reported from the base of this buildup by Coen-Aubert (1992b). The black shales of the Matagne Formation formerly cropped out to the north of the quarry (Maillieux, 1936), but this outcrop, which yielded *Ryocarhynchus tumidus* (Rhynchonellida), has disappeared (Godefroid & Helsen, 1998).

1-3 Couvin 'Falaise de l'Abîme'

References: Marion & Barchy (1999), Tsien (1969), Bultynck (1970).

Location and access: Cliff on the eastern bank of the Eau Noire river in Couvin. Southern limb of the Dinant Synclinorium (Fig. 1). GPS: 50°03'04.54"N 4°29'48.06"E. The cliff is protected (sampling forbidden) and the strata are poorly exposed.

Lithostratigraphy and biostratigraphy: This cliff is part of the type section of the Couvin Fm and of the former Couvinian stage. The biostromes of the Abîme Mbr yielded conodonts representative of the *partitus* to *costatus* zones (Bultynck, 1970) (Fig. 2).

Description: The cliff exposes the upper part of the Abîme Mbr (Fig. 14), dominated by coarse-grained bioclastic limestone, often dolomitised. Stromatoporoids and tabulate corals are abundant and form parabiostromal accumulations. Thin tubular and branched stromatoporoids (*Amphipora, Stachyodes*) form local accumulation in wackestone-packstone matrix.

Figure 14: The Abîme cliff in Couvin, stratotype of the Couvin Fm and former Couvinian stage. The biostromal part of the Abîme Mbr is exposed.

1-4 Fondry des Chiens, Nismes

References: Tsien (1975, 1980), Birenheide et al. (1991), Coen-Aubert (1992b), Bultynck et al. (2001), Préat et al. (2007).

Location and access: Open-sky cryptokarst developed in the hill southeast of the village of Nismes near Couvin, southern limb of the Dinant Synclinorium (Fig. 1). GPS: 50°04'09.01'4°33'22.87'E. Protected area, hammering forbidden!

Lithostratigraphy and biostratigraphy: Hanonet and Trois-Fontaines formations; Lower Givetian (*hemianstatus* Zone, Fig. 2).

Description: The section exposes subvertical and slightly overturned beds. A lower, bedded unit of crinoidal limestone is poorly exposed in the southern part of the karst (Fig. 15). The crinoidal unit acts as the basement for the reef. The upper unit, exposed in the main 'fondry' comprises 66 m of massive limestone with abundant and large stromatoporoids (Bultynck et al., 2001). It corresponds to a small bioherm built by massive, lamellar and bulbous stromatoporoids (*Stromatopora, Stromatoporella, Actinostroma, Parallelopora*, Tsien, 1975), with few tabulate and rugose corals (*Fasciphyllum, Neomphyma*), chaetetids and heliolitids in the upper part. The stromatoporoids are not in living position though they are not heavily reworked as suggest their outer margin. Some of them reach metric sizes. Laterally (in neighbouring 'fondrys'), the bioherm passes to bioclastic and crinoidal limestone with debris of stromatoporoids. Above the bioherm lay c. 20 m of thin-bedded, fine-grained limestone with abundant green algae and gastropods interpreted as a lagoonal deposit (Préat et al., 2006).

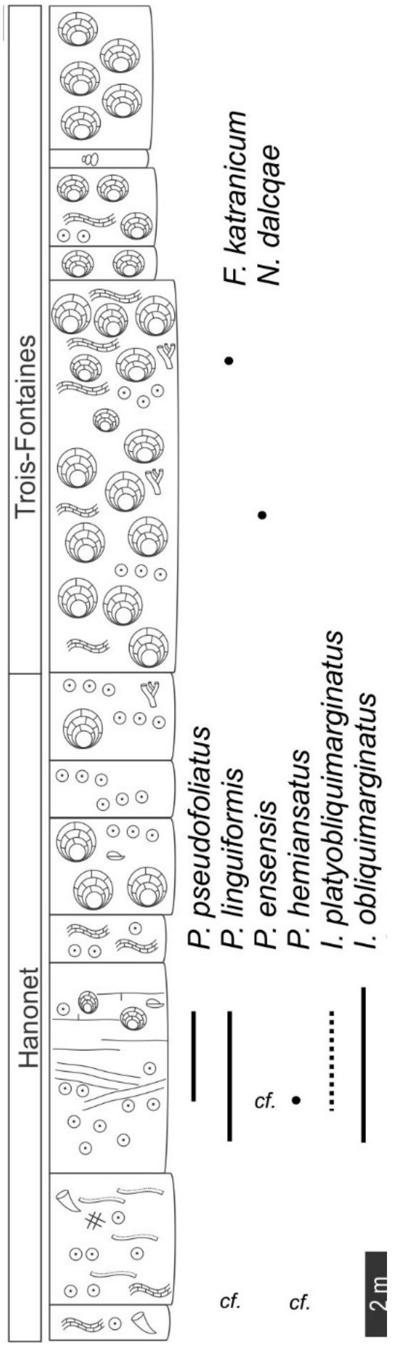

Figure 15: Schematic log of the Fondry des Chiens section, with position of marker taxa (modified after Préat et al., 2006 and Coen-Aubert, 1992b).

<u>1-5 Givet</u>

References: Gosselet (1876), Lecompte (1939), Bonte & Ricour (1948), Errera et al. (1972), Bultynck et al. (1991), Préat et al. (2006), Brice (2016).

Location and access: Cliffs in the northern flank of the Meuse river valley, below the Charlemont citadelle at the western end of Givet, southern limb of the Dinant Synclinorium (Fig. 1). GPS: 50°04'06.91'4°49'12.15'E. The site is the stratotype of the Givetian stage and is protected, however it can be observed easily from the 'Porte de France' and from the Givet bridge.

Lithostratigraphy and biostratigraphy: The Lower Givetian Trois-Fontaines Fm is quarried in the eponymous quarry, west of Givet, the Terres d'Haurs, Mont d'Haurs and Fromelennes formations crop out in the cliff (Fig. 16).

Description: See description in the Resteigne quarry (point 2-7).

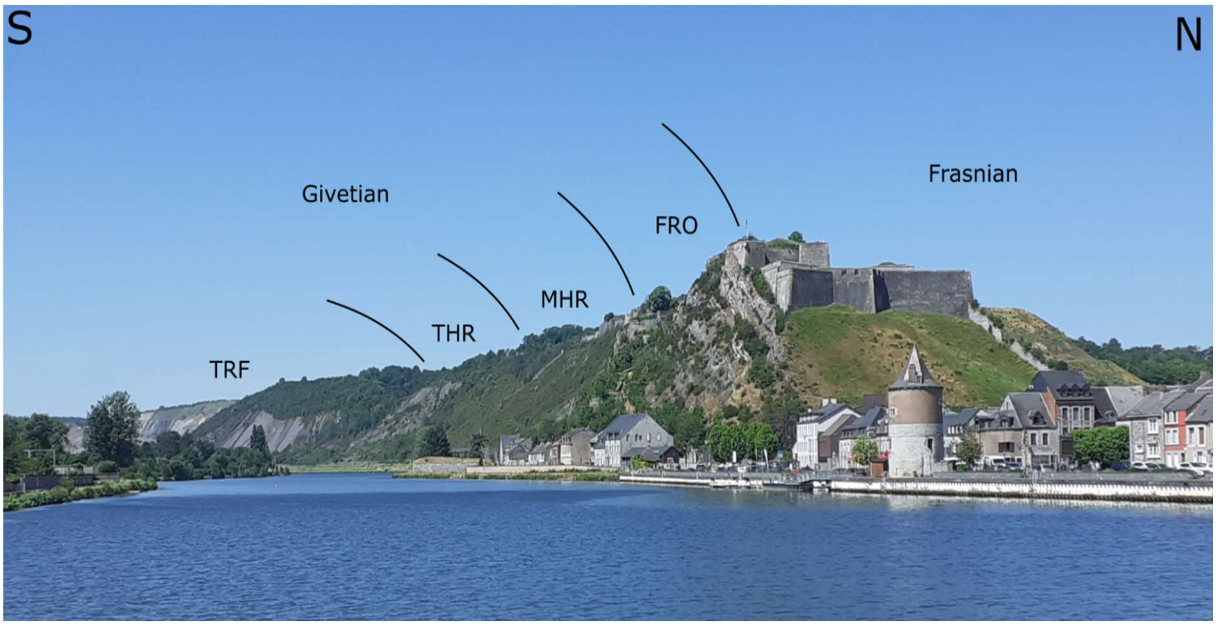

Figure 16: View of the Meuse river valley in Givet, with stratigraphic units of the type Givetian. Abbreviations: TRF: Trois-Fontaines Fm, THR: Terres d'Haurs Fm, MHR : Mont d'Haurs Fm, FRO : Fromelennes Fm.

1-6 Moniat Rocks

References: Lees (1988, 1997, 2006), Lees & Miller (1985, 1995), Lees et al. (1985), Dehantschutter & Lees (1996).

Location and access: Composite section of the Moniat Rocks in the northern flank of the Meuse valley (Fig. 17), 2.5 km south of Dinant, along the road and disused railroad Dinant-Hastière. Dinant Synclinorium (Fig. 1), southern part of the Dinant sedimentation area (Fig. 9). GPS: 50°14'33.83''N4°53'58.84''E.

Lithostratigraphy and biostratigraphy: Waulsort and Leffe formations, late Tournaisian (Ivorian). The foraminifers indicate the MFZ6-8 biozones. Groessens & Noël (1975) recognised the *carina* to *beckmanni* conodont biozones in the Waulsortian facies (Fig. 11).

Figure 17: Eastern Moniat Rock, mainly exposing the (dolomitised) Waulsortian 'veines bleues' *facies of the Waulsort Fm. Abbreviations: LEF: Leffe Fm, WAU: Waulsort Fm.*

Description: The two main Moniat Rocks (eastern and western) are comprised of two Waulsortian buildups, separated by peri-waulsortian facies but forming a large complex. The most striking feature of the Waulsortian facies is its massive structure (Fig. 17).

However, in some cases, a crude stratification is visible. The eastern rock is easily accessible along the road and near the railway tunnel where the Bayard Fm crops out with a very cherty facies. The rock exposes also the *veines bleues* facies, made of fine-grained bioclastic wackestone with sparry calcite patches (in some places, more important volumetrically than the wackestone). The sparry mass occurs under various forms: sparry crusts on fenestellid bryozoans, cavity fillings ('stromatactoids') and neomorphosed pseudospar (Lees, 1997). Associated with the *veines bleues* facies, crinoidal packstone and wackestone occur in the lower part of the buildups (Lees et al., 1985). In the upper part, it is associated with the 'biomicrite' facies, made of pale grey wackestone. Bryozoans are the most common organisms of the '*veines bleues*' facies (Lees, 1988). Brachiopods, gastropods, crinoids, rare *Amplexus* and other fossils occur sporadically or are clustered in pockets. Unfortunately, good outcrops of the fossiliferous facies are rare. The majority of the Moniat Rocks is made of dolomite affecting both Waulsortian and peri-Waulsortian facies. Along the small ravine north of the western rocks, the massive dolomite passes through stratified dolomite. The Leffe Fm includes well-bedded light or medium grey wackestone and mudstone containing intraclasts of various size and nature. Some parts of the formation show clear fining-upward sequences (Lees & Miller, 1985).

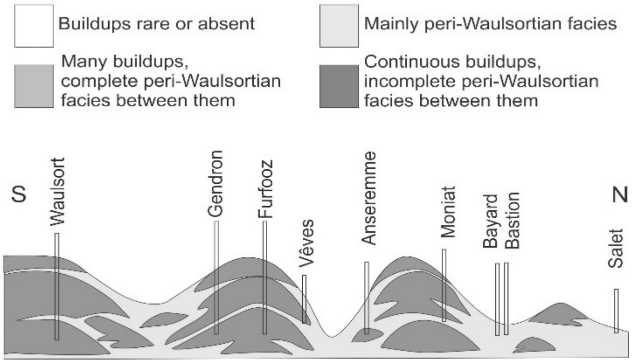

Figure 18: Schematic transect through the southern part of the DSA where the Waulsortian complex displays it greatest development in Waulsort then thins out northwards (Modified from Lees, 1985).

The Waulsortian buildups have been studied in Belgium since the pioneer work of E. Dupont (1863) that yet interpreted it as reef. The most developed and succeeding studies devoted to the Waulsortian are those of Lees (1997), Dehantschutter & Lees (1996), Lees & Miller (1985, 1995), and Lees et al. (1985). Many details can be found in these publications. The main new interpretation is from Hance et al. (2001) that recognized the record of two third-order sequences through the Waulsort Fm and its lateral facies (Fig. 18). These are sequence 3, which initiates the buildup, and sequence 4, which ends it. Poty (2016) emended the sequential scheme and subdivided sequence 4 into sequences 4A and 4B as he recognised a third Waulsortian level (e.g. in Waulsort and Gendron-Celles sections) correlated to the better understood sequences on the proximal CSA and NSA.

1-7 Dinant and the Bayard Rock

References: Conil et al. (1988), Delcambre & Pingot (1993), Groessens (1975), Groessens & Noël (1975).

Location and access: The type section of the Dinantian is composed of the rocky cliff situated on the eastern bank of the Meuse river upstream from the town of Dinant, central part of the DSA (Fig. 9). South-central part of the Dinant Synclinorium (Fig. 1). GPS: 50°14’40.56”N 4°55’16.83”E.

Lithostratigraphy and biostratigraphy: This classical section of the Tournaisian succession exposes almost continuously the Landelies, Maurenne, Bayard and Leffe formations in peri-Waulsortian setting (Figs 10, 17). These facies are relatively poor in microfauna but the foraminifers indicate the MFZ4 to MFZ6. The conodonts are indicative of a late Tournaisian age (see Groessens & Noël, 1975) (Fig. 11).

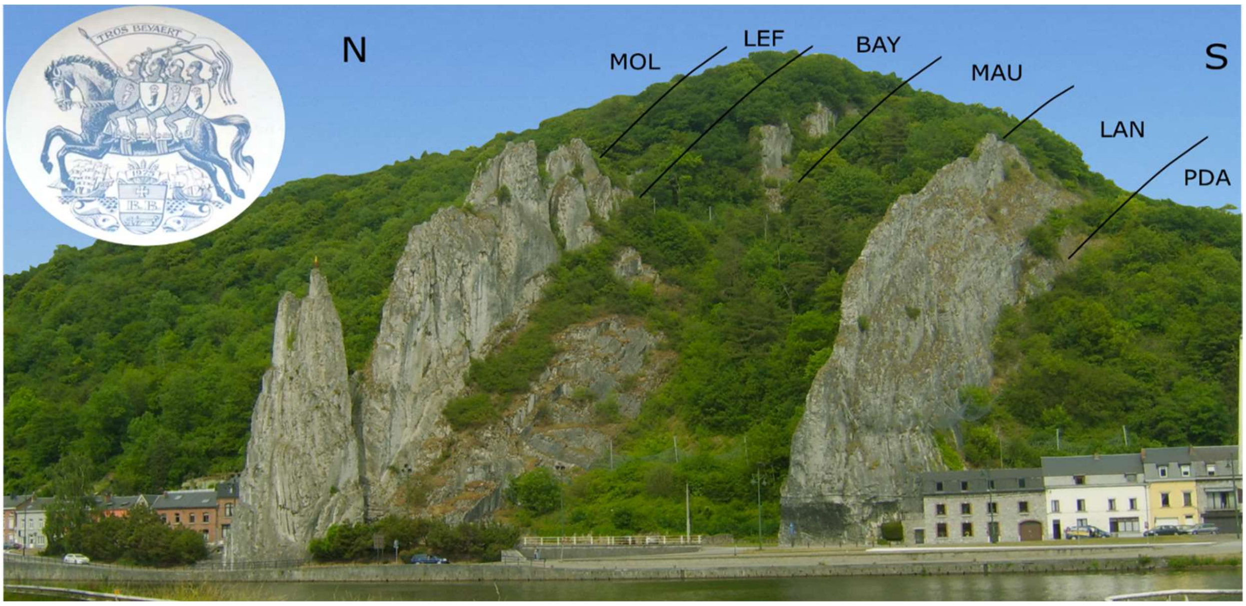

Figure 19: The Bayard Rock in Dinant showing the peri-reefal facies of the Waulsortian facies (the Moniat mound is located 1.5 km westward). B: Le Rocher Bayard (the Bayard Rock). It is completely separated from the rest of the cliff of which it obviously used to be a part. The Rocher Bayard that stands in the southern gate of Dinant, on the right bank of the Meuse river was separated with a canon to provide a passage for the French troops of Louis XIV after they had taken Dinant. However, the popular beliefs say that the legendary Bayard Horse jumped over the Meuse river and split the rock of the cliff with its hoof while driven by the four Aymon Brothers fleeing from King Charlemagne. . Abbreviations: BAY: Bayard Fm, LEF: Leffe Fm, LAN: Landelies Fm, MAU: Maurenne Fm, MOL: Molignée Fm, PDA: Pont d’Arcole Fm, WAU: Waulsort Fm.

Description: Here are exposed lateral equivalents of the Waulsortian buildups (Fig. 19) which have a huge development westwards (Moniat Rocks, see previous point and Dehantschutter & Lees, 1996). The Bayard Fm is abruptly resting on the Maurenne carbonate shale. The formation is a thinly-bedded crinoidal rudstone with some cherty layers. The Leffe Fm consists mainly of finer-grained, grey to purplish blue wackestone to packstone with abundant cherts moulding the bioturbation. The dominant microfacies is a wackestone with coated clasts and common ostracods, trilobites, bryozoans, sponge spicules, few foraminifers and many problematic microfossils. The Bayard crinoidal limestone acted as the sole of the Waulsortian buildups but also occurs within the mounds and, thus, represents a lateral equivalent of the buildups. The transition to the overlying Leffe Fm is rather progressive and marked by a decrease in crinoidal content and increase of mud-coated clasts proportion. The Leffe Fm is the lateral proximal equivalent for the middle and upper part of the Waulsortian buildups and results most probably from the erosion and resedimentation on the flanks of the buildups. The Maurenne Fm is interpreted as the LST of sequence 3, whereas its TST and HST correspond to the Bayard and Leffe formations, respectively. The historical boundary between the Tournaisian and Viséan is located in the nearby 'Lambert Quarry' immediately south of the Bastion Rock (Fig. 20), at the base of bed no. 141 that corresponds to the first intercalation of the 'black marble' facies in the Leffe Fm. It also coincides with the first occurrence of the calcareous foraminifer genus *Eoparastaffella* (Conil et al., 1969), less than 1 m below the first appearance datum (FAD) of the conodont *Gnathodus homopunctatus* (Groessens & Noël, 1977).

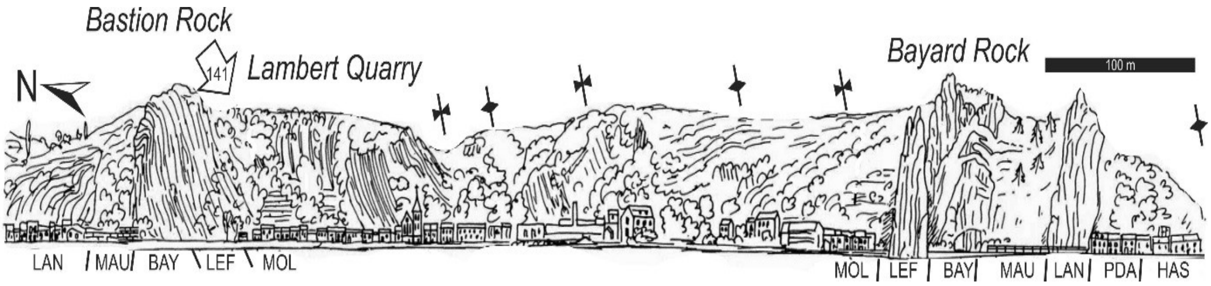

Figure 20: Sketch section along the eastern bank of the Meuse between the Bayard and Bastion rocks in Dinant, with the position of the lithostratigraphic units and historical Tournaisian-Viséan boundary (bed 141) (modified from Groessens, 1975). Abbreviations: BAY: Bayard Fm, HAS: Hastière Fm, LAN: Landelies Fm, LEF: Leffe Fm, MAU: Maurenne Fm, MOL: Molignée Fm, PDA: Pont d'Arcole Fm..

<u>2-1 Triffoy Quarry</u>

References: Mottequin et al. (2021).

Location and access: Disused quarry near the Marchin village in the Hoyoux valley. Condroz area, central part of the Dinant Synclinorium (Fig. 1). GPS: 50°28'11.82'N 5°15'43.62'E.

Lithostratigraphy and biostratigraphy: This quarry is open in the heterolithic facies of the Evieux Fm. The nearby Spontin-Source section has been studied in detail. The base of the section is attributed to the Vco (*Diducites versabilis–Grandispora cornuta*) Oppel zone (*sensu* Streel et al., 1987) (Fig. 2) and the top to the LL (*Retispora lepidophyta–Knoxisporites literatus*) Oppel zone. The conodont *Bispathodus ultimus* indicative of an upper *expansa* to lower-middle *praesulcata* interval was uncovered from the upper part of the section.

Description: This quarry exemplifies the most common facies of the Belgian Upper Famennian, known as the old generic name '*Psammites du Condroz'*. The Evieux Fm exposes continental and proximal siliciclastic facies dominated by micaceous sandstone and siltstone ('psammite') with frequent red beds. The Royseux Mbr is dominated by sandstone and arkosic sandstone alternating with massive or layered evaporitic dolomite, red beds and desiccation cracks. The Crupet Mbr contains sandstone and siltstone, usually arkosic, assembled in finning-upward sequences with common sedimentary structures as planar and undulating stratifications, mega-ripples and submarine dunes, sand bars, cross stratifications and channels (Thorez et al., 2006). Fossil flora are common in all the facies whereas fish remains occur as bone beds in channel lags.

The Evieux Fm has long been interpreted as reflecting proximal environments. Sedimentary structures indicate a deposition as a distal alluvial fan with estuarine influence (northwards), marshes and sabkha-type lagoon with occasional marine influences (southwards) preserved as storm deposits (Paproth et al., 1986; Thorez & Dreesen, 1986).

A relatively diversified plant assemblage has been collected from this quarry (Fairon-Demaret, 1996; Prestianni & Gerrienne, 2006, 2010). Its composition conforms to the other Famennian floras found elsewhere in Southern Belgium and commonly known as the Evieux flora (Stockmans, 1948) of which the two main components are the progymnosperm *Archaeopteris halliana* and the (pre)fern *Rhacophyton condrusorum*. The fish assemblage is mainly dominated by disarticulated remains of the antiarch placoderm *Remigolepis durnalensis* (Olive, 2015).

2-2 Royseux section

References : Austin et al. (1970), Conil et al. (1986), Van Steenwinkel (1990), Denayer et al. (2021).

Location and access: Section along the disused railroad in the Hoyoux valley between Huy and Modave. Central CSA, northern limb of the Dinant Synclinorium (Fig. 1). GPS: 50°28'09.98" N 5°16'03.13"E.

Lithostratigraphy and biostratigraphy: The upper part of the Comblain-au-Pont Fm and the Hastière Fm are exposed near the disused station and the Tournaisian Landelies, Yvoir and Ourthe Fms crop out southwards. The Comblain-au-Pont Fm belongs to the DFZ7 foraminifer biozones. Upsection, the MFZ1 and MFZ2 foraminifer biozones have been recognized, as well as the RC1 rugose coral zone, indicating the lower Hastarian for the Hastière Fm. In the Landelies to Yvoir Fm, the foraminifer biozones MFZ2 to MFZ4 as well as the RC2 and RC3 have been identified (Figs 2, 8, 11).

Description: The Comblain-au-Pont Fm (Fig. 21) consists of an alternation of pluridecimetre-thick beds of dark blue crinoidal and bioclastic packstone-grainstone and pluridecimetre-thick beds of brownish calcareous shale, with some sandy layers. The dominant microfacies is a relatively monotonous crinoidal and peloidal packstone-grainstone with 15-20% of detrital quartz grains. Accumulations of shells (brachiopods, gastropods) and larger crinoidal stems possibly correspond to storm events. The base of the Hastière Fm (beds 104-105) is a blueish sandy crinoidal grainstone-packstone with shelly accumulation (brachiopods, gastropods, crinoids) interrupted by millimetre-thick argillaceous layers. Intraclasts are common. This bed still contains Devonian quasiendothryrid foraminifers, the brachiopod *Sphenospira julii* and phacopid trilobites, and is interpreted as the record of the Hangenberg Sandstone event.

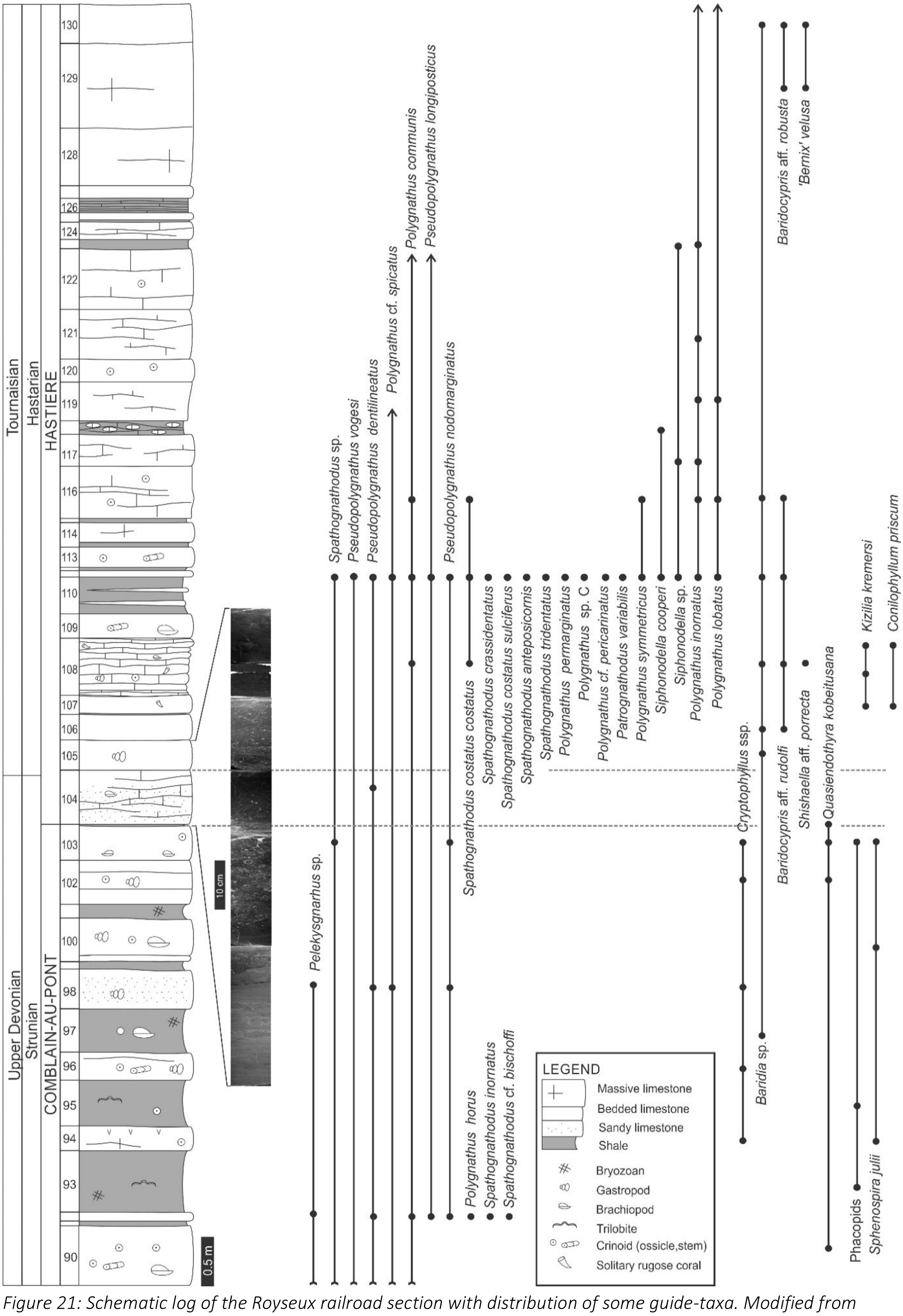

Figure 21: Schematic log of the Royseux railroad section with distribution of some guide-taxa. Modified from Denayer et al. (2015b).

Above this basal horizon, the lower member of the Hastière Fm still displays the same crinoidal grainstone-packstone rich in large crinoidal stems and brachiopod shells with undulating argillaceous boundaries (pression-dissolution nodularisation, Fig. 21), but without quartz grains. The middle member has a similar composition but differs by its massive aspect. The upper member of the Hastière Fm is dominated by thinly-bedded crinoidal grainstone with few shaly interbeds. The Pont d'Arcole Fm is not exposed, but the facies of the Landelies and Yvoir Fms are similar to those observed in the Rivage section (see above) with the particular development of the Royseux dolomitic Mbr at the top of the Landelies Fm. The overlying Yvoir Fm begins with a c. 30 m-thick unit of well-bedded dark cherty limestone (mainly packstone-grainstone), and an upper 5 m-thick unit of massive light grey cherty limestone (grainstone). Macrofossils are common in the formation and particularly in the upper massive bed.

The Ourthe Fm is a 20 m-thick unit topping the Yvoir Fm, which consists of grey-blue, thick-bedded to massive crinoidal limestone (packstone to rudstone). This formation was quarried to produce building stones known as "Petit Granit de l'Ourthe". The Ourthe Fm is typically a monotonous crinoidal packstone-grainstone but, here, it is locally dominated by grainstone to rudstone. Besides crinoid ossicles, which are particularly abundant here, and micheliniid tabulate corals, the fauna is relatively scarce and poorly diverse (Debout & Denayer, 2018).

The base of the Hastière Fm, with its Devonian fauna and atypical sandy facies, is interpreted as the equivalent of the Hangenberg Sandstone event bed (see Fig. 8). The base of the Carboniferous was traditionally placed at the top of this bed 105 where Devonian fauna became extinct (Denayer et al., 2021). Again, the Hangenberg Sandstone event and DCB occur within the TST of sequence 1. The HST corresponds to the massive middle member of the Hastière Fm on top of which the sequence boundary is identified. Sequence 2 covers the upper member of the Hastière Fm, Pont d'Arcole Fm and Landelies Fm (Fig. 10). The Royseux dolomitic Mbr is interpreted as the FSST of this sequence and the next sequence starts with the Yvoir Fm (TST) and Ourthe Fm (HST-FSST). The sequence boundary capping the Ourthe Fm is not exposed in this section.

2-3 Royseux trenches

References: Pirlet (1964, 1968), Poty (1981), Poty et al. (1988), Aretz (2001, 2002), Poty et al. (2011), Denayer et al. (2011, 2016b).

Location and access: Royseux is situated in the Hoyoux river valley (Fig. 1), about 3 km upstream of Pont-de-Bonne. The section Royseux I crops out along the western bank of the Hoyoux river and the section Royseux II along the road from Pont-de-Bonne to Huy. Two other sections exist on the hill east of Royseux II corresponding to two trenches dug in the late 1990s and named Royseux IIIA and IIIB. Only these two latter sections are rich in macrofossils and will be visited. Central part of the CSA (Fig. 9), northern limb of the Dinant Synclinorium. GPS: 50°27'46.70''N 5°16'42.01''E.

Lithostratigraphy and biostratigraphy: Bonne Fm (Poilvache Mbr) and Anhée Fm. Late Viséan (Warnantian substage), RC7 (Asbian) to RC8 (Brigantian) and MFZ14-15 (Fig. 11). Moreover, Poty et al. (1988) documented the conodont fauna.

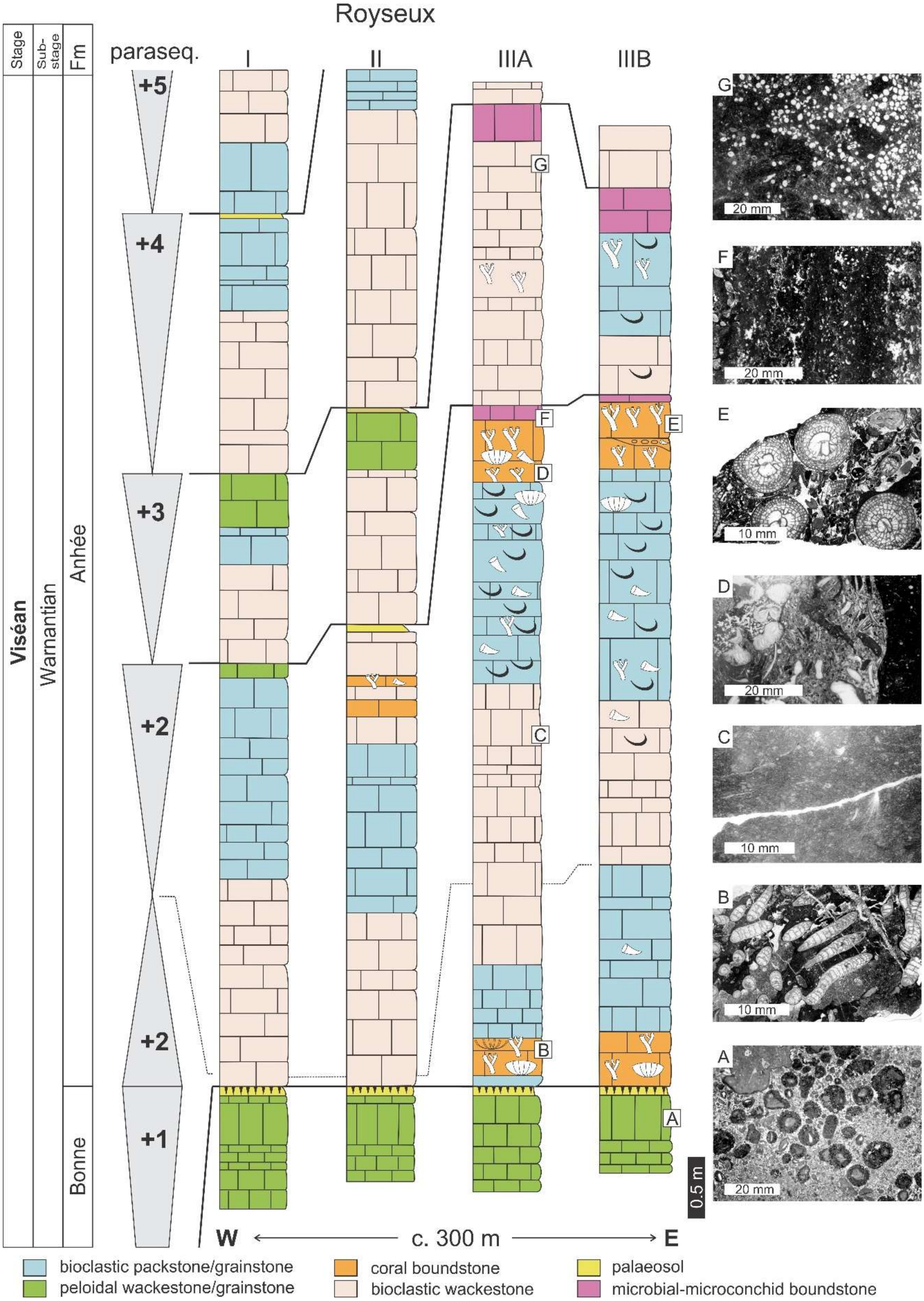

Figure 22: Sections Royseux I–IIIB: Logs with indications of the sequences, main occurrence of macrofossils, and some types of representative facies (after Aretz, 2001 and Denayer et al., 2016b).

Description: The bases of the sections expose the upper part of the Bonne Fm (Poilvache Mbr). It is composed of peloidal, stromatolitic and oncolitic limestones, which are organised in parasequences. The top of some sequences is formed by palaeosols with *Stigmaria* remains. Overall sequences show high lateral and vertical variations in relation to thickness and composition.

The base of the Anhée Fm is defined by a shift from the peloidal facies to the dominance of bioclastic facies. The Royseux trenches expose an uncommon facies of the Anhée Fm, known as the Chabôfosse facies that is very limited laterally (Fig. 22). The first sequence (+2) of the Anhée Fm is a coarse-grained crinoidal pack/grainstone topped by a c. 50 cm-thick coral horizon (Fig. 22). Its base is formed by a layer of *Siphonodendron junceum* and *Lithostrotion maccoyanum*, and is succeeded by a monospecific layer of *S. junceum*. Aretz (2001, 2002) interpreted the first coral horizon as a polyspecific biostrome, which immediately formed because of the availability of new full marine habitats at the base of sequence +2. The top of this first biostrome is significantly diversified, and contains syringoporids, *S. pauciradiale*, and the heterocoral *Hexaphyllia mirabilis*. The coral horizon is topped by a bioclastic packstone, which contains at its base some coral fragments. The grain size decreases and the carbonate mud content increases upwards. Some pelecypods, bryozoans, trilobites and few ammonoids occur in this level. The regressive part of sequence +2 starts within the bioclastic wackestones. The facies recorded the proliferation of *Gigantoproductus* and other brachiopods (*Echinoconchus*, *Podtsheremia*, *Antiquatonia*) as a typical level bottom community with solitary (mainly *Dibunophyllum bipartitum*) and colonial rugose corals (*Siphonodendron, Lithostrotion, Diphyphyllum*). In the second coral horizon, the development of the initial *S. junceum* biostrome quickly ends with deposition of a conglomerate, interpreted as storm layer (hurricane?). Then a *S. martini* meadow developed; some large colonies (>1m^3) are encrusted by microbialites. All coral growth stopped when restricted facies conditions occurred, and microconchids flourished (Fig. 22).

Sequence +3 starts with bioclastic wackestones and packstones containing small coral colonies. Its upper part is a *Saccaminopsis* wackestone topped by small microbial-heterocorals build-ups with local concentrations of microconchids.

The very singular facies observed in the sections IIIA and IIIB (e.g. coral horizons, gigantoproductids beds, small microbial buildups) have no equivalents in the western sections I and II. Aretz (2001, 2002) proposed a synsedimentary fault between sections II and IIIA to explain these differences, and thus a deeper block within the area of sections IIIA and IIIB. The somewhat deeper position enabled the development of coral dominated facies at the base of sequence +2 during a time of non-deposition on higher blocks. These unusual facies yield a very diverse coral fauna: 47 species in 24 genera collected within a c. 25 m-thick sequence cropping on c. 100 m^2. The single sequence +2 (6 m-thick) yields 32 species in 21 genera. Royseux is therefore considered as the richest locality worldwide for late Viséan corals and is interpreted as a diversity hotspot (Denayer et al., 2016b).

2-4 Marche-en-Famenne

References: Barchy & Marion (2014).

Location and access: road cut north of the Marche-en-Famenne town, Famenne area, southern margin of the Dinant Synclinorium (Fig. 1). GPS: 50°14’20.64’N 5°20’25.33’E.

Lithostratigraphy and biostratigraphy: Upper Frasnian Neuville Mbr of the Champ Broquet Fm and Barvaux Fm, rhenana conodont zone (Figs 2, 6)

Description: The section exposes the shale and calcareous shale with nodules of the upper part of the Neuville Mbr. The nodules are either subspherical or contorted, and mostly corresponds to burrows and bioturbation. Accumulations of brachiopod are frequent (e.g. *Warrenella* sp.). Small colonies of the rugose coral *Frechastraea* are rare. Upwards, the section exposes the transition to the Barvaux Fm that appears as purple to violet shale. Calcareous nodules are still present, but in smaller quantities. Moreover, they are smaller and commonly discoid. Brachiopods are not uncommon but less diverse than in the Neuville Mbr. *Cyrtospirifer* spp. are largely dominant, suggesting dysoxic conditions.

2-5 Jemelle section

References: Godefroid (1968), Bultynck & Godefroid (1974), Bultynck et al. (1991), Denayer (2019).

Location and access: Embankments of the disused railroad Jemelle-Rochefort, c. 800 m SW of Jemelle (stratotype). Southern limb of the Dinant Synclinorium (Fig. 1). GPS: 50°09’21.30”N 5°15’24.60”E.

Lithostratigraphy and biostratigraphy: This section exposes the three members of the Jemelle Fm: the Station (its lower 10 m are not exposed), Cimetière and Chavées members (Fig. 23). The overlying sandy Lomme Fm also crops out but will not be visited during the excursion. Based on the occurrences of the conodonts *Polygnathus costatus costatus* and *Tortodus kockelianus kockelianus*, respectively in the lower and upper part of the Chavées Mbr, Bultynck & Godefroid (1974) identified the *costatus* and *kockelianus* zone.

Description: The Station Mbr (c. 40 m-thick after Bultynck et al., 1991) is made of sandy shale in centimetre-thick beds, locally micaceous and containing a rare macrofauna (mainly brachiopods, commonly preserved as internal moulds). The Cimetière Mbr (c. 110 m) is marked by the appearance of calcareous nodules in the shale, becoming bigger upsection. The shale is usually dark, as are the thin interstratified beds of argillaceous limestone. The macrofauna is dominated by the brachiopods and crinoids with solitary rugose corals (*Cystiphyllum*) and tabulate corals (*Favosites*), whereas trilobites are occasional. The boundary between the Cimetière and Chavées members is hidden by the wall of the bridge. The Chavées Mbr differs from the previous members by its carbonate content (Fig. 23). It appears as alternations of argillaceous or nodular limestone and shale (sandy in the upper part). The limestone beds are centimetre- to decimetre-thick and are commonly rich in macrofauna (brachiopods, stromatoporoids, corals, chaetetid sponges; Godefroid, 1968). In the median part of the member, one level is composed of very large domal stromatoporoids associated with favositid and heliolitid corals. It may be a lateral equivalent of the bioherm described in the Wellin and Couvin area or a local accumulation of fauna.

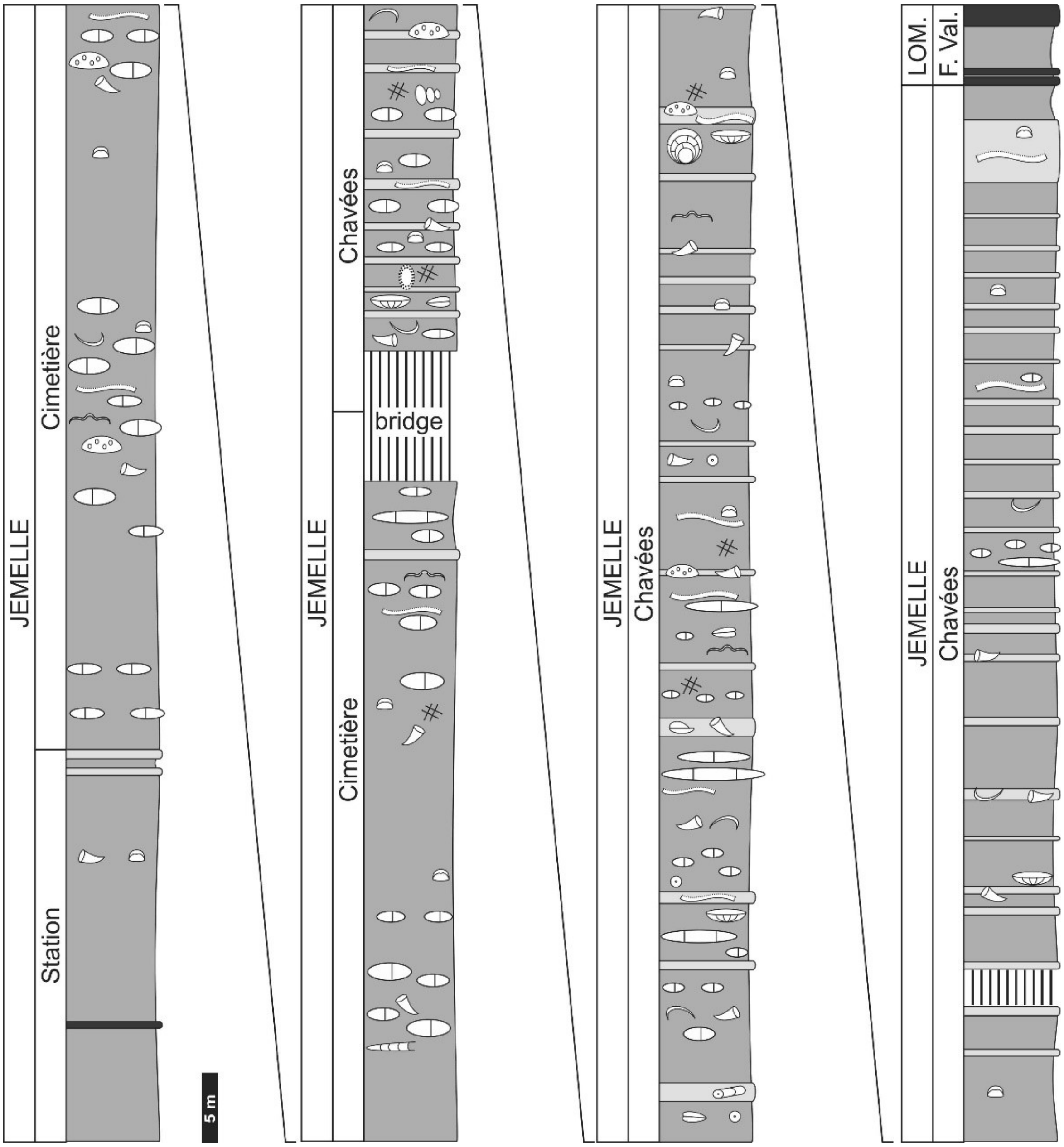

Figure 23: Schematic log of the Upper Eifelian Jemelle Fm in its stratotype (modified from Bultynck et al., 1991). Formations are in uppercase, members in lower case. Abbreviations: LOM: Lomme Fm, F. Val.: Fond des Valennes Mbr. Legend: see Fig. 13.

2-6 Sourd d'Ave section

References: Bultynck (1974, 1982), Godefroid & Jacobs (1986), Bultynck et al. (2001), Birenheide et al. (1991), Narkiewicz & Bultynck (2010), Casier et al. (2013).

Location and access: Outcrop located at the intersection of the Dinant–Neufchâteau road (N48) and Han-sur-Lesse–Wellin road, near Ave-et-Auffe, southern limb of the Dinant Synclinorium (Fig. 1). GPS: 50°06'00.92"N5°07'54.26"E.

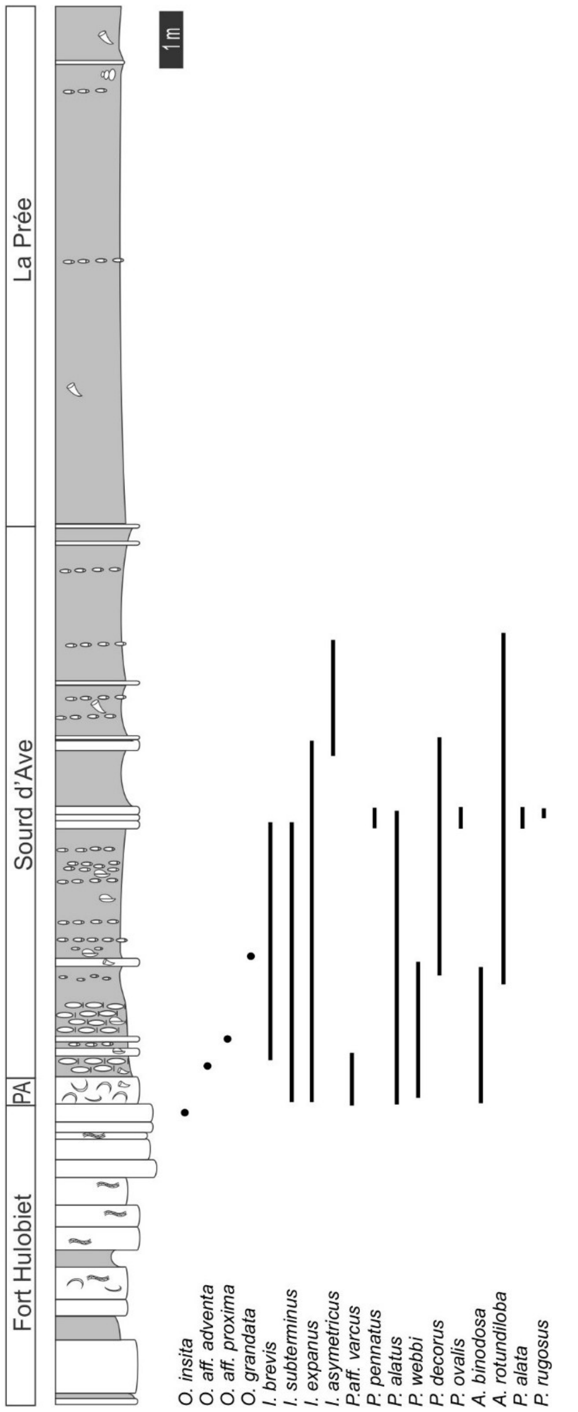

Figure 24: Schematic log of the Sourd d'Ave section with position of selected marker conodont taxa (modified from Bultynck, 1982). Legend: see Fig. 13.

Lithostratigraphy and biostratigraphy: The Upper Givetian Fromelennes Fm is represented by the upper part of the Moulin Boreux Mbr (8 m) and the Fort Hulobiet Mbr (28 m). The Lower Frasnian Nismes Fm is represented by the Pont d'Avignon Mbr (a 45 cm-thick bed of nodular limestone), the Sourd d'Ave Mbr (9.3 m) and the base of the La Prée Mbr. (Fig. 24). The Givetian/Frasnian boundary lays immediately above the Fromelennes Fm/Nismes Fm boundary at the base of the bed where the first *Ancyrodella* have been recorded by Bultynck (1974), after a 15 m-thick episode without any conodonts. Conodonts from the Sourd d'Ave section have been studied by Bultynck (1974, 1982) and Narkiewicz & Bultynck (2010).

Description: The upper 8 m of the Moulin Boreux Mbr, exposed at the base of the section, are composed of fine-grained limestone with massive and branched stromatoporoids. The upper part of the Fort Hulobiet Mbr consists of semi-restricted stromatoporoid boundstones capped by *Amphipora* floatstones, then of fossil-poor units and restricted supratidal laminites with well-developed fenestral fabrics. The boundary between the Fromelennes and Nismes formations is characterized by a dramatic deepening from restricted evaporative lagoonal facies (microfacies 6–13) to open marine interbedded calcareous shale and nodular limestone (microfacies 1–3) (Fig. 24).

The Frasnian Pont d'Avignon Mbr shows a rich faunal assemblage (bryozoans, brachiopods, molluscs, nautiloids, tentaculitids, ostracods) suggesting an abrupt drowning from the marginal Givetian carbonate platform into a Frasnian distal ramp setting or basinal environment below or near the storm wave base. This transgressive event at the Givetian-Frasnian boundary is highlighted by argillaceous shale, calcareous shale and tempestites with open-marine interbedded nodular limestones, and the development of a rich fauna succeeding the depauperate communities that prevailed during the Late Givetian.

2-7 Resteigne Quarry

References: Préat et al. (1984), Coen-Aubert (1988), Boulvain et al. (2009, 2011), Denayer et al. (2015a).

Location and access: Disused quarry of Resteigne in the Lesse valley, north of Wellin. Southern limb of the Dinant Synclinorium (Fig. 1). GPS: 50°05'22.89" N 5°10'47.46"E.

Lithostratigraphy and biostratigraphy: The locality presents several sections exposing the upper part of the Eifelian and the Lower Givetian. The upper Eifelian Lomme Fm is discontinuously exposed along the path leading to the quarry, the Hanonet Fm, Trois-Fontaines Fm and the lower part of the Terre d'Haurs Fm are exposed in the quarry. The Mont d'Haurs Fm is also exposed in the northern part of the quarry but will not be observed during the excursion. Biostratigraphical survey has not been done to date on this quarry, but Coen-Aubert et al. (1991) indicated that the upper part of the Hanonet Fm should be correlated with the base of the Givetian. The Kačák event, recognized at the base of the Hanonet Fm (Jamart & Denayer, 2020) suggests the same interpretation.

Description: The Hanonet Fm is here represented by c. 75 m of argillaceous limestone with abundant fauna. From the base to the top, five lithological units can be distinguished in the quarry. The lower 17 m (unit 1 on Fig. 25) are dominated by greyish argillaceous limestone with some shaly beds. It is followed by unit 2 (c. 35 m) composed of dark argillaceous limestone in 20-30 cm-thick beds interrupted by decimeter-thick beds of calcareous shale. These first two units are extremely rich in fauna: gypidulid brachiopods, solitary rugose corals including *Calceola sandalina*, bryozoans, trilobites, etc. Unit 3 is a 4 m-thick level of dark grey poorly fossiliferous calcareous shale that occurs at the top of the limestone and it may correspond to the Kačak Event. Unit 4 is composed of bedded argillaceous limestone (c. 15 m) in which the carbonate content increases upsection. The fifth unit is dominated by thick-bedded dark limestone with an abundant fauna (laminar stromatoporoids and tabulate corals, rugose corals, brachiopods, crinoids, gastropods). The upper metres of this last unit show the reappearance of shale beds interstratified with coarse crinoidal limestone.

The first 2.5 m-thick unit of the Trois-Fontaines Fm is a crinoidal rudstone with fragments of corals, brachiopods and numerous stromatoporoids that acted as a firm substrate for the reef initiation (Fig. 25). The reef itself starts with tubular stromatoporoids, fasciculate rugose corals, ramose and massive tabulate corals bound by lamellar stromatoporoids.

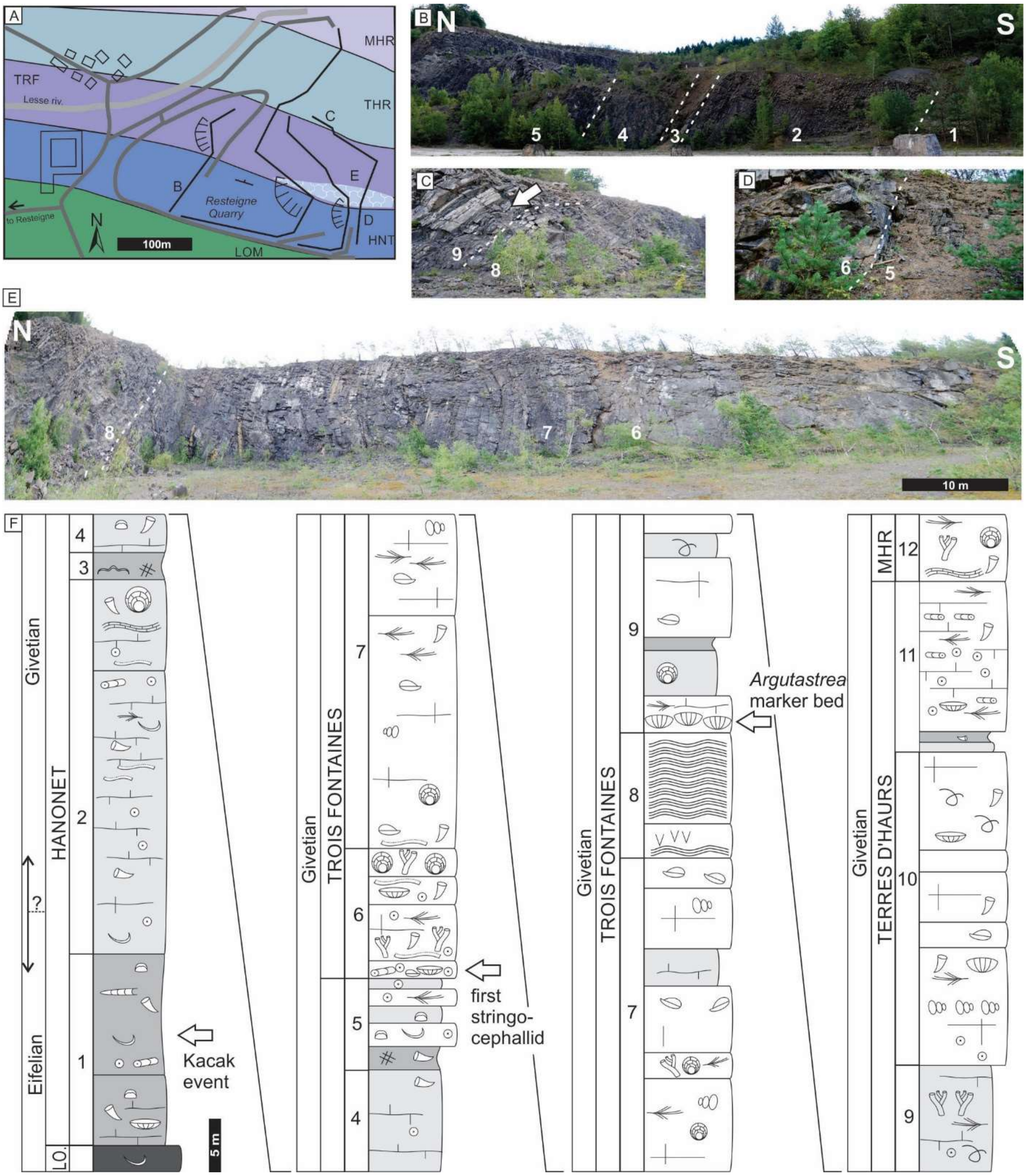

Figure 25: A. Schematic geological map of the the Resteigne quarry (modified after Dumoulin & Blockmans, 2013). B. view of the lower quarry wall exposing the Hanonet Fm lines indicate the lithological units. C. view of the Argutastrea quadrigemina *bed marking the boundary between the Trois-Fontaines and Terres d'Haurs formations. D. base of the Trois-Fontaines Fm marked by crinoidal rudstone. E. view of the upper quarry wall exposing the Trois-Fontaines Fm, the line indicates the top of the reef. F. shematic log of the upper Eifelian and Lower Givetian formations exposed in the Resteigne quarry (modified from Coen-Aubert, 1998, 2003). Abbreviation: HNT: Hanonet Fm, LOM: Lomme Fm, MHR: Mont d'Haurs Fm, THR: Terres d'Haurs Fm, TRF: Trois-Fontaines Fm. Legend: see Fig. 13.*

Upsection, the stromatoporoids become more abundant together with an increasing diversity of calcareous algae (Mamet & Préat, 1986). The successive stages of the reef formation are described in detail by Préat et al. (1984). Brachiopod (stringocephalids) and gastropod coquina beds overlying the biostrome are interpreted as storm deposits. This first transgressive phase is followed by more restricted facies (unit 7 in Fig. 25) that Préat & Boulvain (1982) interpreted as a lagoon created by the southwards progradation of the reef barrier but that could also be interpreted in terms of sea-level change and/or accommodation. The 'lagoonal complex' is composed of fine-grained sediments with a relatively low diversified fauna: leperditid ostracods, murchisonid gastropods, calcispherids and palaeosiphonocladales (Préat & Boulvain, 1982). The 'lagoonal complex' is followed by a 10 m-thick unit (unit 8) of stromatolites witnessing a tidal flat environment (desiccation cracks, palaeosols and horizons rich in organic matters). Open marine facies are recorded at the base of the Terres d'Haurs Fm, witnessing a new transgressive pulse. The base of the formation is marked by a horizon of domal *Argutastrea quadrigemina* that can be traced on several tens of kilometres along the southern margin of the Dinant Synclinorium (unit 9, Fig. 25). Tabulate corals (thamnoporids and favositids), brachiopods and crinoids reappear quickly in the lower part of the formation in a bioturbated argillaceous limestone (unit 10). Biostromal lenses (patch reefs?) rich in trachyporids locally develop in the lower half of the formation (Coen-Aubert, 1988, 2003). The top of the formation is made of crinoidal limestone with tabulate corals (unit 11). The base of the Mont d'Haurs Fm is badly exposed but shows limestone riche in stromatoporoids and crinoids with tabulate corals (unit 12).

3-1 Lives quarry and rock

References: Hance (1979), Lauwers (1992), Poty & Hance (2006), Poty et al. (2011), Pointon et al. (2018).

Location and access: The natural exposures at Lives (Lives Rock) and a disused quarry are situated on the southern bank of the Meuse river, 4 km east of Namur. Central part of the NSA, (Fig. 9), Brabant Parautochthon (Fig. 1). This section is the stratotype of the Livian substage (middle Viséan). GPS: 50°28'02.02''N4°55'38.64''E.

Lithostratigraphy and biostratigraphy: Haut-le-Wastia Mbr, Corphalie Mbr and lower part of the Awirs Mbr of the Lives Fm (Livian, Middle Viséan). The guide taxa for the Livian Substage (MFZ12), the foraminifer *Pojarkovella nibelis* enters 15 m above the base of the Lives Fm in the stratotype (Devuyst et al., 2005). The Haut-le-Wastia Mbr contains the typical association of the rugose coral biozone RC5γ and the appearance of *Lithostrotion araneum* at the base of the Corphalie Mbr defines the base of the RC6 (Fig. 10).

Description: The Lives Rock is the stratotype of the Lives Fm and also the Livian Substage (Conil et al., 1977, Poty & Hance, 2006). The Neffe Fm is partly dolomitised and badly exposed. The Lives Fm begins with a 10-30 cm-thick pedogenetized bentonite known as the '*Banc d'Or de Bachant*' or 'L1' of Delcambre (1989). This horizon is an important marker bed that can be traced through the Namur-Dinant Basin and from the Aachen area (Germany) to the Boulogne-sur-Mer area (Northern France) (Hance et al., 2001). The Lives Fm is subdivided into three members: Haut-le- Wastia, Corphalie and Awirs Mbrs (Fig. 26). The lower Haut-le-Wastia Mbr ('V2bα' of Conil et al., 1977) is composed of 30 m of thick-bedded, pale to medium grey limestone arranged in parasequences, in which stromatolites and mudstones are dominant. Bioclastic facies become more common in the upper part of the member and contain corals.

The Corphalie Mbr ('V2bβ' of Conil et al., 1977) is an 18 m-thick unit composed of thick-bedded, dark bioclastic limestone overlain by thin-bedded, dark mudstones containing small bioclastic levels (Fig. 26).

The lower bioclastic unit contains numerous rugose corals and heterocorals. This member includes two widely known marker beds: an argillaceous and bituminous layer containing *Lithostrotion araneum* colonies at its base (Poty et al., 2006), and an argillaceous bed (bentonite 'L3' of Delcambre, 1989) in its upper part (Fig. 26). The Awirs Mbr ('V2bγ', 'V2bδ', 'V2bε') is 35 m-thick and made of plurimetre-thick parasequences mainly composed of dark grey, bioclastic limestone, sometimes cherty, rich in corals (*Siphonodendron, Clisiophyllum, Haplolasma,* heterocorals), capped by micritic or stromatolitic layers. The colonial corals can be preserved in living position, forming thin biostromes (Aretz, 2002), or broken and forming accumulations of debris. The facies evolved from bioclastic grainstone to a cap of micritic limestones (often peloidal) including thin bioclastic levels interpreted as storm deposits.

The upper part of the Corphalie Mbr is made of thin-bedded dark fine-grained limestone that was long quarried as the 'Marbre Noir de Namur' (Groessens, 2004, Dreesen et al., 2021). It is in fact a finely bioclastic wackestone with rare foraminifers and ostracods. The black colour is due to a residual organic matter associated to the fine-grained matrix. In the upper part of this member, a 5-15 cm-thick clayey horizon, known as L3 (Delcambre, 1989) corresponds to a weathered bentonite of trachy-andesitic composition (Pointon et al., 2018).

The entire Lives Fm represents the LST (Haut-le-Wastia Mbr) and the TST (Corphalie and Awirs Mbr) of the sequence 7. The formation is marked by parasequences known since the 1960s (Michot et al., 1963). The Haut-le-Wastia Mbr includes 12 parasequences (numbered -12 to -1, Fig. 26), mainly stromatolitic.

The Corphalie Mbr is made of one unique parasequence ('sequence 0' of Michot et al., 1963) beginning with a *Lithostrotion araneum* horizon that can be traced as far as the Bristol area in England ('*Lithostrotion basaltiforme* band', 'L.a.' in Fig. 26). This sequence is the thickest of all sequences observed in the Lives Fm (Chevalier, 2004).

The Awirs Mbr is made of eight parasequences (+1 to +8, Fig. 26), mainly bioclastic, indicating a more open-marine environment resulting from the ongoing Livian transgression. The Awirs Mbr ('V2bγ-ε') is 35 m-thick and made of eight parasequences composed of dark bioclastic limestone, sometimes cherty, rich in corals (*Siphonodendron, Clisiophyllum, Haplolasma*, heterocorals), capped by micritic or stromatolitic layers. The colonial corals can be in living position, forming thin biostromes (Aretz, 2002).

3-2 Jambes Rock

References: Delcambre &Pingot (2015), Denayer et al. (2019).

Location and access: This rock is situated on the right bank of the Meuse river, along the road N90 (Fig. 1), 2 km E of the centre of Namur, between Jambes and Lives, NSA (Fig. 9), GPS: 50°27'51"N4°53'43"E.

Lithostratigraphy and biostratigraphy: Chokier Fm (Arnsbergian, Namurian E2) filling a large open-sky karst developed in the middle Viséan Grands-Malades Fm (Fig. 11).

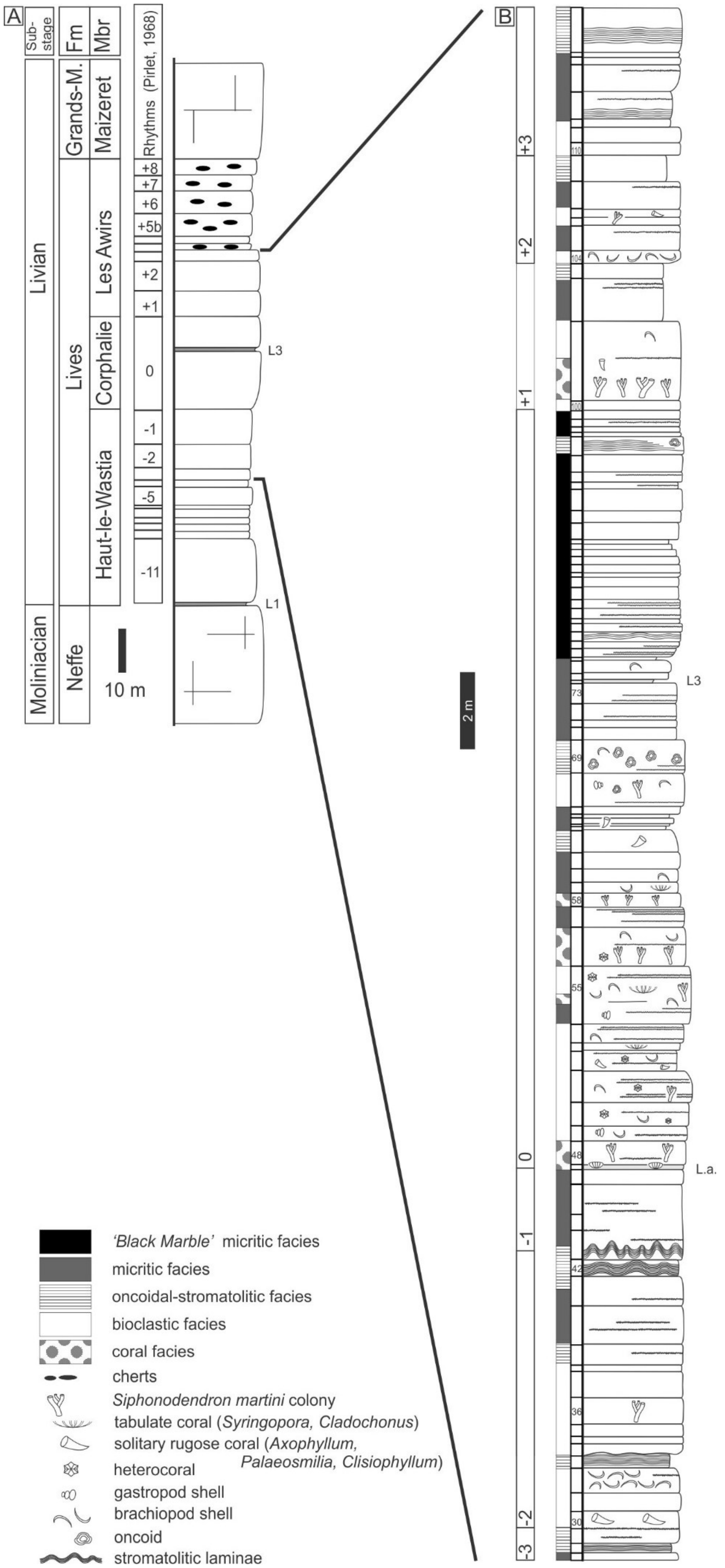

Figure 26: A. Lithostratigraphic column of the Lives Mbr in the type area. The rythms '-11' to '+8' of Pirlet (1968) correspond to parasequences. The sequence '0' forms the middle Corphalie Mbr which contains small bryozoans-microbialites bioherms. Modified after Lauwers (1992). B. Detail log of the Lives Fm at the Lives Rock. Parasequences are numbered, the Corphalie Mbr corresponds classically to sequence - or rythm – '0' (Pirlet, 1968). Legend: L.a: Lithostrotion araneum *layer, L1, L3: cinerite L1 and L3 of Delcambre (1989). Modified from Chevalier (2004) and Dreesen et al. (2021).*

Description: This small outcrop (Fig. 27) displays the typical geometry of the Viséan-Namurian disconformity. As usual in the NSA and VSA, the lower Namurian siliciclastics fill palaeokarstic depressions in the Dinantian formations. The top of the Viséan limestone is usually upper Viséan but large karstic cavities sometimes reache the middle Viséan. In this case, the lower part of the Grands-Malades Fm is affected by the cavity but, laterally, the Namurian deposits rest on the Bonne Fm. The Namurian is represented by siltstones and shales, often black, of the Chokier Fm but sandstone layers are not rare.

The Chokier Fm corresponds to the filling of the tectonically-controlled drowning of the emerged karstified palaeotopography (Dusar, 2006 and references therein). The marine fine-grained siliciclastics were deposited in calm but not deep environments of a pro-delta progressively invading the palaeokarstic emerged shelf (Nyhuis et al., 2014). Palaeotopographical highs and irregularities prevented strong currents or waves to affect the sedimentary basin. The former karstic landscape was most probably similar– but not so photogenic! – to the famous Ha Long Bay (Vietnam) or Phuket (Thailand). The erosion surface topping the Dinantian carbonate platform results of the tectonically-controlled emersion of the shelf associated with the major regression that took place at the end of the Viséan (Poty et al., 2006; Poty, 2016).

Figure 27: Palaeokarst developed in the middle Viséan limestone and filled with Namurian siliciclastics. The boundary between the two units corresponds to the erosion surface capping the Dinantian shelf.Abbreviation: GMA: Grands maladies Mbr.

3-3 Citadelle of Namur

References: Kaisin (1924), Bouckaert (1961, 1967, 1982), Van Leckwijck (1964), Dusar (2006), Delcambre & Pingot (2015).

Location and access: Citadel of Namur (Donjon section) and access road ('Route Merveilleuse' section, see Fig. 28). Central part of the Haine-Sambre-Meuse Overturned thrust sheets (Fig. 1). These combined sections constitute the stratotype of the Namurian regional stage. GPS: from 50°27'24.67''N4°51'56.11''E to 50°27'30.94''N4°5145.56''E.

Lithostratigraphy and biostratigraphy: Chokier and Andenne Fm (Coal Measures Group), Namurian (Chokierian to Kinderscoutian, Fig. 28). The goniatites from the marine horizon described by Kaisin (1924) and Bouckaert (1961) - but no longer visible - indicate the R1-*Reticuloceras* Zone (Kinderscoutian, Namurian B). Rare conodonts and foraminifers from thin calcareous horizon indicate a similar age (Bouckaert, 1982).

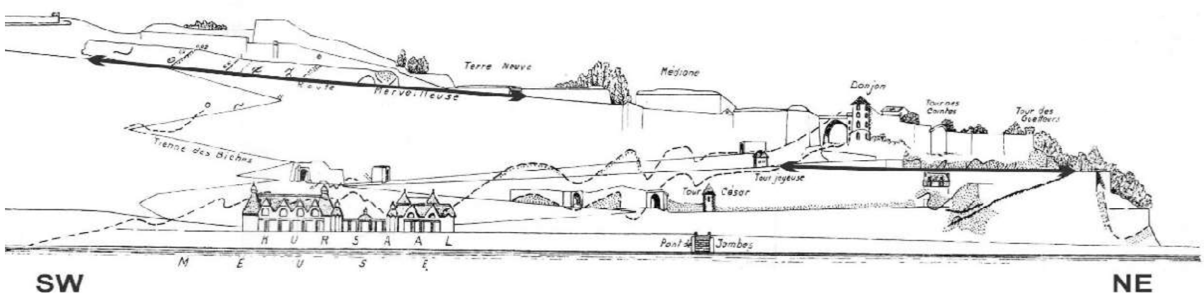

Figure 28: Sketch of the Citadel of Namur with schematic outcrops of Namurian rocks. Arrows indicate the visited sections: 'Route Merveilleuse' and Donjon outcrops. Modified from Bouckaert (1961).

Description: As part of the Belgian Coal Measures Group, the Namurian of Namur has been intensively studied (see synopsis by Van Leckwijck, 1964, Bouckaert, 1961 and Dusar, 2006). Only parts of the Namurian succession are exposed in the visited outcrops, the base, for example is not recorded. The first section, along the 'Route Merveilleuse' (eastern flank of the citadel, Fig. 29) exposes an alternation of shales and sandstones of the Chokier and Andenne formations. The shales are fossiliferous, yielding mainly bivalves, brachiopods and rare fish remains. Synsedimentary deformations are common (load-cast, ball-and-pillow), as well as tectonic deformations related to sandstone lenses, asymmetric and disharmonic folds (Vandenberghe & Bouckaert, 1983; Kenis et al., 2003). The most common facies are proximal but poorly fossiliferous (two thin coal layer) and only one marine horizon, 50 m below the Andenne Fm, yields a goniatite assemblage of Kinderscoutian age (top of Namurian B, Bouckaert, 1961). Along the Donjon section are exposed sandstone and siltstone alternations including some channel structures with cross-stratification and load-casts. The latter facies belongs to the Chokier Fm (Fig. 29). Together with the Westphalian, the Namurian rocks forms, in Western Europe, a thick and monotonous molasse sequence filling the European Variscan foreland basin, later folded and faulted by the Asturian phase of the Variscan Orogeny during the late Carboniferous. The geometry of channelised structures observed in the proximal facies partly indicates a southern origin of the sediments (Bouckaert, 1961, 1964).

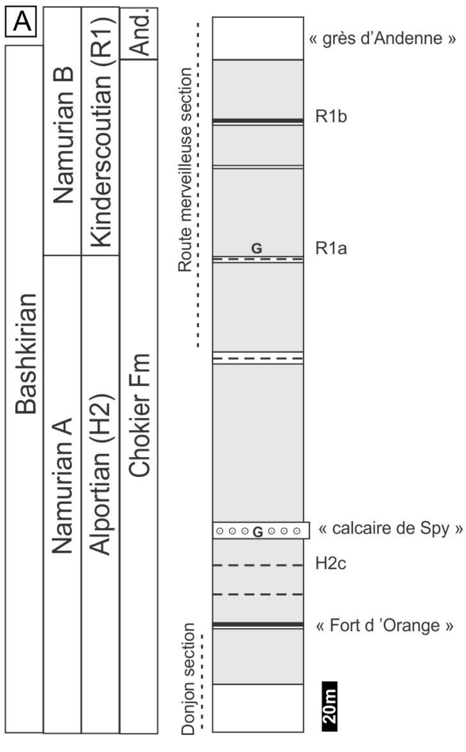

Figure 29: Stratigraphic succession observed in the type section of the Namurian, at the Citadel of Namur. Modified from Bouckaert (1961), Dusar (2006). Legend, see Fig. 13.

3-4 Walgrappe Syncline

References: Delcambre & Pingot (2017).

Location and access: Large quarries on the eastern side of the Meuse river valley between Tailfer and Lustin (Fig. 1). Dinant sedimentation area, Dinant Synclinorium (Fig. 9). GPS: 50°22'58.28'' N 4°52'49.46''E.

Lithostratigraphy and biostratigraphy: The northernmost part of the disused quarry exposes the Middle Frasnian limestone quarried as ornamental stone (Lustin Fm) whereas the active quarry extracts the sandstone of the Famennian Ciney Fm in the Walgrappe Syncline (Fig. 30).

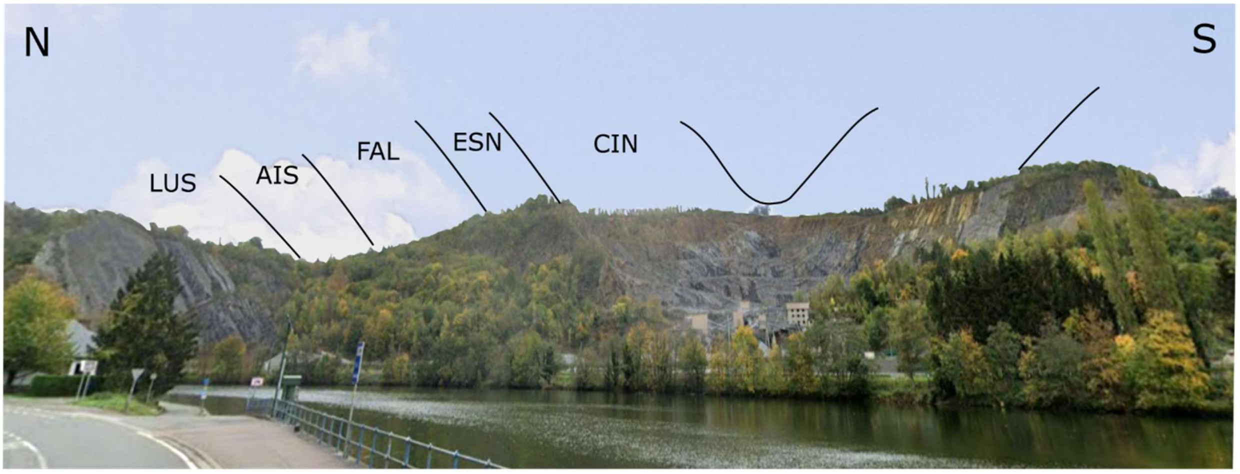

Figure 30: View of the Walgrappe Syncline seen from the western side of the Meuse river valley. The central part exposes the Famennian sandstone quarried for aggregate. Abbreviations: AIS: Aisemont Fm, CIN: Ciney Fm, ESN: Esneux Fm, FAL: Falisolle Fm, LUS: Lustin Fm.

3-5 Tanret quarry and Salet road section

References: Overlau (1966), Groessens (1975), Hance (1988), Lees (1997), Mottequin (2004, 2008a), Devuyst et al. (2006), Poty (2016).

Location and access: The road section is the embankment of the road leading from the Salet village to the Molignée valley (Fig. 1). The Tanret quarry is situated at the southern end of the village. Central part of the Dinant sedimentation area (Fig. 9), north of the main Waulsortian development, Dinant Synclinorium. GPS: 50°18'23.77"N 4°49'40.77"E (quarry), 50°18'38.13"N 4°49'48.31"E (road).

Lithostratigraphy and biostratigraphy: The Bayard, Leffe, Molignée, Salet and Neffe formations (Ivorian to Moliniacian) are well exposed along the road section, the Lives Fm is poorly exposed and the 'black marble' facies are fossiliferous in the Tanret quarry. They correspond to the MFZ6 to MFZ11 foraminifer biozones of Poty et al. (2006). This section is the stratotype of the Moliniacian regionlal substage. Its base was defined at the first thin beds of dark fine-grained limestone known as 'black marble' facies appearing in the upper part of the Leffe Formation (bed 52, Conil et al., 1977; Fig. 31). That level also corresponds to the top of the *S. anchoralis europensis* local range and is about 2 m below the entry of *Mestognathus praebeckmanni* (Conil et al., 1988). These authors considered that this level was correlated with the base of the Viséan in the Bastion section (historical stratotype for the base of the Viséan, see Hance et al., 2006) marked by the

FAD of *Eoparastaffella* and *Gnathodus homopunctatus,* which is 19 m below the base of the Viséan Stage marked by the FAD of *Eoparastaffela simplex*. However, the reinvestigation of the boundary transitional beds allowed Devuyst et al. (2006) to emend the definition of the Moliniacian and to correlate its base with the base of the Viséan Stage.

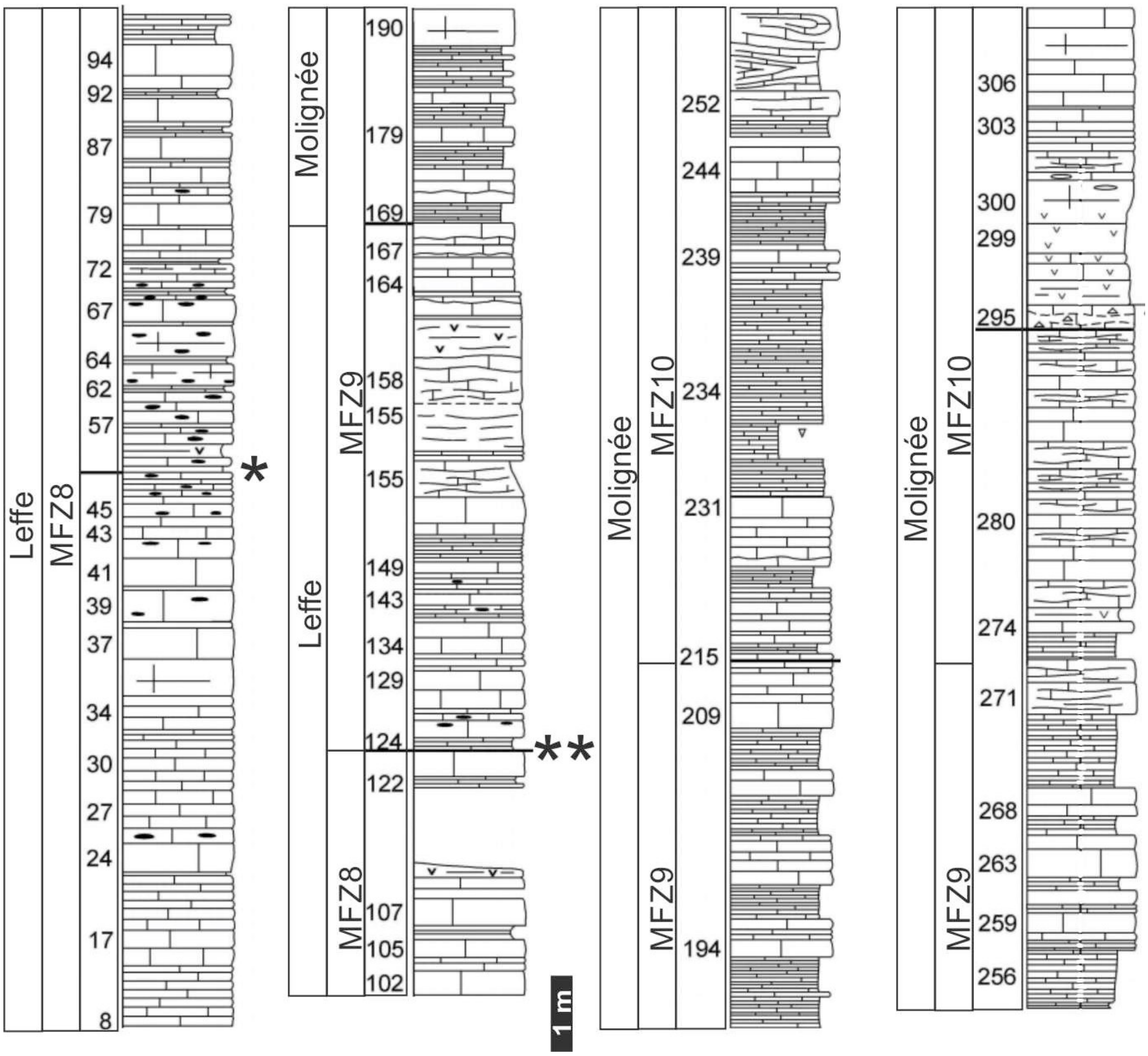

*Figure 31: Schematic log of the Salet road section quarry (modified from Overlau, 1966, emended by Devuyst et al., 2005). *: original base of the Moliniacian after Conil et al. (1977), **: emended base of the Moliniacian after Poty et al. (2006).*

Description: The Leffe Fm is a well-bedded violet-grey cherty mottled wackestone-packstone with an open marine microfauna and abundant microbially coated intraclasts becoming darker progressively to the overlying Molignée Fm, which is locally known as the 'black marble' of Denée.

The lower part of the Molignée Fm is very similar to the previous one but includes thinly-bedded, laminated black limestone becoming dominant upwards. The black limestone facies comprises mudstone with rare radiolarians, calcispheres, ostracods, moravamminiids, peloidal packstone and peloidal and bioclastic packstone-grainstone with calcispheres and algae and rare lithoclasts (Mottequin, 2004, 2008b; Devusyt et al., 2006). The Molignée Fm corresponds mainly to distal turbidites deposited in a deep lagoonal environment setting in the central part of the DSA (Mottequin, 2008b) alternating with background suspension sedimentation (calcispheres and radiolarian mudstone). The alternations are interpreted as parasequences (Mottequin, 2004; Devuyst et al., 2005; Fig. 32) produced by sea-level changes alternatively opening and closing the lagoon with sequential input of oxygenated waters. This formation is one of the rare to record the sequence 5 of Hance et al. (2001) (Figs 10, 11). The 'black marble of Denée' is a Konservat-Lagerstätte (Mottequin, 2004, 2008b) that yielded a rare, but frequently exquisitely preserved fauna (e.g. echinoids, crinoids, dendroid graptolites, fishes; see review in Mottequin et al., 2015). An outstanding collection of fossils from the 'black marble of Denée' is in display in the Centre Grégoire Fournier at the Maredsous Abbey. Most of the fossils were found in the Denée area (c. 5 km northwest of Salet), where the Molignée Formation was intensively quarried, but in fact this particular lithostratigraphic unit is very poor (Mottequin, 2004, 2008b) as is the case for the Tanret quarry where only brachiopods and ichnofossils are occasionally found.

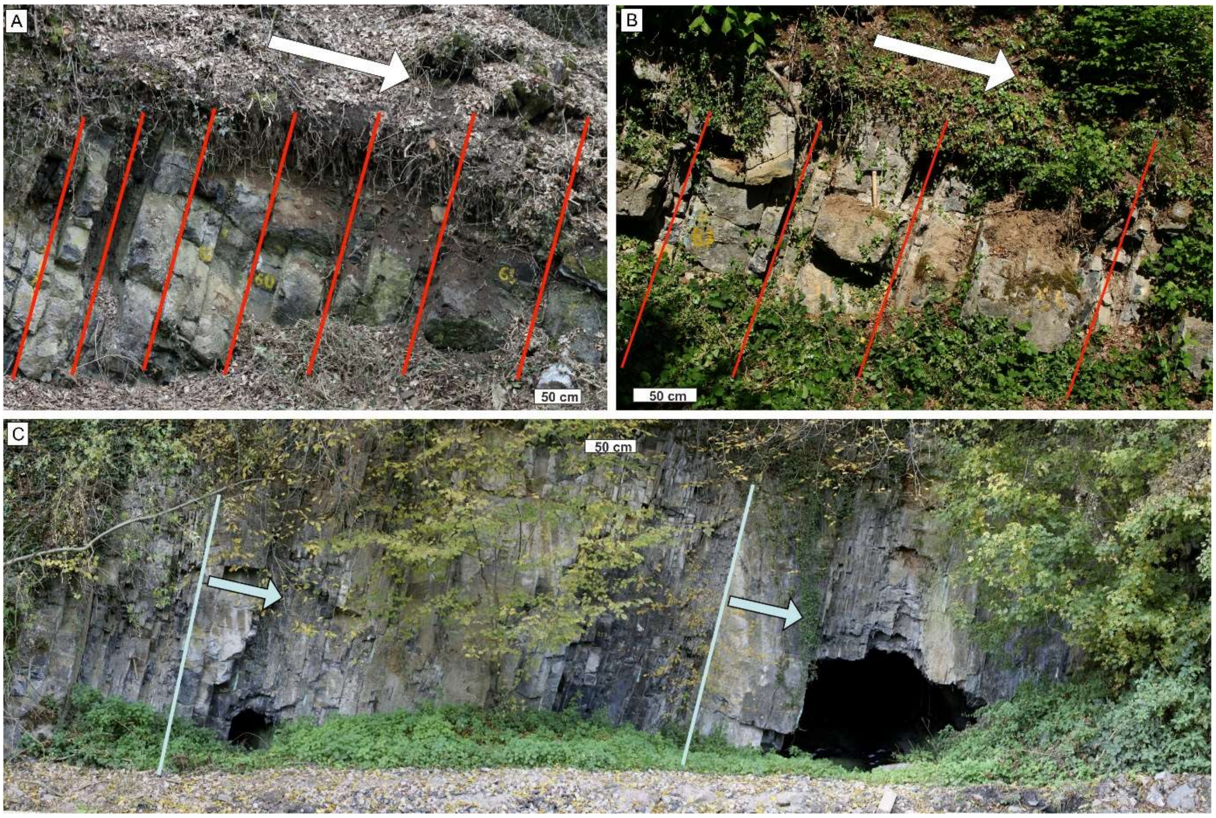

Figure 32: A. Precession cycles (c. 18.6 ky) due to monsoon-dry climate alternation in the Leffe Fm (Ivorian). B. Relatively thick and symmetric cycles (precession + obliquity?) in the upper part of the Leffe Fm (top of the Tournaisian), witnessing a transition in the cycle types. C. Shallowing-upwards parasequences in the Molignée Fm (basal Viséan) (modified from Denayer et al., 2015b and Poty, 2016).

The Salet Fm starts with a breccia bed including dolomitic clasts (debris flow, marking the sequence boundary, well exposed in the quarry). It is typically composed of various shallow-water facies (oolitic, peloidal, bioclastic), partly dolomitised and cherty in the upper part. The Salet Fm corresponds to the TST of sequence 6.

The thick-bedded to massive packstone to grainstone of the Neffe Fm recorded the HST of sequence 6. It was deposited in a high-energy environment and is capped by a marker bed, the '*Banc d'Or de Bachant*' a pedogenetised cinerite that marks the sequence boundary between sequence 6 and 7 (Fig. 11).

The Leffe Fm is dominated by limestone-argillaceous limestone alternations probably due to precession-driven climatic cycles ranging from 60 to 120 cm-thick (Fig. 26). The top of the formation shows a transition with 1-3 m-thick cycles possibly driven by precession and obliquity (Fig. 32). The Molignée Fm recorded the first shallowing-upwards parasequences (4-12 m-thick, Fig. 32) of eustatic origin. Afterwards, the deposition is only driven by parasequence through the whole Viséan. The switch in cycle is interpreted as the onset of the Viséan ice-house period (Poty, 2016).

5. References

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