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Revision of the Frasnian marine deposits from the Booischot borehole (Campine Basin, Belgium)

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ABSTRACT. Above Givetian and Frasnian continental deposits, the Upper Frasnian transgression starts in the Booischot borehole, within the Aisemont Formation which is represented by its middle shaly part and its upper limestone level containing *Frechastraea limitata* (Milne-Edwards & Haime, 1851) and *Phillipsastrea ananas* (Goldfuss, 1826). In the Heibaart borehole also situated in the Campine Basin, the Silurian basement is capped by a few metres of the Middle Frasnian Huccorgne Formation where have been observed *Thecostegites bouchardi* (Michelin, 1846), *Stachyodes* and a very small remain of a massive cerioid rugose coral. Then, the Aisemont Formation seems to be completely developed. At its top, a mineralization of sulphides is similar to that of Chaudfontaine, in the same lithostratigraphic context. Additionally, *Frechastraea pentagona* (Goldfuss, 1826) is present in the Heibaart borehole, at the base of the shaly sequence overlying the Aisemont Formation in the two investigated wells. The Frasnian marine deposits of the Booischot and Heibaart boreholes are related to those of the Soumagne and Bolland boreholes at the southeastern border of the Brabant Massif. But, they are very different from those of the unstable area of Visé located at the eastern end of the same structural unit.

KEYWORDS: Stratigraphy, Frasnian, rugose and tabulate corals, Campine Basin.

1. Introduction

The Booischot borehole situated at the northern margin of the Brabant Massif (Fig. 1) has been drilled in 1963 for the Geological Survey of Belgium. Legrand (1964) provided a complete description of this well. Above a Silurian basement, about 400 m of red and green conglomerates interbedded with sandstone and shale are interpreted as continental deposits. Legrand (1964) assigned them to the Middle and Upper Devonian. Since that time, they have been dated with more precisions by Streel (1965) and Streel & Loboziak (1987). The Booischot Formation has been recently proposed for these Devonian continental sediments by David Lagrou and Ben Laenen to the Belgian Devonian Subcommission on Stratigraphy and that lithostratigraphic unit is waiting for approval by the National Commission on Stratigraphy. Despite several micropalaeontological investigations in the overlying marine Upper Devonian, the lithostratigraphic and biostratigraphic attribution of these deposits was not very clear. Thus, I have decided to revise this part of the Booischot borehole on the basis of the cores still remaining in the Collection from the Geological Survey of Belgium. For stratigraphic and palaeogeographic reasons, it is interesting to compare the Frasnian of this drillhole with that of the Heibaart borehole. Only a few thin sections, which have been prepared by the Laboratory of Palaeontology from the Catholic University of Louvain at Louvain-la-Neuve, have been available for the Heibaart borehole. This material including the rugose and tabulate corals figured in the present paper is now stored in the Collection of Palaeontology from the Institut royal des Sciences naturelles de Belgique at Bruxelles (IRScNB).

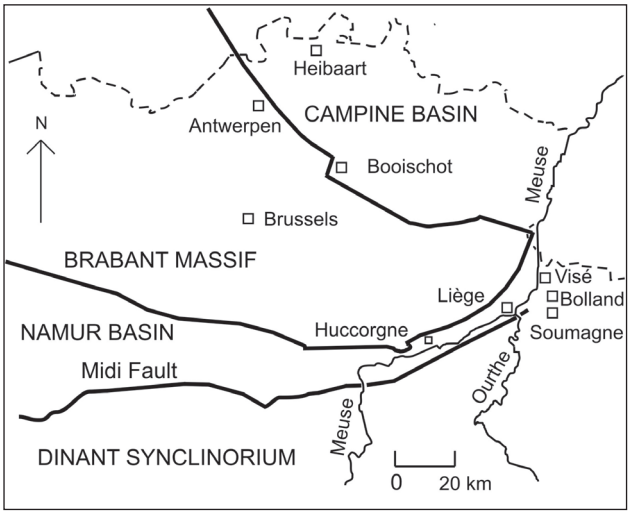

Figure 1. Situation of the Booischot and Heibaart boreholes in the Campine Basin.

2. Description of the Booischot borehole (59E146)

Above the red shales from the top of the Booischot Formation, the Devonian marine deposits (Fig. 2) start with:

- from 892 m to 889 m: 3 m of shales with several beds of oolitic hematite and a few fragments of shells; occurrence of few crinoid fragments at the base, of micaceous sandstone at 890,5 m and of some limestone nodules at the top.
- from 889 m to 882 m: 7 m of grey, often weathered shale, micaceous at 884 m; occurrence of coarse and heterogeneous sandstone at the base.
- from 882 m to 877 m: 5 m of shales weathered at the base and containing some bioclasts, fragments of brachiopods and crinoids.
- from 877 m to 868 m: 9 m of nodular limestone becoming very argillaceous at the base; occurrence of some crinoids at the base and of some brachiopods in the upper part. Some *Alveolites* at 875 m and 871 m where have also been observed *Frechastraea limitata* (Milne-Edwards & Haime, 1851; Fig. 3B), *Phillipsastrea ananas* (Goldfuss, 1826), *Thecostegites* cf. *dumoni* Coen-Aubert, 1980, *Aulopora* and *Stromatoporella*.
- from 868 m to 850 m: 18 m of grey shale, micaceous and locally purple in the upper part; a few fragments of brachiopods and bivalves.
- from 850 m to 849 m: 1 m of green and micaceous sandstone with remains of plants.
- from 849 m to 840 m: 9 m of grey shale, sometimes dark, green or purple with some brachiopods.
- from 840 m to 839 m: 1 m of more or less nodular limestone with spirifers.
- from 839 m to 825 m: 14 m of grey shale, locally green, purple, micaceous or finely laminated; occurrence of spirifers close to the base.

This grey shaly sequence continues up to 801 m where the base of Famennian micaceous sandstones has been intersected.

3. Stratigraphy of the Frasnian from the Booischot borehole

The vegetal remains from the upper part of the Booischot Formation have been mostly investigated by Streel (1965) and Streel & Loboziak (1987). Between 1089.6 m and 908.5 m, there are several levels with *Archaeopteris fimbriata* which is probably synonym of *A. macilenta*. This plant is characteristic of the Upper Devonian. The assemblages of miospores revised by Streel & Loboziak (1987) are also important to date this part of the borehole. Between 1002 and 994.5 m, the zone BM recognized by these authors corresponds in the Boulonnais, France to the conodont zones occurring between the

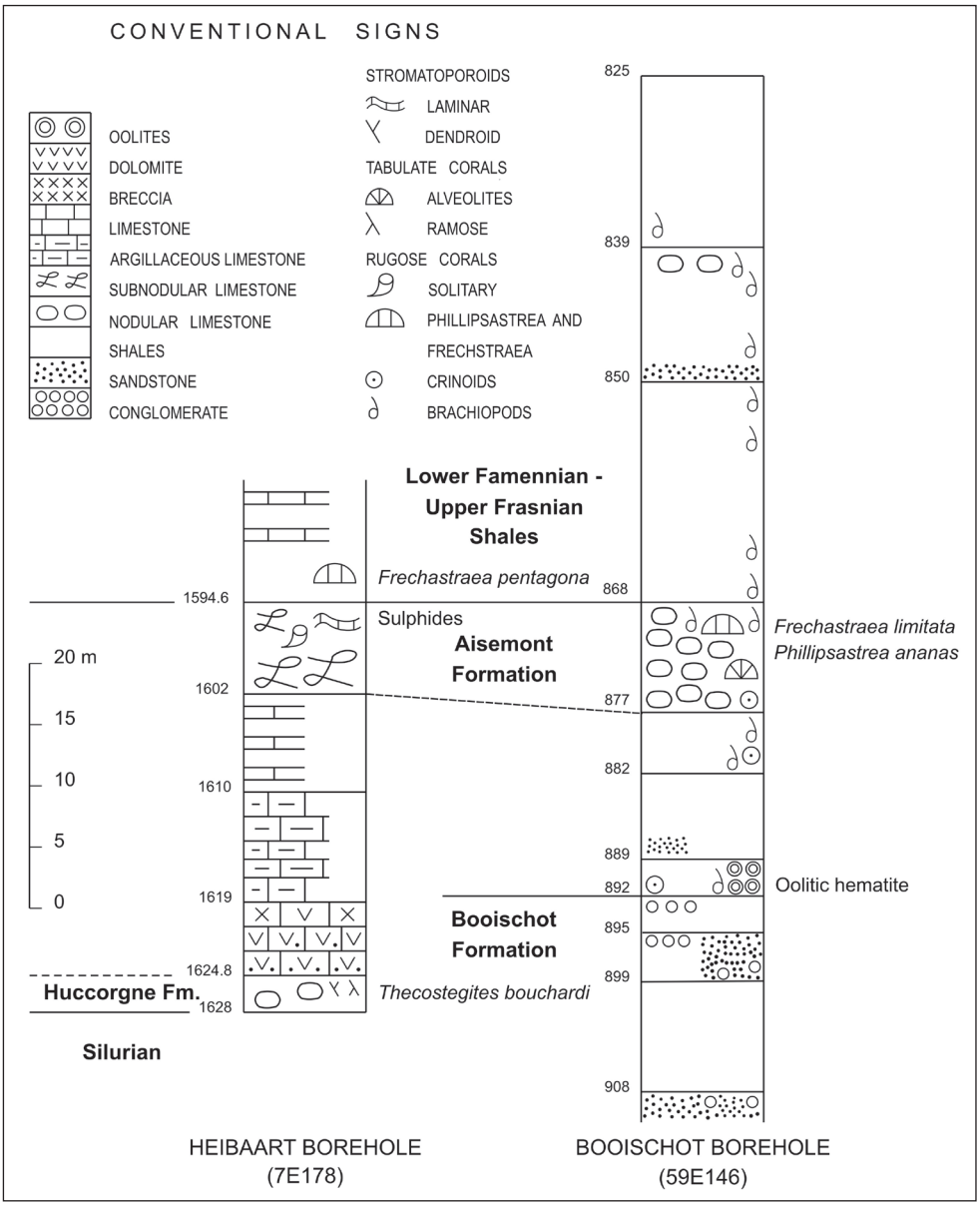

Figure 2. Comparative logs for the Frasnian of the Booischot and Heibaart boreholes with the identification of the rugose and tabulate corals. The lithologic column of the Booischot borehole has been drawn after my personal observations whereas that of the Heibaart borehole has been drawn after the description given in Dejonghe (1983).

Middle *Polygnathus asymmetricus* and *Ancyrognathus triangularis* Zones. Upwards, Streel & Loboziak (1987) have identified between 940 m and 900.5 m the miospore zones IV A, C and E present in the upper part of the Hydrequent Formation from the Boulonnais. More precisely, the last 20 m of the Hydrequent Formation have been studied in detail by Loboziak et al. (1983). Their miospore zonation as well as the distribution of characteristic miospores and acritarchs have been rediscussed by Streel et al. (2000, p. 131, fig. 13). In this more recent paper, the authors correlated the miospore zones IV B, C and partly D with the Upper *Palmatolepis rhenana* conodont Zone. And it seems that two species of acritarchs identified in the miospore zone IV E of the Hydrequent Formation are known from the transitional Upper *P. rhenana-P. linguiformis* Zone. According to all these data, the top of the Booischot Formation is Upper Frasnian in age and the Frasnian transgression occurs very late in the Booischot borehole. This was already the conclusion of Streel & Loboziak (1987).

The Frasnian marine deposits start with 3 m of shales with several beds of oolitic hematite followed first by 12 m of shales often weathered in their lower part and then by 9 m of nodular limestone with some brachiopods, crinoids and corals. According to Coen-Aubert (2012), the two species *Frechastraea limitata* and *Phillipsastrea ananas* identified at 871 m are abundant in the upper limestone level of the Aisemont Formation and in the upper part of the bioherms from the Petit-Mont Member of the Neuville Formation; both lithostratigraphic units occur in the Upper *P. rhenana* Zone. In the Booischot borehole, a very small fragment of *Thecostegites* at 871 m is characterized by narrow corallites whose dimensions are similar to those of *T. dumoni*. Only two colonies are known from this species coming from the Les Valisettes Formation overlying the Neuville Formation in the Philippeville Massif and illustrated by Coen-Aubert (1980). By their lithology and their fauna, the nodular limestones intersected in the Booischot borehole between 868 m and 877 m can be assigned to the upper part of the Aisemont Formation. This lithostratigraphic unit is exposed along the north side of the Dinant Synclinorium, the Vesdre Massif, the south side of the Namur Basin and also at Huccorgne, on the north side of the same structural unit. Between 877 m and 889 m, the shales drilled in the Booischot borehole may be referred to the middle part of the Aisemont Formation. At their base, there are several beds with oolitic hematite whose facies recalls that of the Presles Formation known on the north side of the Dinant Synclinorium, the south side of the Namur Basin and the Vesdre Massif. However, these ferruginous shales are certainly younger than the Presles Formation as indicated by the miospores of the underlying Booischot Formation. As mentioned by Boulvain et al (1999) and Bultynck & Dejonghe (2002), the Presles Formation is well dated by conodonts and belongs to the base of the Frasnian. Such oolitic ironstones have been investigated among others by Dreesen (1982) and Laenen et al. (2002). They appear at the transition from a regressive to a transgressive phase. This is typically the case of the Booischot borehole. Indeed, the continental deposits of the Booischot Formation with three levels of palaeosols close to their top (Legrand, 1964) are abruptly overlain by marine deposits.

A mostly shaly sequence of 67 m occurs in the Booischot borehole between the top of the Aisemont Formation at 868 m and the base of Famennian micaceous sandstones at 801 m. Conodonts, acritarchs and miospores have been investigated in these deposits.

The conodonts identified by E. Groessens are mentioned by Kimpe et al. (1978, p. 59): *Palmatolepis rhenana*? Zone at 842 m-852 m, Lower *P. triangularis*? Zone at 838 m and Middle *P. triangularis* Zone at 803 m-810 m. According to Vanguestaine et al. (1983, p. 156), the acritarchs present at 862 m belong to the Vf Zone characteristic of the Upper Frasnian whereas those found at 830 m, 813 m and 811 m are typically Famennian. Famennian spores have been observed by Streel (1965) at the same depths of 830 m and 813 m. Hence, Vanguestaine et al. (1983) and Streel & Loboziak (1987) concluded that the Frasnian-Famennian boundary is situated in the Booischot borehole between 862 m and 830 m.

4. Comparison with the Heibaart borehole (7E178)

The Heibaart borehole 1-1bis (commune of Loenhout) has been drilled in 1962 by Petrofina. The descriptions and the samples were stored in the past at Labofina (Brussels); coring was discontinuous. The Silurian basement is directly overlain by Frasnian marine deposits which have been described by Dejonghe (1983) after a report written by P. Cornet in 1976 for Labofina. Between 1628 m and 1624.8 m were intersected 3.2 m of shales locally silicified and nodular limestones. Four thin sections have been prepared at 1625 m by the Laboratory of Palaeontology from Louvain-la-Neuve. They contain several sections of *Stachyodes*, *Scoliopora* and ramose *Alveolites*, a fragment of *Thecostegites bouchardi* (Michelin, 1846; Fig. 3A), a transverse section of a rather young *Tabulophyllum* and a very small remain of a massive rugose coral whose wall is characterized by a dark median line. Such a fauna is certainly different from that of the Aisemont Formation. Indeed, I have never observed massive cerioid rugose corals and the dendroid stromatoporoid *Stachyodes* in the Aisemont Formation. According to Coen-Aubert (1980), Coen-Aubert & Lacroix (1985) and Boulvain et al. (1999), *Thecostegites bouchardi* occurs in the Middle Frasnian of the Dinant Synclinorium: in the Boussu-en-Fagne Member of the Grand Breux Formation on its south side, in the Philippeville Formation, in its northwestern part and in the upper part of the Lustin Formation on its north side. Moreover, it is present in the Middle Frasnian from the north side of the Namur Basin: in the lower member of the Rhisnes Formation at Feluy and in the lower and upper members of the Huccorgne Formation at Huccorgne and Horion-Hozémont. The shales and nodular limestones occurring in the Heibaart borehole between 1628 m and 1624.8 m recall the facies of the Rhisnes and the Huccorgne Formations which are laterally equivalent. These sediments are overlain by:

- from 1624.8 m to 1619 m: 5.8 m of calcareous dolomite, sandy at the base and brecciated at the top. Locally very abundant pyrite.
- from 1619 m to 1610 m: 9 m of argillaceous limestone and calcareous shale.
- from 1610 m to 1602 m: 8 m of carbonate shale, more or less silty and micaceous.
- from 1602 m to 1594.6 m: 7.4 m of subnodular limestone; at the top, mineralization of sulphides in a silicified dolomite. Occurrence of *Stromatoporella* accompanied by fragments of tabulate and rugose corals in a thin section at 1596.3 m. Dejonghe (1983, p. 166) mentioned numerous remains of reefal organisms below the mineralized zone.
- from 1594,6 m to 1533 m: 61.6 m of carbonate shale, silto-micaceous with pyrite at the base. At 1593 m, occurrence of *Frechastraea pentagona* (Goldfuss, 1826; Fig. 3C) in a thin section.

This shaly sequence is capped by green or red sandstones which are fine, argillaceous and micaceous. It is considered by Langenaeker (2000, p. 19) as equivalent to the shaly sequence of the Booischot borehole drilled between 868 m and 806 m. *F. pentagona* identified at the base of these deposits in the Heibaart borehole characterizes, according to Coen-Aubert (2012), the Lambermont Formation overlying the Aisemont Formation and the Les Valisettes Formation, rather high in the Upper *Palmatolepis rhenana* conodont Zone typical of the Upper Frasnian. For Dejonghe (1983), the mineralization occurring at Heibaart between 1595.2 m and 1594.6 m is related to that of Chaudfontaine, in the Vesdre Massif, which is present at the top of the Aisemont Formation. This is not really a stratigraphic argument, but it is a striking coincidence.

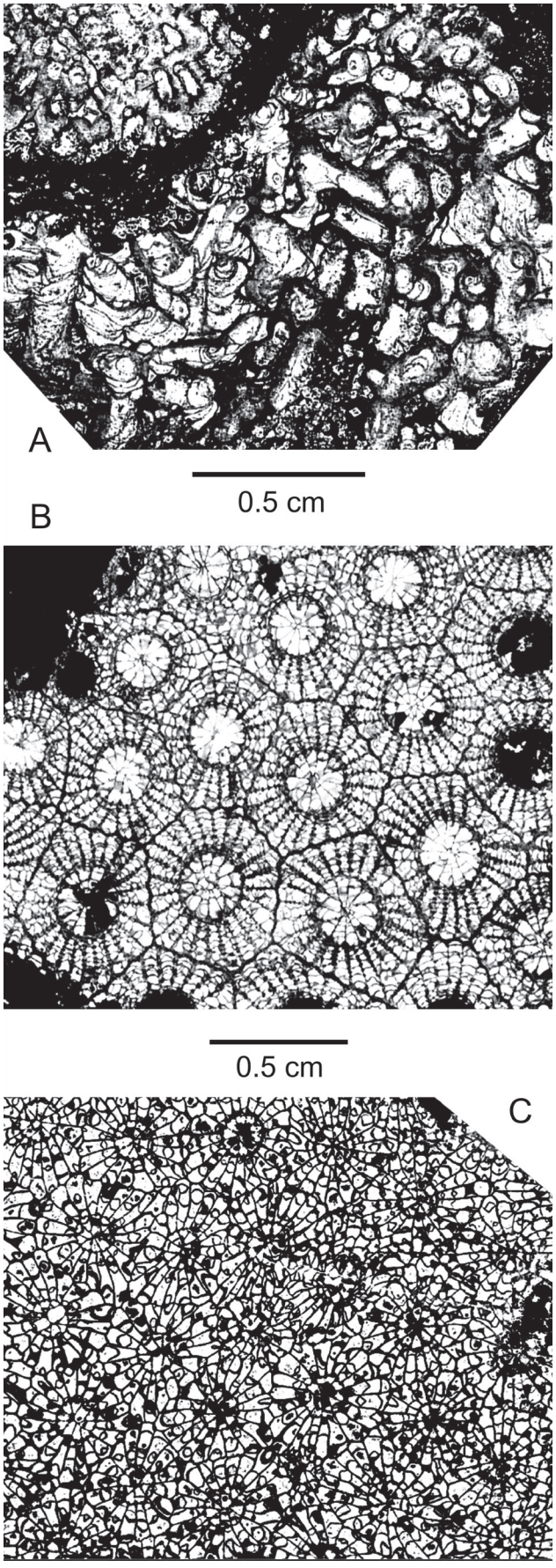

Figure 3. A: *Thecostegites bouchardi* (Michelin, 1846). IRScNB a12900, Heibaart borehole at 1625 m (l. 19467); magnification x 5. B: *Frechastraea limitata* (Milne-Edwards & Haime, 1851). IRScNB a12901, Booischot borehole at 871 m (l. 13893), transverse section; magnification x 4. C: *Frechastraea pentagona* (Goldfuss, 1826). IRScNB a12902, Heibaart borehole at 1593 m (l. 19465), transverse section; magnification x 4.

So it is possible that the 7.4 m of subnodular limestones with some reefal organisms intersected in the Heibaart borehole between 1594.6 m and 1602 m correspond to the upper limestone level of the Aisemont Formation occurring in the Booischot borehole. Below, there are in the Heibaart well 8 m of carbonate shale, between 1610 m and 1602 m, which could be assigned to the middle part of the Aisemont Formation. Normally, this lithostratigraphic unit starts with a lower level of limestone which is more or less thick and which does not exist in the Booischot borehole. In the Heibaart borehole, 14.8 m of different carbonate sediments have been drilled between 1610 m and 1624.8 m; they consist of calcareous dolomite, argillaceous limestones and calcareous shales. These deposits are more or less similar to those described by Coen-Aubert (1974), in the bottom of the Soumagne and Bolland boreholes situated to the east of Liège. More particularly, this author and Dejonghe (1987, p. 109) mentioned brecciated dolomites in the lower limestone level of the Aisemont Formation from these two wells. Hence, it seems that all the Aisemont Formation is developed in the Heibaart borehole, above a few metres belonging to the Huccorgne or to the Rhisnes Formation. Unfortunately, there are no fossil identifications to confirm these lithologic correlations. Likewise, the Frasnian-Famennian boundary cannot be recognized in the shaly sequence starting at 1594.6 m and overlying the Aisemont Formation, by lack of microfossil investigations.

5. Palaeogeographic conclusions

The Frasnian transgression arrived very late in the Campine Basin. In the Heibaart borehole, marine facies started immediately above the Silurian basement, with a few metres of shales and nodular limestones containing *Thecostegites bouchardi* and characteristic of the Huccorgne or of the Rhisnes Formation from the north side of the Namur Basin. Higher up, the Aisemont Formation seems to be completely represented at Heibaart. At its top, there is a mineralization of sulphides similar to that occurring in the same context at Chaudfontaine, according to Dejonghe (1983). *Frechastraea pentagona* is present at the base of the overlying shales from Heibaart and this is also the case in the Vesdre Massif, at the base of the Lambermont Formation above the Aisemont Formation. Moreover, the latter Formation is known at Huccorgne where it succeeds the Huccorgne Formation.

In the Booischot borehole, the Frasnian transgression started within the middle shaly part of the Aisemont Formation. In the upper limestone level of this lithostratigraphic unit, *Frechastraea limitata* and *Phillipsastrea ananas* have been identified. Upper Frasnian conodonts and acritarchs are still observed in the lower part of the overlying shales. In the Booischot borehole, the Silurian basement is separated from the first Frasnian marine deposits by the continental Booischot Formation which is composed of about 400 m of red and green conglomerates interbedded with sandstone and shale. According to the identification of plants and miospores made by Streel & Loboziak (1987), the upper, mostly green part of these sediments is Upper Givetian to Upper Frasnian in age; there are no precise determinations of fossils in their lower, mainly red part. The Booischot Formation is interpreted at the northern margin of the Brabant Massif to represent a non-marine valley fill (Kimpe et al., 1978, p. 62) or the infilling of a graben structure (Langenaeker, 2000, p. 19). The differences between the oldest ages of the marine deposits clearly show that Heibaart was farther from the shore than Booischot and therefore first concerned by the Frasnian transgression.

The same situation occurs at the southeastern border of the Brabant Massif, in the bottom of the Soumagne and Bolland boreholes, above a Lower Devonian basement. According to Coen-Aubert (1974) and Dejonghe (1987, 1990), the Frasnian transgression started at Soumagne with a few metres of limestones belonging to the Lustin Formation and followed by the Aisemont Formation; the latter is succeeded by the Lambermont Formation and a few metres of shales below a thin bed of chamosite oolites and the Frasnian-Famennian boundary marked by acritarchs according to Graulich (1984, p. 47). In the Bolland borehole, the first Frasnian marine deposits correspond to the lower limestone level of the Aisemont Formation; the rest of the succession is nearly similar to that of Soumagne.

In conclusion, it appears that the Upper Frasnian transgression characterized by the sedimentation of the Neuville and Aisemont Formations was very important in Belgium and even reached the Campine Basin, in its northern part. As the corals identified in the Booischot and Heibaart boreholes are similar to those known to the south of the Brabant Massif, there was no palaeogeographic barrier between the faunas of the two regions.

At the eastern end of the axial part of the Brabant Massif, the Frasnian of the Visé area is very different from that of the Booischot and Heibaart boreholes. It has been investigated in detail by Poty (1982 and 1991) and it is mainly represented by a great thickness of a cyclopean breccia with carbonate elements and reefal building organisms attributed to the Middle Frasnian Lustin Formation. These solution-collapse deposits related to palaeokarsts and passing laterally into non-brecciated limestones rest on sandstones, shales and bedded limestones containing Givetian fossils which have been described by Graulich et al. (1975), in the Hermalle-sous-Argenteau borehole. All this succession is also very different from that of the Bolland and Soumagne boreholes. Bolland is situated about 10 km to the south of Visé and is separated from this area by the well known Booze-Le Val Dieu Ridge or by the Booze-Le Val Dieu Block according to Poty (1991) and Poty & Delculée (2011). For these authors, an active block faulting with important vertical movements explains the complex tectono-sedimentary evolution of this highly unstable area of Visé during the Devonian and the Carboniferous.

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