

ACRITARCHS FROM THE ABBAYE DE VILLERS AND TRIBOTTE FORMATIONS IN THEIR TYPE SECTION OF THE THYLE RIVER VALLEY (MIDDLE ORDOVICIAN, BRABANT MASSIF, BELGIUM) AND THEIR STRATIGRAPHIC IMPLICATIONS

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(4 figures, 1 table, 2 plates)

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ABSTRACT. Reinvestigation of the Thyle river section, in the southern part of the Brabant Massif, has led to a better understanding of acritarch distribution in the Middle Ordovician Abbaye de Villers and Tribotte formations, and their stratigraphical significance in the type localities of both formations. The middle and upper parts of the Abbaye de Villers Formation and the lower part of the Tribotte Formation yielded an acritarch assemblage corresponding to the *Frankea hamata*-*Striatotheca rarirrugulata* Acritarch Zone of the English Lake District, demonstrating a late Arenig (late Fennian, early Darriwilian) age. Two species, *Adorfia firma* and *Arbusculidium filamentosum*, not recorded in the overlying Rigenée Formation, probably have their last appearances below the Arenig-Llanvirn boundary. Acritarch (late Arenig, late Fennian) and chitinozoan datings (middle Arenig, Whitlandian pro parte) of the middle part of the Abbaye de Villers Formation suggest correlation with the older part of the *Frankea hamata*-*Striatotheca rarirrugulata* Acritarch Zone. The uppermost part of the Tribotte Formation shows palynological similarities with the overlying Rigenée Formation. The exact position of the Arenig-Llanvirn boundary in the Thyle river section is not yet known and does not necessarily coincide with the Tribotte-Rigenée lithostratigraphical boundary.

KEYWORDS: acritarchs, Middle Ordovician, Brabant Massif, Belgium

1. Introduction

The Brabant Massif is a largely concealed part of the Belgian Caledonian basement, but a relatively complete section of Cambrian to Ordovician strata is exposed in the valley of the Thyle River, a tributary of the Dyle River (Michot, 1978; André et al., 1991; Herbosch et al., 2003). The units of the Lower-Middle Ordovician succession, the Tangissart Member of the Mousty Formation and the Chevlipont, Abbaye de Villers, Tribotte and Rigenée Formations, have been formally defined and their respective ages summarized (Verniers et al., 2001). As graptolites are only found in the Tangissart Member and the Chevlipont Formation, the ages of the overlying units (Abbaye de Villers, Tribotte and Rigenée Formations) depend mainly on microfossil evidence (acritarchs and chitinozoans). Graptolites have been found in the Rigenée Formation in the Sennette valley, however, and indicate the lower Llanvirn, *D. artus* and *D. munchisoni* biozones according to Maletz & Servais (1998).

The strata discussed in the present paper have generally been assigned to the Arenig-Llanvirn. At that time, the Brabant Massif was part of the Avalonia microcontinent (Scotese & Mc Karrow, 1990). Acritarchs from the Middle Ordovician of this area typically belong to the peri-Gondwanan *Arbusculidium filamentosum*, *Coryphidium*

and *Striatotheca* assemblages (Servais et al., 2003 and references therein). Common components include also *Arkonia*, *Dicrodiacrodium* and *Frankea*. Its composition is very different to that of the coeval assemblage recorded in the Baltic area, the Baltic Province of Vavrdová (1974), recently re-defined by Tongiorgi & Di Milia (1999). The peri-Gondwanan assemblage is wide-ranging, being reported from South America (Argentina, Brazil), several localities in Avalonia, North Africa and Southern Europe, and Asia including Turkey, Saudi Arabia, Jordan, Iran, Pakistan and southern China. Playford et al. (1995) and Servais et al. (2003) demonstrated that this assemblage was not climatically controlled, as it crossed lines of latitudes to range from high southern latitudes to lower latitudes. A large amount of literature is concerned with the description of taxa of this assemblage. Unfortunately, stratigraphical control is often poor, limited to some portions of the stratigraphic column, or in some instances absent. For this reason, the stratigraphic references in this paper will be limited to the English Lake District (Molyneux & Rushton, 1988; Cooper & Molyneux, 1990; Cooper et al., 2004). Important contributions do come from elsewhere, however. For example, the Prague Basin in Bohemia has been investigated intensively, mainly by Vavrdová (1966 *et seq.*), who was the first to describe and name many of the taxa recorded in this paper. However,

precise chronostratigraphical information has not been given for Arenig-Llanvirn samples from Bohemia, making precise international correlation difficult. Southern China has also been intensively studied (for example Brocke et al., 2000; Li, 1987; Tongiorgi et al., 2003). Li et al. (2002) indicated a parallel distribution of some selected species between Southern China and peri-Gondwana near the Lower-Middle Ordovician boundary, the stratigraphical interval with which this work is concerned, but most of the species observed in Southern China have not been recorded in Avalonia.

The aim of the present paper is to complement previous biostratigraphical work (Martin, 1977; André et al., 1991) on acritarch distribution in the Abbaye de Villers and Tribotte Formations and to review their stratigraphical significance in the light of newly published chitinozoan data from the same section (Samuelsson & Verniers, 2000). The palynological results discussed herein are based on examination of 25 samples. Several of them were previously studied by Vanguetaine et al. (1989) and André et al. (1991). Others were provided by Jacques Verniers (Ghent University) as toptype samples or residues from chitinozoan studies, and by Alain Herbosch (Université Libre de Bruxelles) (see Appendix 1: sample location). Although the acritarchs are generally poorly preserved, enough material has been observed to allow recognition of a general trend in the distribution of selected taxa of biostratigraphical and chronostratigraphical importance.

2. Previous palynological studies in the Lower-Middle Ordovician of the Thyle valley

2.1. Acritarchs

The first palynological study on the Ordovician of the Brabant Massif was that of Martin (1969). Samples from the Chevliport Formation (= Assise de Chevliport in Martin, 1969) and from the lowermost part of the Rigenée Formation (= assise de Rigenée in Martin, 1969) yielded acritarchs reported to be of Tremadoc (Chevliport) and (?) early Arenig (Rigenée) age. This latter age attribution is considered herein to be too old, as discussed below.

In 1975, Martin (dated as Martin, 1977) analyzed two sections in the same area: parts of the Chevliport and Abbaye de Villers Formations, respectively (as Quartzophyllades of Chevliport and Villers-la-Ville in Martin, 1977). According to Martin (1977, p. 25) the Abbaye de Villers Formation were of Arenig or Llanvirn age (Llanvirn if the stratigraphical ranges of the acritarchs *Baltisphaeridium apertum*, *Tectitheca spinifera* and *Arkonion tenuata* described by Burmann, 1968, 1970, could be confirmed). Unfortunately, *Baltisphaeridium apertum* is a poorly known galeate species, *Tectitheca spinifera* is not well defined, and the first appearance of *Arkonion tenuata* is probably below the Arenig-Llanvirn boundary (Servais, 1997). Martin (1977), however, identified other taxa of stratigraphical importance in the Abbaye de Villers Formation, such as *Adorfia firma*,

Arbusculidium filamentosum, *Coryphidium* aff. *bohemicum* (as *C. bohemicum*) and *Frankea hamata* (as *F. sartbernardensis*). Her work, whilst very detailed in the Abbaye de Villers Formation (12 samples in a sequence of sixty to sixty-five metres thick), only concerned the middle part of the formation, of which the estimated total thickness is 100-150 metres (Verniers et al., 2001; Beckers, 2004). The overlying Tribotte Formation was not sampled.

A more comprehensive sampling of the Abbaye de Villers Formation and the Tribotte Formation was conducted by the author in 1985 and 1989. The entire Rigenée Formation was sampled by Servais (1989, 1991). Based on this new material, Vanguetaine et al. (1989) confirmed that the Chevliport and Abbaye de Villers formations contained different acritarchs assemblages as Martin (1977) had already indicated, and also showed that there were differences between the assemblages from the Abbaye de Villers and Rigenée formations. André et al. (1991, Fig. 10) showed the distribution of selected acritarch taxa from Chevliport to Rigenée formations, including Servais' (1991) observations. According to this work, *Adorfia firma*, *Arbusculidium filamentosum*, *Frankea hamata* var. A and *Frankea sartbernardensis* var. A are characteristic of the Abbaye de Villers Formation (as Abbaye de Villers-la-Ville in André et al., 1991), and *Arkonion virgata*, *Frankea hamata* var. B, *Frankea sartbernardensis* var. B, *Frankea hamulata*, *Aureotesta clathrata simplex* (as *Marrocanium simplex*) and *Vogtlandia multiradialis* are characteristic of the Rigenée Formation. According to the mapping of Herbosch & Lemonne (2000), some samples (89/4, 89/5, 85/4, 85/5) previously placed in the uppermost part of the Abbaye de Villers Formation, are now considered to belong to the lower part of the Tribotte Formation. Furthermore, specimens referred to *Frankea sartbernardensis* var. A in André et al. (1991) are now placed in the species *Frankea breviscula*.

2.2. Chitinozoans

Samuelsson & Verniers (1999, 2000) studied 13 samples from the Abbaye de Villers-Tribotte-Rigenée succession of the Thyle section. In the lower third (middle part herein) of the Abbaye de Villers Formation, the presence of *Eremochitina brevis* (samples JV1 and AH99-12, ① in Fig. 2) is considered to indicate a middle Arenig age (Whitlandian *pro parte*). The species found in the upper part of the same formation (sample JV2, ② in Fig. 2), *Euconochitina vulgaris* and *Lagenochitina obelgis* (also present in JV1 and AH99-12), are less indicative, but suggest an age between middle Arenig and early Llanvirn. The same age is indicated by *Eremochitina vulgaris* occurring in the upper part of the Tribotte Formation (sample JV5, ③ in Fig. 2) and by *Lagenochitina obelgis* (JV7) and *Cyathochitina calyx* (JV6 and JV7) occurring in the lower and middle parts of the Rigenée Formation. Therefore, the Arenig-Llanvirn boundary cannot be precisely located in the sequence based on chitinozoan evidence. However, it is clear that at least the middle part

of the Abbaye de Villers Formation is middle Arenig in age according to Samuelsson & Verniers (2000) and be demonstrated of pre-Llanvirn age for the first time. The chitinozoan data are compared with the acritarch data below (section 7).

3. Acritarch biostratigraphy in the English Lake District

Cooper & Molyneux (1990) and Molyneux *in* Cooper et al. (2004) provided a synthesis of acritarch biostratigraphy in the English Lake District, encompassing the Upper Tremadoc, the Arenig and the Lower Llanvirn (Fig. 3). Acritarch zones are correlated with the Welsh regional stages and the graptolite zonation. The upper Tremadoc-Lower Llanvirn interval is subdivided into five acritarch zones. The fourth and fifth zones, i.e. the *Stelliferidium* aff. *pseudoornatum* and the *Frankea hamata*–*Striatotheca rarirrugulata* zones, correspond approximately to the Whitlandian-Fennian stages of the middle and upper Arenig (Fig. 3). The boundary between these two zones is imprecisely located, although on graptolite evidence it must be within either the upper part of the *Isograptus victoriae* Graptolite Zone or the *Isograptus caduceus gibberulus* Graptolite Zone in the middle of the Fennian Stage. No formal acritarch zonation has been proposed for the Lower Llanvirn in the Lake District, but *Frankea hamulata*, *Frankea longiuscula* and possibly *Striatotheca quieta* make their first appearances at the Arenig-Llanvirn boundary. As demonstrated below (section 7), several of the species recorded from the Abbaye de Villers Formation are characteristic of the *Frankea hamata* – *Striatotheca rarirrugulata* zone of the Lake District.

4. Studied sections, sample locations and palynological techniques

4.1. Samples from the railway section and outcrops along the Porte de Bruxelles to Laroche road in André et al. (1991)

4.1.1. The classical railway section

This section (both western and eastern sides) was sampled in 1985 and 1989 between km 38.699 and 39.309 (Fig. 1). The aim was to complement previous sampling by Martin (1977) between km 38.736 and 38.875. See also André et al., (1991, Fig. 11).

4.1.2. Outcrops along the road from Porte de Bruxelles to Laroche

The western bank of the Porte de Bruxelles to Laroche road and a disused quarry offer discontinuous outcrops of strata, more or less equivalent of the railway section. Samples RB02-19 to -22, JV1, AH99-11 and AH99-12 (see 4.2.2) and samples 85/9, 85/10 are from a sequence of only a few metres (Fig. 1). Samples 85/8, 85/6 and 85/7 were also taken from this section.

4.2. New samples and newly studied samples

4.2.1. Bois de l'Ermitage 89/7 sample

Located near the supposed contact between the Chevlipont and Abbaye de Villers Formations, the strata from which

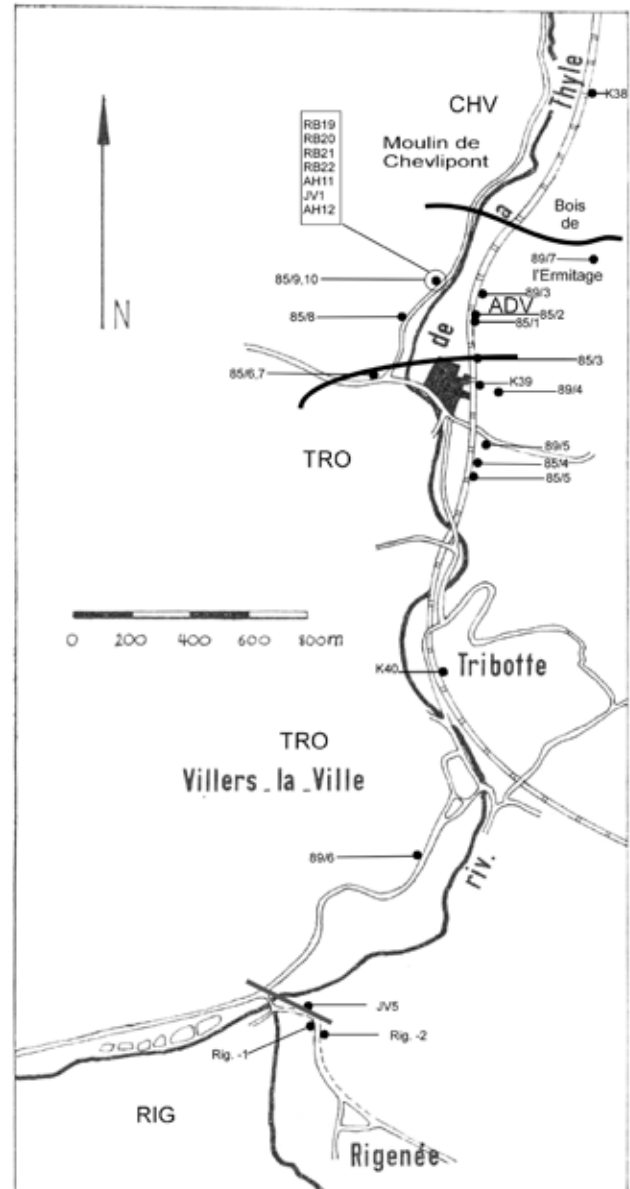


Figure 1. Position of the studied samples in the Thyle valley. Formation acronyms CHV = Chevlipont; ADV = Abbaye de Villers; TRO = Tribotte; RIG = Rigenée. Stratigraphy as in Herbosch & Lemonne (2000).

89/7 was taken are poorly exposed in a path east of the railway (Fig. 1). It was the only outcrop available at the time to try to fill the sampling gap between the two formations.

4.2.2. Outcrops along the road from Porte de Bruxelles to Laroche

Samples RB02-19 to -22, JV1, AH 99-11 and AH 99-12 are topotype samples from material used for chitinozoan studies by Beckers (2003) and Samuelsson & Verniers (2000). RB02-19 to -22 are from the most northerly outcrop along the Laroche road, just north of JV1, AH 99-11 and AH 99-12 in Samuelsson & Verniers (2000). RB02-23 is in the same outcrop as 85/8.

4.2.3. Sample 89/6 from Villers-la-Ville

Scopellerée hamlet in the middle part of the Tribotte Formation.

4.2.4. Sample JV5

This is a topotype sample from material used for chitinozoan studies, located in Samuelsson & Verniers (2000), northern entrance of the “Chemin creux” of Rigenée. Uppermost part of the Tribotte Formation.

4.3. Palynological techniques

The techniques used to isolate the organic matter are described in Strel (1965), and correspond to the standard methodology used in the Palynological Laboratory of Liège University. Residues of samples RB02-19 to -23 were initially prepared at Ghent for chitinozoan studies, and have been slightly oxidized (10 to 15 minutes of “dry Schluzer solution”) before being mounted on slides at the University of Liège. The slides are housed in the Collections of the Laboratory of Palynology, Liège University.

5. Palynological observations

5.1. Preservation of organic matter

The preservation of organic matter is generally poor, but specimens are very numerous so that at least 300 specimens, all samples taken together, exhibit enough characters to be determined to species level. The more productive samples, from base to top, are RB02-19, 85/9 and 85/7.

5.2. Selected species

The stratigraphical distribution of 15 acritarchs species is of particular interest (Fig. 2). Thanks to recent revisions,

the morphology of most of them is now well known. Fatka & Brocke (1999) revised *Arbusculidium filamentosum* and associated taxa; Servais (1993 1997) revised respectively the genera *Frankea*, and *Arkonion* and *Striatotheca*. Brocke, Fatka and Servais (1997) revised *Aureotesta* and *Marrocanium* and proposed that their type species were conspecific. Their proposal is followed herein. Molyneux & Leader (1997) documented the variability of some *Coryphidium* species. Relatively well known taxa such as *Adorfia firma*, *Cymatiogalea granulata* and *Stelliferidium striatulum* have also been considered as having potentially important stratigraphic value. *Adorfia firma* was first described from Arenig strata of Germany (Burmman, 1970), and *Cymatiogalea granulata* and *Stelliferidium striatulum* from the Arenig Klabava shales of Bohemia (Vavrdová, 1966).

5.3. List of selected species

- Adorfia firma* Burmann, 1970, (Pl. I, Figs 2-4),
- Arbusculidium filamentosum* (Vavrdová, 1965) Vavrdová, 1972, (Pl. I, Fig. 5),
- Arkonion tenuata* Burmann, 1970, (Pl. I, Fig. 6),
- Aureotesta clathrata* var. *clathrata* Vavrdová, 1972, (Pl. I, Fig. 7),
- Aureotesta clathrata* var. *simplex* (Cramer et al., 1974) Brocke et al., 1997, (Pl. I, Fig. 8),
- Coryphidium* aff. *bohemicum* Vavrdová, 1972 in Molyneux & Leader, 1997, (Pl. I, Figs 10-12),
- Cymatiogalea granulata* Vavrdová, 1966, (Pl. I, Fig. 13),
- Frankea breviscula* Burmann, 1970, (Pl. I, Figs 14 & 15),
- Frankea hamata* Burmann, 1970, (Pl. I, Fig. 16, 17),

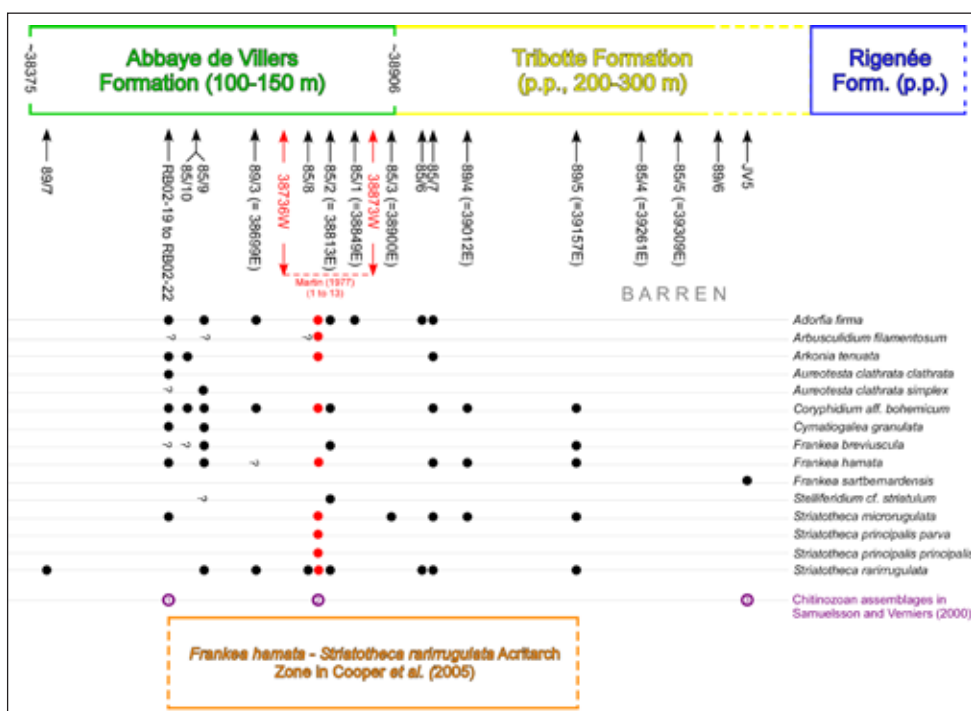


Figure 2. Range chart of 15 selected acritarch species in the Abbaye de Villers and Tribotte formations. Note that Martin’s (1977) observations (12 samples) are concentrated in one line. Acritarch distribution in samples RB02-19 to RB02-22 is given in Appendix 2. Chitinozoan assemblages of Samuelsson & Verniers (2000) are located: ① corresponds to JV1, AH99-12 samples with *Eremochitina brevis* and *Lagenochitina obelgis*; ② to JV2 sample with *Euconochitina vulgaris* and *Lagenochitina obelgis*; ③ to JV5 sample with *Eremochitina vulgaris*.

Frankea sartbernardensis (Martin, 1966) Colbath, 1986,
Stelliferidium striatulum (Vavrdová, 1966) Deunff et al., 1974, (Pl. II, Fig. 5),
Striatotheca microrugulata (Vavrdová, 1972) Eisenack et al., 1976, (Pl. II, Figs 6 & 7),
Striatotheca principalis parva Burmann, 1970,
Striatotheca principalis principalis Burmann, 1970,
Striatotheca rarirrugulata (Cramer et al., 1974) Eisenack et al., 1976, (Pl. II, Figs 8-10).

5.4. Other species

In addition to the above 15 selected species, numerous other taxa were also encountered. Some are recorded under open nomenclature or are questionably determined, whereas others are long-ranging taxa.

?*Acanthodiacrodium costatum* Burmann, 1968, (Pl. I, Fig. 1),
 ?*Buedingiisphaeridium fuscipetiolatum* (Cramer & Del Diez, 1977) Hu Yunxu, 1986 (Pl. I, Fig. 18),
Comasphaeridium sp.
 ?*Dasydorus* sp., (Pl. I, Fig. 9),
Peteinosphaeridium sp.,
Polygonium gracile Vavrdová, 1966, (Pl. I, Figs 19-20),
Solisphaeridium sp. A, (Pl. II, Figs 1 & 2),
Solisphaeridium sp. B, (Pl. II, Figs 3 & 4),
Stellechinatum uncinatum (Downie, 1958) Molyneux, 1987,
Veryhachium aff. *lairdii* Deflandre, 1946 ex Loeblich, 1970, (Pl. II, Fig. 11),
Veryhachium minutum Downie, 1958,
Veryhachium reductum (Deunff, 1958) Downie & Sarjeant, 1964, (Pl. II, Figs 12 & 13),
Veryhachium trispinosum Eisenack, 1938 (Pl. II, Fig. 14),
 ?*Vogtlandia multiangularis* Burmann, 1970.

Remarks: *Solisphaeridium* sp. A is a small acanthomorph acritarch bearing about forty simple conical spines. *Solisphaeridium* sp. B is similar, but has about ten simple conical spines.

Most of these species are observed throughout the succession, in the middle and upper parts of the Abbaye de Villers Formation and the lower part of the Tribotte Formation. ?*Vogtlandia multiangularis* was recorded from the upper part of the Tribotte Formation.

5.5. Systematic Palaeontology

Genus *Acanthodiacrodium* Timofeev, 1958 emend. Deflandre & Deflandre-Rigaud, 1962

?*Acanthodiacrodium costatum* Burmann, 1968 (Pl. I, Fig. A)

1968 *Acanthodiacrodium costatum* n.sp. in Burmann, 1968, p. 640, pl. 1, Fig. 5

?1977 *Acanthodiacrodium tassellii* Martin, 1969 in Martin, 1977, pl. 4, Fig. 25

Description: vesicle ovoidal in outline (L/l = 1.1-1.2); poles ornamented with short processes (cb diam./proc. L. = 3.0-3.5); equatorial zone distinctly costate.

Remarks: The poor preservation of the present material and lack of revision of the type specimens render the determination insecure.

The specimen (L/l = 1.3; cb diam./proc. L. = 2) figured in Martin (1977, pl. 4 Fig. 25) as *Acanthodiacrodium tassellii* Martin, 1969, probably belongs to ?*A. costatum* as understood herein.

Occurrence and abundance: present in middle and upper parts of the Abbaye de Villers Formation and lower part of the Tribotte Formation.

Genus *Adorfia* Burmann, 1970

Adorfia firma Burmann, 1970 (Pl. I, Fig. B)

1970 *Adorfia firma* n.sp. in Burmann, 1970, pl. 5, Fig. 3-4

1977 *Adorfia firma* Burmann, 1970 in Martin 1977, p. 15, pl. 4, Fig. 2

2003 *Adorfia firma* Burmann, 1970 in Tongiorgi et al., 2003, pl. 1, Fig. 2

non 1987 *Adorfia* cf. *firma* Burmann, 1970 in Li, 1987, pl. 70, Fig. 7

Description: Vesicle polygonal (Pl. I, Fig. 2) to rounded (Pl. I, Figs 3-4) in outline, with short ramified processes. The ultimate pinnulae are in the form of small, pedunculate balls. Striation on the wall surface is rarely observed.

Remarks: The specimen figured by Martin, 1977, pl. 4, Fig. 2, whilst incompletely described and poorly preserved, is almost certainly a specimen of *Adorfia firma* as other specimens of this species were recorded in the present study from coeval strata. The specimen figured by Martin was placed in *Adorfia hoffmanensis* by Tongiorgi et al. (2003).

The stratigraphic range, verified by the co-occurrence of other fossils, indicates the mid-Arenig, *A. suecicus* Graptolite Zone (see Tongiorgi et al., 2003).

Occurrence and abundance: present in the middle and upper parts of the Abbaye de Villers Formation and in the lower part of the Tribotte Formation.

Genus *Arbusculidium* Deunff, 1968

Arbusculidium filamentosum (Vavrdová, 1965) Vavrdová, 1972 emend. Fatka & Brocke, 1999 (Pl. I, Fig. C)

1965 *Dasydiacrodium filamentosum* n.sp. in Vavrdová, 1965, p. 355-356, pl. 3, Fig. 3, pl. 4, Figs 1-4, text – Fig. 4a-c

1972 *Arbusculidium filamentosum* (Vavrdová, 1965) nov. comb. in Vavrdová, 1972, p. 81, pl. 1, Fig. 3

1977 *Arbusculidium filamentosum* (Vavrdová, 1965) Vavrdová (1972) in Martin 1977, pl. 5, Fig. 12

1979 *Arbusculidium filamentosum* (Vavrdová, 1965) in Martin & Rickards, 1979, Fig. 2

1999 *Arbusculidium filamentosum* (Vavrdová, 1965) Vavrdová, 1972 emend. in Fatka & Brocke, 1999, p. 163-166, pl. 1, Figs 1-5, 7 & 9; pl. 2, Figs 1-9, pl. 3, Figs 1-10, text-Fig. 8: 1-12

Remarks: This species was identified and figured by Martin (1977); several specimens were recorded from the Abbaye de Villers Formation, but incomplete. They are identified in Fig. 2 by a question mark.

Martin & Rickards (1979) recorded the species in four samples from the Sennette valley section at the eastern side of the Charleroi-Bruxelles canal. In one sample, locality 76.5.17, the species was positively determined. In the other three samples, the species was identified as cf. *Arbusculidium filamentosum*. Locality 76.5.17 belongs to lithological unit C of Martin & Rickards (1979), who described a succession of units A, B, C, D, E and F, supposedly younging in age from A to F and ?late Arenig-Llanvirn to Caradoc in age. Graptolites, previously identified by Legrand (1967) and restudied by Martin & Rickards (1979) and Maletz & Servais (1998), were reported from unit D at km 39.776. They indicate an early Llanvirn age, probably the upper part of the *D. bifidus* graptolite zone (Maletz & Servais, 1998). At the time of Martin & Rickards' study, acritarchs did not allow discrimination of late Arenig and Llanvirn strata. Martin & Rickards (1979) therefore used the term ?late Arenig (as ?upper Arenig) – Llanvirn for units A, B, C, D and E, with only the graptolite bearing unit (D) being demonstrably early Llanvirn in age. As a consequence, the sample 76.5.17, bearing *Arbusculidium filamentosum*, in the unit C, located some 90 m north of the graptolite bearing locality, is not necessarily from the Llanvirn as stated in Brocke *et al.* (1995), Fatka & Brocke (1999) and Tongiorgi *et al.* (2003).

In their extensive review of *Arbusculidium filamentosum*, Fatka & Brocke (1999) found that the species occurs almost exclusively in Arenig strata, except for the putative early Llanvirn specimens cited in Martin & Rickards (1979) discussed above.

Occurrence and abundance: rare in the middle and upper parts of the Abbaye de Villers Formation.

Genus *Coryphidium* Vavrdová, 1972

Coryphidium aff. *bohemicum* Vavrdová, 1972 (Pl. I, Figs F-H)

1977 *Coryphidium bohemicum* in Martin, 1977, pl. 4, Fig. 30, pl. 5, Fig. 4

1989 *Coryphidium* aff. *bohemicum* in Rushton & Molyneux, 1989, Figs 4C, E-G, I, L

1997 *Coryphidium* aff. *bohemicum* in Molyneux & Leader, 1997, p. 91, pl. 1, 12-15; Figs 1H-J

2005 *Coryphidium* aff. *bohemicum* in Cooper *et al.*, 2004

Remarks: Molyneux & Leader (1997) described the species as having dimensions across the centre of the vesicle that were generally smaller than the parallel measurement along its edge, concave sides, and short processes with broad bases, generally more than 0,8 µm wide at the base, mainly concentrated at the corners of the vesicle, and radially disposed in bands that cross the vesicle diagonally (fan-shaped).

Coryphidium bohemicum Vavrdová, 1972, has a square vesicle, with straight or slightly convex sides and slender processes concentrated weakly at its corners. Most processes have a basal width of about 0,8 µm and a length of about 3-4 µm (Molyneux & Leader, 1997).

The six measured specimens (Table 1) do not always correspond to *C. aff. bohemicum* as far as vesicle shape is concerned but the processes and their dimensions are always of the type described for *C. aff. bohemicum*. The observed specimens are therefore placed in that taxon.

Tongiorgi *et al.* (2003) reported that *C. aff. bohemicum* and *C. bohemicum* occurred together in samples from the middle Arenig of South China (Dawan Formation, *Azygograptus suecicus* Graptolite Zone), but maintained that they could make no distinction between the two morphotypes. However, the observations presented herein are mostly in favour of such a distinction.

Occurrence and abundance: relatively common in the middle and upper parts of the Abbaye de Villers Formation and in the lower part of the Tribotte Formation.

Genus *Cymatiogalea* Deunff, 1961, emend. Deunff *et al.*, 1974

Cymatiogalea granulata Vavrdová, 1966 (Pl. I, Fig. I)

1966 *Cymatiogalea granulata* n. sp. in Vavrdová, 1966.

Remarks: Specimens with a distinctly granulate wall surface, large polygonal fields and remnants of veils

Table 1. Morphological features of six specimens of *Coryphidium* from the middle part of the Abbaye de Villers Formation.

Specimen location	L/l	Meas. CENTER	Meas. edge	Sides	Basal Processes Width	Processes length	Processes at the corners	Processes along edges	Processes radially disposed	Distal termination of processes
RB02-19 59664 J57/3	23/21,5	21,5	17/21	straight	≥ 1	2-3	no	yes	yes	trifid
RB02-19 59691 X40/3	27/25	25	23/24,5	straight	± 1	2-2,5	?	?	yes	slightly bifid
RB02-22 59706 X48/1	±24/24	24	27/29	concave	2-3 µ ?	2-3 µ	rather yes	yes	±	bifid
RB02-19 59664 E44	27/26	26	24/?	straight	± 1,5	± 2,5	rather yes	no	yes	capitate
RB02-19 59659 M45	28/27	27	29/27	concave	± 2 µ	± 3 µ	rather yes	no	±	ill defined
85/9 21260 C39	25/23	23	24/23	concave	≥ 1 µ	1,5-2,5	rather yes	rather no	±	ill defined

stretched between generally poorly preserved processes, are attributed to this species.

Occurrence and abundance: rare specimens of the species have been observed in the middle part of the Abbaye de Villers Formation.

Genus *Frankea* Burmann, 1970

Frankea breviscula Burmann, 1970 (Pl. I, Figs J-K)

- 1970 *Frankea breviscula* n.sp. in Burmann, 1970, p. 292, pl. 2, Fig. 2
- 1989 *Frankea sartbernardensis* (Martin, 1966) Burmann 1970 in Rushton & Molyneux, 1989, Fig. 4B
- 1989 *Frankea sartbernardensis* (Martin, 1966) Colbath, 1986 in Vanguetaine et al., 1989, p. 45 (pro parte)
- 1991 *Frankea sartbernardensis* (Martin, 1966) Colbath, 1986 var. A in André et al., 1991, p. 290
- 1993 *Frankea sartbernardensis* var. A; André et al., 1991, p. 290 in Servais, 1993, p. 90
- 1999 *Frankea breviscula* Burmann, 1970 in Vecoli et al., 1999, p. 348, 350, pl. 1 Figs 1-3, pl. 3, Fig. 1

Remarks: In creating the species *F. breviscula*, Burmann (1970, p. 292) indicated a process length/central body diameter ratio of more or less 2/3. According to Servais (1993), the dimensions of 50 specimens in one sample from Krusna Hora, Llanvirn, Bohemia, encompass those of the holotypes of both *Frankea sartbernardensis* and *F. breviscula*, suggesting possible continuous variation between these species and therefore questioning whether they were two distinct species. In contrast, Vecoli et al. (1999) considered that the dimensions of *F. sartbernardensis* (vesicle side length/process length = 3.5-5.5, normally about 5) and those of *F. breviscula* (vesicle side length/process length = about 2) demonstrated two statistically distinct species.

Our specimens, initially confused with *F. sartbernardensis* (Vanguetaine et al., 1989, André et al., 1991, Servais, 1993), have long processes (vesicle diameter/process length = 1.6 or processes length/vesicle diameter = 0.6). No specimens of *F. sartbernardensis* have been encountered in either the Abbaye de Villers Formation or the lower part of Tribotte Formation. The specimen of *F. sartbernardensis* from the Abbaye de Villers Formation figured by Martin (1977, pl. 5, Fig. 7) is a specimen of *F. hamata* (see also Servais, 1993).

Specimens of *F. breviscula* from the Abbaye de Villers Formation were determined as *F. sartbernardensis* var. A in André et al. (1991) and distinguished from *F. sartbernardensis* var. B (a variety observed in the overlying Rigenée Formation). The former has no visible ornamentation at high magnification, whereas the latter generally exhibits a fine but distinct striation parallel to the vesicle sides.

The original diagnosis of Burmann (1970) mentioned 8 distal pinnae. Servais (1993, pl. 1, Fig. 8) figured a specimen from the Lower Llanvirn Sarka Formation of

Bohemia bearing only 3 terminal pinnae. Vecoli et al. (1999) reported 4-8 distal pinnae for Llanvirn specimens from Tunisia and Spain. The Belgian specimens seem to bear no more than 3-4 distal terminations.

Occurrence and abundance: relatively common in the middle and upper parts of the Abbaye de Villers Formation and lower part of the Tribotte Formation.

Frankea hamata Burmann, 1970 (Pl. I, Fig. L)

- 1970 *Frankea hamata* n.sp. in Burmann, 1970, p. 290-291, pl. 2, Figs 7, 9 & 10
- 1977 *Frankea sartbernardensis* in Martin, 1977, pl. 5, Fig. 7
- 1978 *Frankea* cf. *hamata* in Vanguetaine, 1978, p. 195-196
- 1989 *Frankea hamata* in Vanguetaine et al. 1989, p. 45
- 1991 *Frankea hamata* var. A in André et al., 1991, p. 290
- 1993 *Frankea hamata* var. A, André et al. in Servais, 1993, p.83

Remarks: The specimens occurring in both the Abbaye de Villers and Tribotte formations have a ratio of process length/vesicle diameter of about 0.4-0.5/1, which coincides with the ratio given by Burmann (1970).

Martin (1977, pl. 5, Fig. 7) figured a specimen of *F. hamata* from the Abbaye de Villers Formation, which was referred erroneously to *F. sartbernardensis*.

The presence of the species in the Middle Ordovician of the Virginal disused railway section, carefully referred as *F. cf. hamata* in Vanguetaine (1978), is herein confirmed. The specimens of *F. hamata* in Vanguetaine et al. (1989), referred to as *Frankea hamata* var. A in André et al. (1991), are from the Abbaye de Villers and Tribotte formations and apparently have no ornamentation at high magnification. They are thus distinguished from *Frankea hamata* var. B in André et al. (1991) and Servais (1991), which has a striate ornament parallel to the sides of the triangular vesicle.

Occurrence and abundance: relatively common in middle and upper parts of the Abbaye de Villers formation and lower part of the Tribotte Formation.

Genus *Striatotheca* Burmann, 1970

Striatotheca rarirrugulata (Cramer et al., 1974) Eisenack et al., 1976 (Pl. II, Figs T-V)

- 1974 *Rugulidium rarirrugulatum* n.sp. in Cramer et al., 1974, p. 57-58, 61, 63-64; pl. 25, Figs 19, 21 & 23; pl. 26, Fig. 24
- 1976 *Striatotheca rarirrugulata* (Cramer et al., 1974) nov. comb. in Eisenack et al., 1976, p. 775-776
- 1977 *Striatotheca* sp. I in Martin, 1977, p. 14, pl. 5, Figs 5 & 13
- 1989 *Striatotheca rarirrugulata* (Cramer et al., 1974) Eisenack et al., 1976 in Rushton & Molyneux, 1989, Figs 5, B, C,

1991 ? *Striatotheca rarirrugulata* in Servais, 1991, p. 240, 244; pl. 1, Fig. 7

Remarks: The main features of this species are its relatively small size, the more or less square outline of its vesicle, and the presence of a few spaced ridges on the external surface of the body.

Rushton & Molyneux (1989) illustrated two specimens sharing the same features (relatively few striations near and parallel to the edge of the vesicle) as those observed in the study material.

The species is the most frequent *Striatotheca* in the studied strata.

Striatotheca sp. I in Martin (1977) typically corresponds to the concept of *S. rarirrugulata* adopted herein.

S. rarirrugulata is distinguished from *S. principalis* by its square outline, smaller size and ornament of more widely spaced ridges.

Occurrence and abundance: frequent in the Abbaye de Villers Formation and the lower part of Tribotte Formation.

6. Distribution of selected species

6.1. Sample 89/7 from the very base of the Abbaye de Villers Formation

This isolated sample merits special attention as it could be from the lowermost part of the Abbaye de Villers Formation, according to the mapping of Herbosch & Lemonne (2000) (see Fig. 1). Unfortunately, the preservation of the organic matter is very poor. A single species, *Striatotheca rarirrugulata*, was identified, along with long ranging taxa such as undeterminable diacromorph acritarchs and small acanthomorph acritarchs of *Micrhystridium* type.

6.2. All other samples from the middle and upper parts of the Abbaye de Villers Formation, from RB02-19 to 85/3

The assemblages from this part of the succession are relatively homogeneous. *Adorfia firma*, *Coryphidium* aff. *bohemicum*, *Frankea hamata* and *Striatotheca rarirrugulata* are the commonest species and are found in most samples. Secondary species such as *?Acanthodiacrodium costatum*, *Solisphaeridium* sp. A and *Solisphaeridium* sp. B are also well represented. There are no major differences between the middle and the upper parts of the formation. It should be noted, however, that *Cymatiogalea granulata* occurs regularly in RB02-19, RB02-20, RB02-21 and 85/9, but is apparently absent from higher samples. *Aureotesta clathrata clathrata* is only known from RB02-20.

6.3. Samples 85/6 to 89/5 from the lower part of the Tribotte Formation

This part of the succession yielded 4 fossiliferous samples, 85/7 and 89/5 providing the most diverse assemblages. *Coryphidium* aff. *bohemicum*, *Frankea hamata* and

Striatotheca rarirrugulata are present in three samples, and *Adorfia firma* in two. No major differences are observable with respect to the underlying strata, except for a reduction in diversity. Secondary species such as *?Acanthodiacrodium costatum*, *Solisphaeridium* sp. A and *Solisphaeridium* sp. B are restricted to the most productive sample, 85/7. The similarity to assemblages from the underlying strata probably reflects proximity in time and/or progressive vertical facies variation. Samples 85/4, 85/5 and 89/6 from overlying strata are barren. Sampling is probably too scattered to be representative of this 200-300 metre-thick formation.

6.4. Sample JV5 from the uppermost part of the Tribotte Formation

Although isolated and containing badly preserved organic matter, this sample, which has also yielded chitinozoans (Samuelsson & Verniers, 2000), is nevertheless very interesting as it contains typical specimens of *Frankea sartbernardensis* with distinctly striated wall surface, exactly similar to specimens found in the overlying Rigenée Formation. The presence of *Vogtlandia multiradialis* is also suspected but cannot be confirmed due to poor preservation. Nevertheless one, possibly two, species that are commonly found in the Rigenée Formation (André et al., 1991), but are unknown in underlying strata, are observed here.

7. Biostratigraphic and Chronostratigraphical correlations

7.1. Lower part of the Abbaye de Villers Formation

This part yielded one acritarch species, *Striatotheca rarirrugulata*, from a single sample. According to the geological map of Herbosch & Lemonne (2000), the location of the sample is very close the boundary with the underlying Chevlipont Formation. No tectonic disturbances are indicated on the geological map, but Anthoine & Anthoine (1944) interpreted the succession as faulted. The recorded species clearly indicates a late Arenig age in comparison with the Lake District (Cooper et al., 2004), but if the sample is from a faulted sequence, it is not necessarily from the lowermost part of the Abbaye de Villers Formation.

7.2. The *Frankea hamata*-*Striatotheca rarirrugulata* Acritarch Zone of the English Lake District

The *Frankea hamata*-*Striatotheca rarirrugulata* Acritarch Zone of the English Lake District (Cooper & Molyneux, 1990, Cooper et al., 2004) is characterized by the appearance of a number of species, seven of which are found in the middle and upper parts of the Abbaye de Villers Formation. These are *Aureotesta clathrata* (presence not certain in the Lake District), *Coryphidium* aff. *bohemicum*, *Frankea breviscula* (with a question mark in the Lake District), *Frankea hamata*, *Striatotheca principalis principalis*, *Striatotheca rarirrugulata* and

GLOBAL SERIES	GLOBAL STAGES	England and Wales			
		Series/Stages	Graptolite zones	Acritarch zones	
MIDDLE ORDOVICIAN	DARRIWILIAN	LLANVIRN	LLANDEILIAN	<i>D. artus</i>	
			ABEREIDDIAN		
	STAGE 3	ARENIG	FENNIAN	<i>A. cucullus</i> <i>I. c. gibberulus</i> ? <i>I. v. victoriae</i>	<i>F. hamata</i> - <i>S. rarirrugulata</i> ?
			WHITLANDIAN	<i>D. simulans</i>	<i>Stelliferidium</i> aff. <i>pseudoomatum</i>
LOWER ORDOVICIAN	STAGE 2	TREMADOC	MORIDUNIAN	<i>D. varicosus</i> <i>T. phyllograptoides</i>	? <i>C. bohemicum</i> <i>S. trifidum</i> - <i>C. bohemicum</i>
	TREMADOCIAN		MIGNEINTIAN	<i>A. murrayi</i>	<i>C. messaoudensis</i> <i>S. trifidum</i>
			CRESSAGIAN		

Figure 3. Lower and Middle Ordovician chart illustrating the stratigraphic relationships between the global series and stages, and the British regional series, stages and graptolite and acritarch zones (after Webby, 1998; Cooper et al. 2004).

Arkonian tenuata (as *Arkonian* spp. in the Lake District). The unnamed Lower Llanvirn acritarch assemblage that succeeds the *Frankea hamata*-*Striatotheca rarirrugulata* zone in the Lake District is characterised by the appearance of *Frankea longiuscula* and *F. hamulata*, the latter also recorded by Servais (1991) from the middle part of the Rigenée Formation. As a consequence, the middle and upper parts of the Abbaye de Villers Formation belong to the *Frankea hamata*-*Striatotheca rarirrugulata* zone of the Lake District and are older than the unnamed Lower Llanvirn acritarch assemblage of the same area. The assemblage of acritarchs recorded from the lower part of the Tribotte Formation is very similar to the assemblages from the middle and upper parts of the Abbaye de Villers Formation. It is also correlated with the *Frankea hamata*-*Striatotheca rarirrugulata* zone of the Lake District. The eponymous species of this zone are found throughout the lower part of the Tribotte Formation. As the middle and upper parts of the Abbaye de Villers Formation and the

lower part of the Tribotte Formation clearly belong to the *Frankea hamata*-*Striatotheca rarirrugulata* Acritarch Zone of the Lake District (Cooper et al., 2004), a late Arenig, (late Fennian, early Darriwilian) age is therefore clearly indicated, corresponding to the *I. c. gibberulus* and *A. cucullus* (= *hirundo*) graptolite zones (Figs 2 & 3). Samuelsson & Verniers (2000) determined, for their lower third of the Abbaye de Villers Formation (= middle part herein), a middle Arenig age (Whitlandian *pro parte*) based on chitinozoans. The information provided respectively by acritarchs and chitinozoans probably indicates a position in the lower part of the *Frankea hamata*-*Striatotheca rarirrugulata* Acritarch Zone of the Lake District for the middle part of the Formation, possibly corresponding to the *I. c. gibberulus* graptolite zone (Fig. 3). The presence of *Cymatiogalea granulata* and *Aureotesta clathrata* in the middle part of the formation, but not above, could be a further indication of some stratigraphic differences between the middle and upper parts of the formation.

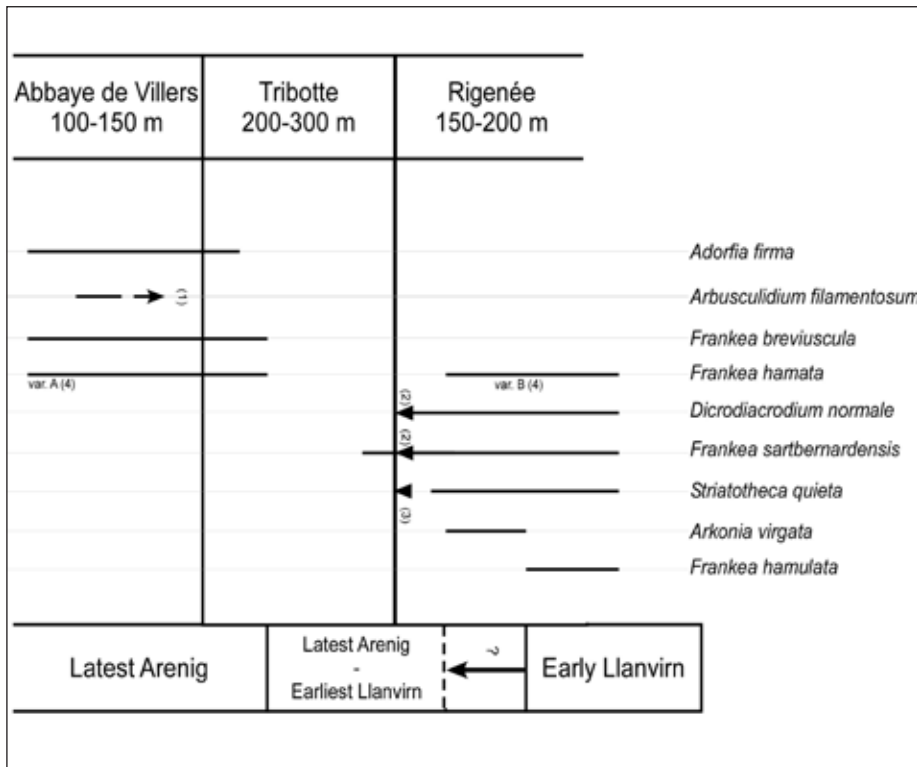


Figure 4. Chronostratigraphy of Middle Ordovician strata in the Thyle valley, according to the ranges of selected acritarch marker species. Arrows in the acritarch ranges indicate that the species is known elsewhere above or below the Arenig-Llanvirn boundary, placed here arbitrarily at the Tribotte-Rigenée lithostratigraphical boundary. (1) Probably erroneous extension of *A. filamentosum* into the Llanvirn (see remarks at section 5.5 of the present paper; (2) species recorded or (3) questionably recorded in the Late Arenig of the Lake District (Cooper *et al.*, in press). (4) *Frankea hamata* var. A (smooth wall surface) and var. B (striated wall surface) as in André *et al.*, 1991, p.290). The figure shows that no marker species is recorded in the lowermost part of the Rigenée Formation, and that either *Arkonia virgata* in the lower part or *Frankea hamulata* in the middle part could be indicative of a Llanvirn age.

7.3. Uppermost part of the Tribotte Formation and Rigenée Formation

Servais (1991) observed the successive appearances of *Frankea sartbernardensis*, *Arkonia virgata* and *Frankea hamulata* in the lowermost, lower and middle parts of the Rigenée Formation. According to Vecoli *et al.* (1999), *Frankea sartbernardensis* is a Llanvirn marker. Molyneux in Cooper *et al.* (2004) recorded the species below the Arenig-Llanvirn boundary. According to Servais (1993, 1997) *Arkonia virgata* and *Frankea hamulata* are both Llanvirn markers, never recorded from Arenig strata. Molyneux in Cooper *et al.* (2004) placed the first appearance of *Frankea hamulata* at about the Arenig-Llanvirn boundary in the Lake District. Depending on the species chosen as a marker for the base of the Llanvirn, the Arenig-Llanvirn boundary could be located at different places in the studied succession: within the Tribotte Formation if the marker chosen is *Frankea sartbernardensis*, in the lower part of the Rigenée Formation based on the first appearance of *Arkonia virgata*, or in the middle part of the Rigenée Formation at the first appearance of *Frankea hamulata*. Fig. 4 provides a chronostratigraphic interpretation of the studied succession based on the known ranges of selected acritarch species. Taking the present data into account, the Arenig-Llanvirn boundary would be in the lower or middle part of the Rigenée Formation.

Adorfia firma and *Arbusculidium filamentosum* are not known from the Rigenée Formation. The known stratigraphic range of both species, as discussed in section 5.4. (Systematic Palaeontology), indicates an exclusively Arenig age. This is in full accordance with the chronostratigraphic deductions outlined above. It should

be noted that Vecoli & Le Hérisse (2004) placed the last appearance (LAD) of *A. filamentosum* immediately below the Arenig-Llanvirn boundary.

8. Conclusions

Distribution of selected acritarch species in the Middle Ordovician Abbaye de Villers and Tribotte formations, both in their type section of the Thyle valley, at the southern border of the Brabant Massif is established based on previous sampling and data (Martin, 1977; Vanguetaine *et al.*, 1989; André *et al.*, 1991) and new topotype material, from samples yielding chitinozoans (Samuselsson & Verniers, 2000).

Specimens erroneously determined as *Frankea sartbernardensis* var. A (André *et al.*, 1991, Vanguetaine *et al.*, 1989) are identified as *Frankea breviscula*. The range of *Aureotesta clathrata simplex* (previously *Marrocanium simplex*) is extended downwards in the Abbaye de Villers Formation below its previous first appearance in the lower part of the Rigenée Formation (Vanguetaine *et al.*, 1989; André *et al.*, 1991). *Coryphidium bohemicum*, *Frankea sartbernardensis* and *Striatotheca* sp. I in Martin (1977) are herein respectively determined as *Coryphidium* aff. *bohemicum* in Molyneux & Leader (1997), *Frankea hamata* and *Striatotheca rarirrugulata*. *Aureotesta clathrata clathrata* and *Cymatiogalea granulata* are observed for the first time.

The lowermost part of the Abbaye de Villers Formation yielded few identifiable specimens, except for *Striatotheca rarirrugulata* in a unique sample in the "Bois de l'Ermitage", north of the classical outcrops of the Formation. The range of the species is restricted to the

upper Fennian (upper Arenig) in the English Lake District.

The middle (= lower third in Samuelsson & Verniers, 2000) and upper parts of the Abbaye de Villers Formation are characterized by a relatively homogeneous assemblage of species corresponding to the *Frankea hamata* – *Striatotheca rarirrugulata* Acritarch Zone of the English Lake District (Cooper et al. 2004) where it is dated as late Fennian (late Arenig) and corresponds to the *I. c. gibberulus* and *A. cucullus* (= *hirundo*) graptolite zones. According to the acritarch evidence, the middle part of the Abbaye de Villers Formation is placed somewhat higher than it is according to the chitinozoans (Samuelsson & Verniers, 2000). These authors suggested a Whitlandian (middle Arenig) for their lower third of the Formation (= middle part herein).

Four fossiliferous samples in the lower part of the Tribotte Formation, yielded an acritarch assemblage comparable to the assemblage recorded from the middle and upper parts of the Abbaye de Villers Formation. They therefore indicate a late Arenig age.

A unique fossiliferous sample, topotype material of sample JV5 of Samuelsson & Verniers (2000) from the uppermost part of the Tribotte Formation, 10 metres below the Tribotte-Rigenée boundary, yielded *Frankea sartbernardensis* (= *Frankea sartbernardensis* var. B in Vanguetaine et al., 1989; in André et al., 1991 and possibly *Vogtlandia multiradialis*, two species known from the Rigenée Formation.

Two acritarch species, *Adorfia firma* and *Arbusculidium filamentosum*, observed in few numbers in the Abbaye de Villers Formation (both species) and the lower part of Tribotte Formation (*A. firma* alone) have not been recorded from the Rigenée Formation. Their known stratigraphic range in Belgium and elsewhere indicates that both have a last appearance data below the Arenig-Llanvirn boundary.

The exact position of the Arenig-Llanvirn boundary in the Thyle valley succession is unclear. Several proposals have been made to identify this boundary, based on the appearance of *Frankea sartbernardensis* (in Vecoli et al., 1999), *Arkonion virgata* (in Servais, 1997), or *Frankea hamulata* (in Cooper et al. 2004). Taking all available data into account, the boundary seems to be within the Rigenée Formation (at the appearance of either *A. virgata* or *F. hamulata*), but not necessarily at its contact with the underlying Tribotte Formation as suggested by Verniers et al. (2001).

9. Acknowledgements

Jacques Verniers is thanked for providing topotype samples from the Abbaye de Villers-Tribotte-Rigenée succession of the Thyle section. Maurice Streel and Luc André are thanked for providing information to finalize the final version, and Jean-Clair Duchesne for his editorial handling.

APPENDIX 1: List of samples in stratigraphic order

89/7: Bois de l'Ermitage, north-east of the ruins of the abbey, on a path south-east of Chevlipont. Lambert coordinates: 161.935/142.685.

RB02-19 to RB02-23: set of 5 samples prepared at the University of Ghent for chitinozoans, the residue of which was mounted on palynological slides at the University of Liège for acritarch study. The sample was oxidized slightly by the addition of... to the residue. All samples are fossiliferous. The best, however, are – 19 and – 21, from outcrops along the Porte de Bruxelles to Laroche road. The most northerly sample, RB02-19, is about 25 m north of AH99-11. RB02-20 to RB02-22 are located between RB02-19 and AH99-11. For RB02-23, see sample 85/8.

JV1: residue from the same sample in Samuelsson & Verniers (2000) location given in that paper. Outcrop along the Porte de Bruxelles to Laroche road. Lambert coordinates: 161.412/142.593.

AH99-11 and AH99-12: topotype material of samples in Samuelsson & Verniers (2000) location given in that paper. Outcrop along the Porte de Bruxelles to Laroche road. Lambert coordinates: respectively 161.413/142.601 and 161.407/142.581.

85/9 and 85/10: outcrop along the Porte de Bruxelles to Laroche road, located at km 30.783 at the western side of the Court-Saint-Etienne road in André et al. (1991, legend of Fig. 10), in a folded sequence. Sample 85/9 is in the hinge of a secondary anticline, and 85/10 a few decimetres stratigraphically above on the northern limb of the anticline.

89/3: eastern side of the railway section, at km 38.699.

85/8: from a small quarry exposing a sequence of about 10 metres along the Porte de Bruxelles to Laroche road, reported as located at km 30.928 at the western side of the road to Court-Saint-Etienne in André et al. (1991, legend of Fig. 10). Sample taken from the southern flank of the quarry, about 1.8 metres above the ground. The excavation is located in front of the northern surrounding wall of the abbey. RB02-23 comes from the same outcrops.

85/1: eastern side of the railway section, at km 38.849 and 7 m south of a railway sign.

85/2: eastern side of the railway section, at km 38.812 and 10 m south of a railway sign.

85/3: eastern side of the railway section, at km 38.900.

85/6 and 85/7: abandoned quarry behind the “Chalet de la Forêt” pub, samples at 10 m from each other.

89/4: in an outcrop below the surrounding wall of the abbey, at about 50 m east of the railway and opposite km 39.012.

89/5: small quarry below the road to the “N.D. des Affligés” Chapel; opposite km 39.157 of the railway.

85/4: eastern side of the railway section at km 39.261.

85/5: eastern side of the railway section at km 39.309.

89/6: Villers-la-Ville, Scopellerée hamlet, opposite Moulin d'Hallers street. Lambert coordinates: 161.720/140.540.

JV5: topotype sample of JV5 in Samuelsson & Verniers (2000). Uppermost part of the Tribotte Formation. About 10 m below the boundary with the Rigenée Formation. Location given in that paper. Lambert coordinates: 160.875/140.075.

APPENDIX 2

Samples RB02-19 to RB02-22 are considered as a whole in Fig. 2 as they were taken in a very narrow sequence, a few metres thick. Their specific content is detailed herein together with the content of samples AH99-11, JV1 and AH99-12 (see Samuelsson & Verniers, 2000, for their exact position) probably corresponding to samples 85/10 and 85/9 herein.

<i>Adorfia firma</i>	RB02-19, RB02-20, RB02-21, AH99-12
<i>Arbusculidium filamentosum</i>	?RB02-19
<i>Arkonina tenuata</i>	RB02-19, RB02-21, JV1
<i>Aureotesta clathrata clathrata</i>	RB02-20
<i>Aureotesta clathrata simplex</i>	?RB02-21
<i>Coryphidium aff. bohemicum</i>	RB02-19, RB02-20, RB02-21, RB02-22
<i>Cymatiogalea granulata</i>	RB02-19, RB02-20, RB02-21
<i>Frankea brevisuscula</i>	?RB02-19
<i>Frankea hamaca</i>	RB02-19
<i>Striatotheca microrugulata</i>	RB02-19, RB02-20, RB02-21, JV1
<i>Striatotheca rarirrugulata</i>	RB02-19, RB02-20, RB02-21, JV1

References

- ANDRÉ, L., HERBOSCH, A., LOUWYÉ, S., SERVAIS, T., VAN GROOTEL, G., VANGUESTAINE, M. & VERNIERS, J., 1991. Guidebook to the excursion on the stratigraphy and magmatic rocks of the Brabant Massif. *Annales de la Société Géologique de Belgique*, 114: 283-323.
- ANTHOINE R. & ANTHOINE P., 1944. Les Assises de Mousty et de Villers-la-Ville du bassin supérieur de la Dyle, *Annales de la Société Géologique de Belgique*, LXVI, Mémoires no 2, 170 pp.
- BECKERS, R., 2003. *Vergelijking van de plooiën in de Abdij van Viller, Thyle-vallei, Massief van Brabant*. Unpublished Master Thesis, Universiteit Gent.
- BECKERS R., 2004. Comparison of folds in the Chevlipont and Abbaye de Villers Formations, near the Abbey of Villers, Thyle Valley, Brabant Massif. In Proceedings of the 5th European coal conference. *Geologica Belgica*, 7 (3-4), 357-359
- BROCKE, R., FATKA, O., MOLYNEUX, S.G. & SERVAIS, T., 1995. First appearance of selected Early Ordovician acritarch taxa from peri-Gondwana. In J.D. COOPER, M.L. DROSER & S.C. FINNEY (eds), Ordovician odyssey: *Short papers for the Seventh International Symposium on the Ordovician System*. –

The Pacific Section for Sedimentary Geology (SEPM), Fullerton, California, USA, 77: 473-476.

BROCKE, R., FATKA, O. & SERVAIS, T., 1997. A review of the Ordovician acritarchs *Aureotesta* and *Marrocanium*. *Annales de la Société Géologique de Belgique*, 120 (1): 1-21.

BROCKE, R., LI, J. & WANG, Y., 2000. Upper Arenigian to lower Llanvirnian acritarchs assemblages from South China: a preliminary evaluation. *Review of Palaeobotany and Palynology*, 113: 27-40.

BURMANN, G., 1968. Diacrodien aus dem unteren Ordovizium. *Paläontologische Abhandlungen, Abteilung B*, 2 (4): 635-652.

BURMANN, G., 1970. Weitere organische Mikrofossilien aus dem unteren Ordovizium. *Paläontologische Abhandlungen, Abteilung B*, 3: 269-332.

COBALTH, G.K., 1986. The lower Paleozoic organic-walled phytoplankton ("acritarch") genus *Frankea* Burmann, 1970. *Micropaleontology*, 32: 72-73.

COOPER, A.H. & MOLYNEUX, S.G., 1990. The age and correlation of Skiddaw Group (early Ordovician) sediments in the Cross Fell inlier (northern England). *Geological Magazine*, 127: 137-157.

COOPER, A.H., FORTEY, N.J., HUGHES, R.A., MOLYNEUX, S.G., MOORE, R.M., RUSHTON, A.W.A. & STONE, P. (2004). The Skiddaw Group of the English Lake District. *British Geological Survey Memoir for 1:50,000 geological map sheets E22, 28, 29, 30, 31, 48 (parts)*.

CRAMER, F.H., KANES, W.H., DEL DIEZ, M.C.R. & CHRISTOPHER, R.A., 1974. Early Ordovician acritarchs from the Tadla Basin of Morocco. *Palaeontographica, Abteilung B*, 146: 57-64.

CRAMER, F.H. & DEL DIEZ, M.C.R., 1977. Late Arenigian (Ordovician) acritarchs from Cis-Saharan Morocco. *Micropaleontology*, 23: 339-360.

DEFLANDRE G., 1946. Hystricosphaeridés. III. Espèces du Primaire. -*Fichier Micropaléontologique, Série 8, Arch. Orig. Centre Doc. F.N.R.S.*, No 257, I-V, Fiches 1096-1185

DEFLANDRE G. & DEFLANDRE-RIGAUD M. (1962) Nomenclature et systématique des Hystricosphères (*sens. lat.*) Observations et rectifications. *Revue de Micropaléontologie*, 4, 190-196

DEUNFF J., 1958. Micro-organismes planctoniques du Primaire armoricain. I. Ordovicien du Veryhac'h (Presqu'île de Crozon), *Bulletin de la Société de Géologie et Mines de Bretagne, n. sér.*, 2, 1-41. Published 1959

DEUNFF J., 1961. Un microplancton à Hystricosphères dans le Trémadoc du Sahara. *Revue de Micropaléontologie*, 4, 37-52

DEUNFF J., 1968. Sur une forme nouvelle d'Acritarche possédant une ouverture polaire (*Veryhachium miloni* n. sp.) et sur la présence d'une colonie de *Veryhachium* dans les Trémadocien marocain. *Comptes Rendus de l'Académie des Sciences de Paris*, 267, 46-49

- DEUNFF, J., GORKA, H. & RAUSCHER, R., 1974. Observations nouvelles et précisions sur les Acritarches à large ouverture polaire du Paléozoïque inférieur. *Geobios*, 7 (1): 5-18.
- DOWNIE, C., 1958. An assemblage of microplankton from the Shineton Shales (Tremadocian). *Proceedings of the Yorkshire Geological Society*, 31: 331-350.
- DOWNIE C. & SARJEANT W. A. S. (1964). Bibliography and index fossil dinoflagellates and acritarchs. *Geological Society of America*, Memoir 94, 1-180
- EISENACK, A., 1938. Hystriosphærideen und verwandte Formen in baltischen Silur. *Zeitschrift Geschieforschung*, 14: 1-30.
- EISENACK, A., CRAMER, F.H. & DEL DIEZ, M.C.R., 1976. Katalog der fossilen Dinoflagellaten, Hystriosphären und verwandten Mikrofossilien. Band IV Acritarcha 2. Teil. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 863 pp.
- FATKA, O. & BROCKE, R., 1999. Morphologic variability in two populations of *Arbusculidium filamentosum* (VAVRDOVÁ, 1965) VAVRDOVÁ, 1972. *Palynology*, 23: 153-180.
- HERBOSCH, A. & LEMONNE, E., 2000. *Carte géologique de Wallonie, Echelle: 1/25.000. Nivelles-Gemappe 39/7-8*. Ministère de la Région Wallone.
- HERBOSCH, A., VERNIERS, J., DEBACKER, T., BILLIAERT, B., DE SCHEPPER, S. & BELMANS, M., 2001. The Lower Palaeozoic stratigraphy and sedimentology of the Brabant Massif in the Dyle and Orneau valleys and of the Condroz Inlier at Fosses: an excursion guidebook. *Geologica Belgica*, 5 (3-4): 71-143.
- HU YUNXU (1986). Micropalaeoflora from the Early Ordovician in Goqiao Region of Shaanxi and its stratigraphic significance. *Bulletin of the Xian Institute of Geology and Mining Research*, Chinese Academy of Geological Sciences, 14, 199-239
- LEGRAND R., 1967. Ronquières. Documents géologiques. *Mémoire Explicatif des Cartes Géologiques et Minières de Belgique*, 6, 60 pp.
- LI, J., 1987. Ordovician acritarchs from the Meitan Formation of Guizhou Province, south-west China. *Palaeontology*, 30: 613-634.
- LI J., SERVAIS T. & BROCKE R., 2002. Chinese Palaeozoic acritarch research: review and perspectives. *Review of Palaeobotany and Palynology*, 118 (1-4), 181-193
- LOEBLICH A., 1970. Morphology, Ultrastructure and Distribution of Palaeozoic Acritarchs. *Proceedings of the North American Palaeontological Convention*, Chicago 1969, G, 705-788
- MALETZ, J. & SERVAIS, T., 1998. Upper Ordovician graptolites from the Brabant Massif, Belgium. *Geobios*, 31: 21-37.
- MARTIN F., 1966. Les Acritarches du sondage de la brasserie Lust, Kortrijk (Courtrai) (Silurien belge). *Bulletin de la Société belge de Géologie, de Paléontologie et d'Hydrologie*, 74 (3), p. 354-400.
- MARTIN, F., 1969. Les Acritarches de l'Ordovicien et du Silurien belges. Détermination et valeur stratigraphique. *Mémoires de l'Institut royal naturelles de Belgique*, 160: 175 pp.
- MARTIN, F., 1977. Acritarches du Cambro-Ordovicien du Massif du Brabant, Belgique. *Bulletin de l'Institut des sciences naturelles de Belgique, Sciences de la Terre*, 51: 33 pp. (dated 1975).
- MARTIN, F. & RICKARDS, B., 1979. Acritarches, Chitinozoaires et Graptolites Ordoviciens et Siluriens de la Sennette (Massif du Brabant, Belgique). *Annales de la Société Géologique de Belgique*, 102 : 189-197.
- MICHOT, P., 1978. L'Ordovicien de la vallée de Thyle: structure tectonique, stratigraphie et lithologies. *Annales de la Société géologique de Belgique*, 100: 223-31.
- MOLYNEUX S., 1987. Acritarchs and Chitinozoa from the Arenig Series of south-west Wales. *Bulletin of the British Museum of Natural History (Geology)*, 41, 309-364
- MOLYNEUX, S.G. & LEADER, R.U., 1997. Morphological variation in *Coryphidium* from the Arenigian Series (Lower Ordovician) of northwestern England. *Review of Palaeobotany and Palynology*, 98: 81-94.
- MOLYNEUX, S.G. & RUSHTON, A.W.A., 1988. The age of the Watch Hill Grits (Ordovician), English Lake District: structural and palaeogeographical implications. *Transactions of the Royal Society of Edinburgh. Earth Sciences*, 79: 43-69.
- PLAYFORD G., RIBECAL C. & TONGIORGI M., 1995. Ordovician acritarch genera *Peteinosphaeridium*, *Liliosphaeridium* and *Cycloposphaeridium*: morphology, taxonomy, biostratigraphy and palaeogeographic significance. *Bollettino della Società Paleontologia Italica*, 34, 3-54
- RUSHTON, A.W.A. & MOLYNEUX, S.G., 1989. The biostratigraphic age of the Ordovician Skiddaw Group in the Black Combe Inlier, English Lake District. *Proceedings of the Yorkshire Geological Society*, 47: 267-276.
- SAMUELSSON, J. & VERNIERS, J., 1999. Middle to Late Ordovician Chitinozoan Biozonation of the Sennette, Dyle-Thyle and Orneau Valleys, Brabant Massif, Belgium. *Acta Universitatis Carolinae-Geologica*, 43 (1-2): 299-302.
- SAMUELSSON, J. & VERNIERS, J., 2000. Ordovician chitinozoan biozonation of the Brabant Massif, Belgium. *Review of Palaeobotany and Palynology*, 113: 105-129.
- SCOTESE, C.R. & MCKERROW, W.S., 1990: Revised world maps and introduction. In Mc Kerrow, W.S. & Scotese, C.R. (eds), Palaeozoic Palaeogeography and Biogeography, *Geological Society*, Memoir 12: 1-21.
- SERVAIS, T., 1989. The Rigenée Formation in the Brabant Massif. Abstract International Meeting on the Caledonides of the Midlands and the Brabant Massif, Brussels 20-23 September 1989, p.40.

- SERVAIS, T., 1991. Contribution to the stratigraphy of the Ordovician Rigenée formation (Brabant Massif, Belgium) with preliminary studies on Acritarchs. *Annales de la Société Géologique de Belgique*, 114: 233-245.
- SERVAIS, T., 1993. The Ordovician acritarch *Frankea*. *Special Papers in Palaeontology*, 48: 79-95.
- SERVAIS, T., 1997. The Ordovician *Arkonja-Striatotheca* acritarch plexus. *Review of Palaeobotany and Palynology*, 98: 47-49.
- SERVAIS, T. & MALETZ, J., 1992. Lower Llanvirn (Ordovician) graptolites and acritarchs from the "assise de Huy", bande de Sambre-et-Meuse, Belgium. *Annales de la Société Géologique de Belgique*, 115: 265-285.
- SERVAIS, T., LI, J., MOLYNEUX, S.G. & RAEVSKAYA, E., 2003. Ordovician organic walled microphytoplankton (acritarch) distribution: the global scenario. *Palaeogeography Palaeoclimatology Palaeoecology*, 195: 149-172.
- STREEL, M., 1965. Techniques de preparation des roches détritiques en vue de l'analyse palynologique quantitative. *Annales de la Société géologique de Belgique*, 88: 107-117.
- TIMOFEEV B. V., 1958. Über das Alter Söchsischer Grauwacken. Mikropaleophytologische Untersuchungen von Proben aus der Weisensteiner und Lausitzer Grauwacke. *Géologie*, 7, 826-845
- TONGIORGI, M. & DI MILIA, A., 1999. Differentiation and spread of the Baltic Acritarch Province (Arenig-Llanvirn). *Bollettino della Società Paleontologica Italiana*, 38: 297-312.
- TONGIORGI, M., YIN, L.-M. & DI MILIA, A., 2003. Lower Yushanian to lower Zejiangian palynology from the Yangtze Gorges area (Daping and Huanghuachang sections, Hubei Province, South China). *Palaeontographica, Abteilung B*, 266: 1-160.
- VANGUESTAINE, M., 1978. Données palynologiques nouvelles dans l'Ordovicien inférieur du Bassin de la Senne, Massif du Brabant, Belgique. *Annales de la Société Géologique de Belgique*, 100: 193-198.
- VANGUESTAINE, M., CHAKIR, A. & SERVAIS, T., 1989. Cambrian (?) and Ordovician acritarchs from the Thyle Valley. *Abstracts of an International Meeting on the Caledonides of the Midlands and the Brabant Massif*, 45.
- VAVRDOVÁ, M., 1965. Ordovician acritarchs from central Bohemia. *Vestník Ustředního Ústavu Geologického*, 40: 351-357.
- VAVRDOVÁ, M., 1966. Palaeozoic microplankton from central Bohemia. *Easopsis pro Mineralogii a Geologii*, 11: 409-414.
- VAVRDOVÁ, M., 1972. Acritarchs from the Klabava Shales (Arenig). *Vestník Ustředního Ústavu Geologického*, 47: 79-86.
- VAVRDOVÁ, M., 1974. Geographical differentiation of Ordovician acritarch assemblages in Europe. *Review of Palaeobotany and Palynology*, 18: 171-176.
- VAVRDOVÁ, M., 1977. Acritarchs from the Sarka Formation (Llanvirnian). *Vestník Ustředního Ústavu Geologického*, 52: 109-118.
- VECOLI, M., TONGIORGI, M. & PLAYFORD, G., 1999. The Ordovician acritarchs *Frankea brevisuscula*, *F. longiuscula*, and *F. sartbernardensis*: a new study. *Bollettino della Società Paleontologica Italiana*, 38: 343-358.
- VECOLI, M. & LE HERISSE, A., 2004. Biostratigraphy, taxonomic diversity and patterns of morphological evolution of Ordovician acritarchs (organic-walled microphytoplankton) from the northern Gondwana margin in relation to palaeoclimatic and palaeogeographic changes. *Earth-Sciences Reviews*, 67: 267-311.
- VERNIERS, J., HERBOSCH, A., VANGUESTAINE, M., GEUKENS, F., DELCAMBRE, B., PINGOT, J.-L., BELANGER, I., HENNEBERT, M., DEBACKER, T., SINTUBIN, M. & DE VOS, W., 2001. Cambrian-Ordovician-Silurian lithostratigraphic units (Belgium). In Bultynck, P. & Dejonghe, L. (eds), *Guide to a Revised Stratigraphic Scale of Belgium*, *Geologica Belgica*, 4: 5-38.
- WEBBY, B.D., 1998. Steps toward a global standard for Ordovician stratigraphy. *Newsletters on Stratigraphy*, 36 (1): 1-33.

Plate I

Scale bar = 20µm on all photographs. All specimens are specified with sample number, palynological slide number and English Finder coordinates.

- A : *Acanthodiacrodidium costatum* Burmann, 1968 : VLV-85/2, 21259, R42-3
 B : *Adorfia firma* Burmann, 1970 : VLV-85/7, 21257, M40 (composite photograph)
 C : *Arbuluscidium filamentosum* (Vavrdová, 1965) Vavrdová, 1972 : VLV-85/8, 2113, L36-1
 D : *Arkonina tenuata* Burmann, 1970 : VLV-85/7, 21257, R51 1-3
 E : *Aureotesta clathrata* var. *clathrata* Vavrdová, 1972 : RB02-20, 59714, Z36-2
 F-H : *Coryphidium* aff. *bohemicum* Vavrdová, 1972 in Molyneux & Leader, 1997
 F : VLV-85/7, 21257, XY50
 G : VLV-85/2, 21259 Y39-2 (composite photograph)
 H : VLV-85/9, 21260, N57-4
 I : *Cymatiogalea granulata* Vavrdová, 1966 : VLV-85/9, 21260, D56
 J-K : *Frankea breviscula* Burmann, 1970 :
 J : VLV-85/2, 21259 S41-1
 K : VLV-85/9, 21260 K45-2
 L : *Frankea hamata* Burmann, 1970 : VLV-85/2, 21259, P36-2
 M : *Peteinosphaeridium* sp. : VLV-85/9, 21260 P57-4 (composite photograph)
 N : *Polygonium gracile* Vavrdová, 1966 : VLV-85/9, 21260 Q57-4
 O-P : *Solisphaeridium* sp A :
 O : VLV-85/2, 21242 M41-2
 P : VLV-85/7, 21257, C42 3-4
 Q-R : *Striatotheca microrugulata* (Vavrdová, 1972) Eisenack et al., 1976 :
 Q : VLV-85/7, 21257 P-Q 37
 R : RB02-19, 59691, ST32 (composite photograph)
 S : *Striatotheca principalis principalis* Burmann, 1970 : VLV-85/7, 21527 S52-53
 T-V : *Striatotheca rarrirugulata* (Cramer et al., 1974) Eisenack et al., 1976 :
 T : VLV-85/9, 21260 P47-4 1 (composite photograph)
 U : VLV-85/1, 25258 F41-3
 V : VLV-85/2, 21259, J57-4
 W : *Veryhachium* aff. *Lairdii* Deflandre, 1946 ex Loeblich, 1970 : VLV-85/7, 21257 DE41
 X : *Veryhachium reductum* (Deunff, 1959) Downie & Sarjeant, 1964 : VLV-85/7, 21257 R53

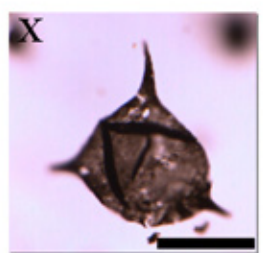
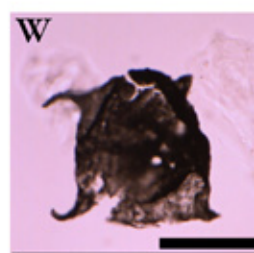
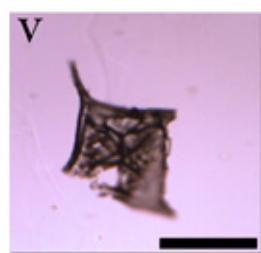
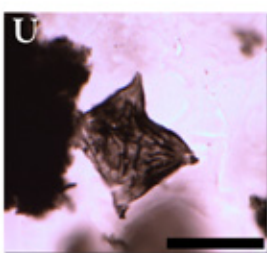
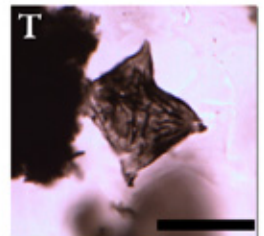
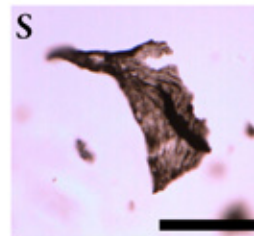
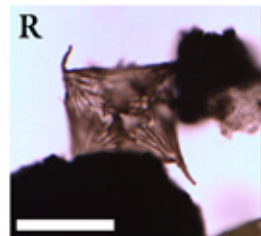
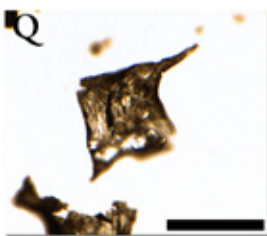
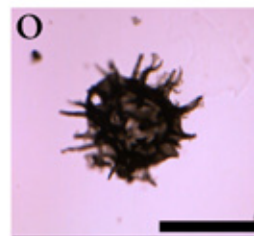
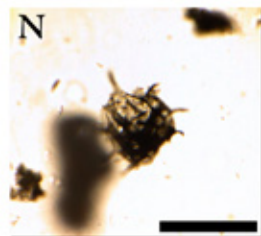
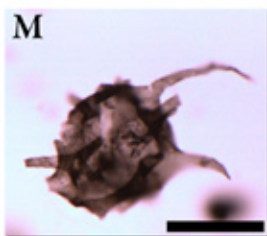
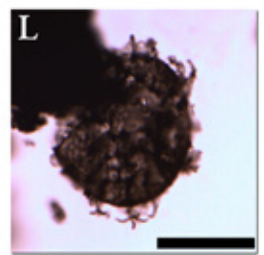
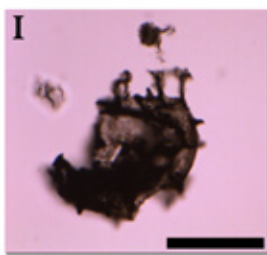
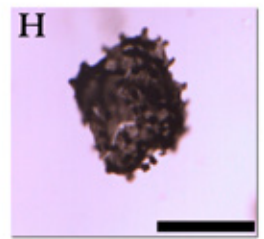
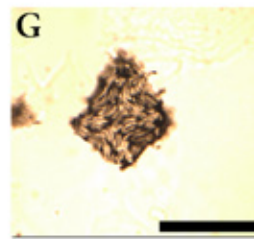
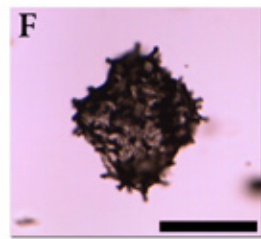
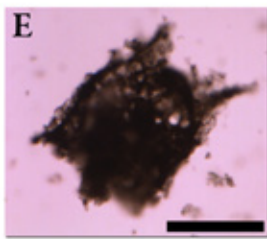
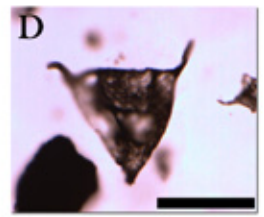
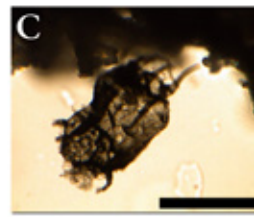
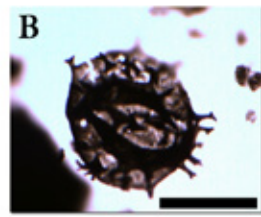
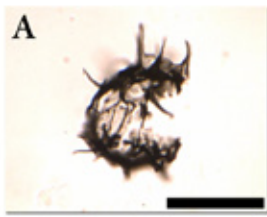
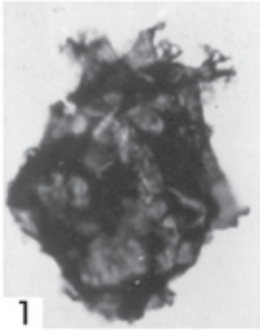
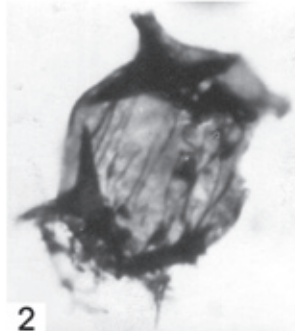


Plate II

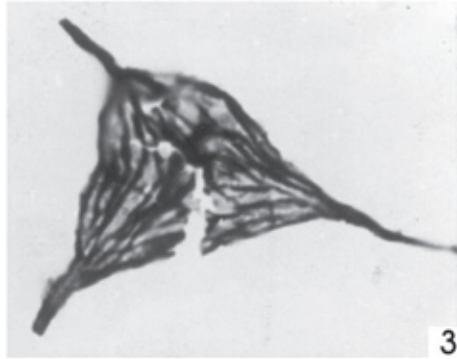
- 1, 2 : *Solisphaeridium* sp A
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2: VLV-85/7, 21257, C42/3-4: \pm 40 conical, simple processes
- 3, 4 : *Solisphaeridium* sp B: VLV-85/7, 21257, 2204.
- 5 : *Stelliferidium striatulum* (Vavrdová, 1966) Deunff et al., 1974.
- 6, 7 : *Striatotheca microrugulata* (Vavrdová, 1972) Eisenack et al., 1976.
6: VLV-85/7, 21257, 1180-1181
7: RB02-19, 59691, ST32
- 8, 9, 10 : *Striatotheca rarrirugulata* (Cramer et al., 1974) Eisenack et al., 1976.
8: VLV-85/2, 21259, 1327
9: VLV-85/1, 25258, F41/3
10: VLV-2, 21259, 1315
- 11 : *Veryhachium* aff. *lairdii* Deflandre, 1946 ex Loeblich, 1970.
VLV-85/7, 21257, DE41
- 12, 13 : *Veryhachium reductum* (Deunff, 1959) Downie & Sarjeant, 1963
12: VLV-85/7, 21257, R53: vesicle diameter: 28 μ m; processes height 12 μ m.
- 14 : *Veryhachium* sp
VLV-85/7, 21257, 0923



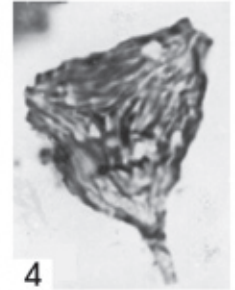
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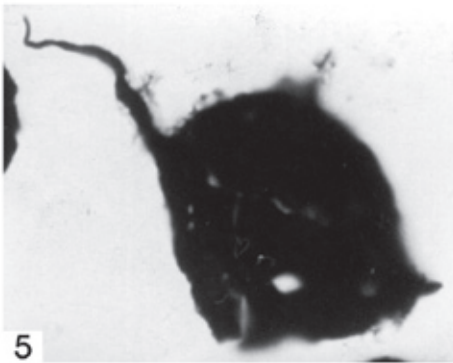
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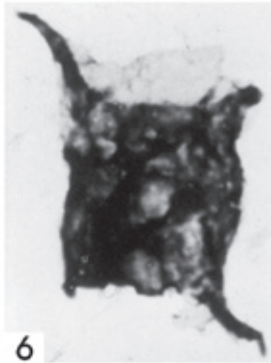
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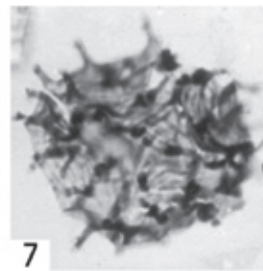
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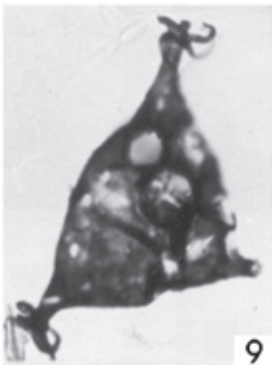
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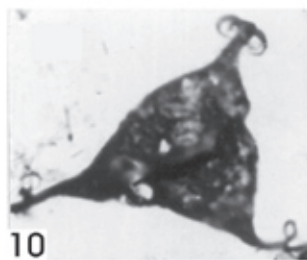
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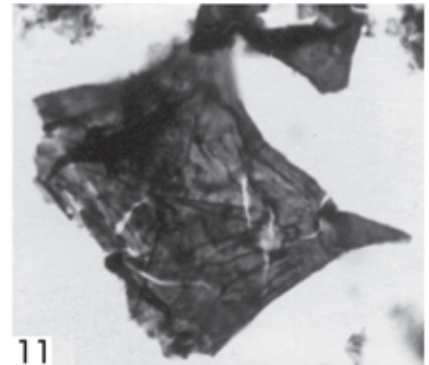
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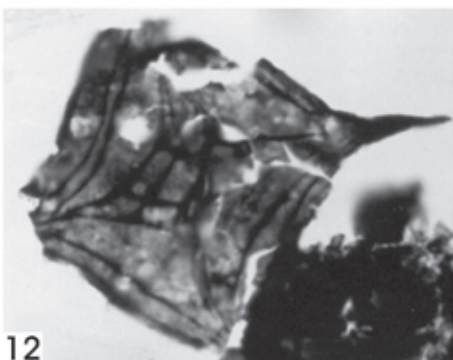
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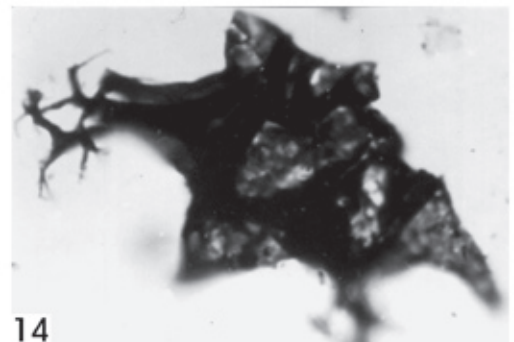
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