GEOLOGICA BELGICA (2013) 16/3: 179-190

The Red Marble of Baelen, a particular historical building stone with global geological importance and local use

Roland DREESEN[1], Jean-Marc MARION[2] & Bernard MOTTEQUIN[2]

[1]*Geological Survey of Belgium, Jenner street 13, 1000 Brussels, Belgium.*
[2]*Unité de Paléontologie animale et humaine, Université de Liège, Allée du 6 Août, Bât. B18, B 4000 Liège 1, Belgium.*

ABSTRACT. The Red Marble of Baelen is a local ornamental stone from the Limbourg area (Vesdre valley, Eastern Belgium), where it has been quarried at least since the 16th century, possibly even from the 9th century. It represents a local Member of the Middle Famennian (late Upper Devonian) Souverain-Pré Formation. It is the only known or at least the only well-documented Mid Famennian red-stained carbonate mudmound complex worldwide. Carbonate microfacies comprise nodular to lenticular algospongal pack/bindstones and massive stromatactis-bearing microbialitic mudstones, both enclosing lenticular crinoidal grain- to rudstones. Silty nodular bioclastic wacke/packstones, strongly affected by pressure solution, mark the transition with underlying and overlying micaceous sandstones and occur as interbeds within the mudmound core. The Red Marble of Baelen displays a few varieties that have been used for a large spectrum of building and decorative purposes, mostly within a short radius of the production sites, in the former Duchy of Limbourg. Its usage was rural and vernacular, although it has been exceptionally employed in prestigious buildings such as the Antwerp town hall.

KEYWORDS: Middle Famennian, Devonian, mudmound, Souverain-Pré Formation, building stone.

1. Introduction

Historical geological research on the "Marbre rouge à crinoïdes de Baelen" (Red Crinoidal Marble of Baelen) focused mainly on the stratigraphical aspects of this particular Famennian (late Upper Devonian) carbonate deposit (Dumont, 1832; Davreux, 1833; Dewalque, 1881, 1882, Dewalque in Forir & Dewalque, 1881; Dupont, 1886; Gosselet, 1888; Bellière, 1953, 1954; Fourmarier, 1953; Lombard, 1957; Sartenaer, 1957; Bouckaert et al., 1967). More recently, Dreesen & Flajs (1984), Marion (1984, 1985) and Dreesen et al. (1985) were first to identify its (microbial) mudmound origin, to stress its particular synsedimentary tectonic setting and to highlight its unusual biota. Its geological uniqueness results from the fact that it probably represents the only well-documented mudmound anywhere at this particular stratigraphical level, after the worldwide Frasnian–Famennian extinction boundary (the so-called Kellwasser Event). Aretz & Chevalier (2007) confirmed the microbial origin but considered the Baelen limestones rather to represent microbial reefs. Webb (2002) interpreted the Baelen carbonate buildups as deeper water mudmounds. However, the abundance of biota such as crinoids and algae may point to shallower depositional environments. A forthcoming paper by the current authors will present new palaeoecological evidences allowing to reinterpret the depositional environment and discuss the palaeobathymetry of the Baelen mudmounds or microbial reefs. The Red Marble of Baelen *sensu stricto* corresponds to the red-stained core of a mudmound complex. The pink to red-coloured stromatactis-bearing massive limestones are of "marble" quality, strongly resembling the classical Frasnian "Marbre rouge" (Rouge belge). However, the total absence of corals and stromatopores and the conspicuous abundance of crinoids and algae in the latter is striking, which allows to easily distinguish it from its Frasnian red marble analogues. Most conspicuous and rather unique, is the argillaceous red-stained crinoidal limestone variety of the Baelen Marble, locally known as "pierre poitée" (see below). The Red Marble of Baelen is a rare but highly valued historical building-ornamental stone with an essentially local use. Evidence for quarrying goes back to at least the 16th century.

2. Litho-, bio- and event-stratigraphical setting

The Red Marble of Baelen belongs to a local member of the Middle Famennian Souverain-Pré Formation (Dreesen et al., 1985; Bultynck & Dejonghe, 2002; Thorez et al., 2006) (Fig. 1). The latter corresponds to the first major reappearance of marine carbonates in the otherwise siliciclastic Famennian shelf sediments, after the disappearance of widespread shelf carbonates that flourished during the previous Frasnian greenhouse episode.

The base of the Souverain-Pré Formation (Fig. 2), in the Baelen-Limbourg area, coincides with a thin phosphatized black microstromatolitic hardground (Fig. 3A), incorporated within a

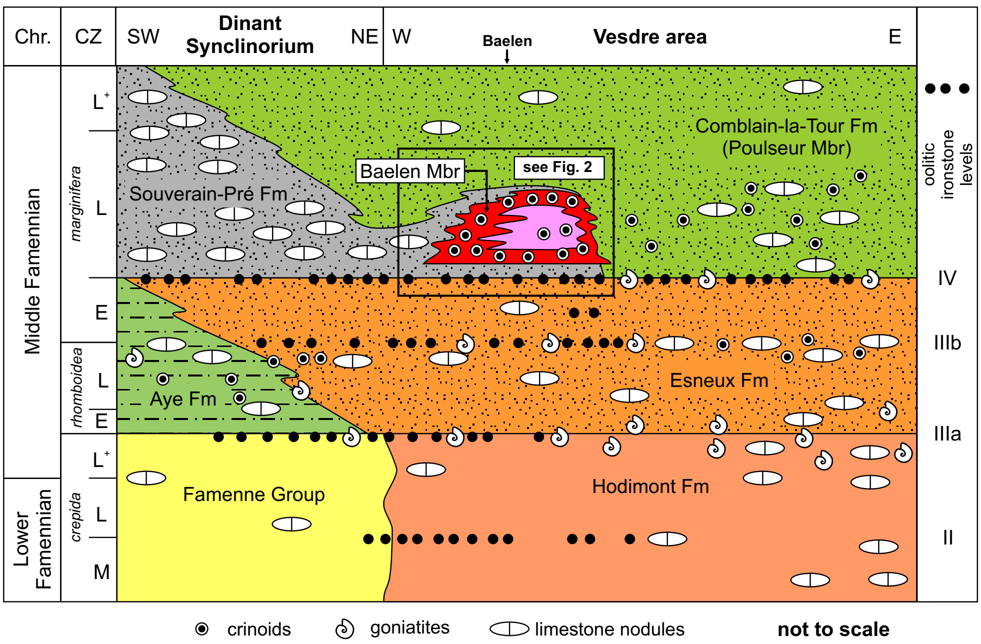

Figure 1. Lithostratigraphical and biostratigraphical framework of the Middle Famennian in the Dinant and Vesdre Synclinoria (modified after Dreesen, 1989). Abbreviations: CZ: conodont zone, E= early, L= Late, L+= Latest, Fm= Formation; Mb= Member.

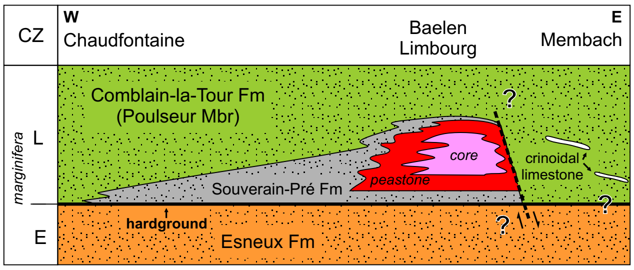

Figure 2. Detail of the lithostratigraphical context of the Baelen Member in the Baelen–Limbourg area, showing the spatial-temporal relationships of the core facies and the "peastone facies" as well as the abrupt facies changes towards the East in the Vesdre Synclinorium.

25 cm-thick bioclastic limestone bed at the top of thin-bedded micaceous silt- and sandstones of the underlying Esneux Formation (Figs 3B-C). This hardground grades laterally into a ferruginous pseudo-ooid-bearing bioclastic limestone, representing oolitic ironstone level IV, a conspicuous lithostratigraphical event-stratigraphical marker bed in the Dinant and Verviers synclinoria (Dreesen, 1982a, 1982 b, 1987) (Fig. 1).

The base of the Baelen Member *sensu stricto* corresponds to the first entry of thick, lenticular and coarse crinoidal grainstones / rudstones in a series of silty nodular stylocumulated crinoidal-algal-algospongal limestones (see below). The top of the Baelen Member corresponds to the reappearance of silty nodular limestones of the Souverain-Pré facies and /or micaceous sandstones of the Montfort Formation (Poulseur Member). The Baelen Member thus displays a cyclic lithological character.

Towards the West, the Baelen Member becomes gradually replaced by the "classical" or "regular" nodular bioclastic limestone facies of the Souverain-Pré Formation, although this lithological contact has never been observed in the field. Towards the East, we observe a rather abrupt facies change, from mudmound complex limestones into micaceous sandstones, locally and occasionally enclosing thin lenses of pink to grey crinoidal limestones (Fig. 2). The latter are considered as storm-generated debris deposits, the bioclastic elements of which (mainly crinoid ossicles) are supposed to have been derived from the nearby Baelen carbonate buildups. This abrupt facies change is interpreted as the result of synsedimentary fault activity, along faulted blocks (Marion, 1984 and 1985). The supposed presence of such blocks in the Verviers Synclinorium is in good agreement with the presence of a chess-board like configuration of tilted blocks, bordered by NNW-SSE and SSW-NNE lineaments in the adjacent Dinant Synclinorium (Thorez & Dreesen 1986; Thorez et al.,1988; Paproth et al., 1986)

Rich conodont faunas recovered from the bioclastic limestone beds containing hardgrounds at the extreme base of the Baelen Member, indicated an Early to Late marginifera age. Otherwise, samples taken from bioclastic and crinoidal limestones at different stratigraphical levels within the mudmound complex, contained rather poor conodont faunas characteristic of the Late marginifera Zone (Dreesen, 1978; Dreesen et al., 1985). The Baelen mudmounds are thus of early Mid-Famennian age.

The development of the Baelen mudmounds corresponds to a major but short-term eustatic sea-level rise ("transgressive event") that interrupted the Famennian regressive siliciclastic megasequence. The mounds accumulated during one single 4th-order eustatic cycle, the duration of which is possibly less than 0.5 my (the Late *marginifera* Conodont Zone *pro parte*; Thorez & Dreesen, 1997). According to Sandberg et al. (2002) this time interval corresponded to an interglacial episode during the latest Devonian. The "Baelen event" correlates also with the first appearance of clymeniid goniatites (the "post-Enkeberg Event" of House, 1985 [see also Becker, 1993]) and with an important migration of plurilocular foraminifera (the Df3 foraminifera zone with the index species *Quasiendothyra bella*) from Eastern Europe (Bouckaert et al., 1976; Dreesen et al., 1986; Conil et al., 1986).

After the collapse of the metazoan coral-sponge reef ecosystem at the F/F extinction boundary, only rare, small and isolated stromatoporoid sponge or lithisitid patch reefs returned episodically during the Famennian in North America, Western Europe, Australia and China. Calcimicrobes were otherwise the dominant reef formers during the Famennian, often forming stromatolite-mounds (Copper, 2002). The most reasonable explanation for the demise of the Mid-Palaeozoic coral-sponge reef ecosystem appears to be the combined effect of cooling climates and major sealevel lowstands during cooling and glacial

Figure 3. A. Lithostratigraphical base of the Souverain-Pré Formation (Limbourg Playground section), bioclastic limestone bed enveloped by micaceous silt- and sandstones. B. Detail of previous photograph. Note presence of black rip-up clasts of phosphatized hardground occurring at the top of a bioclastic limestone bed. C. Microstromatolithic phosphatized hardground in a silty bioclastic grainstone. Micrograph of thin section, top of limestone bed depicted in Fig. 3B, transmitted light (scale bar: 5 mm).

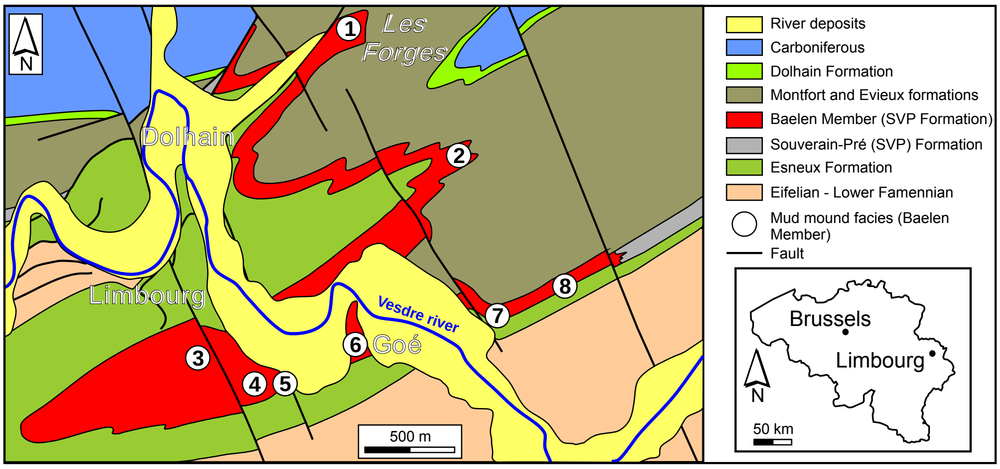

Figure 4. Simplified geological map of the Limbourg area (modified from Ghysel et al., 1995) pointing to the location of individual mudmound complexes within the Baelen Member. Section numbers: 1, Baelen-Les Forges; 2, Dolhain (La Belle Vue); 3, "Mali" quarry; 4, Limbourg municipal waste deposit; 5, Limbourg La Beverie (playground); 6, Goé; 7, Botterweck (western section); 8, Botterweck (eastern section).

episodes that dominated during the Famennian, punctuated by interglacial high-stands. The Baelen Member represents such an interglacial highstand, allowing the exceptional development of (crypt)-algal-sponge-algospongal-crinoidal mudmounds on tectonically controlled mounding sites, during a temporary waning of the siliciclastic supply, on the shallow epicontinental shelf.

3. Geographical and tectonic setting

Although most historical quarries and current outcrops actually occur in the vicinity of the medieval town of Limbourg (la Ville Haute), the name of the Red Marble of Baelen is derived from the last active quarry (which is now disused), located in Les Forges on the territory of the village of Baelen-Les Forges, NE of Limbourg (Fig. 4). The castle and medieval town of Limbourg otherwise are located on an uplifted section of mid-Famennian micaceous silt- and sandstones of the Esneux Formation, W of a NNW-SSE trending fault.

The Baelen Member contains several mounding sites that occur within SW-NE directed fold limbs, in between the towns and villages of Limbourg, Baelen and Goé, within the Verviers Synclinorium (Fig. 4). The latter mounding sites are believed to be located on a block-faulted basement (Marion, 1984 and 1985; Dreesen et al., 1985). Moreover, this cluster of mounds apparently coincides with the northern extremity of a deep-seated NNW-SSE oriented transversal fault, known as the Verviers-Trier dislocation (Dvorak, 1973).

Interestingly, Matyja (1993, 2009) reported possible relicts of Famennian mudmound-type carbonate buildups (the Bielica Member of the Czluchow Formation) in subsurface core material from Pomerania (NW Poland) from a coeval stratigraphical interval (Late *marginifera* conodont Zone). However, these facies are not so well-documented, the mudmound interpretation being based on the presence of unusual biota (among which the algospongal genus *Baculella*) and sites of increased carbonate productivity only. The deposits of the Bielica Member were considered by Matyja as off-mound facies, comparable to Waulsortian mound facies. Furthermore, the author suggests a similar tectonical control of the mounding sites: the carbonate buildups probably grew on tectonically controlled intrabasinal highs (connected with the so-called Teisseyre-Tornquist Tectonic Zone).

Up to 7 or 8 individual mounding sites occur in the studied area, more precisely at Les Forges (abandoned quarries East of Baelen), Dolhain La Belle Vue, Limbourg Hors-les-Portes (possible underground historical quarry), the Limbourg municipal waste deposit, Limbourg La Beverie (playground), Goé (sections on both banks of the Vesdre river) and Botterweck (western and eastern sections) (Fig. 4).

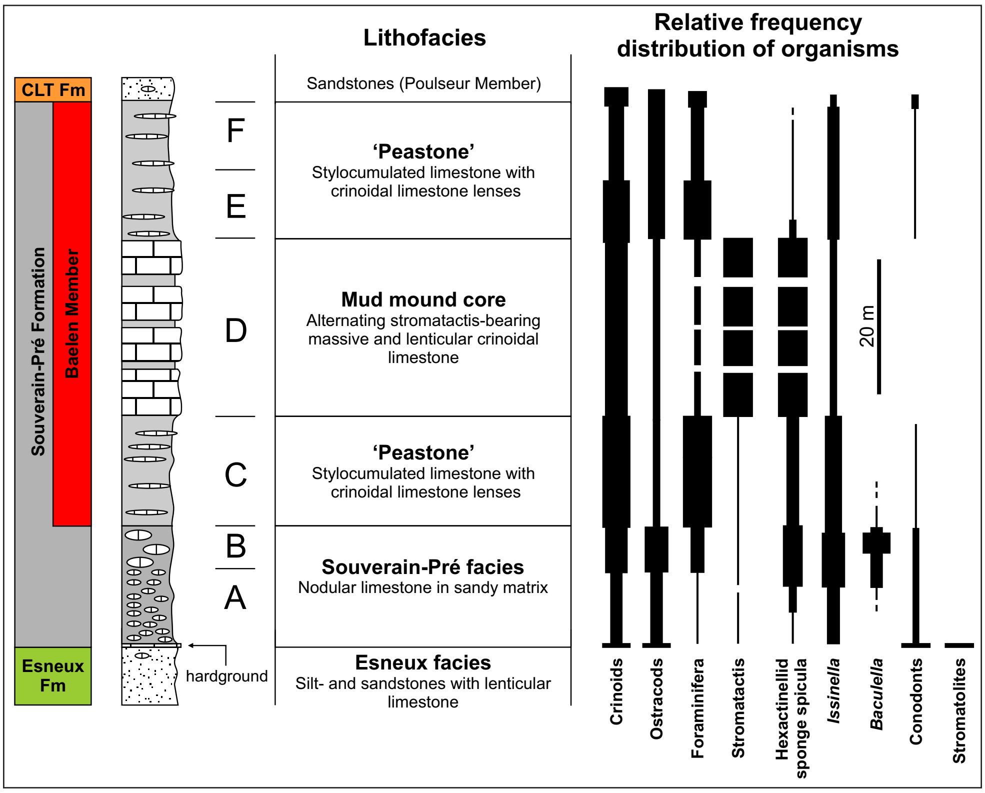

Figure 5. Composite litholog showing the distribution of the main lithofacies types within the Baelen Member and the relative frequency distribution of the observed micro-organisms (modified from Dreesen et al., 1985 and Dreesen et al., 1993).

Figure 6. Nodular limestones affected by pressure solution within silty shales affected by cleavage. Hors-les-Portes section, Limbourg la Ville Haute.

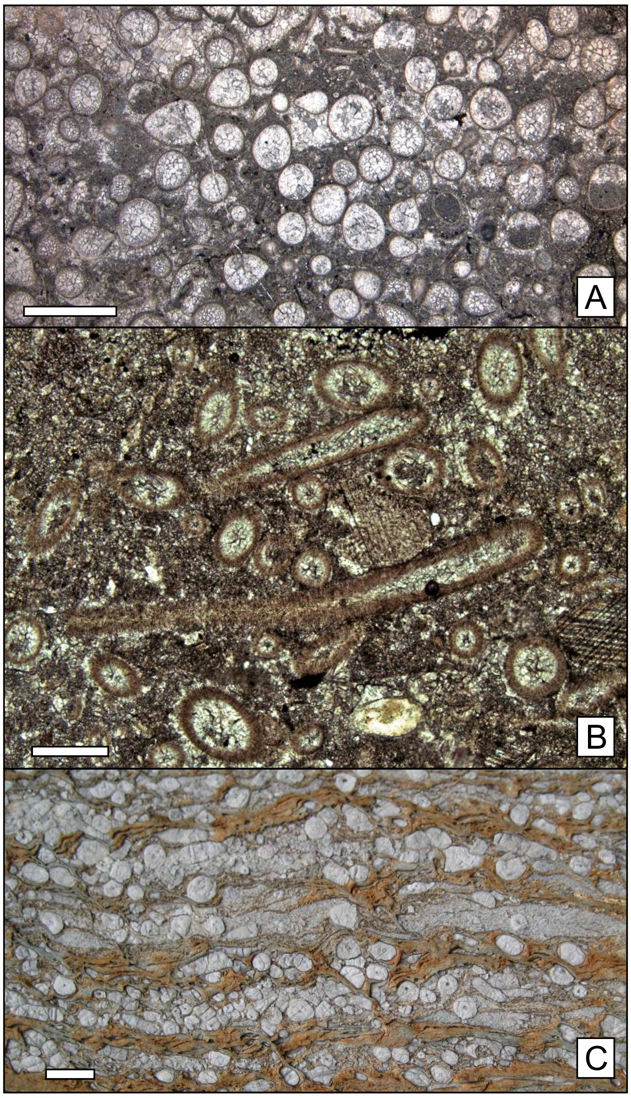

Figure 7. A. Algospongal wackestone/packstone with numerous sections of *Baculella gemina* (micrograph of a thin section, transmitted light), Goé-North section (scale bar: 5 mm). B. Silty algospongal wackestone/packstone displaying sections of Issinellids (micrograph of thin section, transmitted light), Goé-North section (scale bar: 500 µm). C. Weathered surface of a building stone made of "pierre poitée", displaying the characteristic stylocumulated fabric with numerous sections of crinoid ossicles. Home St Joseph, Baelen (scale bar: 5 mm).

Because of strong tectonic disturbances (frequent faulting) and poor outcrop conditions, only incomplete sections could be measured in the field. Therefore, a composite lithostratigraphical log of the Baelen Member has been made (Fig. 5) that is based on an assembly of partial sections of the different mudmound complexes. The given thicknesses are approximate only and the individual mudmounds may strongly differ in size and extension. The maximum thickness of the Baelen Member may have exceeded 100 m, because of the impact of strong pressure solution affecting all of the composing carbonate facies.

4. Lithofacies and carbonate microfacies

The best actual and accessible sections for observing the base of the Souverain-Pré Formation (and the lowest part of the Baelen

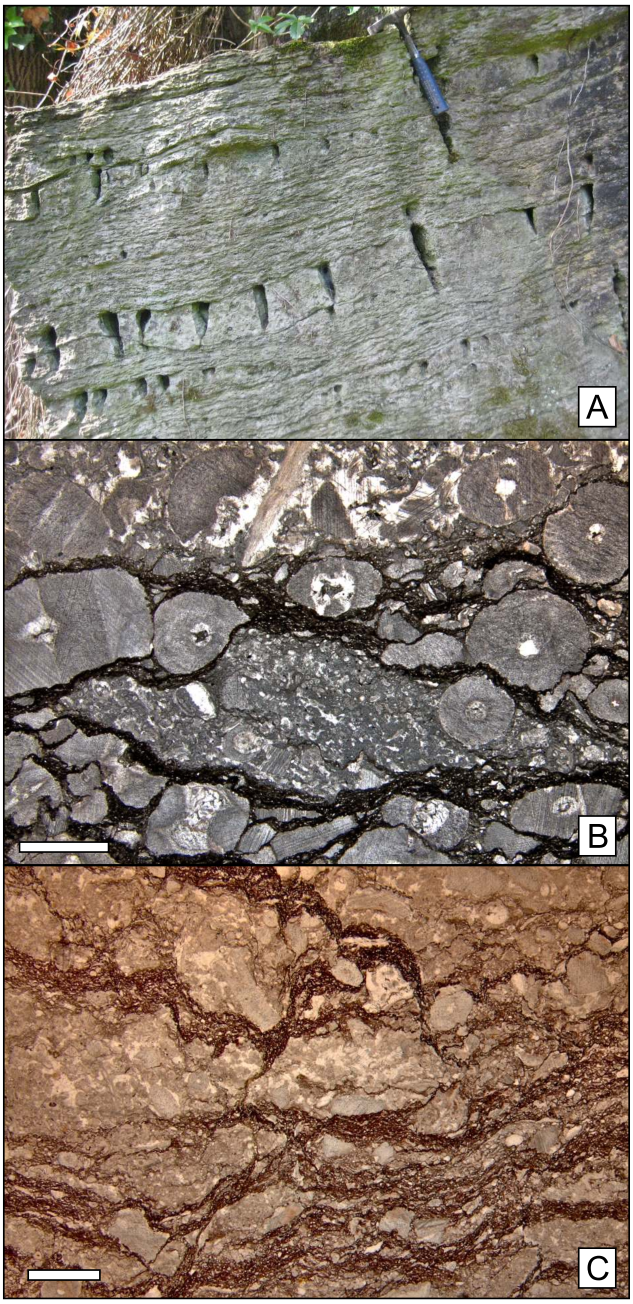

Figure 8. A. Lenticular crinoidal encrinites (crinoidal grain- and rudstones) interrupting the stylocumulated "argillaceous" limestones. The coarse crinoidal limestones are affected by incipient karst, preferentially along diaclases. Limbourg Hors-les-Portes. Mali section. B. Micrograph of a thin section in a stylocumulated silty limestone ("pierre poitée") displaying mixed carbonate facies: crinoidal grainstones and algospongal wacke/packstones strongly affected by pressure solution (corroded contacts). Hors-les-Portes section,"Mali quarry" (scale bar: 5 mm). C. Micrograph of a thin section in a stylocumulated argillaceous or silty limestone with corroded crinoidal grainstone and crinoid ossicles ("pierre poitée") (scale bar: 2 mm).

Member) are: the Limbourg La Beverie section (showing the transitional beds with the underlying Esneux Formation), the Limbourg Hors-les-Portes section (a former medieval town moat), and the Goé section (along the Vesdre river, northern embankment). The latter two sections show also the gradual transition to the core facies of the mudmound. The mudmound core itself can still be observed in the disused quarries of Les Forges (Baelen) and of Limbourg Hors-les-Portes (also a historical and possibly underground quarry, former Mali private property), the section near Goé (along the Vesdre river, southern embankment) and in a few scattered outcrops near Botterweck. The upper part of the Baelen Member and the transitional beds with the overlying Poulseur Member (micaceous sandstones) are exposed in the abandoned quarry of Les Forges (Baelen) and in the Botterweck sections (discontinuously, however). The Baelen mound complex displays a conspicuous cyclic lithological aspect, reflecting changes in carbonate microfacies and in the detrital (silt, clay) content.

In the areas of the mounding sites, 12-15m of silty nodular limestones embedded in calcareous micaceous silt/sandstones (Souverain-Pré facies) represent the "basement" of the mudmound *sensu stricto* (corresponding to the former sequences A-B of Dreesen et al., 1985) (Fig. 6). The size of the nodular limestone beds seems to increase towards the top. Microscopically the latter limestones correspond to silty algal mudstones, bioclastic wackestones and algospongal bindstones (locally floatstones), often affected by bioturbation. Very conspicuous is the abundance of algospongae, in particular that of Issinellids (*Issinella* and *Baculella*) over a few meters in the upper part of the nodular limestone sequence (Fig. 7A-B). This particular occurrence represents a true lithostratigraphical reference horizon in the field due to the abundancy of silicified tests of *Baculella gemina* Conil & Dreesen, 1985 (= *Dreesenulella* Vachard, 1991. Indeed, the subspherical or ovoid tests of *Baculella* strongly resemble large hollow ooids that can easily be seen with the naked eye or with the hand lens. These particular organisms previously identified as *incertae sedis* are now being assigned to the new order of Algospongae by Vachard & Cozar (2010). Other biota include palaeoeberesellids, hexactinellid sponge spicules, few plurilocular foraminifera, bryozoans, thin-shelled ostracodes, crinoids and rare spire-bearing and productidine brachiopods. The latter microfacies characteristics clearly differ from those of the "regular" nodular limestones of the Souverain-Pré formation, containing more open marine-influenced bioclastic wacke/

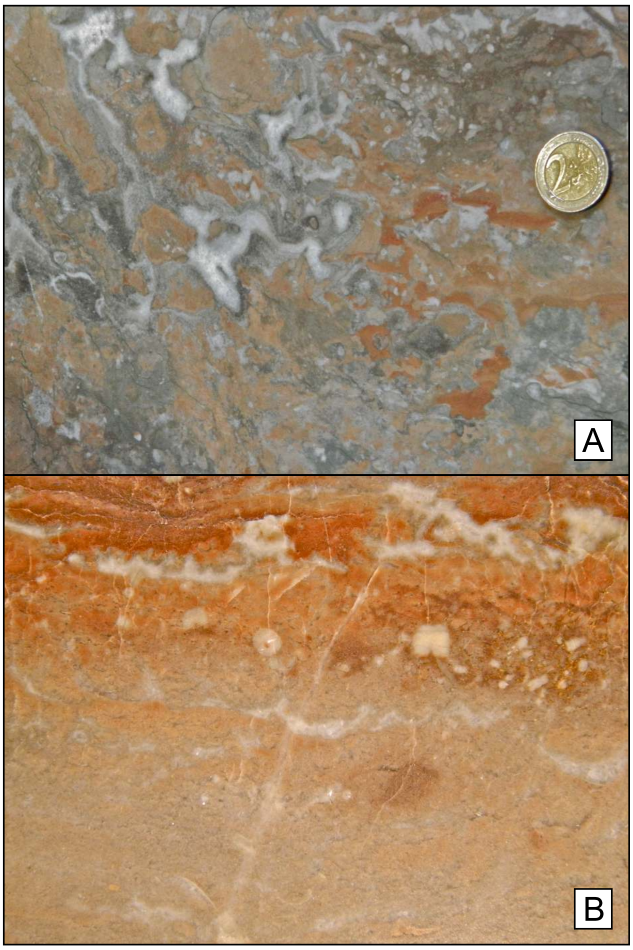

Figure 9. A–B. Polished slabs of Baelen mudmound core facies showing stromatactoid structures and crinoid ossicles. The total absence of stromatoporoids and corals is striking. A. Verviers station, ticket-window ledge. B. Botterweck section (largest crinoid ossicle is 5 mm).

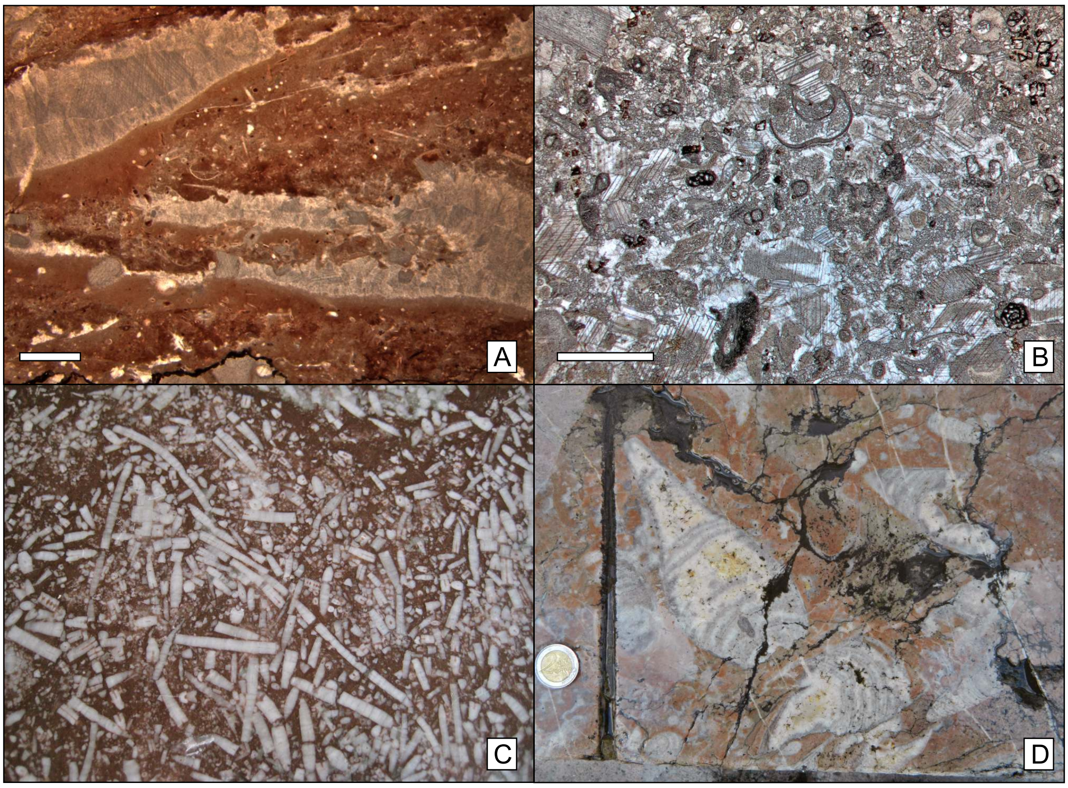

Figure 10. A. Stromatactis-bearing spiculitic mudstones characteristic of the mudmound core facies. Micrograph of thin section, transmitted light. Note red staining, presence of small stromatactoid structures (fenestral fabric) and sections of hexactinellid sponge spiculae. Baelen, Les Forges quarry (scale bar: 2 mm). B. Crinoidal grainstone frequently enclosing plurilocular endothyrid-tournayellid foraminifera (micrograph of a thin section, transmitted light), Les Forges section, Baelen (scale bar: 2 mm). C. Polished slab of the second variety of Red Marble of Baelen: the red-stained "pierre poitée" ("peastone") or argillaceous limestone with numerous sections of crinoid ossicles. Baelen, Les Forges quarry. Width of crinoid stems is about 5 mm. Rock specimens sampled not *in situ* from Baelen Les Forges. D. Sections of large probable oncocerides observed in doorsteps made of red Baelen marble slabs, in Limbourg La Ville Haute, Place Saint-Georges.

Figure 11. Large slumps affecting limestone beds of unit E (crinoidal limestones) in the upper part of the Baelen Member, Hors-les-Portes section (“Mali” quarry).

grainstones with crinoids, plurilocular foraminifera, girvanellids, palaeoberesellids, thick-shelled ostracodes, bryozoans, brachiopods and conodonts.

The overlying sequence (C) is composed of alternating lithologies with a total thickness of at most 30 m: it consists of silty nodular and lenticular limestones that are strongly affected by pressure solution and produce so-called stylocumulated “argillaceous” limestones (Fig. 7C), randomly enclosing thick and coarse lenticular crinoidal limestone beds (Fig. 8A). Microscopically, the former correspond to algospongal wackestones/packstones and spiculitic/cryptalgal mudstones, the latter to densely packed crinoidal grainstones. Due to strong pressure solution, the actual grainstone/mudstone ratio is exaggerated with respect to the original mudmound composition. In the stylocumulated limestones (Fig. 8B-C), abundant crinoid ossicles occur, forming so-called “pierres poitées” or “peastones” (because of the presence of numerous white circular sections of the crinoid ossicles, resembling peas).

The mudmound core (sequence D) is composed of a sequence up to a maximum of 30 m of rather massive, greyish to red-stained (pinkish to reddish) stromatactis- or zebra-bearing limestones (Fig. 9) (the Red Marble of Baelen) that frequently but randomly incorporate pale-grey lenticular coarse-grained crinoidal limestones. The stromatactoid limestones consist of spiculitic/microbialitic mudstones enclosing palaeoberesellids, algosponges, ostracods, fenestellid bryozoans and crinoids (Fig. 10A). Besides the presence of characteristic stromatactis and zebra structures (dark mud/wackestone alternating with cm-sized parallel layers of white calcite), both filled in with radiaxial fibrous calcite cements, we observe microbial textures and small stromatactoid laminoid-fenestral fabrics. The pale-grey crinoidal limestone lenses otherwise consist of crinoidal-foraminiferal packtone/grainstones and rudstones, that are often partially dolomitized and silicified (Fig. 10B). Successive plurimetric beds of massive stromatactoid limestone are separated by decimetric to metric interbeds of red-stained crinoid-rich stylocumulated limestones (“pierre poitée”) producing the second variety of Red Marble of Baelen (Fig. 10C), conspicuous by the numerous white sections of crinoid ossicles (locally undissociated crinoid stems of over 25 cm in length have been observed). The red staining of the above limestones results from finely disseminated hematite, probably related to the activity of chemo-autotrophic iron bacteria (Boulvain, 1989; Mamet & Préat, 2005). Both (red-stained) lithofacies have been extracted and used as ornamental stone.

In the top layers of the stromatactoid limestone, milky-white sparite-filled neptunian dykes locally occur (e.g. in the historical underground quarry at Limbourg Hors-les-Portes).

Large cephalopods have also been occasionally observed elsewhere in the massive mudmound core facies as shown by their occurrence in Red Baelen marble slabs used in door steps of the medieval town of Limbourg (Fig. 10D).

The mound core facies is overlain by a sequence of stylocumulated crinoid-rich limestones (“pierre poitée”)

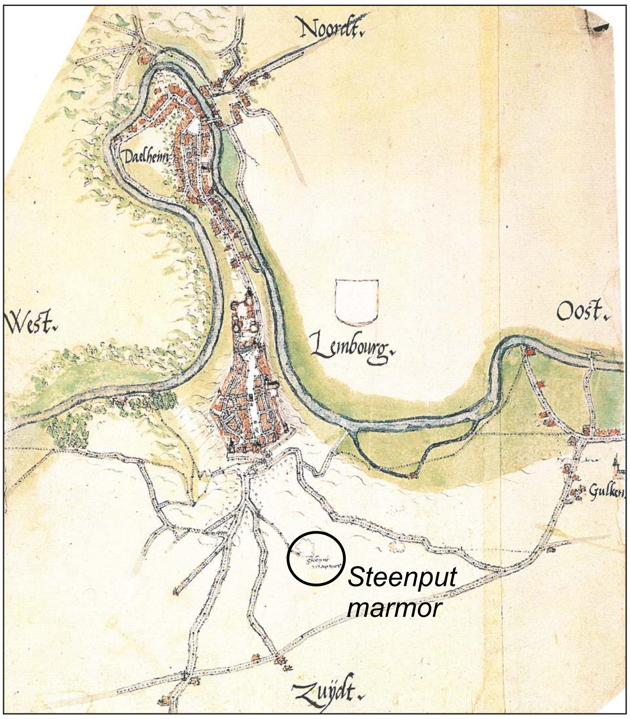

Figure 13. Reproduction (scan) of a 16th century map made by Jacob van Deventer showing the location of a marble quarry (“steenput marmor”) corresponding to the location of the relicts of the partially underground “Mali” quarry at Limbourg, Hors-les-Portes (modified from Van Ermen et al, 1985).

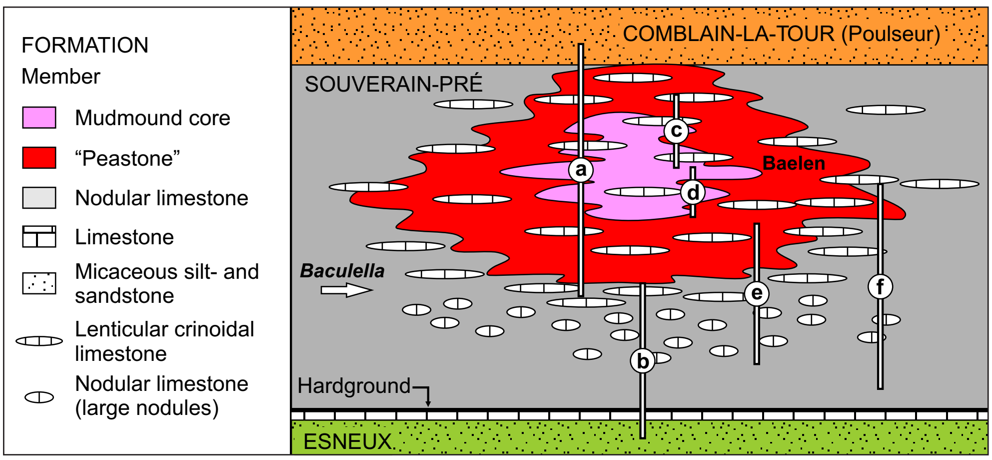

Figure 12. Cartoon with the new model (not to scale) for the Baelen Member showing the temporal-spatial relationships (lithofacies framework) of the different lithologies observed in the field. Note location within the model of the different facies observed within the individual sections. Abbreviations: a, Baelen Les Forges; b, Limbourg La Beverie (playground); c, “Mali” quarry; d, Goé south; e, Goé north; f, Hors-Les-Portes.

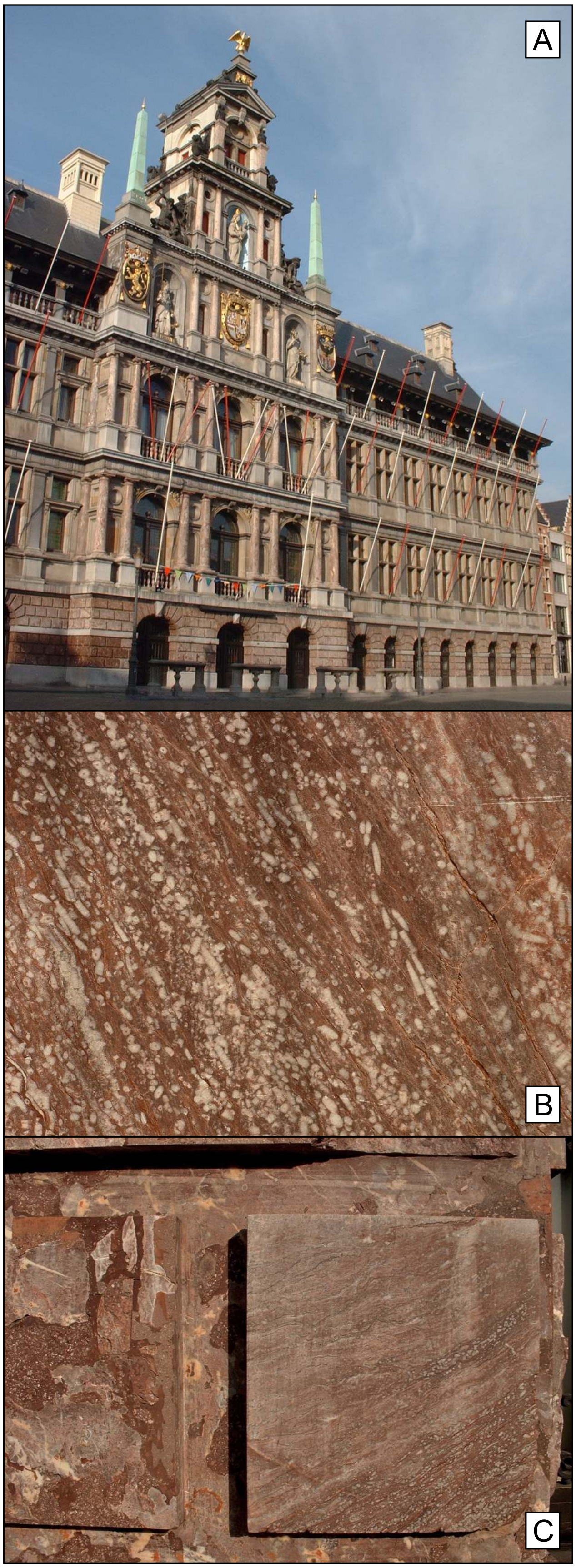

Figure 14. Antwerp town hall, substructures made of red Belgian marbles (A). Detail of cladding made of polished slabs in red marble, originally Red Marble of Baelen (B) but replaced during historical restoration by Frasnian red marbles (C).

Figure 15. A. Large oval stoop on a foot completely made of the crinoid-rich variety of Red Marble of Baelen (Val-Dieu Abbey). B. Armored baptismal font made of Red Marble of Baelen, on a (restored) foot of Frasnian red marble, dating from 1664 (Val-Dieu Abbey). C. 12th century piscina made in pink crinoid-rich Red Marble of Baelen. Originally part of the romanesque church of the Stavelot Abbey, Museum of the Abbey in Stavelot. D. 19th century chapel of Baelen: communion bench in "pierre poitée" facies and floor tiles made of polished pink Marble of Baelen (mudmound core facies) alternating with polished black Belgian marble (Lower Carboniferous wackestones).

(sequences E–F), mimicking the carbonate facies just below the mound core (sequence C). Thick lenticular and coarse crinoidal limestones are randomly interlayered, the number of which seems to decrease towards the top. The red staining is totally gone and the carbonates are becoming silty again. This "argillaceous" carbonate sequence rather ends abruptly and changes into thin-

Figure 16. A–C. Lower part of 20th century middle-class house (Art Nouveau style) with substructure made of irregular blocks (B) of grey and pink Marble of Baelen. C. Detail of irregular block showing contact between red-stained "pierre poitée" facies (below) and pink stromatactis-bearing limestone (above). Hasselt, Guffenslaan n°100.

bedded micaceous sandstones with rare and scattered limestone nodules.

Large slumps have been described from the upper mound flank facies (Dreesen et al., 1985) (Fig. 11): they are related to conditions of instability or reduced rigidity of the mound, with flank dips up to 15°–35° (as suggested by Aretz & Chevalier, 2007).

Based on old data (Marion, 1984; Dreesen et al., 1985) and recent field observations, a new lithofacies model is proposed by the authors for the Baelen Member (Fig. 12), showing the spatial relationships of the described different lithologies. This model confirms also earlier observations made by Aretz & Chevalier (2007): a red-stained siliciclastics-free mudmound core is surrounded by mixed siliciclastic-carbonate facies ("pierre poitée"). The latter, in turn, is enveloped by silty nodular limestones that are embedded in fine-grained siliciclastic sediments (the "regular" Souverain-Pré facies). Coarse-grained crinoidal limestones occur as lenticular interbeds in all if not most of the above lithofacies. They have also been encountered in the coeval micaceous silt- and sandstones outside the mounding site, e.g. as debris or storm deposits (pluricentimetric to decimetric lenses mostly).

The end of the mound growth is probably related to reduced accommodation space as a consequence of a regression (Aretz & Chevalier, 2007) or as a result of synsedimentary block faulting activity, combined with a renewed influx of siliciclastics.

Baelen-type carbonates finally have also occasionally been reported outside the Vesdre Synclinorium, e.g. in the eastern and central parts of the Dinant Synclinorium.

Stainier mentioned already in 1893 a temporary outcrop of red Baelen-type crinoidal limestones during the construction of a railway tunnel in the Lesse Valley.

Dusar & Dreesen (1984) described up to 3 m thick domal-shaped accumulations of large crinoidal debris in shale in the Hamoir area, near the top of the Esneux Formation. This deposit is coeval with the strata directly underlying the Baelen Member (Early? *marginifera* Zone). Recently, we have also observed large (20-30 cm thick) and silty nodular limestones composed of bioclastic wackestone containing abundant algosponges (Issinellids) in strata of the same age (basalmost Souverain-Pré Formation) in the area of Briquemont (NW of Rochefort, Dinant Synclinorium). This facies might well be analogous to preliminary stages of the Baelen Member or it might well point to the existence of Baelen-type deposits in the neighbourhood.

5. Diagenetic history

The diagenetic history of the Baelen mudmounds is quite complex (Dreesen et al., 1985; Belmans, 1992). Indeed, it consists of succeeding marine phreatic, mixed water, meteoric phreatic as well as burial phases, all subsequently overprinted by Variscan tectonics. The mound carbonate facies are also frequently cross-cut by calcite-infilled veins, occasionally resulting in a brecciated texture. Stable carbon and oxygen isotope data for different bioclasts and individual phases (e.g. radiaxial fibrous marine cements in the stromatactis cavities) have been measured. The stable carbon isotope data indicate an Upper Devonian marine water signature, whereas the stable oxygen isotope data point to diagenetic overprinting (Belmans, 1992). The carbon signature suggests that the system has been buffered by the host rock, while the oxygen signature would point to a resetting of the oxygen isotope signal by hot late diagenetic fluids. Influence of these hot fluids is as well confirmed by the presence in the brecciated and calcite-veined stromatactis limestone of ferroan blocky calcite and that of a few dispersed galena cubes.

6. Building and ornamental stone: historical data

The Red Marble of Baelen is known under different names, such as: "Marbre de Bailou" for the stone quarried in Les Forges and "Jaspe fleuri rouge" for the stone coming from the quarries SE of the Ville Haute of Limbourg (Camerman, 1961; Groessens, 1981; De Jonghe et al., 1996; Tourneur, 2004).

The oldest known historical quarry is located immediately south of the medieval town centre of Limbourg, in the area called "Hors-les-Portes". The oldest known reference to the historical extraction of the Red Marble of Baelen has been found in the Limbourg archives (1518-1522), describing the existence of a marble quarry between Limbourg and Goé (Thisquen, 1909). Furthermore, a map made by Jacob van Deventer (1540-1575) on behalf of Charles V and Philip II and redrawn by C. Ruelens in 1881, most probably shows that same quarry ("steenput marmor"), located S of the castle of Limbourg and W of Goé (Gulken) (see Fig. 13). Relicts of this partially underground quarry are still visible today. The quarry is locally known as the "Mali" quarry, referring to its previous owner.

In his epigraphical study of the Limbourg tombstones, G. Poswick (1963) describes a tombstone made of "pink Marble of Limbourg" of Pierre Blancheteste, son of Gauthier, mayor of Limbourg, who died in 1596. Another historical document from 1562 refers to Renier Ratloe, mayor of the town of Limbourg, who sold Baelen marble to the Antwerp community for the building of the town hall. These building stones can still be admired inside and outside of the town hall (Fig. 14). Two years earlier, in February 1560, the Antwerp town hall architect Cornelis Floris de Vriendt and his stonemason Colijn Mido, went to the quarry of Limbourg (the actual "Mali" quarry?) looking for the best quality of building material (Adriaenssens, 1980).

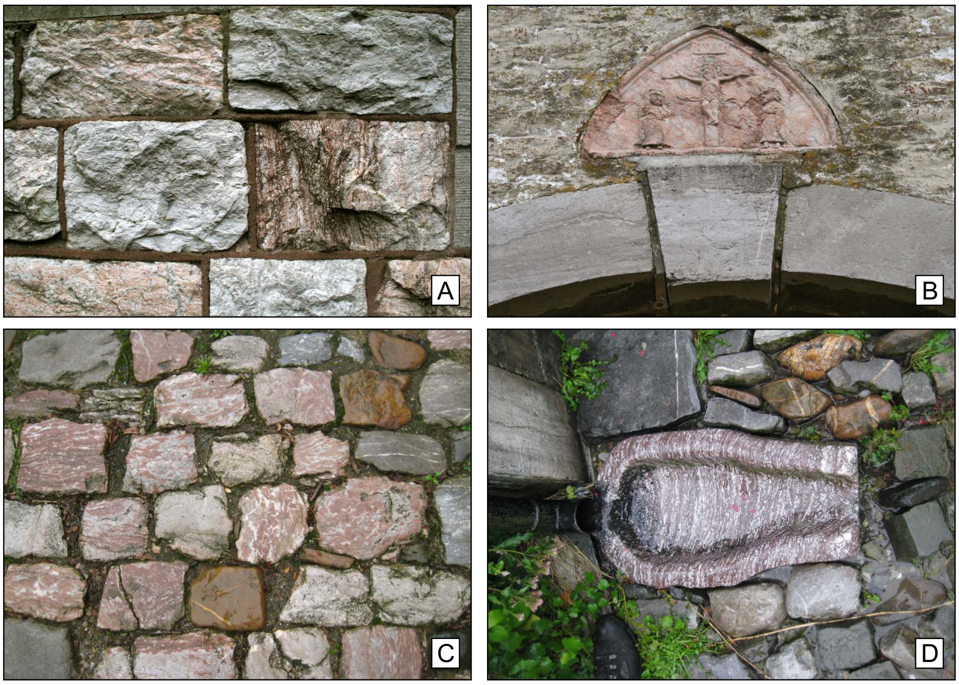

Figure 17. A. Substructure of 20th century middle-class house in Noorbeek (Zuid-Limburg, The Netherlands). Corner of Dorpsstraat en Sint-Maartensweg. Roughly hewn blocks of different varieties of the Red Marble of Baelen. B. Calvary in Red Marble of Baelen (located above door frame made of leight-grey patinated Lower Carboniferous limestone). Old rectory, Teuven (eastern Belgium) (photograph courtesy of Robert Croes). C. Various facies of Red Marble of Baelen used as cobblestones. Limbourg Ville-Haute, Place Saint-Georges. D. Particular application of the Red Marble of Baelen: drip catcher. Limbourg Ville Haute, Place Saint-Georges.

The church of Val-Dieu owns an enormous stoop on a foot and an armoured baptismal font made of Red Marble of Baelen, dating from 1664 (Fig. 15A-B). However, the oldest usage of the Red Marble of Baelen dates back to the 11th-12th century, as suggested by the existence of a “lithurgic piscina” (Fig. 15C) belonging to the Romanesque church of the Stavelot Abbey and actually housed in the Museum of the Abbey (C. Meessen, 1994).

A few exceptionally large blocks of red argillaceous crinoidal limestone occurring in the western part of the Palatine Chapel (Pfalzkapelle) of the Aachener Dom (W-Germany) have recently been discovered during restoration works (Heckner & Schaab, 2012). These have preliminary been identified by us as Red Baelen Marble. This part of the building has been assigned to the Carolingian period, so that the earliest usage of Baelen Marble may even go back to the beginning of the 9th century! However, these isolated occurrences need further study.

The last marble quarries to be active were those of Les Forges, located on the right hand side of the road from Dolhain to Baelen: these have been intensively quarried between 1925 and 1940. However, the oldest known quarry of Les Forges was located opposite an old paper factory: it dates from 1742 and closed shortly after World War II (De Jonghe et al., 1996; A. Meessen, 1998). The most spectacular examples of the decorative use of the Red Marble of Baelen can still be admired in the 19th century chapel of the ancient convent (former boarding-house of St. François – now the “home St. Joseph”) in Les Forges (Baelen), just in front of these former quarries of Les Forges. Here, one sees splendid examples of an altar, a communion bench (Fig. 15D), window bays, columns, pavements, etc., all made of different varieties of Red Marble of Baelen and all worth of being conserved and classified as cultural heritage!

During almost four centuries the production of Red Marble of Baelen remained quite constant. A temporary increase in the production for construction purposes occurred during the 18th century. Moreover, the effects of architectural trends or fashions are responsible for the temporary increased production of tombstones (at the end of the 17th century) and that of substructures in ashlar (in the beginning of the 20th century) (A. Meessen, 1998). The latter frequently occur in 20th century houses, as recently observed in Art Nouveau-style houses in Liège, Tongeren (Fig. 16), Hasselt, Leuven, Antwerp and Ghent. Characteristically, rough-hewn blocks of different lithofacies are used (Fig. 17A).

7. Uses of the Baelen marble and geographical spreading of its use

The Red Marble of Baelen offers a wide variety of applications and decorative uses. The latter have been essentially local and the geographical spreading of the usage of the Red Marble of Baelen has been geographically restricted, as clearly demonstrated by the study of A. Meessen (1998). Most probably, because of high transport costs and competition by other ornamental stones (e.g. the Dinantian “blue limestones” and Frasnian red marbles), the quarries of the Red Baelen Marble were rather small and maintainted a rather familial character. The small-scaleness of the extraction can also be concluded from its restricted geographical spreading (see below). The major reason for this is that its use responded essentially to a local demand. Furthermore, its expansion has certainly been hampered by competition from other small sandstone and limestone quarries in neighbouring towns or villages, such as those of Eupen, Goé or Stembert.

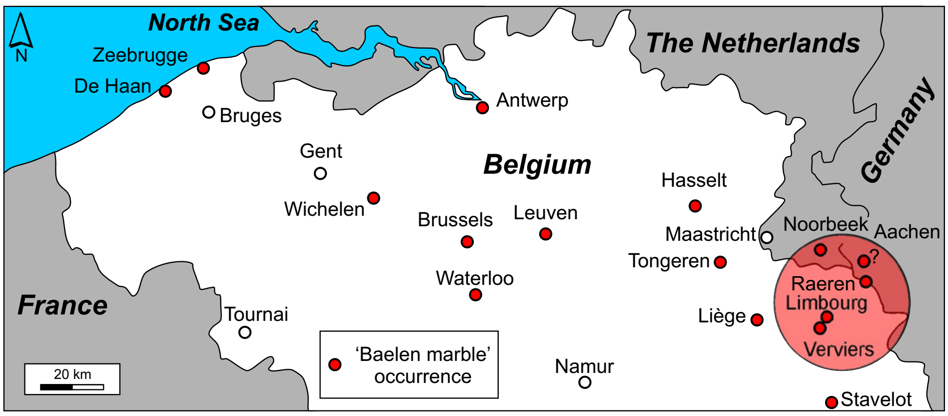

Figure 18. Map showing the geographical spreading of the occurrences of Red Marble of Baelen in Belgium and adjacent areas. Note the strong concentration in the immediate surroundings of the town of Limbourg.

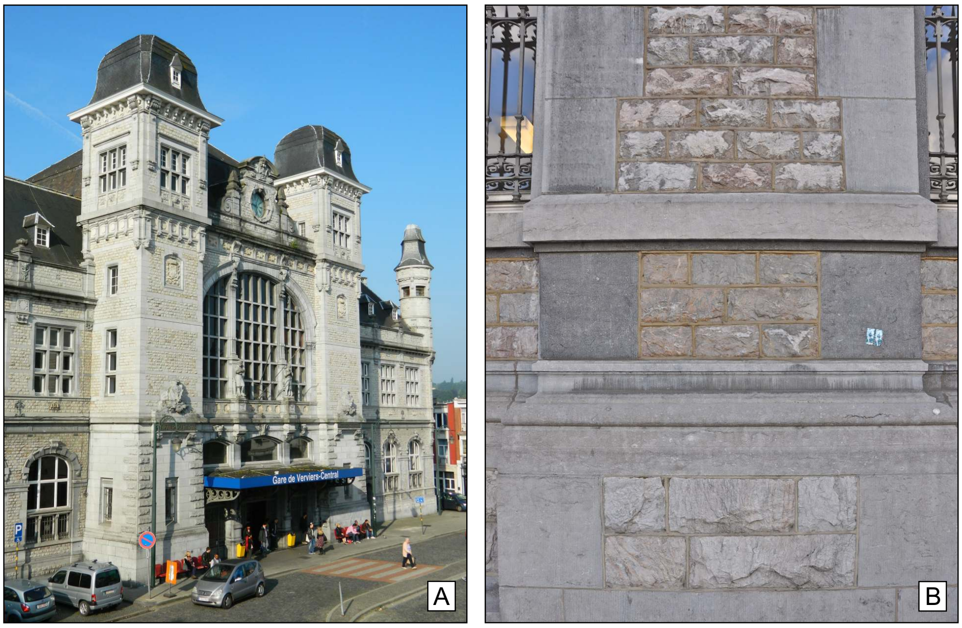

Figure 19. A. Verviers station, predominantly made of ashlars in Red Marble of Baelen. Due to the humid outdoor conditions the marble turned pinkish grey to light-grey (patina). B. Detail of the front of the station: roughly hewn blocks of Red Marble of Baelen in combination with dark-grey Lower Carboniferous (Tournaisian) crinoidal limestones ("Petit Granit") (photograph courtesy of Karel Breda).

Moreover, the price of the marble and the slowness of transport were also probable factors inhibiting its expansion.

The broad spectrum of applications includes different categories (De Jonghe et al., 1996; A. Meessen, 1998): construction, decoration, funerary and "others". Unfortunately, no reliable numerical data have been found in the literature on the mechanical properties of the Red Marble of Baelen. According to De Jonghe et al. (1996), the Red Marble of Baelen displays a good compressive strength, good frost resistance and low sensibility to air pollution. Construction represents its major use (58%), funeral art is the second most important application (20%), whereas usage for decoration and others reaches10% and 12% respectively. This rather diversified spectrum results from the fact that the distribution area was quite restricted, so that the quarry owners had to diversify their production to a maximum in order to keep their exploitation profitable (A. Meessen, 1998).

All facies have been used in construction, although the "pierre poitée" facies was less appropriate due to the presence of weathering-prone argillaceous laminae, especially when the stone was placed perpendicular to the stratification. The use of rough-hewn wall ashlar is very common, often in combination with blue stone limestones ("pierre bleue"), bricks and/or sandstones. Other common construction applications of the Baelen Marble include lintels, mullions, window bays and doorsteps (Fig. 17A). Funerary applications include tombstones, grave crosses and armoured grave-stones.

Less than 10% of the production has been used as ornamental stone, especially in church decoration and furniture: here, the polished "pierre poitée" facies is on its best (e.g. in baptismal fonts and stoops, communion benches or calvaries, see Fig. 17B). The category "others" include interesting applications such as cobble stones (Fig. 17C), drip catchers (Fig. 17D), street furniture and fencing pillars.

The diffusion or the geographical extension of the Red Marble of Baelen is remarkably restricted (Fig. 18). Its highest concentration falls within the borders of the former Duchy of Limbourg, including the actual border region of Germany (e.g. near Aachen) and that of The Netherlands (e.g. Noorbeek). Up to 88% of the inventoried production occurs within a radius of 5 km, 10% within a radius of 10 km and about 2% within a radius of 15 km of the production centres near the town of Limbourg (De Jonghe et al., 1996; A. Meessen, 1998).

Occurrences outside the area of the former Duchy of Limbourg are less common: these are related to 20th century architectural trends and include substructures in ashlars such as in middle-class houses of Tongeren, Hasselt, Leuven, Brussels, and Ghent. Exceptionally, the Baelen marble has been used in larger or more prestigious buildings such as the 16th century townhall of Antwerp, the 20th century school building of Saint-Michel in Etterbeek (Brussels) or the Verviers station (Fig. 19) or in particular statues, such as that of Victor Hugo in Waterloo, near Brussels (Groessens, 1981).

8. Conclusion

The middle Famennian Red Marble of Baelen, a red-stained massive or argillaceous crinoidal limestone, belongs to a local Member of the Souverain-Pré Formation in the eastern part of the Vesdre Synclinorium, Belgium. It represents a unique post-late Frasnian biological crisis mudmound complex in Belgium. It is probably the only well-documented red-stained crinoidal-sponge-algospongal carbonate mudmound complex worldwide, at this particular stratigraphical level. It corresponds to a short-term middle Famennian transgressive pulse and highstand, possibly coinciding with an interglacial episode. The initial triggering mechanisms remain still unclear but the role of block-faulting activity is strongly suspected. Very conspicuous is the total lacking of corals and stromatopores as well as the abundance of Algospongia and especially that of crinoids, its real hallmark. The stone has been quarried at least since the 16th century, in small quarries within the Duchy of Limbourg. It has been used both for building and ornamental purposes, mostly within a short radius of the production sites. However, more prestigious buildings have been constructed with the same stone outside the borders of the former Duchy. Its local usage was mainly rural and vernacular. The stone represents an important and less-known historical but highly valued building and ornamental stone from Belgium, adding to the reputation of the better-known Frasnian aged Belgian red marbles. It is a true silent witness of the former glory of the Duchy of Limbourg. At least one historical quarry still exists: this geo-site should urgently be protected as an important Belgian geological heritage site.

9. Acknowledgments

Mr. Hans Engels (Limbourg) kindly gave us free access to the underground "Mali" quarry and allowed us to study and sample the sections on his property. Sabine Blockmans and Virginie Dumoulin (Université Libre de Bruxelles) guided us in the field and located outcrops of particular Souverain-Pré facies in the Briquemont area. Digital microphotographs have been made with the optical microscope facilities at the Flemish Institute for Technological Research VITO (Mol). The remarks and suggestions of the reviewers Timo Nijland and Francis Tourneur are greatly appreciated.

10. References

Adriaenssens, R., 1980. Sur l'Hôtel de ville d'Anvers et les apports des carrières Wallonnes dans son édification. Bulletin de la Commission Royale des Monuments et des Sites, 9, 123.

Aretz, M. & Chevalier, E., 2007. After the collapse of stromatoporoid-coral reefs – the Famennian and Dinantian reefs of Belgium: much more than Waulsortian mounds. In Alvaro, J.J., Aretz, M., Boulvain, F., Munnecke, A., Vachard, D. & Vennin, E. (eds), Palaeozoic Reefs and Bioaccumulations: Climatic and Evolutionary Controls. Geological Society, London, Special Publications, 275, 163-188.

Bouckaert, J. & Dusar, M. 1976. Description du sondage de Tohogne (Transition Dévonien-Carbonifère). Service géologique de Belgique, Professional Paper, 133, 1-24 .

Becker, T., 1993. Anoxia, eustatic changes, and Upper Devonian to lowermost Carboniferous global ammonoid diversity. The Systematics Association Special Volume, 47, 115-164.

Bellière, J., 1953. Note sur le calcaire famennien de Baelen et ses stromatactis. Annales de la Société géologique de Belgique, 76, B115-B128.

Bellière, J., 1954. Le Néodévonien. II – Le Famennien. In Prodrome d'une description géologique de la Belgique. Vaillant-Carmanne, Liège, 206-216.

Belmans, H., 1992. Sedimentologische en diagenetische studie van het "rode rif van Baelen" in het synclinorium van Verviers. Unpublished master thesis, KULeuven, 90 p.

Bouckaert, J., Conil, R. & Thorez, J., 1967. Position stratigraphique de quelques gîtes famenniens à Foraminifères. Bulletin de la Société belge de Géologie, de Paléontologie et d'Hydrologie, 75, 159-175.

Boulvain, F., 1989. Origine microbienne du pigment ferrugineux des monticules micritiques du Frasnien de l'Ardenne. Annales de la Société géologique de Belgique, 112, 79-86.

Bultynck, P. & Dejonghe, L., 2002. Devonian lithostratigraphic units (Belgium). Geologica Belgica, 4, 39-69.

Camerman, C., 1961. Les pierres naturelles de construction. Annales des Travaux publics, 4, p. 325-368.

Conil, R., Dreesen, R., Lentz, M.-A., Lys, M. & Plodowski, G., 1986. The Devono-Carboniferous transition in the Franco-Belgian Basin with reference to foraminifera and brachiopods. Annales de la Société géologique de Belgique, 109, 19-26.

Copper, P., 2002. Reef development after the Frasnian/Famennian mass extinction boundary. Palaeogeography, Palaeoclimatology, Palaeoecology, 181, 27-65.

Davreux, C.J., 1833. Essai sur la constitution géognostique de la province de Liège. Mémoires couronnés de l'Académie royale des Sciences et Belles-Lettres de Bruxelles, 9, 1-297.

De Jonghe, S., Gehot, H., Genicot, L., Weber, Ph. & Tourneur, F., 1996. Pierres à bâtir traditionnelles de la Wallonie-Manuel de terrain. DGRNE, Ministère de la Région wallonne, 261 p.

Dewalque, G., 1881. Présentation de divers échantillons de marbre à crinoïdes des Forges (Baelen), appartenant à l'étage des psammites du Condroz. Annales de la Société géologique de Belgique, 8, Bulletin, 122-124.

Dewalque, G., 1882. Carte géologique de la Belgique à 1:40.000, Limbourg-Hestreux-Brandenhaeg n°136. Commission géologique de Belgique.

Dreesen, R., 1978. La Formation de Souverain-Pré: reconstruction paléogéographique dans le Massif de la Vesdre. Mededelingen Rijks Geologische Dienst, Nieuwe Serie 2, 28, 17-32.

Dreesen, R., 1982a. A propos des niveaux d'oolithes ferrugineuses de l'Ardenne et du volcalisme synsédimentaire dans le Massif Ardenno-Rhénan au Dévonien supérieur. Essai de corrélation stratigraphique. Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, 1, 1-11.

Dreesen, R., 1982b. Storm-generated oolitic ironstones of the Famennian (Fa1b-Fa2a) in the Dinant and Vesdre Synclinoria (Upper Devonian), Belgium. Annales de la Société géologique de Belgique, 105, 15-129.

Dreesen, R., 1987. Oolitic ironstones as event-sratigraphical marker beds within the Upper Devonian of the Ardenno-Rhenish Massif. In Young, T. & Taylor, W. (eds), Phanerozoic ironstones. Geological Society, Special Publication, 46, 65-78.

Dreesen, R., 1989. The "*Cheiloceras* Limestone" a Famennian (Upper Devonian) event-stratigraphical marker in Hercynian Europe and Northwestern Africa? Bulletin de la Société belge de Géologie, 98, 127-133.

Dreesen, R. & Flajs, G., 1984. The "Marbre rouge de Baelen", an important algal-sponge-crinoidal buildup in the Upper Devonian of the Vesdre Massif (Eastern Belgium). Comptes-rendus de l'Académie des Sciences de Paris, 299 (II, 10), 639-644.

Dreesen, R., Bless, M.J.M., Conil, R., Flajs, G. & Laschet, Ch., 1985. Depositional environment, paleocology and diagenetic history of the "Marbre rouge à crinoïdes de Baelen" (Late Upper Devonian, Verviers Synclinorium, Eastern Belgium). Annales de la Société géologique de Belgique, 108, 311-359.

Dreesen, R., Paproth, E. & Thorez, J., 1986. Events documented in Famennian sediments (Ardenne-Rhenish Massif, Late Devonian, NW Europe). Memoirs of the Canadian Society of Petroleum Geologists, 14, 295-308.

Dreesen, R., Marion, J.-M. & Poty, E., 1993. Famennian reefal beds in the Vesdre Syncline (Eastern Ardenne, Belgium). International Union of Geological Sciences, Commission on Stratigraphy, Subcommission on Carboniferous Stratigraphy, Excursion Guide Book, Liège.

Dumont, A., 1832. Mémoire sur la constitution géologique de la province de Liège. Mémoires couronnés de l'Académie royale des Sciences et Belles-Lettres de Bruxelles, 8, 1-374.

Dupont, E., 1886. Sur le Famennien de la plaine des Fagnes. Bulletins de l'Académie royale des Sciences, des Lettres et des Beaux-Arts de Belgique, 3e série, 12, 501-527.

Dusar, M. & Dreesen, R., 1984. Stratigraphy of the Upper Frasnian and Famennian deposits in the region of Hamoir-sur-Ourthe. Belgian Geological Survey, Professional Paper, 209, 1-52.

Dvorak, J., 1973. Die Quer-Gliederung des Rheinischen Schiefergebirges und die Tektigenese des Siegener Antiklinoriums. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen, 143, 133-152.

Forir, H. & Dewalque, G., 1881. Compte rendu de la session extraordinaire tenue à Verviers du 17 au 20 septembre. Annales de la Société géologique de Belgique, 8, Bulletin, 155-187.

Fourmarier, P., 1953. La position stratigraphique du "Marbre de Baelen". Annales de la Société géologique de Belgique, 77, B29-B37.

Ghysel, P., Laloux, M., Dejonghe, L., Hance, L. & Geukens, F., 1995. Carte géologique de la Wallonie 1:25.000: Limbourg-Eupen (n°43/5-6). Ministère de la Région Wallonne. Direction Générale des Ressources naturelles et de l'Environnement, Namur.

Gosselet, J., 1888. L'Ardenne. Mémoires pour servir à l'explication de la carte géologique détaillée de la France. Baudry et cie, Paris, 889 p.

Groessens, E., 1981. L'industrie du Marbre en Belgique. Mémoires de l'Institut Géologique de Louvain, 31, 219-253.

Heckner, U. & Schaab, Ch., 2012. Baumaterial, Bautechnik und Bauausführung der Aachener Pfalzkapelle. In Heckner, U. & Beckmann, E.-M. (eds), Die Karolingische Pfalzkapelle in Aachen. Arbeitsheft der rheinischen Denkmalpflege 78, LVR-Amt für Denkmalpflege im Rheinland, 117-228.

House, M., 1985. Correlation of mid-Paleozoic ammonoid evolutionary events with global sedimentary perturbations. Nature, 313, 17-22.

Lombard, A., 1957. La série calcaire de Baelen (Famennien, Belgique) et son évolution. Annales de la Société géologique de Belgique, 80, B431-B447.

Mamet, B. & Préat, A., 2005. Why is "red marble" red? Revista Española de Micropaleontologia, 37, 13-21.

Marion, J.-M., 1984. Etude sédimentologique et stratigraphique du Marbre de Baelen et des faciès associés. Unpublished Master thesis, Liège University, 66 p.

Marion, J.-M., 1985. La présence de mud mounds famenniens sur un site en block-faulting, à Baelen (Belgique). In FNRS Sédimentologie – Groupe de contact "Sédimentologie", Liège, 28 mai 1985. Re Sedimentologica, 2, (2 p.).

Matyja, H., 1993. Upper Devonian of Western Pomerania. Acta Geologica Polonica, 42, 27-94.

Matyja, H., 2009. Depositional history of the Devonian succession in the Pomeranian Basin, NW Poland. Geological Quaterly, 53, 63-92.

Meessen, C., 1994. Le Marbre de Baelen. In Wille, M., Corbiau, M.-H. & Fondation Roi Baudouin (eds), Des pierres pour le dire. Autour de Limbourg, la Gileppe, Baelen. Crédit Communal, Bruxelles, 60-61.

Meessen, A., 1998. Le Marbre de Baelen, étude d'une production locale. Revue des archéologues et historiens d'art de Louvain (Louvain-la-Neuve), 31,105-116.

Paproth, E., Dreesen, R. & Thorez, J., 1986. Famennian paleogeography and event stratigraphy in North-western Europe, In Bless, M.J.M. & Streel, M. (Eds) Late Devonian event around the Old Red Continent. Annales de la Société géologique de Belgique, 109, 175-186.

Poswick, G., 1963. Pierres tombales et épigraphie de Limbourg. Archives Verviétoises, 7, 199.

Sandberg, C.A., Morrow, J.R. & Ziegler, W., 2002. Late Devonian sea-level changes, catastrophic events and mass extinctions. In Koeberl, C. & MacLeod, K.G. (eds), Catastrophic Events and Mass Extinctions: Impacts and Beyond. Geological Society of America, Special Paper, 356, 473-487.

Sartenaer, P., 1957. À propos d'un faciès particulier du niveau de Souverain-Pré (Famennien). Bulletin de la Société belge de Géologie, de Paléontologie et d'Hydrologie, 66, 138-153.

Stainier, X., 1893. Marbre rouge à crinoïdes dans le Famennien de la Lesse. Bulletin de la Société belge de Géologie, de Paléontologie et d'Hydrologie, 7, 177.

Thisquen, J., 1909. Histoire de la Ville de Limbourg. Bulletin de la Société Verviétoise d'Archéologie et d'Histoire, 10, 49.

Thorez, J. & Dreesen R., 1986. A model of regressive depositional system around the Old Red Continent as Exemplified by a field trip in the Upper Famennian "Psammites du Condroz" in Belgium. In Bless, M.J.M. & Streel, M. (Eds) Symposium on the Old Red Continent, Aachen 1986. Annales de la Société géologique de Belgique, 109, 285-323.

Thorez, J. & Dreesen, R., 1997. Sequence- and (bio)event-stratigraphy: a tool for global correlation in Euramerica, as exemplified by the Late Upper Devonian in Belgium. 1st International Conference on North Gondwana Mid-Paleozoic biodynamics (IGCP 421), Vienna, 17-21 September, Abstract: 56-61

Thorez, J., Goemaere, E. & Dreesen, R., 1988. Tide- and Wave-influenced depositional environments in the Psammites du Condroz (Upper Famennian) in Belgium. In de Boer, P.L. et al. (eds), Tide-Influenced Sedimentary Environments and Facies. D. Reidel Publ., The Netherlands, 389-415.

Thorez, J., Dreesen, R. & Streel, M., 2006. Famennian. Geologica Belgica, 9, 27-45.

Vachard, D. & Cozar, P., 2010. An attempt of classification of the Palaeozoic *incertae sedis* Algospongia. Revista Española de Micropaleontologia, 42, 129-241.

Tourneur, F., 2004. Marbres wallons: esquisse d'un repertoire. In Pouvoir(s) de Marbres. Commission royale des Monuments, Sites et Fouilles de la Région wallonne, 240 p.

Van Ermen, E., Van Mingroot, E., Minnen, B. & Van Der Eycken, M., 1985. Limburg in kaart en prent. Historisch Cartografisch overzicht van Belgisch en Nederlands Limburg. Lannoo, Tielt & Fibula-van Dishoeck, Weesp, Illustration 3, 12.

Webb, G., 2002. Latest Devonian and Early Carboniferous reefs: depressed reef building after the Middle Paleozoic collapse. In Kiessling, W. Flügel, E. & Golonka, J. (Eds) Phanerozoic Reef Patterns. Society of Economic Paleontologists and Mineralogists, Special Publication, 78, 239-269.

Manuscript received 11.07.2013, accepted in revised form 20.08.2013, available on line 05.09.2013