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Field trip A1:

The Uppermost Devonian and Lower Carboniferous in the type area of Southern Belgium

Julien DENAYER[1], Cyrille PRESTIANNI[2], Bernard MOTTEQUIN[2] & Edouard POTY[1]

Strunian – Tournaisian – Viséan – Mississippian – Belgium – Visé – Dinant – sequence stratigraphy

ABSTRACT. The uppermost Famennian (Strunian) is typically a mixed carbonate-siliciclastic unit that deposited during the transgressive phase of the first 3rd order sequence. The Devonian-Carboniferous boundary, recognised at the top of the Hangenberg Sandstone event occured during the transgression. The Hastière Fm represent the first carbonate deposit of the Tournaisian. With the shaly Pont d'Arcole Fm and limestone of the Landelies Fm, its forms the sequence 2. Sequence 3, 4A and 4B are recorded in different units depending on the position on the shelf, notably in the Waulsortian mudmound complex in the southern Dinant sedimentation area and as mostly crinoidal and oolitic limestones in the Condroz sedimentation area. In more proximal areas, these sequences are often dolomitic and only the highstand system tracts are recorded. Sequence 5 filled the inherited depressions around the Waulsortion complex as calci-turbidites forming the 'Black marble' of the Molignée Fm. Sequence 6 finished to smooth the topographic irregularities with the deposition of massive oolithic limestone of the lower Viséan Neffe Formation capped by a pedogenetised cinerite. The middle and upper Viséan formations are monotonous shallow-water deposits, usually stromatolithic and arranged in parasequences with some marine interval such as in the biostromal Chabôfosse facies. In the Visé sedimentation area the late Viséan is represented by a large microbial reef in the stratotypic locality of Visé. Finally, the carbonate shelf has emerged at the end of the Viséan, was karstified and then covered by the Namurian.

CONTENT

Adresses of the Authors:
[1]Université de Liège, Département de Géologie, Evolution & Diversity Dynamics Lab, Allée du Six-Août B18, Sart-Tilman, B-4000 Liège, Belgium; e-mail: e.poty@ulg.ac.be, julien.denayer@ulg.ac.be.
[2] Royal Belgian Institute of Natural Sciences, O.D. Earth and History of Life, rue Vautier 29, B-1000 Brussels, Belgium; c.prestianni@naturalsciences.be, bmottequin@naturalsciences.be.

INTRODUCTION

This three-day field trip in southern Belgium illustrates uppermost Devonian ('Strunian') and Lower Carboniferous fossiliferous sections and outcrops, some being the classical sections where the Tournaisian and Viséan stratigraphy was first established (Fig. 1). Quality and accuracy of available data differ from one section to another but the collection of fossils is generally possible. Changing exposure quality or weather may alter slightly the visited localities during this trip.

The first day focuses on the Viséan type area with an overview on the classical Visé quarries (stop 1, Fig. 1) and fossil karsts associated to block faulting in this area and Namurian regression (2). The 'Strunian' (uppermost Famennian) and lower Tournaisian can be observed in the Ourthe (3-4) and the Hoyoux valleys (5). The day ends with the upper Viséan coral biostromes in the Hoyoux valley (6).

The second day focuses on the Namur and Dinant areas. Sections in the Meuse, Molignée and Bocq valleys are visited: the upper Tournaisian and lower Viséan of Dinant (stop 7), the classical succession of the Salet section, including the 'Black marble' facies (8), the fossiliferous section in Spontin and Chansin exposing the Devonian-Carboniferous transition (9) and the Tournaisian can be seen in the 'Nutons' quarry in Chansin (10). Sections presenting the middle and upper Viséan can be observed (11-12) as well as the contact with the basal Namurian (13). The second day ends in the Namur Citadel, the type section of the Namurian (14).

The third and last day of the field includes sections exposing the Waulsortian facies (15-16), the lower-middle Viséan of the Dinant area and a quarry exposing the lacunar succession near the German border (17)

1. HISTORICAL BACKGROUND

Southern Belgium is the cradle of Lower Carboniferous (= Dinantian) geology, stratigraphy and palaeontology. Following the pioneer works of DUMONT (1832), who subdivided the Carboniferous limestone in two stages that later became 'C*alcaire de Tournai'* (or Tournaisian) and '*Calcaire de Visé'* (or Viséan), GOSSELET (1860) added a third stage '*étage houiller*' that corresponds to the Upper Carboniferous coal measures. The name 'Dinantian' as synonym of Lower Carboniferous was chosen by DE LAPPARENT (1893) in reference to the Dinant area where these rocks are particularly well exposed and to honour the pioneer works of E. Dupont in the Meuse valley (GROESSENS 2006). Based on the palaeontological works of de KONINCK (1842–1851) and especially of DEMANET (1958), the base of the Dinantian was placed at the first limestone unit capping the Upper Devonian (now Uppermost Famennian, 'Strunian' Substage) and its top at the first appearance of the goniatite *Eumorphoceras*. The boundaries were subsequently used until the 1970's.

In 1971, during the Krefeld International Congress on geology and stratigraphy, the division of the Lower Carboniferous in Tournaisian and Viséan was decided officially. CONIL et al. (1977) refined the stratigraphic column of the Dinantian by the introduction of five stages (Hastarian, Ivorian, Moliniacian, Livian and Warnantian) based on foraminifer and conodont biostratigraphy in conformity with international stratigraphic rules. CONIL et al. (1977) used the Strunian as the first stage of the Dinantian but the Devonian affinity of the Strunian fauna and flora was long known (STREEL 1969). The substage was therefore reintroduced as the uppermost part of the Famennian when the Devonian-Carboniferous was defined in the 1990's (PAPROTH et al. 1991). The 'Strunian', often incorrectly used in lithostratigraphic viewpoint (shallow-water carbonate facies) is however stratigraphically defined: its base corresponds to that of the upper *expansa* conodont Zone marked by the entry of *Bispathodus ultimus ultimus* at approximatively the same level than the base of the *Quasiendothyra kobeitusana kobeitusana* foraminifer Zone according to STREEL et al. (2004). The Strunian is consequently synonymized with the uppermost Famennian substage (STREEL et al. 2004, 2006).

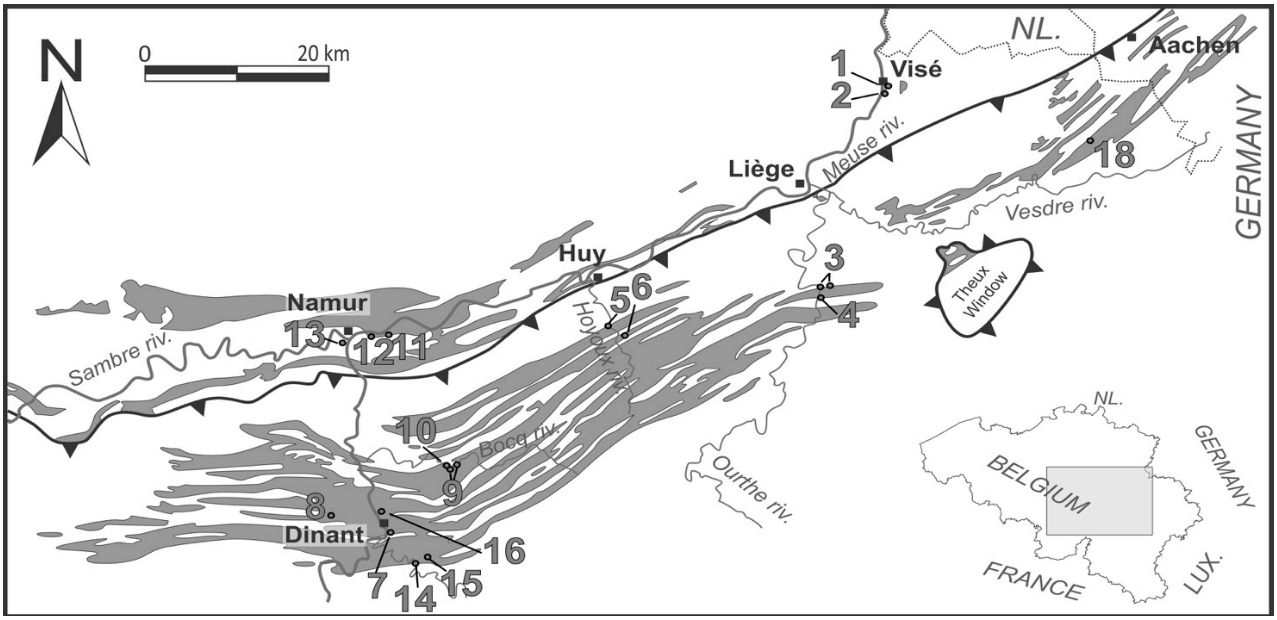

Fig. 1: Schematic geological map wit Dinantian strata in grey (modified after DE BETHUNE 1954) with location of the visited sections: (1): Visé quarries, (2): Argenteau Castle Rock, (3): Chanxhe sections, (4): Rivage road section, (5): Royseux railroad section, (6): Royseux trenches, (7): Dinant and the Bayard Rock, (8): Tanret quarry and Salet road section, (9): Spontin and Chansin sections, (10): Chansin 'les Nutons' quarry, (11): Lives Rock and quarry, (12): Jambes Rock, (13): Citadel of Namur, (14): Gendron-Celles railroad section, (15): Vève Castle section, (16): Leffe quarry, (17): Eupen 'Carnol' quarry.

After a decade of discussion, the Devonian-Carboniferous boundary was re-defined. The former base defined by the first appearance of the conodont *Siphonodella sulcata* in the evolutionnary lineage *Siphonodella praesulcata–S. sulcata* whose entry immediately preceedes that of *Gattendorfia* (SANDBERG 1972; SANDBERG et al. 1978). Research in Belgium failed to find the conodont lineage (BOUCKAERT & GROESSENS 1976), and the base of the Carboniferous was placed in a very pragmatical way at the end of the extinction event that drove the Devonian fauna and flora to extinction. In 2004, the International Union of Geological Sciences ratified the division of the Carboniferous System in two sub-systems, namely the Mississippian and the Pennsylvanian. This division is not applicable in Western Europe but the term Dinantian is much more Hence, this term is still in use to designate the Lower Carboniferous carbonate succession at the regional scale (GROESSENS 2006) and proves its usefulness at the global scale (POTY et al. 2014; POTY 2016).

The palaeontological studies began with DE KONINCK (e.g., 1842–1851, 1872) then DELEPINE (1911) and DEMANET (1923, 1958 among others) who described the highly diverse fauna from the extremely fossiliferous Tournaisian from Tournai and Viséan from Visé. The Lower Carboniferous stratigraphy was investigated from a lithological point of view by PIRLET (1963, 1964, 1968) and from a biosratigraphical point of view by CONIL (1964, 1968), CONIL et al. (1977, 1986, 1989, 1991) and CONIL & PIRLET (1970) for the foraminifers, GROESSENS (1975) and GROESSENS et al. (1982) for the conodonts and POTY (1981) and POTY et al. (2011) for rugose corals. Combined biostratigraphies are due to POTY et al. (2006), emended by POTY et al. (2011, 2014) and POTY (2016).

2. GEOLOGICAL SETTINGS

Southern Belgium is part of the Rhenohercynian Fold Belt, which extends across Europe from Southern Portugal through southern England, northern France, Belgium, and Germany, into Poland and resulting of the Variscan deformation.

During the Late Devonian and Early Carboniferous, the Namur–Dinant Basin (Fig. 1) recorded proximal facies in its northern part whereas its southern part acted as a shallow basin with deeper facies. However, deeper water environment of Kulm facies are not known in Belgium but were suggested to the south of the Namur–Dinant Basin, on the basis of the westward facies prolongation of the German Kulm into S Ireland where a southern Kulm-type basins existed during most of the Lower Carboniferous. Conversely, the presence of proximal carbonate facies in the southern Avesnois suggests a local or regional shelf area southwards rather than a basin (POTY 2016).

The Namur–Dinant Basin was divided in six sedimentation areas by POTY (1997) corresponding to tectono-sedimentary units (Fig. 2, 3). The Namur sedimentation area (NSA) located on the southern margin of the London-Brabant Massif, displays an incomplete succession of proximal facies. The Condroz sedimentation area (CSA) extends south of the NSA and also exposes proximal facies with several stratigraphic hiatuses increasing eastwards. The Dinant sedimentation area (DSA) is characterised by a deeper-water (but still not deep) sedimentation and was strongly influenced by the development of Waulsortian buildups during the late Tournaisian–earlyViséan. The Hainaut sedimentation area (HSA) was strongly subsident and recorded a 2500 m-thick sequence of Dinantian rocks of various facies, including several thick evaporitic intercalations. The southern Avesnois sedimentation area (ASA), in northern France and southwestern Belgium, displays facies similar to those of the CSA. The Visé sedimentation area (VSA) is a small area at the southeastern end of the Brabant Massif, affected by synsedimentary block-faulting and tilting. It was connected with the NSA during the Upper Devonian and Tournaisian and connected to a graben open eastwards to the Campine Basin (KB) during the Viséan (POTY 1997). POTY et al. (2011) defined a last sedimentation area, the Vesdre-Aachen Sedimentation Area (VASA) is the eastern continuation of the CSA and NSA that recorded a similar but incomplete stratigraphic succession of the latter areas (POTY 2016).

3. LITHOSTRATIGRAPHY, SEQUENCE STRATIGRAPHY AND DEPOSITIONAL EVOLUTION

The litho- and biostratigraphy of the Dinantian has been reviewed recently by POTY et al. (2006, 2011, 2014) and POTY (2016). The rugose coral biozonation of POTY et al. (2006) is a useful tool in the field. The foraminifer biozonation established and enhanced by Conil during more than 30 years was summarised by POTY et al. (2006) with the redefinition of 17 biozones through the uppermost Famennian and Lower Carboniferous. Coupled with the sequence stratigraphy, these biozonations are powerful tools for global correlation as proven by HANCE et al. (2002, 2011), etc. The conodonts are of poor interest in the Viséan but are rather abundant in the Tournaisian (GROESSENS 1975). Figure 4 summarises the Dinantian biostratigraphy and lithostratigraphy of Belgium with reference to bio- and sedimentological events. HANCE et al. (2001, 2002) emended by DEVUYST et al. (2005), POTY et al. (2006) and POTY (2016) proposed a sequence stratigraphic model for the Dinantian of the Namur-Dinant Basin (Fig. 3-4). It is based on a new litho- and biostratigraphic interpretations of the Dinantian (e.g. POTY et al. 2002, POTY et al. 2006). Nine third-order sequences have been recognized in the Belgian Tournaisian and Viséan. System tracts follow the terminology of PLINT & NUMMEDAL (2000). The following description of the sequences is mainly from POTY et al. (2005), emended by POTY (2016).

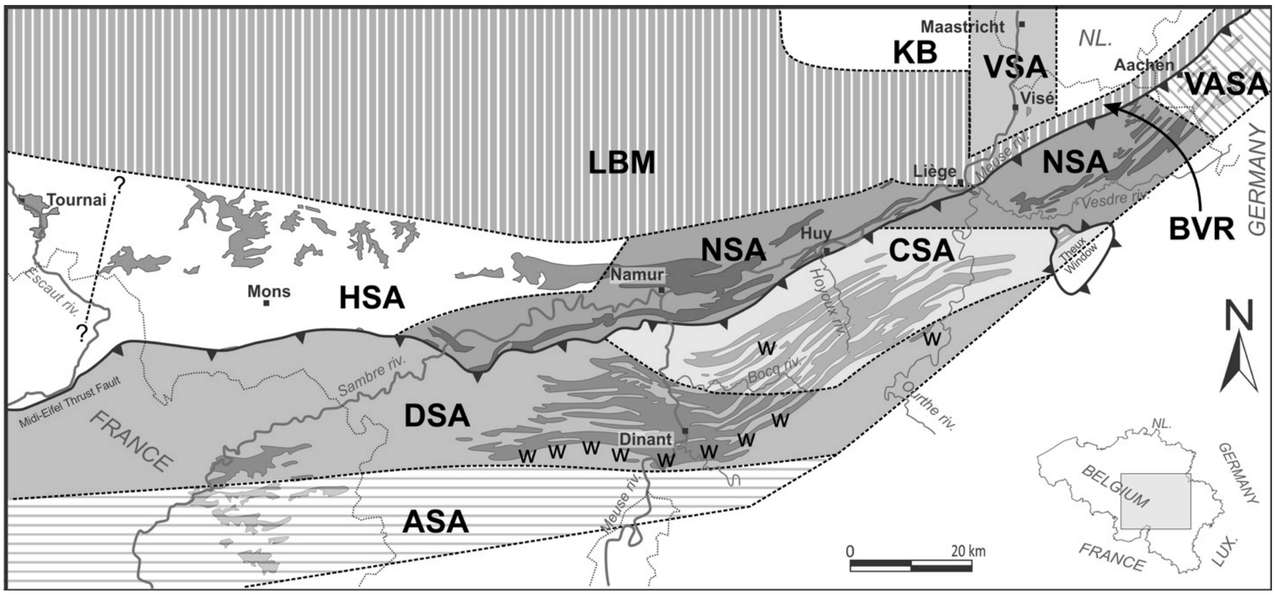

Fig. 2: Sedimentation areas in Belgium and surrounding areas during the Dinantian. ASA: Avesnois sedimentation area, CSA: Condroz sedimentation area, DSA: Dinant sedimentation area, HAS: Hainaut sedimentation area, KB: Kampen Basin, LBM: London-Brabant Massif, NSA: Namur sedimentation area, VSA: Visé sedimentation area, VASA: Vesdre-Aachen sedimentation area, W: main Waulsortian developments (modified from POTY 2016).

3.1. Latest Famennian (Strunian) and the Devonian-Carboniferous Boundary

In Belgium, the mixed carbonate-siliciclastic sedimentation typical of the Strunian follows the dominantly siliciclastic succession of the Famennian (POTY 2016). The facies indicate an environment close to the base of the fair-weather wave zone and under the influence of both detrital and marine inputs, with common storm deposits (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 (Fm) in the northeastern part of the Namur–Dinant Basin (CSA) and Etroeungt Fm in the Avesnois area (ASA) where the latter shows stromatoporoid facies. The Dolhain Fm, known in the eastern part of the basin (VASA) is characterised by stromatoporoid biostromes. These three formations are lateral equivalent of each other and their composition shows a proximal-distal gradient oriented N-S (DEVYUST et al. 2005). To these lithostratigraphic units succeeds the carbonate of the Hastière Fm, first of the Carboniferous succession in the basin but its extreme base is still Devonian as it contains quasiendothyrid foraminifers, campophyllid corals, phacopid trilobites, etc. In most section, the basal bed of the Hastière Fm contains clues of reworking such as silt- to sand-sized quartz grains, ichnoclasts, intraclasts and reworked fossils. Not all fossils are reworked as they often display very good state of preservation. They were indeed contemporaneous with the reworking (DENAYER et al. in prep.). This unusual facies was identified as corresponding to the Hangenberg Sandstone event which it correlates with had that was interpreted as resulting of a strong but short-living regressive event (MOTTEQUIN & POTY 2014; POTY 2016). The out-of-sequence identity of the Hangenberg Sandstone event is demonstrated by both its occurrence within the Strunian transgression (the sequence boundary being situated upwards in the middle part of the Hastière Fm) and by its sedimentary expression in rupture with the cyclic pattern characterising the Strunian and Hastarian deposits (DENAYER et al. in prep). Whereas VAN STEENWINKEL (1990) concluded to a hiatus associated to a sequence boundary at the DCB, new interpretation points to a continuous record. The so-called hiatus was based on the non-recognition of the palynological biozone LN that has been proven to be an ecozone with few stratigraphical value (PRESTIANNI et al. 2016). The first Tournaisian fauna occurs directly above the basal bed of the Hastière Fm interpreted as the Hangenberg Sandstone event equivalent. These include the typical unilocular foraminifer association of the MFZ1 and corals of the RC1 zone (POTY et al. 2006) in the crinoidal grainstone-rudstone facies – note that richer associations with plurilocular foraminifers exist where the facies are less hydrodynamic.

From a sequence stratigraphy viewpoint, the third-order sequence 1 of HANCE et al. (2001) straddles the Devonian-Carboniferous boundary. Its transgressive system tract (TST) covers the Etroeungt/Comblain-au-Pont/Dolhain formations as well as the lower member of the Hastière Fm. The highstand system tract (HST) is represented by the middle member of the Hastière Fm (POTY 2016, DENAYER et al. in prep).

3.2. Tournaisian

The Hastarian (lower Tournaisian) succession is rather uniform throughout all the sedimentation areas of the Namur–Dinant Basin (Fig. 3). The inherited Upper Devonian palaeotopography showing slightly deeper facies in the south indicates a very regular platform (and not a ramp as previously published, e.g. by HANCE & POTY 2006). The Hastière Fm recorded bioclastic and crinoidal accumulation with locally some argillaceous interbeds. The Pont d'Arcole Fm is one of the rare argillaceous units through the Dinantian carbonate succession. It corresponds to the development of dysaerobic facies on the lower Hastarian carbonate shelf 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 stratographically correlatable Alum Shale Event (POTY et al. 2001). 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. Sequence 2 starts abruptly in the DSA and CSA with the upper member of the Hastière Fm (LST) 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 cycle (greenhouse-icehouse precession cycles, POTY 2016). The cycles varry from alternations of shale and calcareous shale (mainly in the Pont d'Arcole Fm) to alternations of calcshale and limestone (essentially in the Hastière Fm), and to limestone dominated (mainly in the upper part of the Landelies Fm). Their thickness varies from about 0.2 m to 1 m (average c. 0.4 m), and is strongly influenced both by the sediment production and by the compaction in the argillaceous levels and pression dissolution in the limestone levels (POTY 2016).

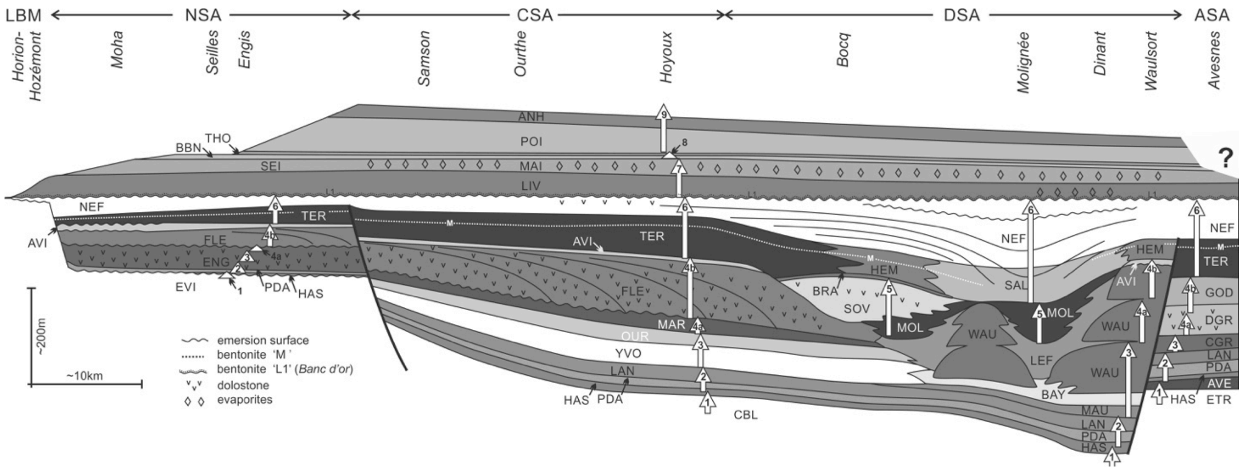

Fig. 3: North-South transect through the Dinant-Namur Basin showing the spatial relationship of the lithostratigraphic units and their eustatic interpretation. Modified from HANCE et al., (2001) and POTY (2016). Abbreviations: ANH: Anhée Fm, AVE: Avesnelles Fm, AVN: Avins Mbr, BAY: Bayard Fm, BBN: Bay-Bonnet 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.

Considering the sequences as the result of precession cycles, it is possible to calibrate the duration of the Hastarian Substage but also of the third-order sequence 2. According to BERGER et al. (1989), precession cycles for the lower Tournaisian are about 17 and 20.2 ky, and it is possible to consider 18.6 ky as a rough average for their duration. On the other hand, according to GILES (2009) who calibrated the three last third-order sequences of the Viséan to 2.4 My and considered that they could correspond to eccentricity cycles, we consider that the Tournaisian ones also could last about 2.4 My. Therefore the 93 precession sequences recognized in the third-order sequence 2 may represent 1.73 My, suggesting that the erosion surfaces marking the sequence boundaries between sequence 1 and 2, and 2 and 3, could correspond to gaps as long as about 0.67 My if we consider a similar number of precession sequences in both sequences 1 and 3. So, considering the duration of the 31 precession sequences in the Hastarian part of the third-order sequence 1, i.e. 0.577 My (not including the unknown time corresponding to the 1.75 m-thick unit at the base and the 3.65 m-thick unit at the top), + 0.67 My, + 1.73 My, + 0.67 My, + 31 sequences in the Hastarian part of the third-order sequence 3, i.e. 0.577 My, we obtain 4.224 My as a possible duration for the Hastarian (POTY 2016).

After the deposition of the Landelies Fm, the topography of the shelf changed and a strong proximo-distal pattern developed (Fig. 3). It is probably due to synsedimentary faulting and consequent deepening of the Dinant sedimentation area where Waulsortian complex started growing (Bayard, Leffe, Waulsort, Molignée and Salet formations). North of the Yvoir-Ciney line, the facies are typically shallower in the CSA in the Ivorian (late Tournaisian Yvoir, Ourthe, Martinrive and Longpré formations, see POTY et al. (2002) for detailed description). Similarly, south of the Waulsortian development, the ASA shows shelf facies similar to those of the CSA. In the NSA and VASA, the succession is similar but often dolomitised (Namur and Vesdre dolostone groups). The Maurenne Fm, Bayard Fm and Hun Mbr (Yvoir Fm) correspond to the LST whereas the Yvoir and Waulsort formations form the TST respectively in the CSA and DSA. The HST is represented by Waulsortian facies (Waulsort and Leffe Fm) in the DSA whereas in the CSA and HAS, the highstand recorded a very monotonous accumulation of crinoidal limestone in the Ourthe Fm and Soignies Mbr (DEBOUT & DENAYER 2018). In more proximal facies, the crinoidal limestone passes to oolithic grainstone ("*Vaughanites* Oolite", Hastenrath Mbr, POTY 2016) which is often dolomitised in the NSA (Namur Group). Sequence 4 sensu HANCE et al. (2001) was re-investigated by POTY (2016) who recognised two distinct sequences, namely 4A and 4B. 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 deposits of the wackestone forming the lower part of the Martinrive Fm. The HST is recorded in the Leffe and

Waulsort Fm of the DSA and in the upper, packstone part of the Martinrive Fm, capped by an emersion surface witnessing the emersion of the shelf at the sequence boundary. The crinoidal rudstone of the Flémalle Mbr and the overlying oolithic limestone of the Avins Mbr correspond to the TST and HST-FSST of the sequence 4B in the CSA and NSA whereas in the DSA, this sequence is entierely recorded in the Waulsort and Leffe formations (POTY 2016).

3.3. Viséan

During the Moliniacian (early Viséan), the Waulsortian complex still influenced the sedimentation in the DSA (Fig. 3) with the deposition of the restricted turbiditic facies (e.g. Overlau 1966; Hance 1988; Mottequin 2004) of the Molignée Fm ('Black marble' facies) developed in a depression at the prograding inner-outer shelf transition (Lees 1997). This peculiar facies records a switch recorded only in the DSA (Fig. 3, 4) and in the VSA. In the transition CSA-DSA, it corresponds to the Sovet Fm and its equivalents to the south in the Molignée Fm. Submarine topographic irregularities inherited from different sedimentation rates and Waulsortian buildups were smoothed out in the late Moliniacian. In the CSA and NSA restricted and evaporitic facies developed (lower part of the Terwagne Fm) and are

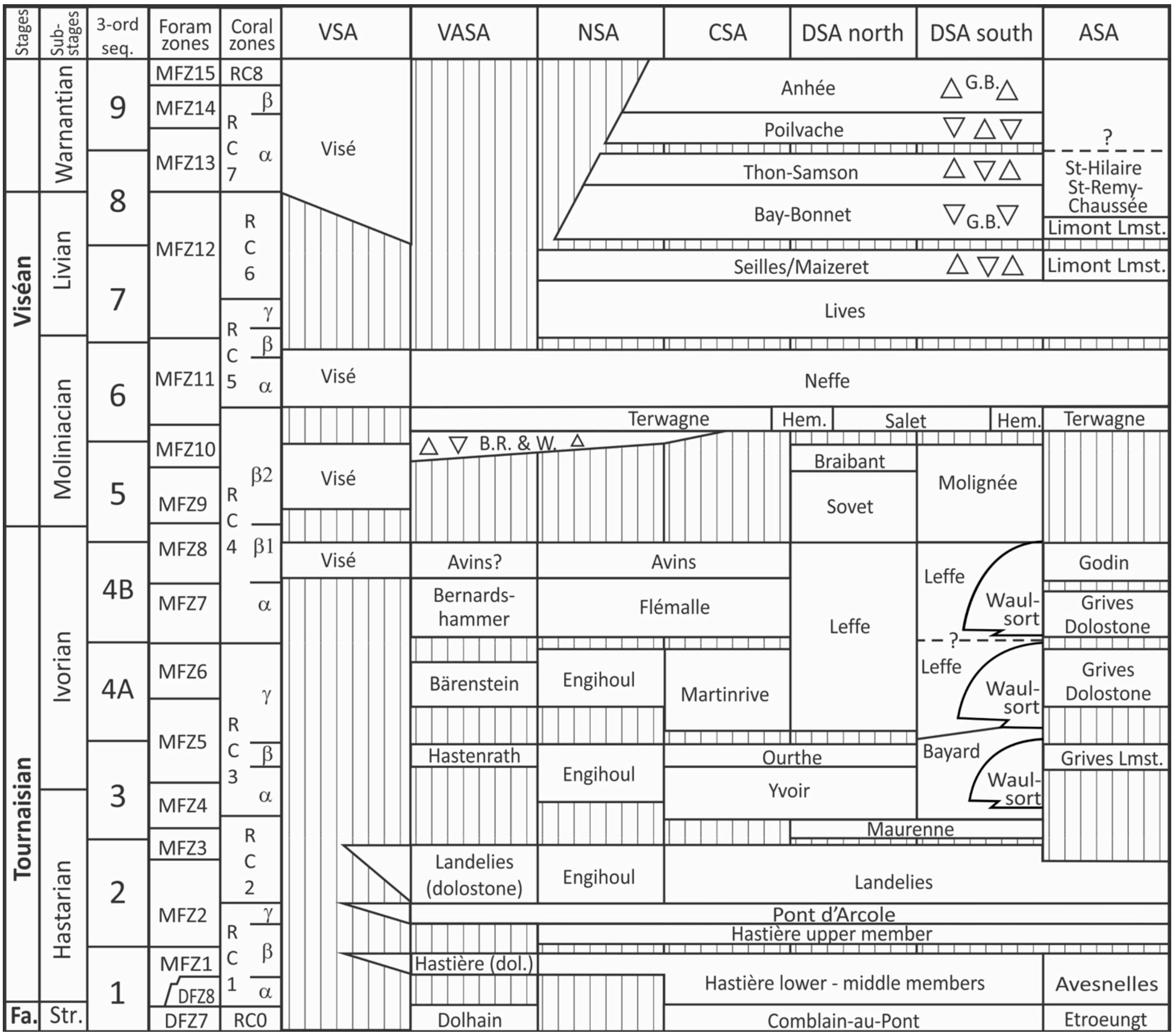

Fig. 4: Lithostratigraphic, biostratigraphic and sequence stratigraphic framework for the uppermost Devonian, Tournaisian and Viséan of Southern Belgium and surrounding areas. Gaps are indicated by light gray zone. Abbreviations: G.B.: Grande Brèche, B.R. & W.: Belle Roche & Walhorn breccia, Lmst.: limestone. Third-order sequences according to HANCE et al. (2001) and DEVUYST et al. (2005) emended by POTY (2016). Biostratigraphy (foraminifers and rugose corals biozones) after POTY et al. (2006) and POTY (2016). Modified after POTY et al. (2006, 2011, 2014) and POTY (2016).

interpreted as the LST of sequence 6, or possibly to the only deposits witnessing sequence 5 in the CSA.The latter rest disconformably upon the underlying Avins Mbr (FSST of sequence 4) with local karst development in the NSA and VASA. In these sedimentation areas, the TST corresponds to the upper part of the Terwagne Fm. The dissolution of the evaporites produced a collapse breccia in the CSA and VASA known as the Belle Roche Breccia (SWENNEN et al. 1990). In the DSA, the Salet Fm forms the TST with a 3 m-thick debris-flow horizon at its base corresponding to the LST (POTY 2016). Further south, black limestone of the Molignée Fm continued to form during the TST of sequence 6 (HANCE et al. 2002). In the entire Namur–Dinant Basin, the sequence 6 ends with the thick-bedded packstones and grainstones of the Neffe Fm as the HST and FSST (high energy oolitic, peloidic and bioclastic facies). This formation filled the inherited topographic irregularities in the DSA and was subsequently capped by the '*Banc d'Or de Bachant*', a bentonite, partly reworked in palaeosol (DELCAMBRE 1989).

During the Livian (mid 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 Great 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 developed to the north, whereas restricted facies and evaporites (and associated collapse breccia) are recorded in the south. Sequence 7 includes the LST (Haut-le-Wastia Mbr), TST (Corphalie and Awirs Mbrs) and HST(-FSST?) (Seilles and Maizeret members). Sequence 8 is the thinnest sequence observed in the basin. It corresponds to the Bay-Bonnet Mbr (LST and TST), characterised by stromatolitic limestone, and to the bioclastic limestone of the Thon-Samson Mbr (HST) of the Bonne Fm. This shallow-water sedimentation continues through the Warnantian 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 (POTY & HANCE 2006b). Very locally in the DSA, inner platform sedimentation (sequential microbialithic 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 (Fig. 3).

3.4. Namurian

In the NSA and VSA, the lower Namurian siliciclastics fill palaeokarstic depressions reaching down to the Livian formations. The gap extends up to the Arnsbergian E2 goniatite Zone (westwards) to the the Chokierian H1 Zone (eastwards, BOUCKAERT 1967). Only the Gottignies Fm in the western HSA contains questionably the Viséan/Namurian boundary.

The stratigraphic gap is related to emergence of the entire basin and palaeokarst formation is widely observed. Lower Namurian sediments are mainly dark, marine mudstones to siltstones, local with interbedded limestones (Tramaka limestone, E2, GROESSENS 1982). The base of the 'Namurian black shales' represents rather shallow water facies as evidenced by their various compositions (mudstones to few sandstones, with some carbonate content), associated sedimentological features (erosional surfaces, cross-stratification), and associated carbonate shoals (Tramaka). Organic geochemistry data suggest the preservation of organic matter due to rapid burial rather than intense anoxity (NYHUIS et al. 2014). Endobenthic activity and various simple ichnofabrics prove at least temporary dysoxic conditions as confrmed by relatively low TS/TOC ratios. Together with the Westphalian, the Namurian rocks forms, in Western Europe, a thick and monotonous molasse sequence filling the European Variscan foreland basin, during the Late Carboniferous. Contrary to most of the Devonian-Dinantian, the origin of the Namurian sediments is situated south of the Namur-Dinant Basin, as pointed by the occurrence of shallower facies in the south and deeper facies in the northernpart, as well as the geometry of the channelised structures (BOUCKAERT 1961).

4. FIELD TRIP ITINERARY

1 - VISE QUARRIES

Highlights

Historical type locality of the Visé, late Viséan bioherm, Namurian unconformity.

References

CONIL et al. (1977), HANCE et al. (2006b), PIRLET (1967), POTY (1982, 1991, 1997), POTY & DELCULÉE (2011), POTY et al. (2011)

Location and access

Disused quarries along the road from Liège to Visé, on the eastern bank of the Meuse River (Figs. 5). The quarries are mostly in private properties and, unfortunately, inaccessible. Meuse valley, Visé

Sedimentation Area (VSA, Fig. 1, 2). GPS: from 50°43′35″N5°41′37″E to 50°43′18″N5°41′35″E.

Description
The Visé quarries are the historical type locality for the Viséan (due to the quality and abundance of its fossils) but the base of the stage cannot be located here. The Visé Fm is a complex formation with a thickness varying locally from zero to several hundreds of meters due to the syn-sedimentary tectonics of the area (POTY 1982, 1991, 1997; POTY & DELCULÉE 2011). BARCHY & MARION (2000) and POTY et al. (2002) recognized four main facies in the Visé Fm (Fig. 5):

(1) sedimentary limestone breccias with centimetric to pluri-decametric blocks of Frasnian age ("cyclopean breccia");

(2) thick-bedded packstone to rudstones forming pluri-decimetric to metric parasequences often beginning with brecciated level, fining-upward and ending with laminated levels corresponding to calciturbidites.

(3) thick-bedded packstone to rudstones beds;

(4) massive buildups (microbial-metazoan reefs) composed of light grey microbial boundstones with abundant macrofossils (mainly brachiopods) (ARETZ & CHEVALIER 2007).

This last facies, exposed in the quarry F-G (Fig. 5), has yielded the famous Visé fossils, extracted during the 19th century. The unit is locally topped by yellowish dolomitised limestone, and capped with silicified shales and limestones (lydites or "phtanites") of the Souvré Fm (Fig. 6).

Lithostratigraphy and biostratigraphy
Visé Fm: upper Warnantian MFZ14 and RC7β zones; Souvré Fm: lower Namurian (E_2) MFZ15 and RC8 zones.

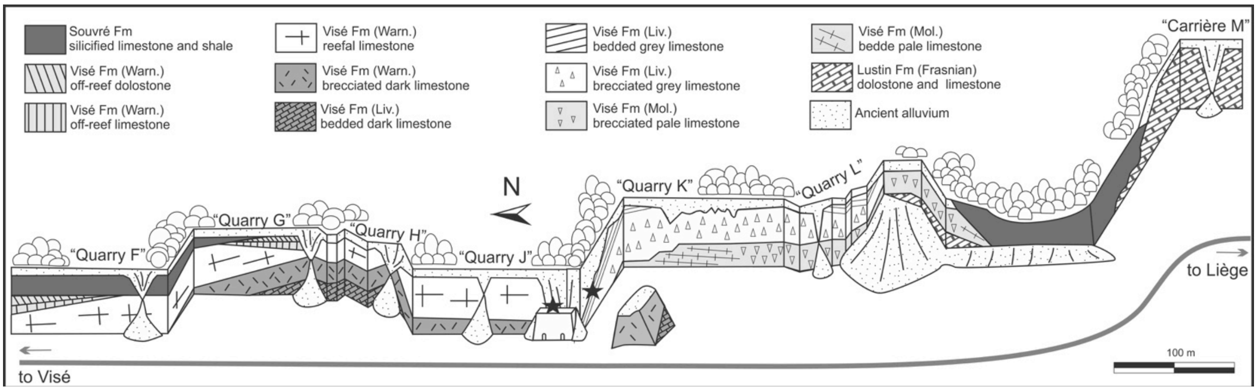

Fig. 5: Schematic representation of the classical Visé quarries showing the main facies. Modified after PIRLET (1967).

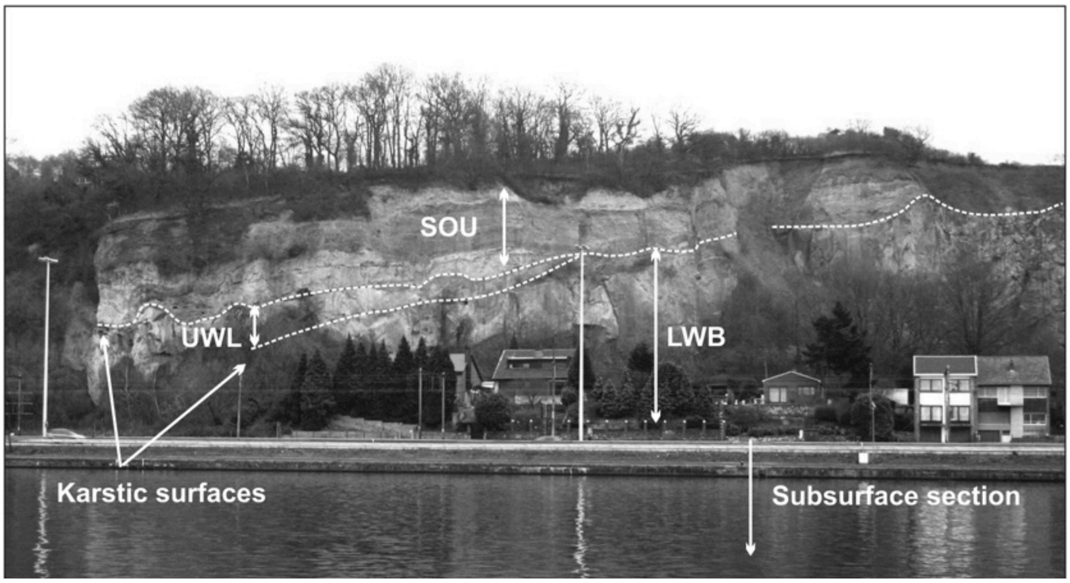

Fig. 6: Visé F-G quarry. SOU: Souvré Fm (silicified limestone and shale), UWL: upper Warnantian off-reef limestone and dolostone of the Visé Fm, LWB: lower Warnantian bioherm. Modified after POTY & DELCULÉE (2011).

Interpretation
The limestones of the Visé quarries were deposited on the Hermalle-sous-Argenteau tectonic block of POTY (1991), close to a cliff of Frasnian limestone corresponding to another block (Souvré Block). The Hermalle-sous-Argenteau block is limited southwards by the Booze–Le-Val-Dieu high, and is open northwards to the Maastricht graben. The continuous erosion of the Souvré cliff resulted in the deposition of the cyclopean breccia during the Viséan (POTY 1991, 1997). The palaeogeography (including tectonics) and the sequence stratigraphy of the Visé area have been re-interpreted recently by POTY & DELCULÉE (2011). The lower Warnantian microbial buildup (Fig. 6) corresponds to the highstand of sequence 9 of HANCE et al. (2001), whereas the silicified limestone and shale of the Souvré Fm correspond to the sequence 10 (POTY & DELCULÉE 2011).

2 - ARGENTEAU CASTLE ROCK

Highlights
Block tectonics, Namurian karsts.

References
POTY (1982, 1991, 2016), POTY & DELCULÉE (2011).

Location and access
Rock below the Castel of Argenteau, east of the motorway bridge at Argenteau. The section is situated about 2 km south of the historical stratotype area for the Viséan. Visé sedimentation area (VSA, Fig. 2). GPS 50°42’39”N5°41’10”E.

Description
Argenteau is situated on the Hermalle-sous-Argenteau Block, one of the southern tectonic blocks in this area (POTY 1991). Most parts of the section consist of pale, well-bedded (decimetre thick) to massive bioclastic grainstones of the Visé Fm. The beds dip with approx. 20° towards the south. The fauna consists of corals, crinoids, foraminifera, bryozoans, and few brachiopods. Several pockets of various size and shape occur in this outcrop. These pockets are often filled with brownish to greyish fine- to medium-grained siliciclastic sediment, which may locally contain some carbonate. The bedding of this sediment is concave in the pocket left of the statue (Fig. 7). Other pockets may contain lithoclasts, mainly mudstones, and lydites of the Souvré Fm, in a fine-grained siliciclastic matrix. It is worthwhile to mention that the road cut only displays the lowest part of the Viséan strata at Argenteau. The base of the Namurian is some tens of meters uphill. Small outcrops uphill showed the development of microbial reefs (ARETZ & CHEVALIER 2007) in the upper Viséan.

Interpretation
The Argenteau outcrop offers a good insight into the depositional and tectonic processes of the Visé Sedimentation area. The dating of the limestones was somewhat complicated by the co-occurrence of a lower Viséan foraminifera fauna (CONIL in KIMPE et al. 1978) and an upper Viséan coral fauna (POTY in KIMPE et al. 1978). Since GRAULICH (1975) reported reworked lower Viséan lithoclasts in the upper Viséan rocks of the Hermalle-sous-Argenteau borehole, which is located on the left bank of the Meuse River only some hundred meters to the west of the outcrop, the same process was proposed for this outcrop (POTY 1982). However, new analyses showed that the coral fauna is in fact of early Viséan age, which is then in accordance to the foraminiferan ages. The succession can be attributed to the HST-FSST of the third-order sequence 5 of HANCE et al. (2001) (POTY & DELCULÉE 2011). Since this sequence is only recorded in the deepest parts of the Namur-Dinant Basin, its presence in this outcrop illustrates the important and fast tectonic movements of the Hermalle-sous-Argenteau block at that time. The block became emerged around the Viséan/Namurian boundary.

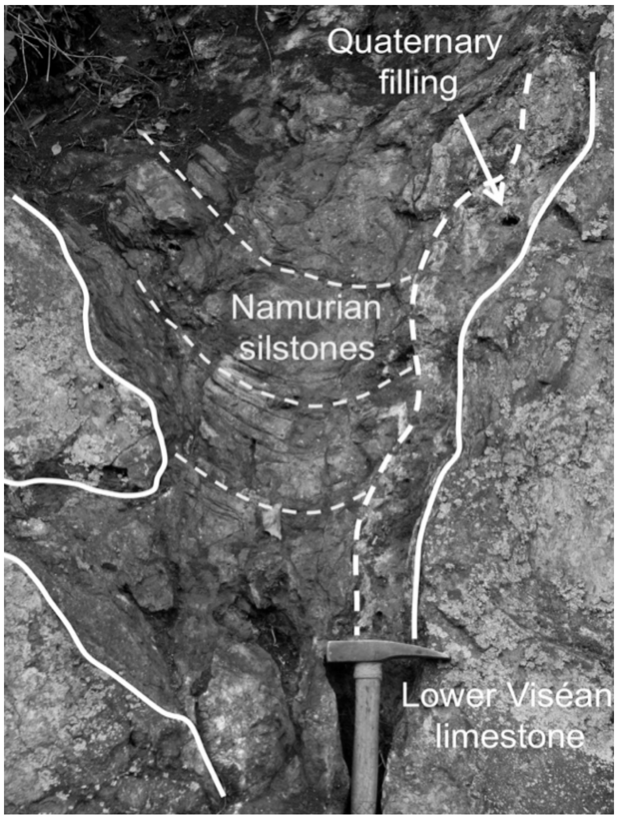

Fig 7: Lower Viséan limetones of the Visé Fm with palaeokarst pockets, which are filled with fine-grained silicilcastics; width of the photo c. 1,5 m (after POTY 2016)

The limestones are subsequently intensely karstified. The important early Namurian transgression (E_2) results in renewed marine sedimentation and the former karst depressions, pockets, and cave systems are contemporaneously filled with Namurian siliciclastics or material eroded from the top of this karst surface (Souvré Fm.). Not all karst systems have been completely filled with sediments and thus remaining pore space has subsequently been cemented. The development of karst systems is a common feature in the Visé sedimentation area, which helps to differentiate the individual blocks. The E_2 age of the karst fillings at Argenteau is in agreement with the age of shales which are exposed up-hill, and the general observation that karst phenomena and stratigraphic gaps widely occur at the Viséan/Namurian boundary in Belgium. The karst system at Argenteau shows features, which indicate its reactivation during the Quaternary. Some of the pockets contain gravel typically for the Meuse terrasses, and limonite crusts.

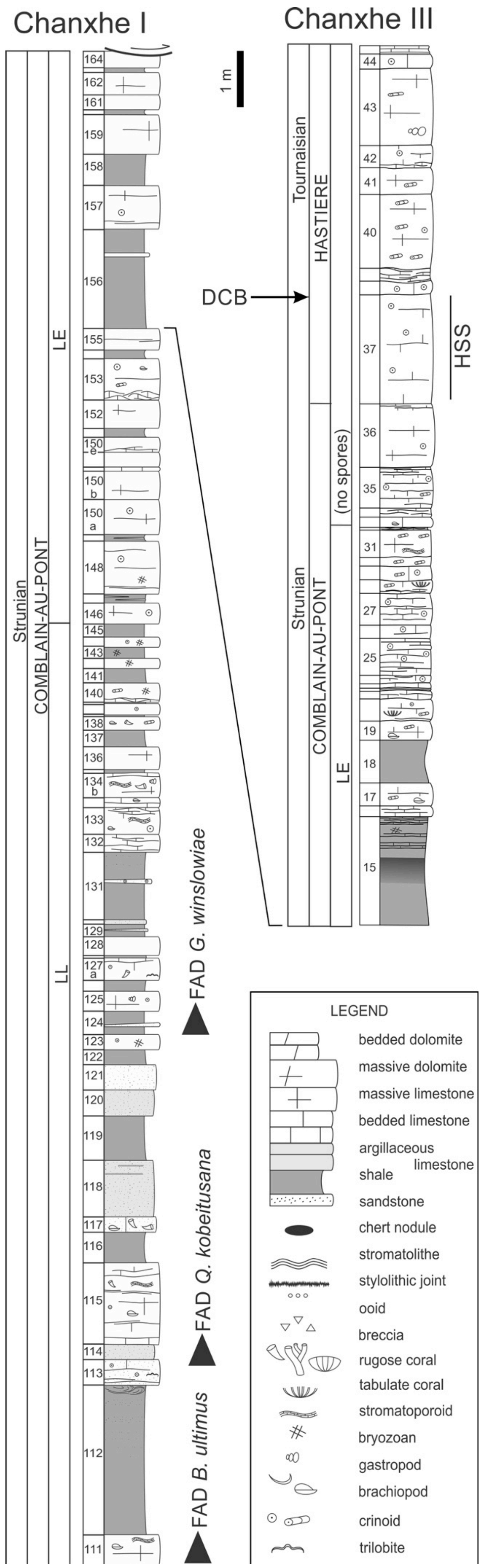

Fig. 8: Log of the Chanxhe section. LL and LE corresponds respectively to the *R. lepidophyta – K. literatus* and *R. lepidophyta – I. explanatus* palynozones (adapted from PRESTIANNI et al. 2016) and DENAYER et al. (in prep.).

3 - CHANXHE SECTIONS

Highlights

Typical Strunian transgressive sequence, Devonian-Carboniferous boundary.

References

CONIL (1964), STREEL (1966), BOUCKAERT et al. (1974), MAZIANE et al. (1999, 2002), PRESTIANNI et al. (2016 and numerous references therein).

Location and access

The renowned Chanxhe section (Chanxhe I) is situated on the right bank of the Ourthe river, 500 m north of the brige, along the road towards the Richopré quarry. The Chanxhe road section (Chanxhe III) is situated along the road from Chanxhe to Sprimont, c. 350 m E of the Chanxhe I section, along the same syncline limb. Eastern part of the CSA in the Dinant Synclinorium (Fig. 1, 2). GPS: 50°30'17"N5°35'48"E (Chanxhe I), GPS: 50°30'18"N5°36'07"E (Chanxhe III).

Lithostratigraphy and biostratigraphy

Comblain-au-Pont Fm: Strunian (DFZ7, RC0, LE zones); Hastière (middle and upper members): Hastarian (MFZ1, RC1 zones). The Devonian-Carboniferous Boundary is not exposed in the classical section due to a fault, but it is exposed in the eastwards Chanxhe-road section (Fig. 8).

Description

Chanxhe I has been intensively studied despite the fact that the DCB is not exposed because a fault cuts out the last c. 4 m of the Comblain-au-Pont Fm. The section indeed exposes almost continuously the uppermost Famennian.

The most interesting interval starts with two beds of sandy limestone separated by a silty interbed (beds 101-103). Bed 111 is the first thick carbonate horizon and yields the first stromatoporoids and brachiopods. It also yielded conodont fauna typical of the lower part of the *Bispathodus ultimus*, equivalent to the upper *expansa* conodont zone of ZIEGLER & SANDBERG (1990), and thus to the base of the Strunian Substage as suggested by STREEL & HARTKOPF-FRÖDER (2005). This bed is topped by grey siltstone containing several sandy horizons and showing convolute bedding at its top. The next carbonate bed (113, Fig. 4) yields the first *Quasiendothyra kobeitusana kobeitusana* (foraminifers) (CONIL 1964). The following unit (beds 113 to 155) corresponds to a cyclic succession of bioclastic sandy grainstone or crinoidal sandstone alternating with siltstone or shaly siltstone with a calcareous cement. The amount of detrital quartz grains decreases up-section. The carbonate beds are rather rich in large bioclasts of crinoids, brachiopods, gastropods and rugose corals. The first occurrence data of the acritarch *Gorgonisphaeridium winslowiae* has been noted in bed 123 (MAZIANE & VANGUESTAINE 1997). The rest of the section is dominated by bioclastic grainstone or packstone with few detrital quartz grains and a rich fauna of brachiopods, corals, crinoids and foraminifers.

The siliciclastic and carbonate beds alternate with an irregular but cyclic pattern that most probably corresponds to c. 18.6 ky Milankhovich climatic cycles caused by precession (POTY 2016). Periods of wet climate caused intensive weathering on continents that delivered fine siliciclastic material into the sedimentary basin whereas period of dry climate, with reduced siliciclastic inputs allows the development of carbonates. Upsection the amount of siliciclastic material decreases, witnessing the transgressive character of the Comblain-au-Pont Fm. The last thick shaly interval is rather dark in colour and yields small pectenid pelecypods witnessing its dysoxic character.

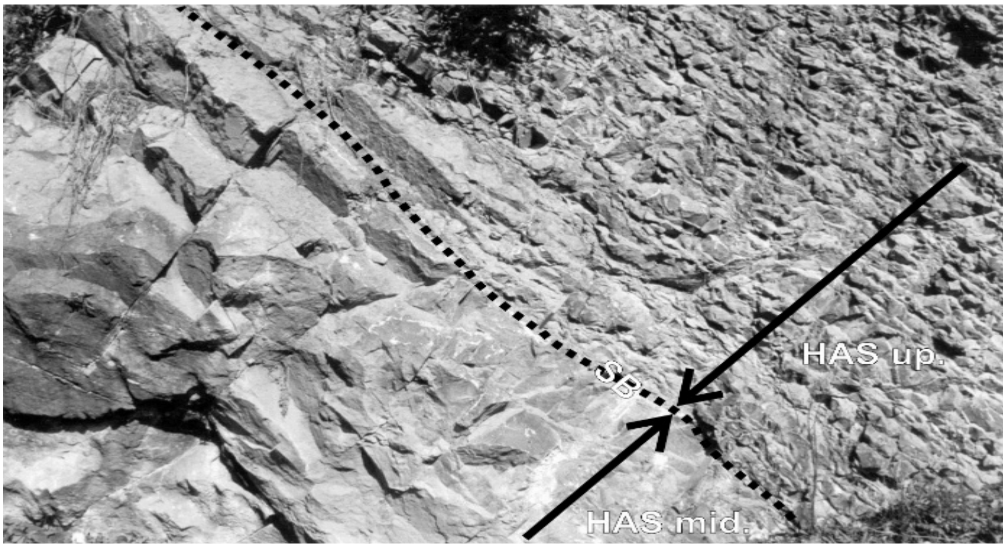

Fig. 9: Contact between the middle and upper members of the Hastière Fm, forming respectively the HST-FSST of sequence 1 and the LST of sequence 2, Chanxhe section I.

Interpretation
The DCB and basal Hastière Fm exposed in the near by Chanxhe-road section (Chanxhe III, Fig. 8) where bed 37 records a c. 1 m-thick unit of crinoidal grainstone with abundant detrital quartz grains and some small intraclasts. The fauna is rare in this facies but small quasiendothyrids have been observed in thin section. The Hastière Fm is almost entirely exposed in both sections. The top of the Hastière lower Mbr, as exposed in the Chanxhe I section is carbonate dominated with few thin shale alternations corresponding to the late TST. The middle Mbr of the Hastière Fm is a several metre-thick bed of crinoidal rudstone corresponding to the HST of sequence 1. Its top is marked by a subaerial erosional surface interpreted as the sequence boundary of this first sequence (Fig. 9). Above this last surface, the upper member of the Hastière Fm displays a very distinctive sedimentary pattern as it is still composed of crinoidal grainstone and rudstone but in small nodular-like centimetre to decimetre-thick beds. This upper member is interpreted as the LST of sequence 2.

4 - RIVAGE ROAD SECTION

Highlights
Third-order sequence 1 and 2.

References
CONIL et al. (1986), POTY et al. (1991, 2011), DEVUYST et al. (2005)

Location and access
Road section between the Rivage train station and the Pont-de-Scay village, on the eastern bank of the Ourthe River (Fig. 13). Eastern part of the Condroz Sedimentation Area (CSA). GPS: 50°29′02″N5°35′15″E.

Lithostratigraphy and biostratigraphy
Hastière (mid. and upper members), Pont d'Arcole, Landelies and Yvoir Fms. The foraminifer biozones MFZ1, MFZ2 and MFZ3 are identified respectively in the lower and middle members of the Hastière Fm, from the upper member of the Hastière Fm to the lower part of the Landelies Fm and in the upper part of the latter. The rugose corals biozones RC1 and RC2 correspond respectively to the Hastière Fm and to the Pont d'Arcole and Landelies Fms (POTY et al. 2006).

Description
The section (Figs. 10, 11) along the road begins with the middle member of the Hastière Formation (′Tn1bβ′) consisting of thick-bedded crinoidal packstones and grainstones. The upper member (′Tn1bγ′) consists of some metres of thin-bedded limestone. The succeeding 10 metres-thick Pont d'Arcole Fm (Fig. 14) consists mainly of greenish to black shales. The carbonate content decrease progressively from the base to the middle part of the formation then increases towards the top, and thin-bedded crinoidal limestone beds occur. The formation is highly fossiliferous, especially in parts with carbonate concentrations. The fauna comprises bryozoans, crinoids, syringoporids, partly dissolved rugose corals and brachiopods including the guide *Spiriferellina peracuta*.

The Pont d'Arcole Fm is topped by bedded limestones of the Landelies Fm. An alternation of thick-bedded, often nodular limestone with thin dark calcareous shale horizons characterises the lower part of the formation. The limestones consist of crinoidal-peloidal packstones to grainstones, which are rich in rugose corals and brachiopods. The upper part of the formation is dolomitised (Royseux Mbr). The boundary with the overlying Yvoir Fm (thinly-bedded cherty limestone) is hidden by a wall.

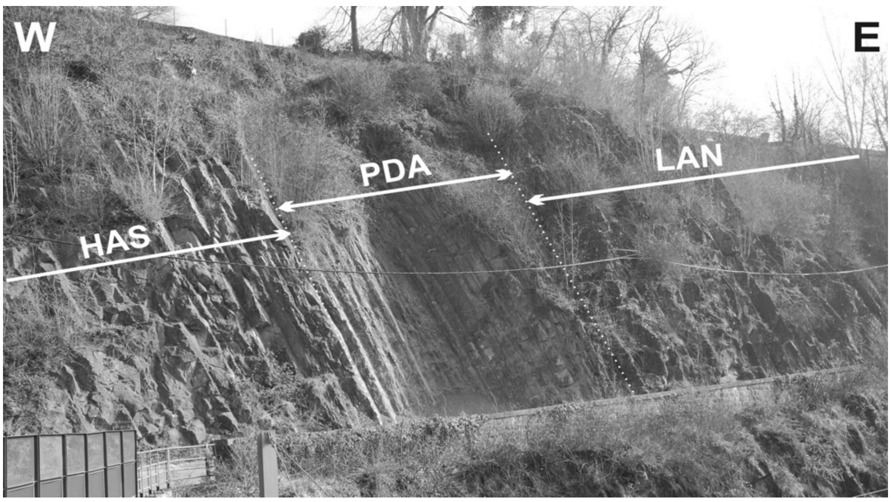

Fig. 10: Rivage road section showing the upper member of the Hastière Fm (HAS), the Pont d'Arcole Fm (PDA) and the base of the Landelies Fm (LAN).

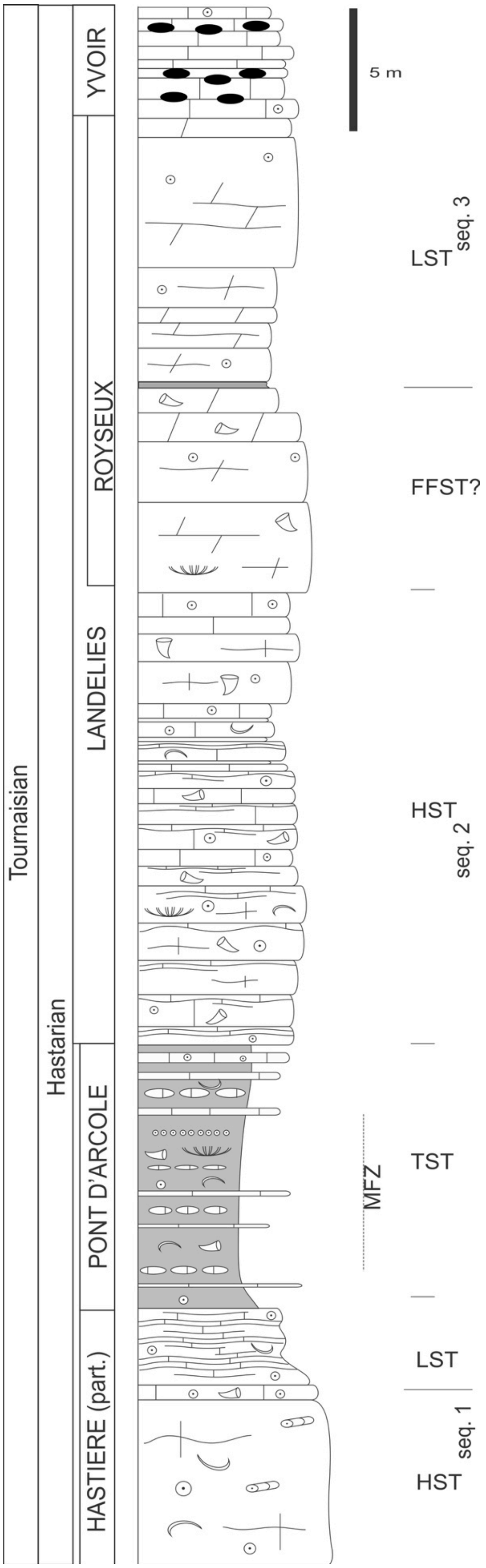

Fig. 11: Lithostratigraphic log of the Rivage road section and interpretation of the sequence stratigraphy. Modified from POTY et al. (2011). Legend in Fig. 8.

Interpretation
The entire Comblain-au-Pont Fm and the lower Mbr of the Hastière Fm form the TST of the first third-order sequence of HANCE et al. (2001). The HST-FSST of the sequence 1 is recorded in the middle Mbr of Hastière Fm whereas the upper member and the Pont d'Arcole Fm form the LST-TST. The Pont d'Arcole Fm is correlated with the Lower Alum Shale Event of Germany but does not display any anoxic facies and the fauna is abundant, even in the greyish facies. The limestone part of the Landelies Fm corresponds to the HST of the sequence 2, the dolomitic part corresponding to the FSST (Fig. 11). The LST of sequence 3 in not recorded in the CSA and the Yvoir Fm is interpreted as the TST of this sequence. Note that all units display cyclic pattern of limestone beds alternating with shaly interbeds. These cycles are interpreted as climatic ones (POTY 2016, see 2-5 - 'les Nutons' quarry).

5 - ROYSEUX RAILROAD SECTION

Highlights
Strunian, Hangenberg Sandstone event, Devonian-Carboniferous boundary, third-order sequences 1 to 3.

References
AUSTIN et al. (1970), CONIL et al. (1986), VAN STEENWINKEL (1990), AZMY et al. (2009), DENAYER et al. (2015).

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"N5°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. The first bed of the Hastière Fm still contains Devonian fauna. The base of the Carboniferous is consequently placed at the base of the overlying bed (Fig. 12). Upsection, the MFZ1 and MFZ2 foraminifer biozones have been recognized, as well as the RC1 rugose coral zone, indicating the lower Hastarian.

Description
The Comblain-au-Pont Fm (Fig. 12) 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 pelloidal 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 intrepretted as the record of the Hangenberg Sandstone event.

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), 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 dolomictic 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 of 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 for the production of 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 here are particularly abundant, and micheliniid tabulate corals, the fauna is relatively scarce and poorly diverse (Debout & Denayer 2018).

Interpretation

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 (Denayer et al. 2015).

The base of the Carboniferous was traditionally placed at the top of this bed 105 where Devonian fauna became extinct. Again, the Hangenberg

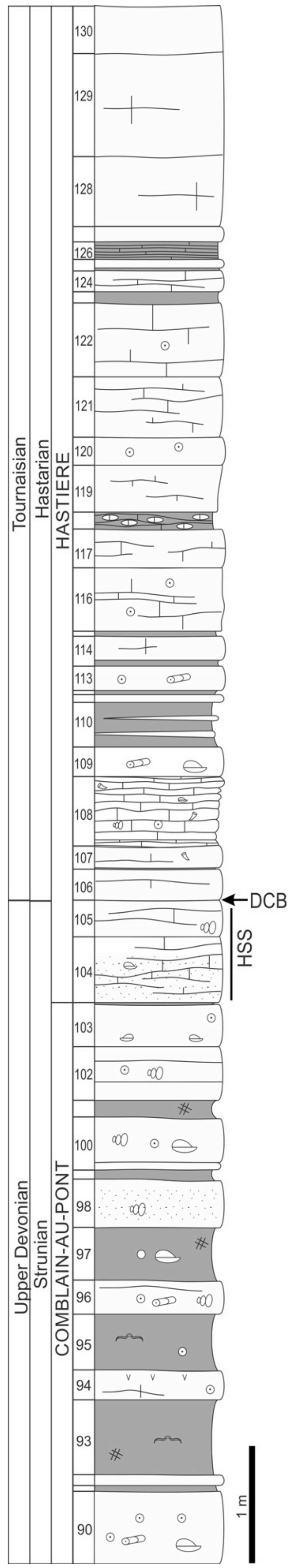

Fig. 12: Schematic log of the Royseux railroad section. Modified from Denayer et al. (2015). See Fig. 8 for legend.

Sandstone event and DCB occur within the transgressive system tract 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. 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.

6 – ROYSEUX 'CHABOFOSSE' TRENCHES

Highlights

Late Viséan coral biostromes, diversity hotspot, third-order sequence 8.

References

PIRLET (1964, 1968), POTY (1981), ARETZ (2001, 2002), POTY et al. (1988, 2011), DENAYER et al. (2016)

Location and access

Royseux is situated in the Hoyoux Valley, 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 duged in the late 1990´s and named Royseux III A and B. Only these two latter sections are rich in macrofossils and will be visited. Central part of the CSA (Fig. 1), northern limb of the Dinant Synclinorium. GPS: 50°27'46"N5°16'43"E.

Lithostratigraphy and biostratigraphy

Anhée Fm (Chabôfosse facies). Upper Viséan (Warnantian Substage), biozones MFZ15-16. The base of the Anhée Fm coincides with the base of the rugose coral biozone RC7β but joined occurrences of the corals *Lonsdaleia* and *Palastrea* in the uppermost part of the section indicates the biozone RC8 (POTY et al. 1988; ARETZ 2002).

Description

The bases of the sections expose the upper member of the Bonne Fm (poilvache Mbr) composed of peloidal, stromatolitic and oncolitic limestones organised in parasequences. The top of sequence 0 (sensu PIRLET 1964) displays paleosols with *Stigmaria* remains. Sequences are shallowing upwards. The base of the Anhée Fm is defined by a shift from the peloidal facies to the dominance of bioclastic facies (PIRLET 1968). Most parts of an individual sequence display fully marine deposits but more restricted facies locally formed on top. The Royseux trenches expose an uncommon facies (Chabôfosse facies) of the Anhée Fm which is very limited laterally (Fig. 13). The first bed of the Anhée Fm is a coarse crinoidal packstone-grainstone overlaid by a c. 50 cm-thick coral biostromal horizon (Fig. 14). The biostrome starts with a horizontal made of in situ large colonies of *Siphonodendron junceum* and *Lithostrotion maccoyanum*, covered by a monospecific layer of *S. junceum*. The upper part of the 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. Upwards, the carbonate mud content increases and bioclasts are scarcer. Some red algae, crinoids, fenestellid bryozoans, pelecypods, trilobites and few nautiloids were found around this level.

The regressive part of sequence +2 starts within the bioclastic wackestones. The facies recorded the proliferation of *Gigantoproductus* and other brachiopods (*Antiquatonia*, *Echinoconchus*, *Podtsheremia*) 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 *Siphonodendron junceum* biostrome quickly ends with deposition of a conglomerate, interpreted as storm layer with a very high diversity in corals and brachiopods (DENAYER et al. 2016). Then a *Siphonodendron martini* meadow developed, some large colonies (>1m^3) are encrusted by microbialites. All coral growth stopped when restricted facies conditions occurred (*Saccaminopsis* wackestone), and microconchids flourished at the top of sequence +3.

The base of sequence +4 is the youngest strata exposed in the two trenches. It starts in both sections with bioclastic packstone containing a coral fauna indicating the Brigantian (RC8).

Interpretation

The very peculiar facies observed in the sections IIIA and IIIB (coral horizons, gigantoproductids beds, small microconchid build-ups) 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 'deeper blocks' forming small pools (c. 1000s m^2) covering sections III A and B.

The somewhat deeper position enabled the development of coral dominated facies at the base of sequence +2 during a time of non-deposition on other blocks were only stromatolitic facies occasionally developed (Fig. 13).

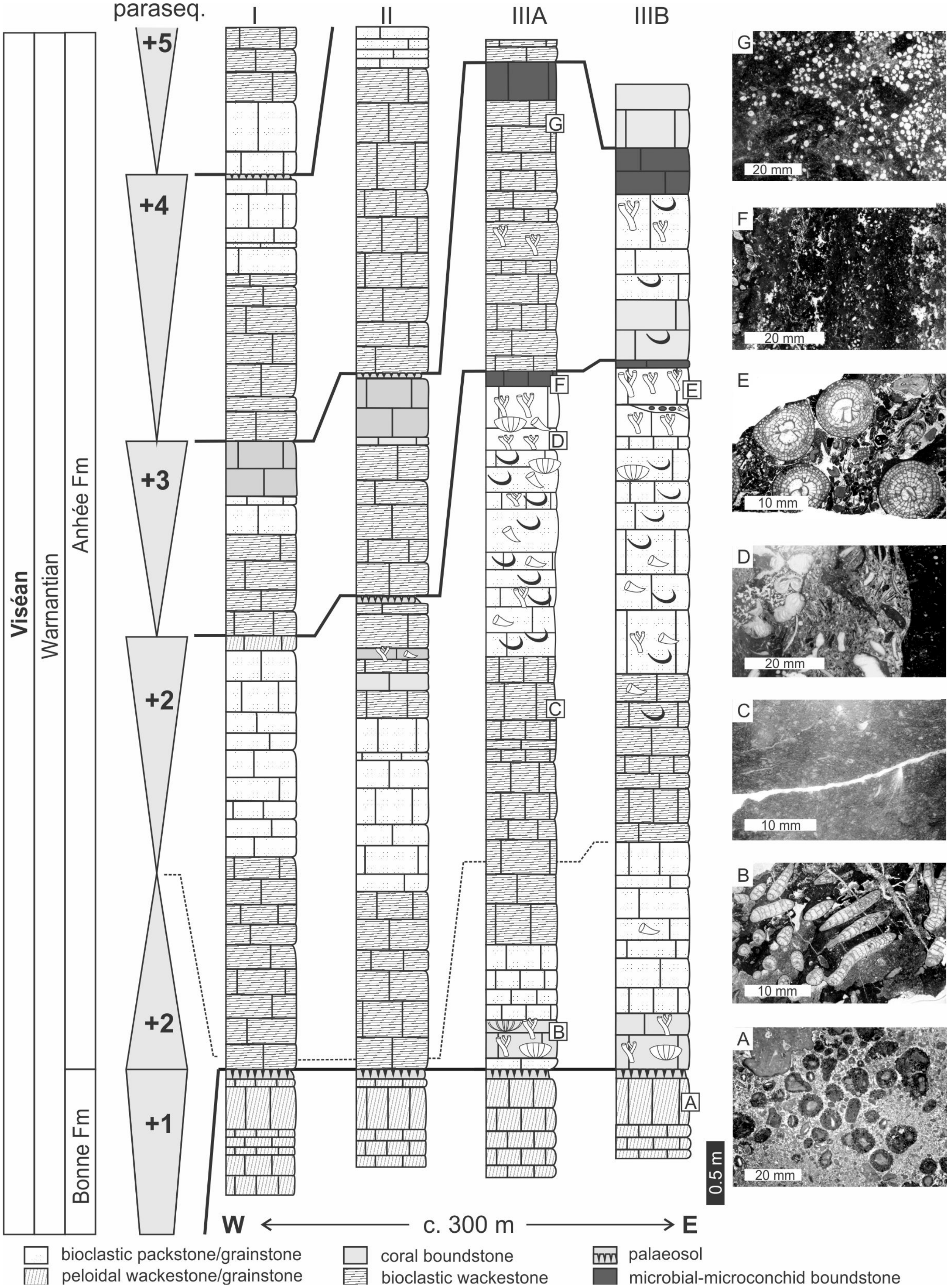

Fig. 13: Sections Royseux I – IIIB: Logs with indications of the sequences, main occurrence of macrofossils, and some representative facies types (after DENAYER et al. 2016).

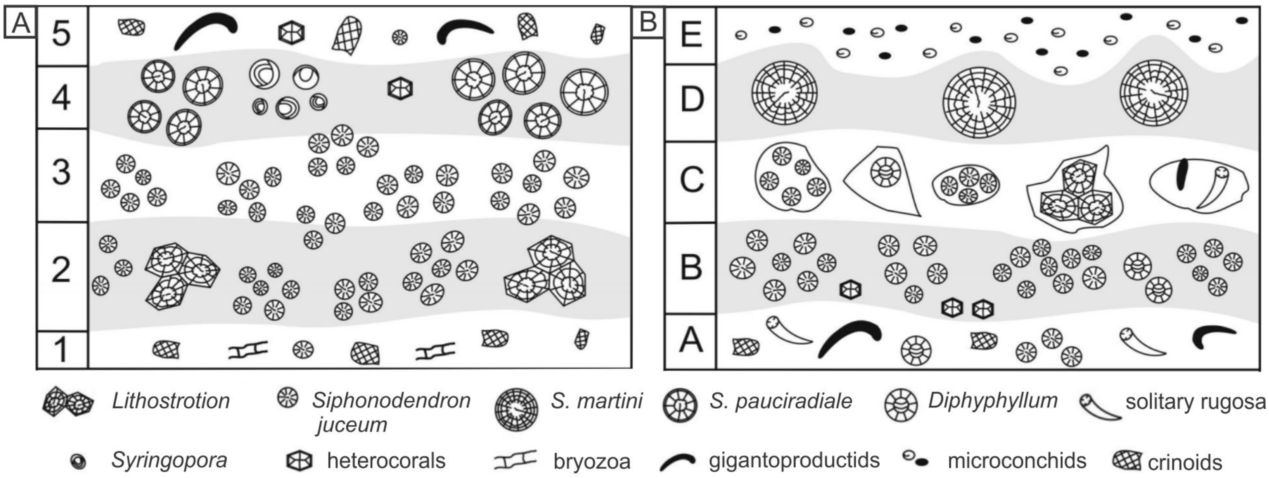

Fig. 14: Sketch of the lower (units 1-5) and upper (units A-E) coral horizons on top of sequence +2 in the Anhée Fm at Royseux III (from ARETZ 2001).

ARETZ (2001, 2002) interpreted the first coral horizon as a polyspecific biostrome, which immediately formed as a consequence of the availability of the new full marine habitats at the base of sequence +2. The regressive part of sequence +2 starts within the bioclastic wackestones. The facies rich in gigantoproductids is a typical level bottom community of Dinantian time and in this community solitary and colonial rugose corals occur in variable abundance. In the second coral horizon the development of the initial *Siphonodendron junceum* biostrome quickly ends with deposition of a conglomerate, interpreted as storm layer (hurricane?). A *Siphonodendron martini* meadow then developed. All coral growth stopped when restricted facies conditions returned with the development of the classical stromatolitic facies of the Anhée Fm.

7 – DINANT AND THE BAYARD ROCK

Highlights

Peri-waulsortian facies and historical type section for the Dinantian 'system'.

References

CONIL et al. (1989), DEVUYST et al. (2005), GROESSENS (1975), GROESSENS & NOËL (1975).

Location and access

Rocks situated on the eastern bank of the Meuse river upstream from the town of Dinant, central part of the DSA (Fig. 1), South-central part of the Dinant Synclinorium. GPS: 50°14'40.56"N 4°55'16.83"E.

Lithostratigraphy and biostratigraphy

This classical section of the lower-upper Tournaisian succession exposes almost continuously the Landelies, Maurenne, Bayard and Leffe formations in peri-Waulsortian setting (Fig. 15). These facies are relatively poor in microfauna but the conodonts and foraminifers indicate the upper Tournaisian MFZ4 to MFZ6 zones.

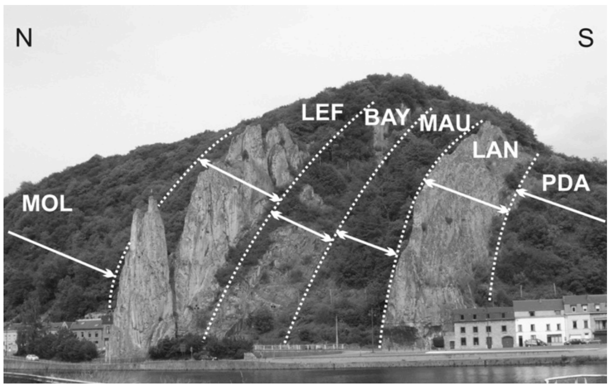

Fig. 17: Bayard Rock in Dinant showing the peri-reefal facies of the Waulsortian facies (the Moniat mound is located 1.5 km westward). Legend: PDA: Pont d'Arcole Fm, LAN: Landelies, MAU: Maurenne, BAY: Bayard, LEF: Leffe, MOL: Molignée Fm.

Description

This classical section exposes lateral equivalents of the Waulsortian buildups which have a large development westwards and southwards (DEHANSCHUTTER & LEES 1996).

The Bayard Formation is a thinly-bedded crinoidal rudstone with some cherty layers. It passes upwards to the overlying Leffe Fm through a progressive decrease of crinoidal content and increase in mud-coated clasts proportion. The Leffe Fm mainly consists of finer-grained, grey to purplish blue wackestone to packstone with abundant cherts moulding the bioturbations as

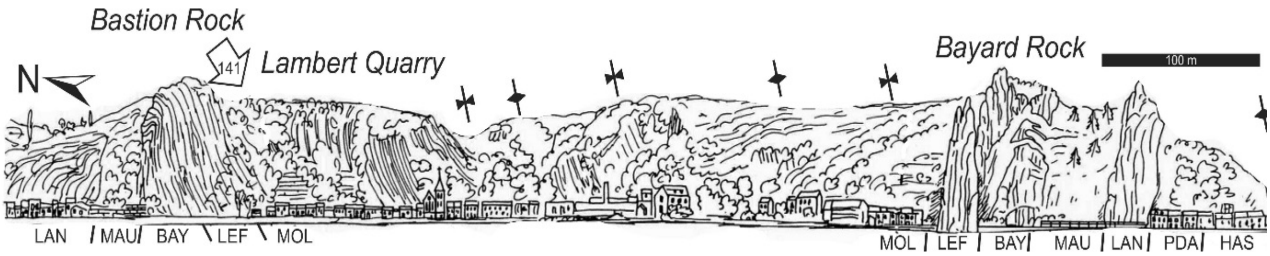

Fig. 16: Sketch section along the Eastern bank of the Meuse between the Bayard Rock and Bastion Rock in Dinant, with the position of the lithostratigraphic units and historical Tournaisian-Viséan boundary (bed 141) modfifed from GROESSENS (1975).

exposed in the famous Bayard Rock. The dominant microfacies is a wackestone with coated clasts and common ostracods, sponge spicules, few foraminifers and many problematic microfossils.

Interpretation

The Bayard Fm is interpreted as the TST of sequence 3, whereas its HST correspond to the Leffe Fm (pro parte). The Bayard Fm is commonly interpreted as the sole of the Waulsortian buildups but also occurs within the mounds and thus represents a lateral equivalent of the u part of the buildups (DEHANSCHUTTER & LEES 1996).

The Leffe Formation 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 (LEES 1997).

The historical boundary between the Tournaisian and Viséan was established by CONIL et al. (1969) in the nearby 'Lambert Quarry' immediately south of the Bastion Rock, at the base of bed n°141 that correspond to the first intercalation of the black marble' facies in the Leffe Fm (Fig. 16). It also coincides with the first occurrence of the calcareous foraminifer genus *Eoparastaffella* (CONIL et al. 1969), less than 1 m below the first occurrence datum of the conodont *Gnathodus homopunctatus* (GROESSENS & NOËL 1977).

8 – TANRET QUARRY AND SALET ROAD SECTION

Highlights

Lower Viséan 'Black Marble' facies and Lagerstätte, Tournaisian-Viséan transition.

References

OVERLAU (1966), GROESSENS (1975), HANCE (1988), LEES (1997), MOTTEQUIN (2004, 2008), DEVUYST et al. (2006), DENAYER et al. (2015), POTY (2016).

Location and access

The road section is the embankment of the road leading from the Salet village to the Molignée valley. The Tanret quarry is situated at the southern end of the village. Central part of the Dinant sedimentation area (Fig. 7), north of the main Waulsortian development, Dinant Synclinorium (Fig. 1). GPS: 50°18'23.77"N 4°49'40.77"E (quarry), 50°18'38.13" N4°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 (Fig. 17, the Livian formations are 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).

Cultural notice: *Le Rocher Bayard stands in the southern gate of Dinant, on the right bank of the Meuse river. It is completely separated from the rest of the cliff. The legend says that the rock was split by the hoof of the giant Bayard Horse driven by the four Aymon Brothers. Chased by King Charlemagne, they were escaping the Ardennes Forest, sit on the back of the Bayard Horse when it jumped over the Meuse river and split the rock from the cliff and creating one of the most legendary rock of Belgium. The Rocher Bayard was in fact separated with an explosion to provide passage for the French troops of Louis XIV after they had taken Dinant in 1692.*

This section is the stratotype of the Moliniacian 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. 17). That level corresponds also 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. 2006b) marked by the first appearance datum 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 that of the Viséan Stage.

Description

The Leffe Fm is a well-bedded violet-grey cherty mottled wackestone-packstone with an open marine microfauna and abundant the microbially coated intraclasts becoming darker progressively to the overlying Molignée Fm. The transition is exposed along the Salet road section where the first occurrence of the foraminifer *Eoparastafalla simplex*, marking the base of the Viséan is recorded in bed 124 (DEVUSYT et al. 2006).

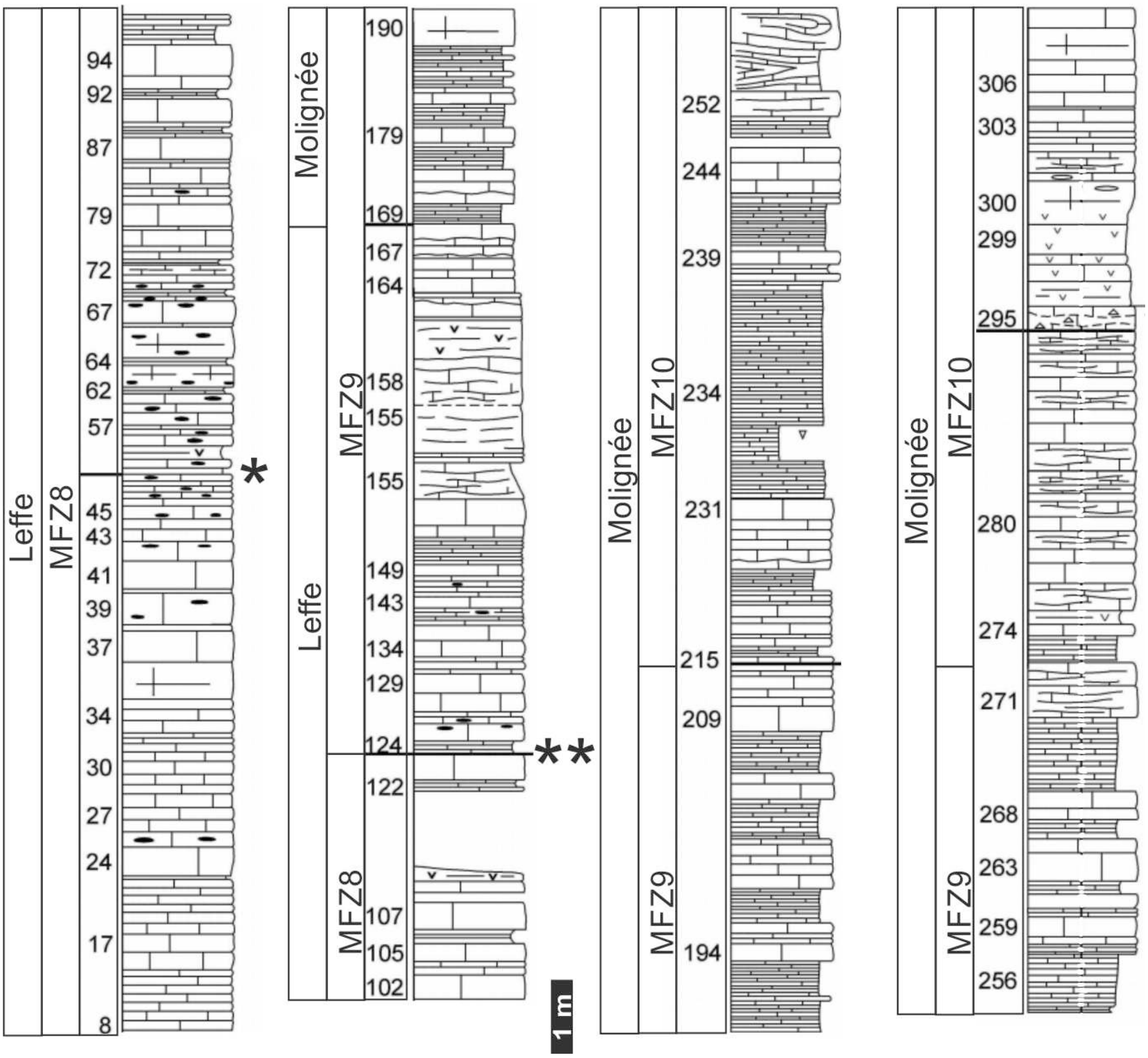

Fig. 17: Schematic log of the Salet road section quarry (modified from OVERLAU 1966, emended by DEVUYST et al. (2005). *: original base of the Moliniacian after CONIL et al. 1977), **: emended base of the Moliniacian after POTY et al. (2006).

The lower part of the Molignée Fm is very similar to the previous one but included thinly-bedded, laminated black limestone becoming dominant upwards. The black limestone comprises mudstone with rare are radiolarians, calcispheres, ostracods, moravamminiids, peloidal packstone and peloidal and bioclastic packstone-grainstone with calcispheres and algae and rare lithoclasts (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 2004) alternating with background suspension sedimentation (calcispheres and radiolarian mudstone). The alternations are interpreted as parasequences (DEVUYST et al. 2005) produced by sea-level changes alternatively opening and closing the lagoon with sequential input of oxygenated waters. The 'Black marble' is a Konservat-Lagerstätte (MOTTEQUIN 2004, 2008) that preserved exquisitely a rare fauna of echinoids, graptolites, fishes and soft organisms (MOTTEQUIN et al. 2015). 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.

Interpretation

The upper part of the Leffe Fm and base of the Molignée Fm are interpreted as the HST of sequence 4A (DEVUSYT et al. 2006, POTY 2016). The major part of the Molignée Fm however recorded the TST and HST of sequence 5, a sequence developed only in the deepest part of the Namur-Dinant Basin and lacking in other more proximal settings. The Salet Fm corresponds to the LST (debris flow horizon) and TST of sequence 6. 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. 18). The top of the formation shows a transition with 1-3 m-thick cycles possibly driven by precession and obliquity (Fig. 18). The Molignée Fm recorded the first shallowing-upwards parasequences (4-12 m-thick, Fig. 18) 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).

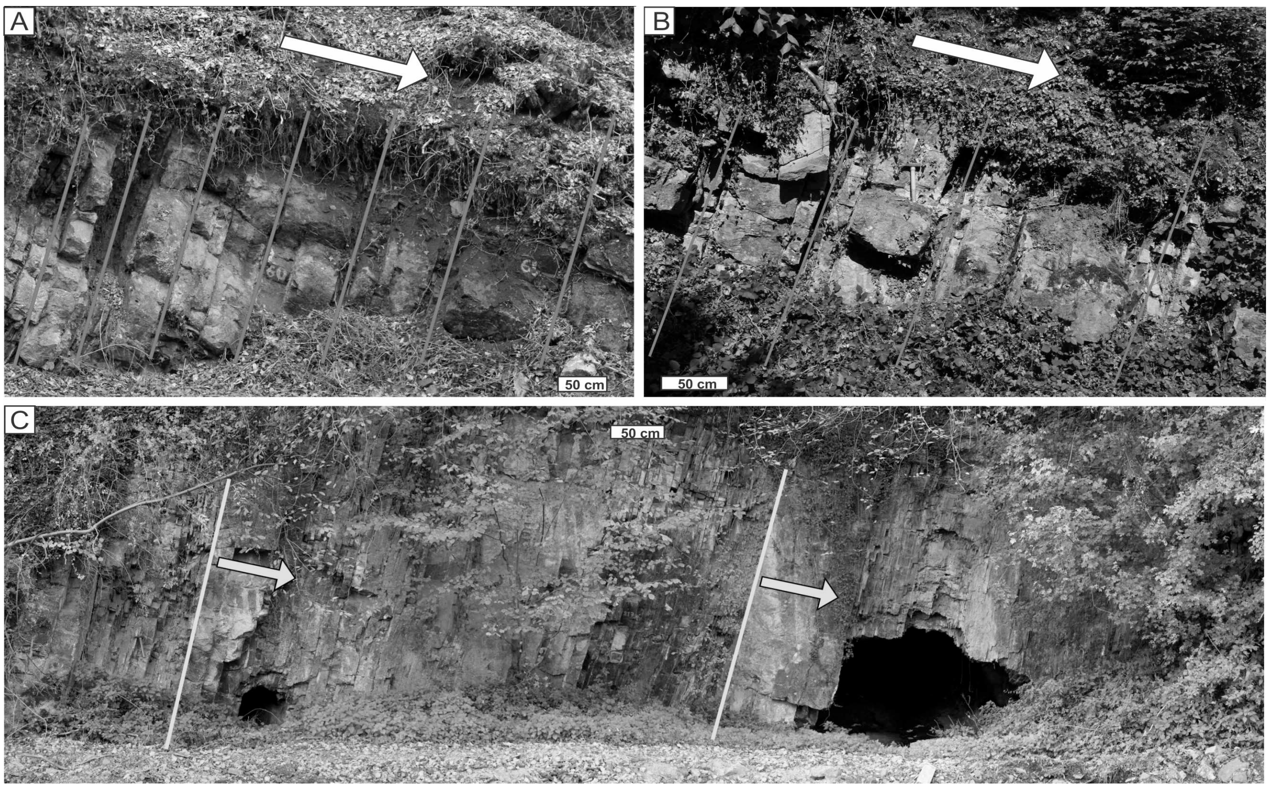

Figure 18: A. Precession cycles (c. 18.6 ky) due to monsoon-dry climate alternation in the Leffe Fm (Ivorian). B. Relatively thick and symmetric cycles (precession + obliquity?) in the upper part of the Leffe Fm (top of the Tournaisian), witnessing a transition in the cycle types. C. Shallowing-upwards parasequences in the Molignée Fm (basal Viséan). Modified from Denayer et al. (2015) and Poty (2016).

9 – SPONTIN AND CHANSIN RAILWAY SECTIONS

Highlights
Hangenberg events and Devonian-Carboniferous boundary.

References
CONIL (1964), DENAYER et al. (2018, in prep).

Location and access
Railroad cut southeast of the Spontin station in the Bocq river valley and east of the former Durnal station, southern edge of the DSA, central part of the Dinant Synclinorium (Fig. 1). GPS: 50°19’14”N5°00’42”E and 50°19’41”N4°59’16”E.

Lithostratigraphy and biostratigraphy
Comblain-au-Pont and Hastière (lower and middle members) formations, latest Famennian to early Tournaisian, DFZ7 to MFZ2 foraminiferal zones, with nice exposure of the Devonian-Carboniferous Boundary and Hangenberg events (Fig. 19).

Description
The Comblain-au-Pont and Hastière formations present a cyclic pattern that has been interpreted as recording orbitally-forced climatic cycles (POTY 2016). In the Comblain-au-Pont Fm, these cycles appear as rather regular carbonate-siliciclastic couplets. The Hastière Fm (lower Mbr) first displays irregular carbonate-siliciclastic couplets, passing upwards to 80-100 cm-thick limestone-dominated couplets. The limestones are mostly bioclastic and crinoidal packstone-grainstone with abundant brachiopods and crinoids. The shaly beds are either shale or siltstone, often with a part of carbonate due to the bioclastic content. All lithologies are strongly bioturbated. A 30 cm-thick layer of a dark (not black!) shaly bed with small pelecypods is noticed in bed 9 in the spontin section. An unusual 1.2-m-thick unit (beds 23-26 in Spontin and 107-114 in Chansin, Fig. 19) of coarsely-grained bioclastic limestone with centimetric clasts (ichnoclasts, intraclasts and flat pebbles) and abundant fauna is recorded in both sections. The macrofauna is abundant and well preserved in this level suggesting that they are not reworked but contemporaneous of the reworking.

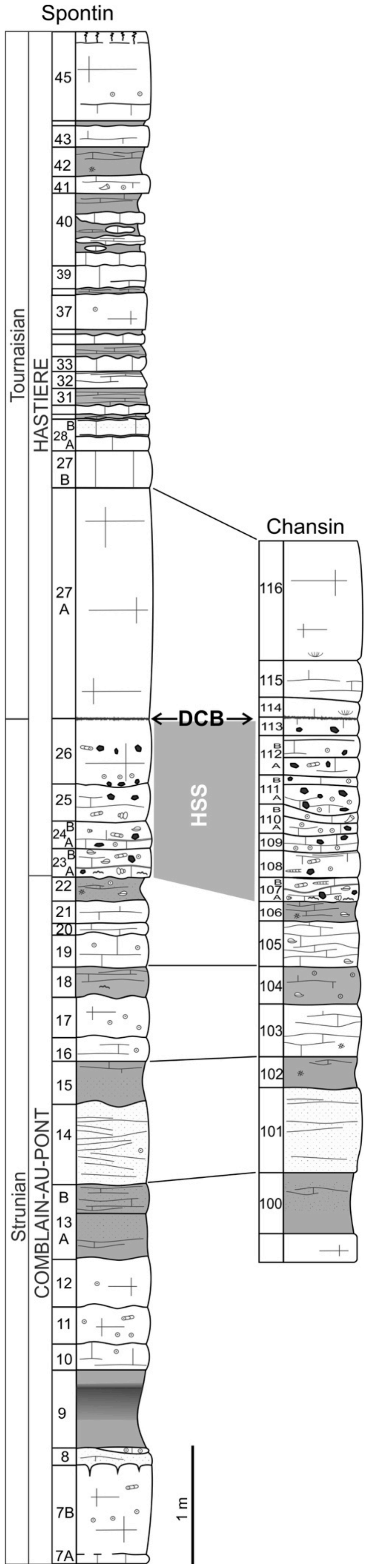

Fig. 19: Log of the Spontin-railroad section showing the Devonian-Carboniferous transition in neritic facies. Abbreviations: DCB: Devonian-Carboniferous Boundary, HSS: Hangenberg Sandstone event. Modified from DENAYER et al. (2018) and (in prep). Legend: see Fig. 8.

The most common fossils are brachiopods (*Sphenospira jullii*, *Araratella moresnetensis* and small rhynchonellides), pelecypods, gastropods, phacopid trilobites (*Omegops accipitrinus* and *O. maretiolensis*), and crinoids. Orthoconic nautiloids and dental plates of cochliodontidae are occasional. The microfauna is composed of quasiendothyrid foraminifers and protognathodid conodonts. Above this clast horizon is developed a 2.7 m-thick bed of oolithic grainstone containing rare foraminifers and conodonts. The typical facies Hastière Fm lower member are exposed in the Spontin section as irregular alternation of crinoidal packstone and bioclastic shale and argillaceous limestone. This unit yields a poor macrofauna (spiriferide brachiopods, rare proetid trilobites) but rugose corals (*Conilophyllum* and *Eostrotion*) occur in the middle member of the Hastière Fm.

Interpretation

The dark shale with pelecypods observed in the Spontin section is interpreted as an equivalent of a part of the Hangenberg Black Shale event probably corresponding to the very limited and short-living spreading of dysaerobic waters on the shelf.

This dark horizon however correlates stratigraphically with the dark shale beds observed in the Chanxhe sections. Normal aerobic conditions persisted, allowing the development of benthic fauna. The clast horizon observed in the Spontin and Chansin sections is interpreted as the result of a consequent but short-living fall of sea level followed by a rapid transgression. The abundant fauna displays very few traces of reworking and are therefore regarded as contemporaneous of the reworking of intraclasts rather than entirely reworked.

Based on palaeontology, sequence stratigraphy and sedimentology, the Devonian-Carboniferous Boundary is placed on the top of bed 26 of the Spontin section and bed 114 of the Chansin section (Fig. 19), after the reworking due to the Hangenberg Sandstone event. The early Carboniferous transgression is here recorded by a 2.7 m-thick bed of oolithic grainstone (bed 27 in Sontin and beds 115-116 in Chansin).

10 - CHANSIN "LES NUTONS" QUARRY (DURNAL)

Highlights

Third-order sequence 2 and 3, precession climatic cycles.

References

TOURNEUR et al. (1989), HIBO (1994), POTY et al. (2011), DENAYER et al. (2015)

Location and access

The quarry is open 800 m south of Durnal village, in the northern bank of the Bocq valley. Central part of the Dinant Synclinorium, transitional zone between Condroz sedimentation area (CSA) and Dinant sedimentation area (DSA) (Fig. 1, 2). GPS: 50°19′43″N4°59′10″E.

Lithostratigraphy and biostraigraphy

Pont d'Arcole Fm (poorly exposed), Landelies Fm (‘*Petit-Granit du Bocq*’ ornamental and building stone), Yvoir Fm (including basal Hun Mbr), Hastarian to Ivorian, RC2 and MFZ2-3 biozones. The Hastarian-Ivorian boundary is situated about 15 m above the top of Landelies Fm, close to the first cherty band in the Hun Member

Description

The base of the Landelies Fm is made of a 20 m-thick alternation of 40 cm-thick limestone beds and centimetric argillaceous limestone layers. These alternations are very regular in thickness and facies (Fig. 20). The limestone is mainly wackestone-packstone more or less rich in crinoids (10-20%) and brachiopods. The argillaceous layers are rich in bryozoans. The following 20 m are made of decimetre to metre-thick beds, among which the most massive are quarried as ‘*Petit Granit du Bocq*’. The facies are still wackestone and packstone but the crinoid content increases to 35-40 % (Hibo 1994).

Oblique and cross-stratification are common in these crinoidal limestones. Stratigraphic joints and/or stylolites define 60-100 cm-thick beds. The macrofauna is common and comprises large solitary rugose corals (*Siphonophyllia rivagensis*), tabulate corals (michelinids, *Yavorskia*, cladochonids) and brachiopods. The boundary with the overlying formation is sharp and marked by argillaceous and sandy limestones units belonging to the Hun Member of the Yvoir Fm (lateral equivalent of the Maurennes Fm). The overlying limestone beds are cherty, with a very rich macrofauna, especially in the upper part: small solitary rugose corals, michelinids, cladochonids, bryozoans, brachiopods, trilobites, crinoids, etc. Splendid silicified fossils can be found in the weathered debris of the rock. The rest of the Yvoir Fm is exposed in the uppermost part of the quarry. It is dominated by a regular succession of c. 30 cm-thick beds of bioclastic and crinoidal packstone containing abundant cherts that usually mold bioturbations. Coquina beds (tempestites?) are common but the fauna is poorly diverse (brachiopods, small solitary rugose corals), except in this upper part of the formation where large corals, brachiopods, gastropods and even rostroconchids occur. The uppermost part of the formation is dolomitic, the top however is not reached in the quarry.

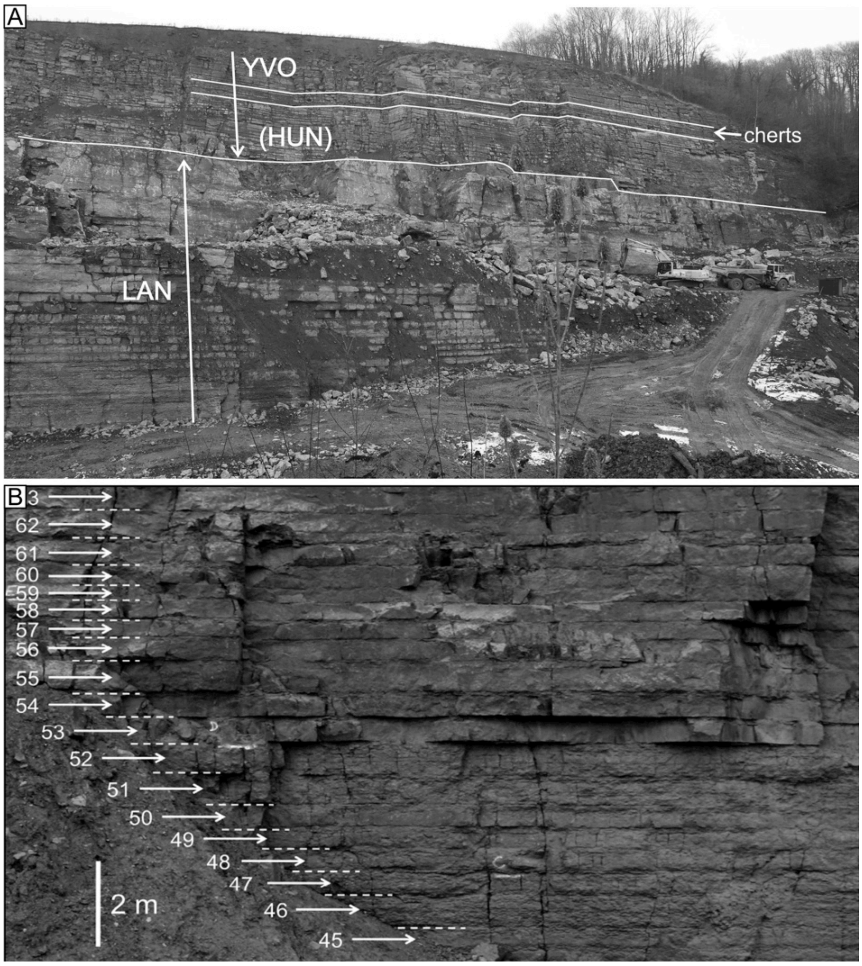

Fig. 20: A: overview of the Nutons quarry in Chansin, exposing most of the Landelies Fm (LAN), including the massive uppermost part, and the Yvoir Fm (YVO) with the basal siliciclastic unit of the Hun Mbr and the chert beds that yields an abundant silicified fauan; B: Orbitaly forced (n° 45 to 63) in the HST of sequence 2, at the base of the Landelies Fm (modified from POTY 2016).

Interpretation

The Landelies Fm corresponds to the HST (bedded part) and FSST (massive beds) of sequence 2. The sharp contact with the overlying Hun Mbr of the Yvoir Fm corresponds to the sequence boundary. The latter member is interpretted as the LST of sequence 3 and contains the base of the Ivorian Substage (base of Upper Tournaisian, base of *Polygnathus communis carina* Zone).

All these lithostratigraphic units shows a striking cyclic development, interpreted as precession cycles (DENAYER et al. 2015; POTY 2016).

11 – LIVES ROCK AND QUARRY

Highlighgts

Middle Viséan parasequences, 'Black marble' facies.

References

HANCE (1979), LAUWERS (1992), CHEVALIER (2004), POTY & HANCE (2006a), POTY et al. (2011)

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. Northern limb of the Namur Synclinorium, central part of the Namur sedimentation area (NSA, Fig 1). GPS: 50°28′05″N4°55′43″E.

Lithostratigraphy and biostratigraphy

Haut-le-Wastia, Corphalie 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.

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).

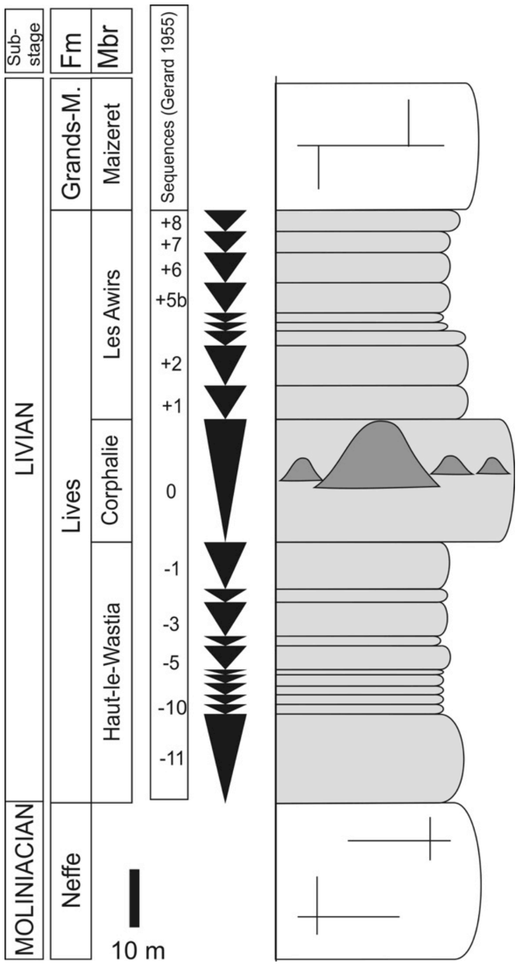

Fig. 21: Lithostratigraphic column of the Lives Mbr in the type area. The rythms "-11" to "+8" of PIRLET (1968) correspond to parasequences. The sequence "0" forms the middle Corphalie Mbr, which contains small bryozoans-microbialites bioherms. Modified after LAUWERS (1992).

The Lives Fm is subdivided in three members: Haut-le- Wastia, Corphalie and Awirs Mbrs (Fig. 21). 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 (Fig. 22). Bioclastic facies become more common in the upper part of the member and contains corals. The Corphalies Mbr ("V2bβ" of CONIL et al. 1977) is a 18 m-thick unit composed of thick-bedded, dark bioclastic limestone overlain by thin-bedded, dark mudstones containing small bioclastic levels (Fig. 22). 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. 22).

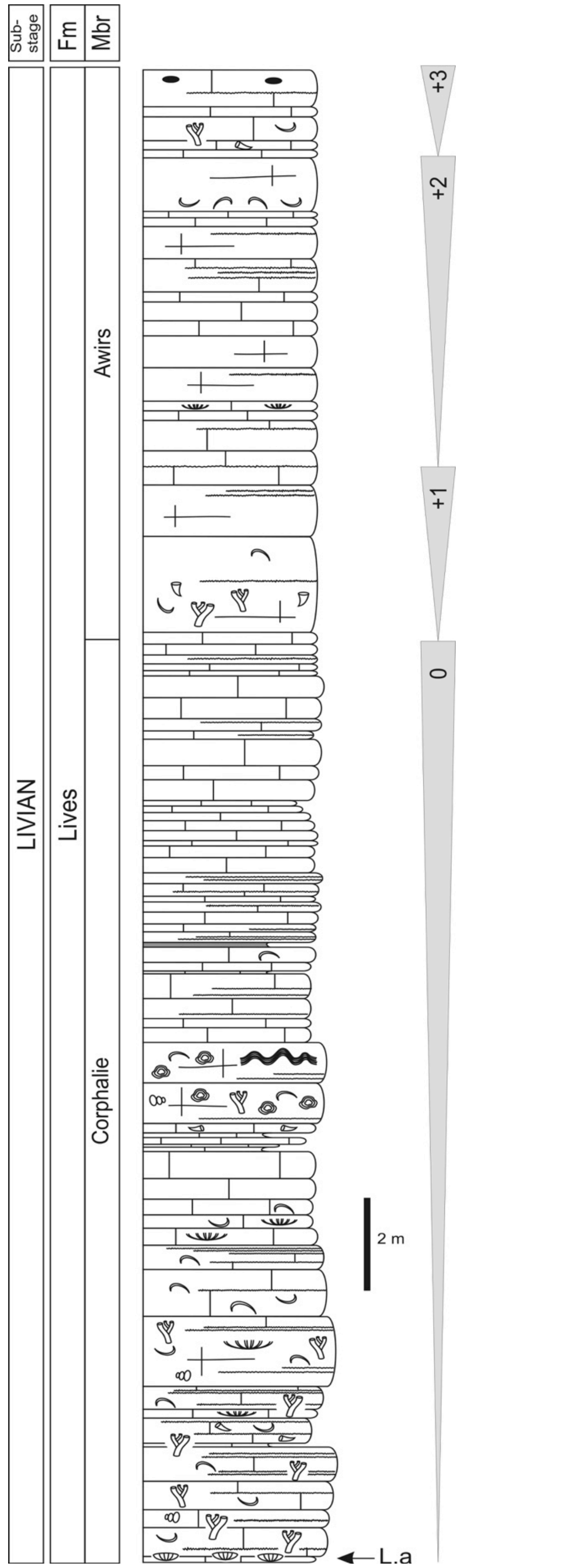

Fig. 22: Detail log of the Lives Fm at the Lives Rock. Parasequences are numbered, the Corphalie Mbr corresponds classically to sequence - or rythm - "0" (PIRLET 1968). Legend: L.a: *Lithostrotion araneum* layer, L2: cinerite L2 of DELCAMBRE (1989). Modified from CHEVALIER (2004). See Fig. 8 for legend.

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 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 thinly-bedded dark fine-grained limestone that was long quarried as the 'Marbre Noir de Namur' (GROESSENS 2001). It is in fact a finely bioclatic wackestone with rare foraminifers and ostracods. The black colour is due to a residual organic matter associated to the fine-grained matrix.

Interpretation
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 1950' (GERARDS 1955; MICHOT et al. 1963). The Haut-le-Wastia Mbr counts 12 parasequences (numbered -12 to -1, Fig. 21), mainly stromatolitic (Fig. 24).

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" of VAUGHAN 1906, "L.a." in Fig. 22). This sequence is the thickest of all sequences observed in the Lives Formation. (CHEVALIER 2004).

The Awirs Mbr is made of eight parasequences (+1 to +8, Fig. 21), mainly bioclastic, indicating a more open-marine environment resulting from the ongoing Livian transgression.

12 – JAMBES ROCK

Highlights
Namurian resting disconformably in Viséan karsts.

References
Delcambre &Pingot (2015)

Location and access
This rock is situated on the right bank of the Meuse river, along the road N90, 2 km E of the center of Namur, between Jambes and Lives, NSA, GPS: 50°27′51″N4°53′43″E.

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

Description
This small outcrop displays the typical geometry of the Viséan-Namurian disconformity. As usual in the NSA nd 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 cse, the lower part of the Grands-Malades Fm is affected by the cavity but laterally the Namurian deposits rests on the Bonne Fm. The Namurian is represented by siltstones and shales, often black, of the Chokier Fm but sandstone layers are not rare.

Interpretation
The Chokier Fm corresponds to the filling of the tectonically-controlled drowning of the emerged karstified paleotopography (DUSAR 2006 and references therein). The marine fine-grained siliciclastics were deposited in calm but not deep environements of a pro-delta progressively invading the palaeokarstic emerge 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).

Fig. 23: 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.

13 – CITADEL OF NAMUR

Highlights
Type section of the Namurian stage, Hercynian molasses deposits.

References
Kaisin (1924), Bouckaert (1961, 1967, 1982), Van Leckwijck (1964), Dusar (2006).

Location and access
Citadel of Namur (Donjon section) and access road ("Route Merveilleuse" section, Fig. 24). GPS: 50°27’36”N4°51’51”E.

Lithostratigraphy and biostratigraphy
Chokier and Andenne Fm, Namurian (Chokierian to Kinderscoutian, Fig. 25). The goniatites recognized in the marine horizon described by KAISIN (1924) and BOUCKAERT (1961) indicate the R1-*Reticuloceras* zone (Kinderscoutian, Namurian A/B).

Description
As part of the Belgian Coal Measure Group, the Namurian of Namur has been intensively studied (see syntheses by VAN LECKWIJCK 1964; BOUCKAERT 1961; DUSAR 2006a). The first section, along the ‚Route Merveilleuse‘ (Fig. 24) exposes an alternation of shale and sandstone of the Chokier and Andenne Fms. Synsedimentary deformations are common (load-cast, ball-and-pillow), as well as tectonic deformations related to sandstones lenses, asymetric and dysharmonic folds (VANDENBERGHE & BOUCKAERT 1983; KENIS et al. 2003). Common facies are proximal but poorly fossiliferous (two thin coal layer) and only one marine horizon, 50 m below the Andenne Fm yielded a goniatite assemblage Kinderscoutian in age (top of Namurian A, BOUCKAERT 1961). Along the Donjon section are exposed sandstone and siltstone alternations including some channel structures with cross-stratification and load-cast. The latter belongs to the Chokier Fm (Fig. 25).

Interpretation
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, after BOUCKAERT (1961) a southern origin of the sediments.

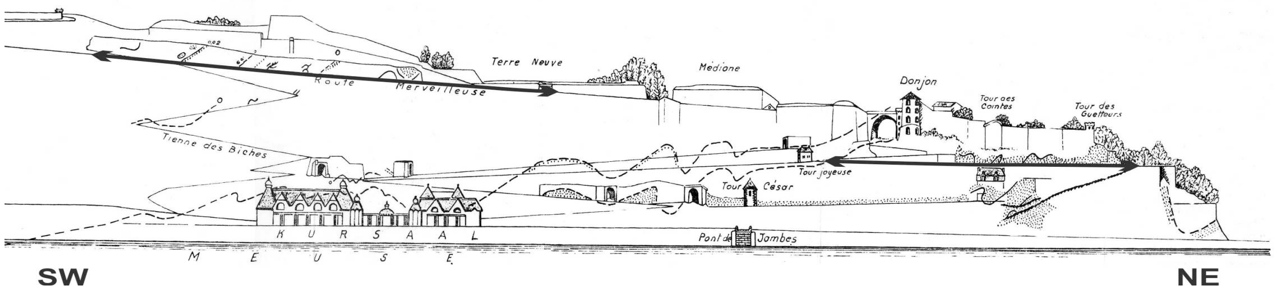

Fig. 24: Sketch of the Citadel of Namur with schematic outcrops of Namurain rocks. Arrows indicate the visitied sections: “Route Merveilleuse” and Donjon outcrops. Modified from BOUCKAERT (1961).

Cultural notice: *The Citadel of Namur is a fortress siting on the strategic hill at the confluence of the Meuse and Sambre rivers. The prehistorical occupation dates back to the Neolithic but the first fortress was probably pre-Roman. The Castle from which only the Donjon survived, was built in the Xth century. The present three-fold form (Castle, Mediane and Terra Nova places) witnesses the progressive addition of military elements between the XIIth and XVIIth centuries. After Namur was taken (once more) by the French army in 1692, the military architect Vauban improved the site then by the Dutch in the XIX century. Several kilometers of galleries and underground passages and mines still exist under the hill. For that reason, Napoléon named the Citadelle ‘Europe’s termite nest’.*

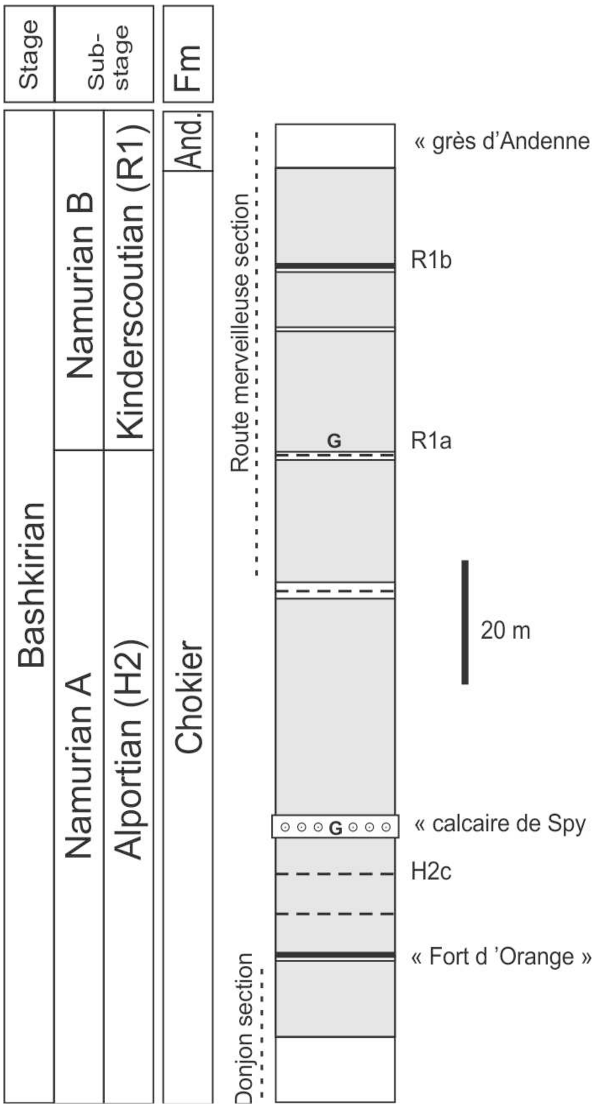

Fig. 25: Stratigraphic succession observed in the type section of the Namurian, at the Citadel of Namur. Modified from Bouckaert (1961), Dusar (2006).

14 - GENDRON-CELLES RAILROAD SECTION

Highlights

Devonian-Carboniferous boundary, Waulstortian complex.

References

CONIL (1968), GROESSENS (1975), LEES et al. (1985), VAN STEENWINKEL (1990, 1993), DEVUYST et al. (2005), POTY et al. (2011).

Location and access

Section along the railway Dinant-Bertrix, 200 m north of the Gendron-Celles station, in the Lesse valley. Dinant Synclinorium, southern part of the Dinant sedimentation area (DSA, Fig. 1). GPS: 50°12'43"N4°57'53"E.

Lithostratigraphy and biostratigraphy

Comblain-au-Pont Fm (upper part), Hastière Fm, Pont d'Arcole Fm, Landelies Fm (bad outcrop), Maurenne Fm, Bayard Fm and Waulsort Fm (lower part) (Fig. 26). The uppermost Devonian Comblain-au-Pont Fm belongs to to the DFZ7 foraminifer biozone and to the RC0 rugose coral biozone of POTY et al. (2006) and classically attributed to the upper *praesulcata* conodont biozone of CONIL et al. (1991).

The Hastière Fm yields a poorly diversified coral and foraminifer fauna typical of the RC1 and MFZ1 zones. The Pont d'Arcole, Landelies and Maurenne Fm covers the RC1γ to RC2 coral zones and MFZ2 foraminifer zones. The Bayard and Waulsort Fm are included in the RC3 biozone but they yielded a very poor coral fauna. The foraminifers of these formations indicate MFZ1 to MFZ6 after DEVUYST et al. (2005). GROESSENS (1975) recognized conodonts belonging to the *duplicata* to *Dollymae* biozones.

Description

The upper 15 m of the Comblain-au-Pont Fm consist of bioclastic and crinoidal limestones, nodular marly limestone and calcareous shale, usually very fossiliferous and passing upwards to more carbonate facies.

The lowermost bed of the Hastière Fm is a 2 m-thick massive crinoidal limestone containing traces of reworking (intraclasts and reworked? Strunian fauna) at its base (VAN STEENWINKEL 1990). The lower member of the Hastière Fm (15 m) consists of pluridecimetre-thick crinoidal packstone interbedded with centimetre-thick shale beds. A 3 m-thick bed of crinoidal packstone/rudstone compose the middle member. The upper member is similar to the lower one but shows more shale layers. The Pont d'Arcole Fm is a 13 m-thick unit of calcareous shale and siltstone, usually dark, containing dissolved fossils. Some argillaceous limestone beds occur in the upper part of the formation.

The overlying Landelies Fm (38 m) begins with the first thick crinoidal packstone to grainstone bed rich in brachiopods, gastropods and corals alternating with shaly interpbeds.

The Maurenne Fm is abruptly resting on the last thick crinoidal limestone bed of the Landelies Fm. It consists of calcshale containing shell layers with some small solitary rugose corals in the upper part. The formation is topped by a few beds of cherty argillaceous limestone. Note that an asymmetrical fold artificially increases the thickness of the formation (Fig. 26).

The Bayard Fm begins with 20 m of well-stratified crinoidal limestone, dark grey or brownish grey containing cherts. The upper part of the formation

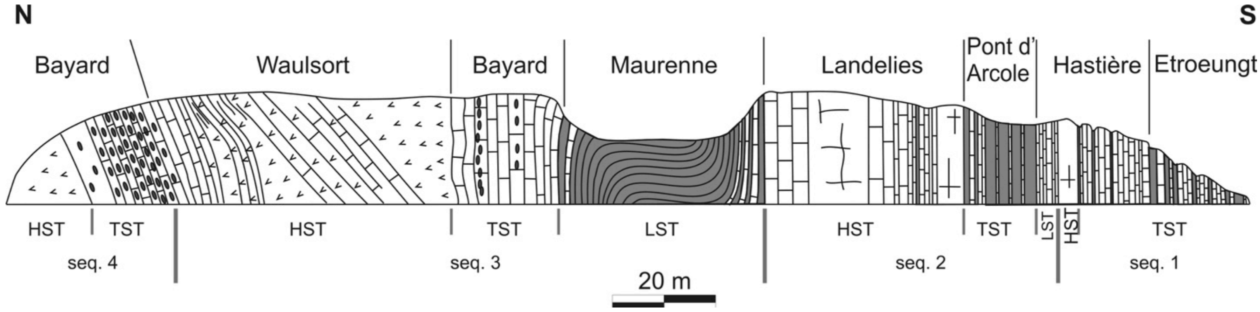

Fig. 26: Schematic sketch of the Gendron-Celles railroad section with the sequence stratigraphical interpretation (modified after CONIL 1968 and DEVUYST et al. 2005).

is less stratified and locally dolomitic. It passes upwards and laterally into the Waulsortian facies (Waulsort Fm). It appears as massive light-grey to beige limestones and diagenetic dolomite devoid of cherts, in which three main facies are easily recognized: (1) Well stratified crinoidal packstone to rudstones, in the lower part of the mounds, passing laterally to the Bayard Fm. (2) The '*Veines Bleues*' (blue veins) facies, particularly typical in the lower and middle part of the mounds. The "veins" corresponds to voids and cavities (decayed soft organisms, stromatactoid-like cavities) filled with sparry calcite. Fenestellid bryozoans are abundant in the lower part of this facies (LEES 1997). (3) Massive or poorly stratified bioclastic wackestones developed in the upper part of the section indicates the recurrence of the Bayard facies, overlaid by a second level of Waulsortion mound. A second recurrence of 20 m of the Bayard Fm but with much more cherts topped by a few metres of a third Waulsortian buildup (Fig. 26).

Interpretation

HANCE et al. (2001) interpreted the mixed facies unit of the Comblain-au-Pont Fm as the TST of their sequence 1. The upper part of the TST corresponds to the lower member of the Hastière Fm.

The first Tournaisian fauna (including the rugose coral *Conilophyllum priscum*) appears at the base of the overlying bed. The HST of sequence 1 is indentified in the middle member of the Hastière Fm, whereas its upper member corresponds to the LST of the overlying sequence 2 of HANCE et al. (2001). The TST of this sequence corresponds to the Pont d'Arcole Fm in which the dark shale corresponds to the maximum flooding surface. The Landelies Fm corresponds to the HST-FSST of sequence 2. The sharp contact with the overlying Maurenne Fm corresponds to the sequence boundary. The Maurenne shale forms the LST of sequence 3 whereas both the Bayard and the Waulsort Fms form the TST and HST. The Waulsortian buildups started to grow during the TST and reached their maximum development during the HST.

The reappearance of the Bayard facies followed by a new Waulsortian development indicates the TST of the following sequence 4A and 4B of POTY (2016). Note that this reccurence was previously interpreted as lateral variation of the Waulsortian facies (Fig. 27)

15 - VÊVES CASTLE SECTION

References

LEES (1997), DEHANTSCHUTTER & LEES (1996).

Location and access

Dicsontinuous section along the road facing the Vêves Castle in the Lesse valley, c. 1.5 km NE of the Gendron-Celles train station. Southern part of the DSA (Fig. 1). GPS: 50°13′21″N4°58′57″E.

Lithostratigraphy and biostratigraphy

Waulsort and Leffe Fm (Fig. 27). The foraminifers allow the recognition of MFZ6, MFZ7 and MFZ8 biozones. The conodont biostratigraphy was precised by GROESSENS & NOËL (1975).

Description

The section starts north of the castle where the basal facies of the Waulsort Fm is exposed. It is mainly a crinoidal packstone rather light in colour, and poorly bedded. Along the road going down to the castle are exposed the massive structure of the Waulsortian facies.

The '*Veines bleues*' facies, made of fine-grained bioclastic wackestone with sparry calcite patches (in some places, more important volumetrically than the wackestone) is exposed. The sparry mass occurs under various forms: sparry crusts on fenestellids, cavity fillings and neomorphosed pseudospar (LEES 1997). Associated are crinoidal packstones and wackestone occur in the lower part of the buildups (LEES et al. 1985). In the upper part, it is associated with the 'biomicrite' (wackestone) facies. Bryozoans are the most common organisms of the '*Veines Bleues*' facies (LEES 1997). Brachiopods, crinoids and other fossils occur sporadically or are clustered in pockets. In front of the Castel is a poor exposure of the Leffe Fm that appears as a bedded cherty limestone. The facies includes well-bedded light or medium grey wackestone and mudstone containing intraclasts (LEES & MILLER 1985).

Interpretation
The Waulsortian buildups have been studied in Belgium since the pioneer work of DUPONT (1863) and most detailed studies devoted to the Waulsortian are those of LEES (1997), DEHANSCHUTTER & LEES (1996), LEES et al. (1985), and LEES & MILLER (1985, 1995). HANCE ET AL. (2001) recognized the record of two third-order sequences through the Waulsort Fm and its lateral facies (sequence 3, initiating the buildup, and the sequence 4 finishing it). POTY (2016) however recognized a third sequence, namely 3, 4A and 4B).

16 - LEFFE QUARRY

Highlights
Third-order sequence 5 to 7, evaporitic deposits.

References
PIROTTE (2004), DEVUYST et al. (2005).

Location and access
This operating quarry is located north of Dinant, about 500 m NE of the Leffe Abbey. Central part of the DSA (Fig. 1, 2), north of the main Waulsortian development. GPS: 50°16'28"N4°54'41"E.

Lithostratigraphy and biostratigraphy
Molignée, Salet and Neffe Fm (Moliniacian) and Lives Fm (Livian), "Grande Brêche Viséenne" breccia facies.

Description
The section is continuous from the Molignée Formation to the 'Grande Brèche', on the southern flank of a syncline. The Molignée Formation ('Black Marble') is composed of dark mudstone to micropackstone corresponding mainly to turbidites deposited in a deep lagoonal environment setting in the central part of the DSA (see Salet and Tanret sections). The transition to the overlying Salet Fm is not clearly exposed. The thick-bedded to massive packstone to grainstones of the Neffe Formation are capped by a marker bed, the '*Banc d'Or de Bachant*'. The Haut-le-Wastia Member (Lives Fm) is c. 40 m-thick. It displays parasequences with stromatolitic tops; breccias (after evaporite dissolution), locally reddish are characteristic at this level in the central part of the DSA. Beds of cryptocrystalline calcite are most probably pseudomorph of anhydrite deposits (Fig. 28). Macrofauna is restricted to some rare corals and more abundant brachiopods concentrated in thin shelly layers. The Corphalie Member is c. 20 m-thick. Medium to thick-bedded bioclastic packstone to grainstones are overlaid by mud- to wackestones with stromatolites and oncoids (often developed around the brachiopods). The presence of anhydrite pseudomorphs in the core of the syncline allowed the development of peculiar tectonic features such as mushroom-shaped folds (Fig. 28).

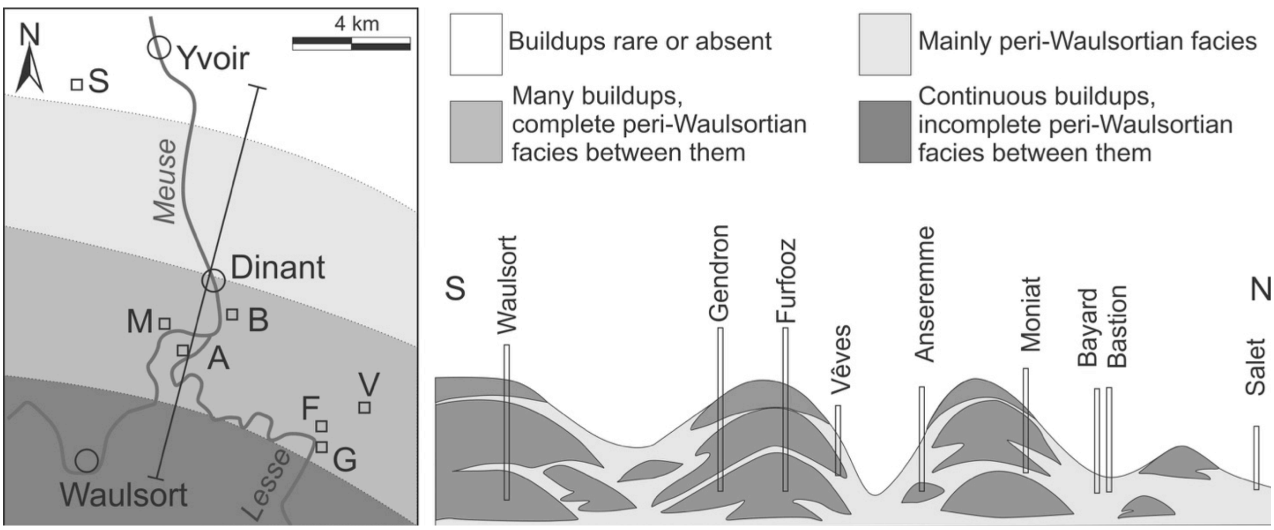

Fig. 27: Development of Waulsortian complex in the Waulsort-Dinant area with the location of the classical section through the Waulsortian. Modified after LEES (1997).

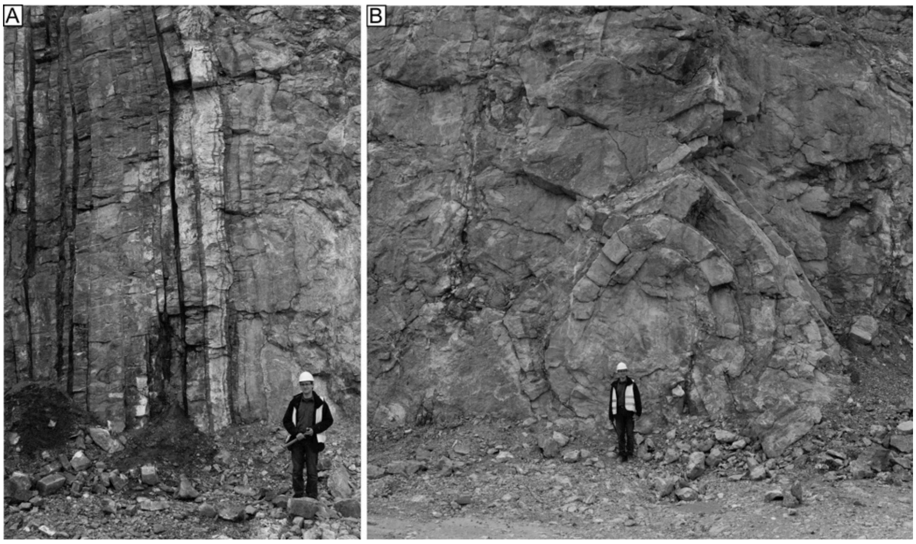

Fig. 28: A: Calcitic pseudomorphs after anhydrite in the lower part of the Lives Fm, Leffe quarry; B: Mushroom-shaped antiform in the Leffe quarry.

Interpretation
The Molignée Fm corresponds to the sequence 5 whereas the Salet and Neffe correspond respectively to the TST and HST of sequence 6, capped by the '*Banc d'Or de Bachant*' interpreted as the sequence boundary. The overlying Lives Fm, as the TST of sequence 7 displays here facies that are clearly more shallow-water and restritced than in the Lives section. The depot center obviously migrated towards the north of the Namur-Dinant Basin during the middle Viséan, triggering the shallowing of the southern part of the basin. Meanwhile, more marine conditions developed in the northern part. The evaporitic sequences deposited in the southern part of the basin, after dissolution, lead to the formation of thick collapse breccia units (HANCE et al. 2001, 2002).

17 – EUPEN 'CARNOL' QUARRY

Highlights
Almost continuous but lacunar section from the lower Tournaisian to the middle Viséan, proximal facies and dolomitisation.

References
LALOUX et al. (1996), POTY (2016)

Location and access
This active quarry is situated c. 2 km north of the Eupen town in eastern Belgium. It is located in a tectonic thrust sheet of the Vesdre area and exposes facies similar to those known in the NSA (Fig. 1, 2). GPS: 50°39′29″N6°01′31″E.

Lithostratigraphy and biostratigraphy
Pont d'Arcole Fm, Vesdre Group (dolomitised Landelies, Yvoir, Ourthe and Longpré formations), lower to upper Viséan, Neffe and Lives formations, lower to middle Viséan.

Description
The lithological composition of the Vesdre Group (or Vesdre Fm of LALOUX et al. 1996) differs from the east (e.g. Carnol quarry near Eupen) to the west (e.g. Bay-Bonnet quarry, Fléron). In the west, it is identical to the Engihoul Fm with the typical facies of the central NSA. In the east, the Vesdre Group is thicker and its composition announces the lacunar succession known from the Aachen area. After POTY (2016), the Carnol quarry exposes (Fig. 29):

- < 6 m of shale belonging to the Pont d'Arcole Fm;
- 37 m of crinoidal dolostone with syringoporids and *Siphonophyllia rivagensis* (unit 1);
- 44 m of decimetre- to pluridecimetre-thick beds of dolostone, cherty in its upper part (unit 2);
- 13 m of dolostone and dolomitic limestone, with some cherts and numerous *Cyathoclisia uralensis* in its lower part then becoming oolitic, without chert and with *Keyserlingophyllum obliquum, Uralinia* cf. *multiplex* and *Vaughanites flabelliformis* in its upper part (unit 3);
- 8 m of laminated, dark dolostone, in decimetre- to pluridecimetre-thick beds, resting on the underlying unit via a paraconformity (unit 4);
- 15 m of coarse-grained crinoidal dolostone in pluridecimetre-thick beds (unit 5);
- 4 m of massive, coarse-grained, dolostone (unit 6);
- after a c. 10 m-thick gap of observation (possibly corresponding to the Walhorn
- dolomitic breccia), 5 m of bedded dolostone (unit 7);
- c. 10 m of dolomitic breccia (unit 8).

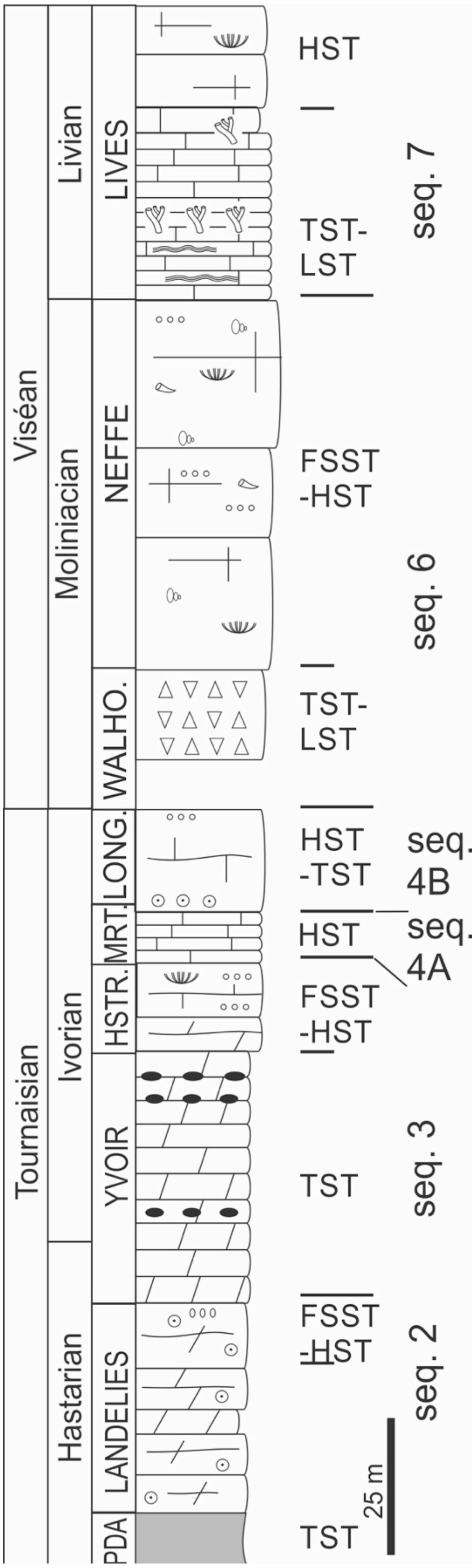

Fig. 29: schematic log of the stratigraphical succession in the Eupen 'Carnol' quarry, after Poty (2016). Abbreviations: LSt: lowstand system tract, TST: transgressive system tract, HST: highstand system tract, FSST: falling-strage system tract, HSTR.: Hastenrath Mbr, MRT.: Martinrive Fm, LONG.: Longpré Fm, WALHO.: Walhorn Breccia.

Above this dominantly dolomitic set of units, all included in the Vesdre Group, the southern part of the quarry exposes:

- 40 m of dark, fine-grained, limestone in pluridecimetre-thick beds of the upper part of the Terwagne Fm. An argillaceous palaeosol corresponding to the cinerite 'M' of Delcambre (1989) and a horizon rich in *Dorlodotia briarti densa* respectively occur 10 m and 4 m below the top of the formation. Both levels can be traced throughout the NSA and CSA;
- c. 20 m of massive oolitic and bioclastic grainstone with *D. briarti briarti* (Neffe Fm), capped by;
- 3-4 m of dark limestone with intraclasts, carbonaceous limestone and shell levels typical of the top of the Neffe Fm;
- 30 m of limestone displaying parasequences dominated by stromatolitic facies, of the Haut-le-Wastia Mbr (Lives Fm).
- c. 15 m of grey limestone rich in *Siphonodendron martini* and *Lithostrotion araneum* (base of RC6 Zone) of the Corphalie Mbr (Lives Fm).

Interpretation

Unit 1 corresponds to the dolomitised Landelies Fm as suggested by the presence of *Siphonophyllia rivagensis* (RC2 Zone), i.e. the HST-FSST (?) of sequence 2. The cherty unit 2 corresponds to the dolomitised Yvoir Fm where corals are typical of the RC3α-β Zone (Poty 2016) and therefore to the upper part of TST of sequence 3. The oolitic unit 3, clearly correlates with the Hastenrath Mbr, a fossiliferous non-crinoidal equivalent of the Ourthe Fm (HST 3). Units 4 and 5 respectively correspond to the dolomitised upper member of the Martinrive Fm and to the dolomitised Flémalle Mbr of the Longpré Fm (i.e. HST4A and HST4B). Unit 6 corresponds to the dolomitised Avins Mbr of the Longpré Fm (HST5). The Neffe Fm (HST6) and Corphalie Mbr (HST7) complete the section.

As noted by Poty (2016), only the highstands are recorded in this area, LST and most TST are lacking, suggesting a proximal position of the area on the shelf (Fig. 29).

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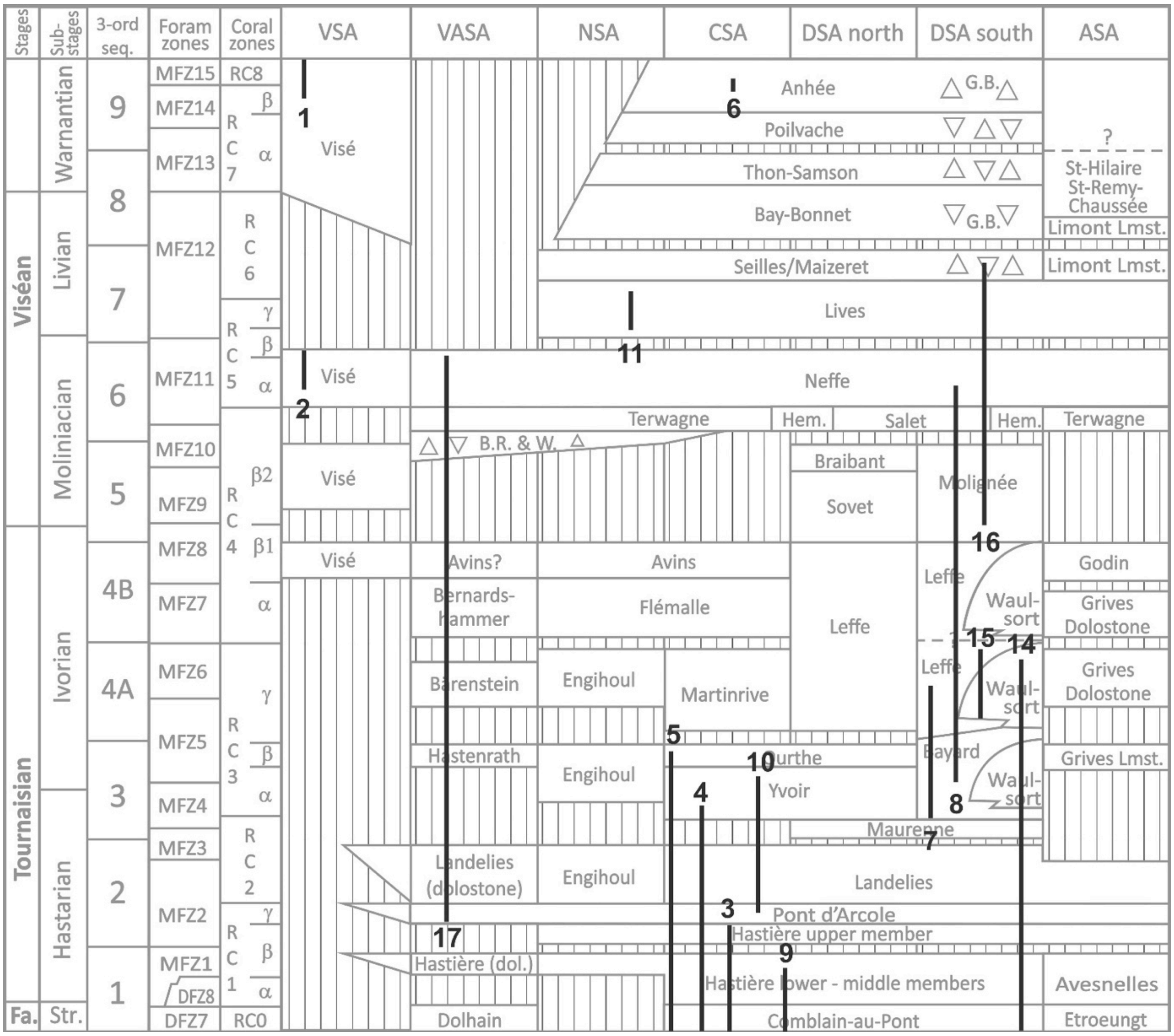

Appendix 1: Position of the visited outcrops and sections in the lithostratigraphic, biostratigraphic and sequence stratigraphic framework for the uppermost Devonian, Tournaisian and Viséan of Southern Belgium and surrounding areas. Gaps are indicated by light gray zone. Abbreviations: G.B.: Grande Brèche, B.R. & W.: Belle Roche & Walhorn breccia, Lmst.: limestone. Third-order sequences according to Hance et al. (2001) and Devuyst et al. (2005) emended by Poty (2016). Biostratigraphy (foraminifers and rugose corals biozones) after Poty et al. (2006) and Poty (2016). Modified after Poty et al. (2006, 2011, 2014) and Poty (2016). Outcrops ad sections legend: (1): Visé quarries, (2): Argenteau Cawtle Rock, (3): Chanxhe sections, (4): Rivage road section, (5): Royseux railroad section, (6): Royseux trenches, (7): Dinant and the Bayard Rock, (8): Tanret quarry and Salet road section, (9): Spontin and Chansin sections, (10): Chansin 'les Nutons' quarry, (11): Lives Rock and quarry, (12): Jambes Rock, (13): Citadel of Namur, (14): Gendron-Celles railroad secyop, (15): Vève Castle section, (16): Leffe quarry, (17): Eupen 'Carnol' quarry.