

## Ordovician chitinozoan biozonation of the Brabant Massif, Belgium

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### Abstract

Chitinozoans from seven Ordovician units (Abbaye de Villers, Tribotte, Rigenée, Ittre, Bornival, and Brutia formations and a new unnamed unit, here provisionally called the Asquemont unit) belonging to the mainly concealed Brabant Massif, Belgium are described herein. Fifty-six samples were taken from rocks cropping out at the south-eastern rim of the massif in the Orneau, Dyle–Thyle and Senne–Sennette valleys. Microfossil preservation is moderate to poor, and the chitinozoans occur in low numbers. Taxonomically, the recovered chitinozoans are distributed into 29 taxa, some placed under open nomenclature. Together with earlier published graptolite and acritarch data, the analysis of the chitinozoan assemblages resulted in an improved chronostratigraphy of the investigated formations. We propose a local chitinozoan biozonation with 11 zones for the Brabant Massif. The oldest investigated units yielded chitinozoans typical for North Gondwana, and younger units (starting in the middle Caradoc), yielded some taxa also common in Baltica. As the Brabant Massif formed part of the microcontinent Avalonia, the chitinozoan assemblages recovered from the massif support the inferred drifting of Avalonia from high latitudes towards middle latitudes in the Ordovician as was suggested earlier. © 2000 Elsevier Science B.V. All rights reserved.

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### 1. Introduction

The Brabant Massif is a largely concealed part of the bedrock basement underlying 38% of Belgium (Verniers et al., 1991; Fig. 1). Since Servais et al. (1993) presented their review of the Belgian Ordovician stratigraphy, new geological mapping has led to improved descriptions and definitions of the lithostratigraphic units within the massif (e.g. Van Grootel and Verniers, 1998; Herbosch and Lemonne, 2000). The aim of the present study is to

complement previous biostratigraphic work (e.g. Martin, 1969, 1974, 1977; Martin and Rickards, 1979; Servais, 1991; André et al., 1991; Van Grootel et al., 1997; Maletz and Servais, 1998) by describing and evaluating the chitinozoan faunas in three of the most important outcrop areas of the Brabant Massif: the Orneau, the Dyle–Thyle and the Senne–Sennette valleys (Fig. 1). Together with graptolite and acritarch data, the identified chitinozoan faunas significantly improve the understanding of the temporal relationships of the Ordovician Brabant Massif units.

Herein, 56 samples were palynologically investigated. Although the microfossils are only moderately well-preserved, biostratigraphically important taxa were recognised, and 11 new local chitinozoan biozones were identified within the investigated units.

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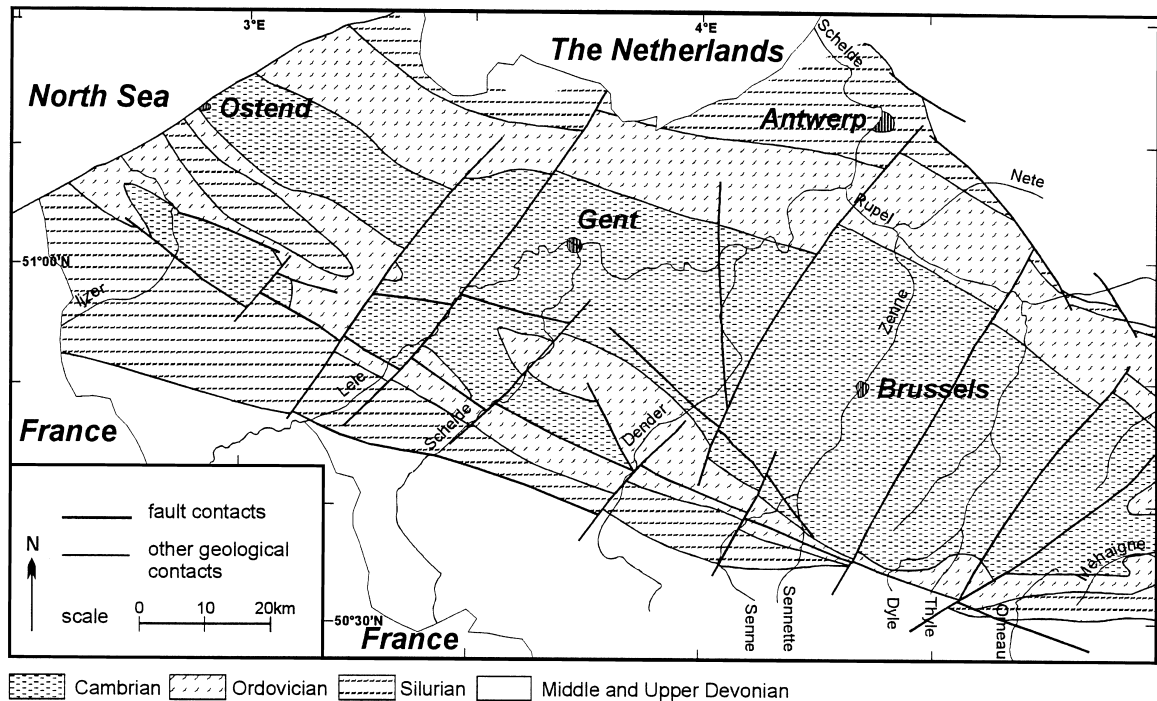


Fig. 1. Map of the Brabant Massif showing the main outcrop areas along the valleys of the Senne-Sennette, Dyle-Thyle and Orneau rivers in its south-eastern part. Modified after De Vos et al. (1993).

### 1.1. Previous chitinozoan studies in the Ordovician units of the Brabant Massif

Ordovician chitinozoans of the Brabant Massif were first studied by Martin (1971, 1974) in the Caradoc to middle Llandovery of the Deerlijk borehole, in western Belgium. Martin and Rickards (1979) found some specimens of *Ancyrochitina* sp. in their unit F in the Asquempont canal section, now named the Ittre Formation. This allowed them to date the unit as Caradoc, supported by their graptolite data and confirmed as lower Caradoc by Maletz and Servais (1998). Servais (1988) recovered chitinozoans from the Ittre and Fauquez formations of the Lessines borehole (Dendre valley), the Rigenée Formation in the Dyle valley and in the Ittre Formation in the Asquempont canal section (Sennette valley). A sample from each of the two latter units were tentatively investigated by F. Paris (in Servais, 1988), who confirmed the presence of moderately preserved and diverse chitinozoan assemblages.

Van Grootel (1990, 1995) investigated Ordovician and Silurian chitinozoan faunas of the western buried part of the Brabant Massif in a number of drillholes. Van Grootel et al. (1997) reported a local chitinozoan biozonation for the lithological Units I and II of Lessines, the Harelbeke unit, the Lichtervelde section and the Fauquez outcrop area (Sennette valley). In an internal unpublished report for the Belgian Geological Survey, Van Grootel and Verniers (1998) presented the lithostratigraphy of the Fauquez area where five Upper Ordovician units were described in detail and accompanying chitinozoan faunas listed. In the same report, a preliminary chitinozoan biozonation of the Ordovician of the Brabant Massif was presented (Samuelsson and Verniers, 1998). An improved version of this biozonation was presented by Verniers et al. (1999) together with some new chitinozoan data from the Condroz Inlier. Preliminary data from the present investigation were presented by Samuelsson and Verniers (1999).

## 2. Geology of the Brabant Massif

### 2.1. General overview

The Brabant Massif is the south-east part of the Anglo-Brabant fold belt, known from subcrop and small outcrop areas in Belgium. It contains up to 8000 m of ?uppermost Proterozoic and Lower Palaeozoic siliciclastic sediments, deformed and transformed under anchi- or epimetamorphic conditions during the Lower Devonian to Eifelian Acadian Orogeny. The massif is unconformably covered by Givetian, Upper Devonian and Carboniferous sediments (Verniers and Van Grootel, 1991; Pharaoh et al., 1993; De Vos et al., 1993). As a part of the microcontinent Avalonia, it drifted off Gondwana in the Ordovician (Prigmore et al., 1997) to collide with Baltica closing the Tornquist Ocean probably in the Ashgill (e.g. Katzung et al., 1995; Samuelsson et al., 2001).

Numerous isolated and in most cases discontinuous Ordovician sections crop out in some small river-valleys in the southern part of the massif. The samples investigated here come from three of these: the Orneau, Dyle–Thyle and Senne–Sennette valleys (Fig. 1). In addition, parts of the massif are known from numerous drillings outside the outcrop area (De Vos et al., 1993).

### 2.2. Lithology of the units investigated herein

The Middle and Upper Ordovician in the Brabant Massif contains the following 10 formations in ascending order (see Servais et al., 1993; Van Grootel et al., 1997; Verniers et al., 2001, for descriptions and references). The Abbaye de Villers Formation, 100–150 m thick, contains grey or dark grey siltstone and mudstone, with a distinct lenticular lamination, frequently bioturbated along the bedding planes. Occasional decimetre-scale cross-bedded fine to medium sandstone beds, turbiditic in nature, and also metre-scale beds with through cross-bedding is characteristic for the unit. The lower boundary with the Tremadoc-aged Chevlipont Formation was never directly observed, and hence the nature of the hiatus as fault, non-deposition or condensed section is unknown. The upper boundary with the Tribotte

Formation as observed in the Dyle–Thyle valleys is gradual.

In the Sennette valley, an unnamed unit was discovered near Asquemont, below the Tribotte Formation, with a minimum thickness of 25 m. This unit contains decimetre-scale black sandstone beds alternating with dark to medium grey siltstone and slate beds, not observed in other parts of the Brabant Massif. Geometrically, it can be interpreted as either situated below the Abbaye de Villers Formation, a lateral equivalent of the top of the latter unit, or a unit present between the Abbaye de Villers and the Tribotte formations.

The Tribotte Formation, 150–300 m thick, consists in its lower part of brownish grey, clayey sandstone and siltstone with coarse lamination and strongly bioturbated, mainly (sub)vertical burrows. In its middle and upper part, yellowish grey to greenish grey sandstone more clayey than below occurs. The clayey sandstone is followed by a gradual transition of dark grey, very fine slate and mudstone of the 80–200-m thick Rigenée Formation. The latter is compact with some vague laminations.

The Rigenée Formation passes via a short 10-m thick transition into the up to 180-m thick Ittre Formation, which consists of dark to medium grey mudstone, micaceous siltstone and decimetre-scale fine sandstone, of a Bouma turbidite type. Close to the base, 5-m thick volcanic tuffs occur. The unit passes by the gradual disappearance of the decimetre-scale fine sandstone beds into the Bornival Formation. The latter formation, with a minimum estimated thickness of 150 m contains a centimetre-scale alternation of medium grey siltstone and dark grey mudstone with coarse silt grains distributed throughout, and occasional thin beds of fine sandstone. Contact with the overlying unit is unknown and either by fault or covered.

The succeeding more than 60-m thick Huet Formation is made up of greenish to grey mudstone, siltstone and fine poorly sorted sandstone, with many levels containing a decalcified macrofauna (bryozoans, brachiopods, crinoids and trilobites). The decimetre- to metre-scale beds are sometimes vaguely laminated. The oxic unit passes rapidly into the anoxic Fauquez Formation, up to 58 m thick, containing black fine and dark grey silty slate, with either no stratification or centimetre- to millimetre-scale alternation of darker

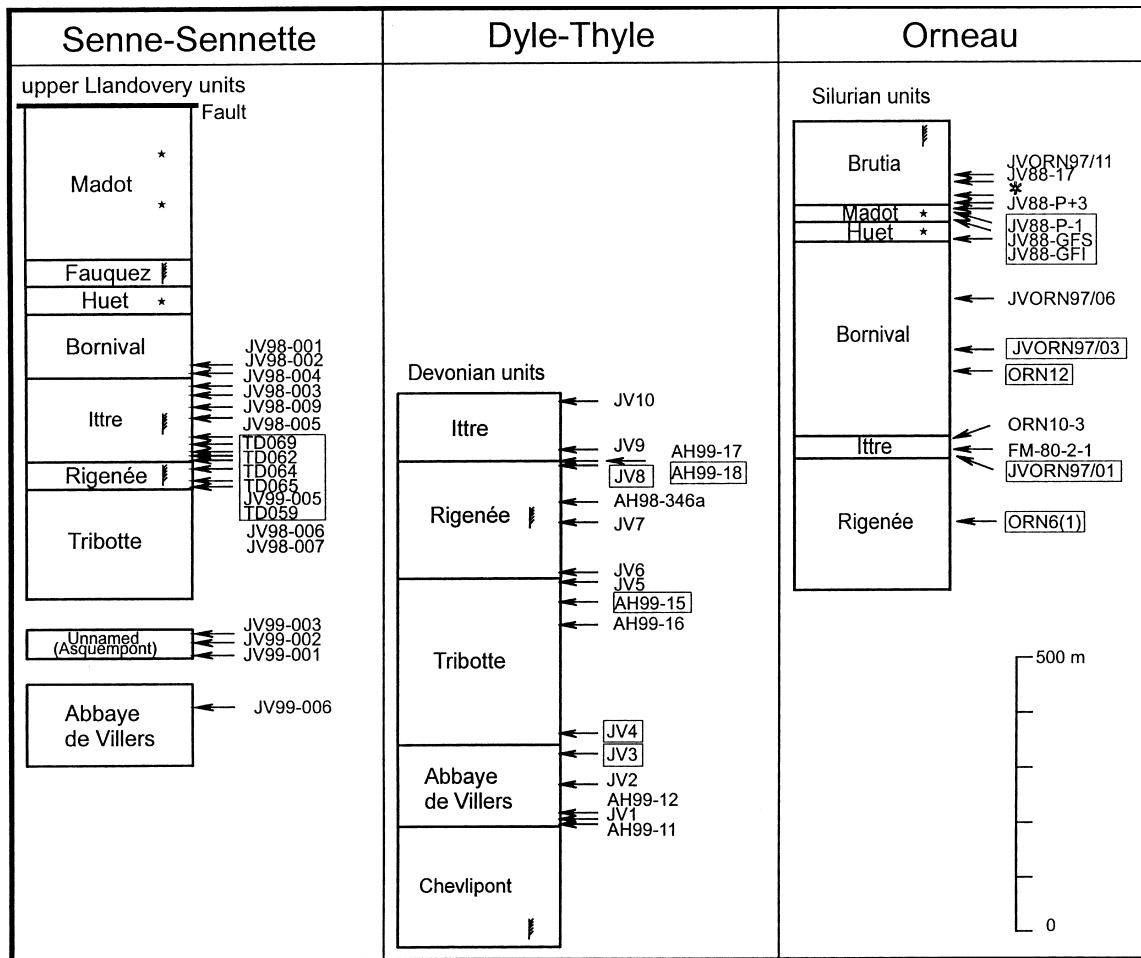


Fig. 2. Schematic overview of the Ordovician lithostratigraphy in the three valleys of the outcrop area in the Brabant Massif. The approximate sampling horizons are indicated (see Appendix A for the exact location). The formation thicknesses are only approximately drawn to scale. A frame around the sample name indicates that the sample is barren. The star (\*) indicates the location of the barren samples JV88-P + 7 to JV88-P + 15, and JV88-P + 16 which yielded a single chitinozoan (see Fig. 3). The five-pointed stars indicate that macrofossils such as bryozoans, brachiopods, cystoids and trilobites are recovered in these units (see Section 6 in the main text for references). The stylised graptolites denote levels with graptolites.

Chitinozoans from the Bornival (upper members), Huet, Fauquez and Madot formations from the Sennette valley were studied by Van Grootel et al. (1997) and Van Grootel and Verniers (1998).

and lighter grey slate, underlined by either pyrite- or graptolite-rich levels. It is not proven to occur in the Orneau valley.

The anoxic Fauquez Formation passes again into the Madot Formation (which is 10 m thick in the east and up to 220 m thick in the Sennette valley, where seven local members can be distinguished). It contains volcanic rocks (brecchias, tuffs and volcano-sedimentary rocks) interstratified in either oxic,

greenish-grey coarse mudstone and siltstone with macrofaunal levels (bryozoans, brachiopods, crinoids, corals, trilobites and pelmatozoans), or anoxic dark grey fine slate or mudstone, with finely distributed volcanic minerals.

The contact with the succeeding up to 100 m thick Brutia Formation is observed in the Orneau valley. This non-turbiditic unit consists of dark greenish grey and grey mudstone and slate with no sedimentary

structures. One-third up in the formation a few metre thick sub-unit is present with dark grey millimetre-scale mottles in a medium grey mudstone, indicating an oxic, bioturbated horizon. This formation continues into the Rhuddanian (lower Silurian).

### 3. Material and methods

Fifty-six samples, in most cases collected specifically for chitinozoan analysis were investigated (Fig. 2). In some cases (see Appendix A), the samples were collected from outcrops that were only temporarily accessible during construction work. Great care was taken to sample only fine-grained, unweathered rocks, as little deformed as possible.

The chitinozoans were extracted from the rock samples using standard palynological techniques that includes breaking down the rock matrix with HF and HCl (Paris, 1981). The chitinozoans were then handpicked and mounted for optical and scanning electron microscopy (SEM) studies. Slides for optical microscopy were prepared using Canada Balsam as mounting medium. The SEM micrographs were taken on a JEOL Scanning Microscope JSM-6400 at 10 kV of the Department of Geology and Pedology, Ghent University. All illustrated specimens are housed in the collections of the Research unit Palaeontology, Department of Geology and Pedology, Ghent University, Belgium.

### 4. Palynological results

#### 4.1. State of preservation, abundance and taxonomic diversity

Thirty-one out of 56 samples from the three investigated areas yielded moderately to poorly preserved chitinozoans (Figs. 2–5). The microfossils are generally opaque, and brown to dark-brown in colour. Poor microfossil preservation is likely a result of the Acadian deformation of the Brabant Massif under epi- to anchimetamorphic conditions (Van Grootel et al., 1997).

The chitinozoans occur in low numbers, between less than one to 15 chitinozoans/g rock (Figs. 3–5). Almost all the chitinozoans are flattened. Because of the generally poor preservation and limited number of

specimens, a large portion of the observed chitinozoans remain undetermined. Where specific determination was possible, the number of available specimens is generally low. In summary, the present material consists of forms certainly determined to any of 15 species, and another five taxa uncertainly determined to the species level. Nine taxa are determined to the genus level only.

For the measurements in the following sections, the symbols are used as in Paris (1981) where  $L$  = total length;  $L_p$  = chamber length;  $D_p$  = chamber diameter,  $D_c$  = diameter of oral tube. The dimensions given below are with an approximate accuracy of  $\pm 2 \mu\text{m}$ . Measurements and statistical analyses were made on the flattened specimens and no correction factors sensu Paris (1981) were employed to obtain presumed three-dimensional sizes.

#### 4.2. Orneau Valley

In the Orneau valley, only seven out of 21 investigated samples yielded chitinozoans (Fig. 3). The microfossils were generally poorly preserved, especially delicate details such as spines and appendages. From the Ittre Formation the sample ORN 10-3 yielded e.g. *Belonechitina* cf. *robusta* (Eisenack; average:  $D_p = 64 \mu\text{m}$ ;  $N = 3$ ), with the randomly distributed spines showing the characteristic  $\lambda$ - and multirooted-shape at the base. However, the preservation of these fine details are rather poor (Plate II: 8), and we therefore treat the specimens under open nomenclature. In sample FM-80-2-1, also in the Ittre Formation, three specimens of *Spinachitina*, probably *S. bulmani* (Jansonius) were observed.

In the Bornival Formation, a fossiliferous sample (JVORN 97/06) yielded six specimens of *Belonechitina* cf. *robusta* (Eisenack) ( $D_p = 80 \mu\text{m}$ ,  $N = 6$ ) and a single specimen uncertainly attributed to *Euconochitina* sp. In the Huet Formation, no chitinozoans were found.

In the Madot Formation, a fossiliferous sample (JV88-P + 3) yielded 32 specimens of *Lagenochitina baltica* Eisenack (average size:  $L_p = 203 \mu\text{m}$ ,  $N = 19$ ;  $D_p = 110 \mu\text{m}$ ,  $N = 21$ ;  $D_c = 59 \mu\text{m}$ ,  $N = 20$ ; Fig. 3; Plate III: 3, 4). Furthermore, the same sample yielded 24 specimens here attributed to *Conochitina* sp. A (average size:  $L_p > 195 \mu\text{m}$ ,  $N = 16$ ;  $D_p = 77 \mu\text{m}$ ,  $N = 17$ ;  $D_c < 54 \mu\text{m}$ ,  $N = 13$ ). Specimens attributed

FORMATION	Orneau	Chitinozoan species														undetermined Chitinozoa	number of chitinozoans/g rock	number of Chitinozoa/sample	sample weight (g)		
		<i>Hercochitina</i> cf. <i>gamachiana</i>	<i>Lagenochitina</i> sp.	<i>Conochitina</i> spp.	<i>Cyathochitina campanulaeformis</i>	<i>Lagenochitina baltica</i>	? <i>Tanuchitina</i> sp.	<i>Conochitina</i> sp. A	<i>Conochitina</i> sp. B	<i>Conochitina</i> sp. C	<i>Conochitina</i> sp. D	<i>Conochitina</i> sp. E	<i>Conochitina</i> sp. F	<i>Conochitina</i> sp. G	<i>Conochitina</i> sp. H					<i>Conochitina</i> sp. I	
Brutia	JVORN 97/11	5	1															4	<1	10	29
	JV88-17	18	12	7														1	1	38	42
	JV88-P+16																	1	<<1	1	10
	JV88-P+15																				10
	JV88-P+13																				11
	JV88-P+12																				11
	JV88-P+10'																				10
	JV88-P+10																				11
	JV88-P+8																				11
JV88-P+7																				28	
Madot	JV88-P+3			1	32	1	24	9	1	1	2							3	6	73	12
	JV88-P-1																				39
	JV88-GFS																				30
Huet	JV71-GFI																				31
Bornival	JVORN 97/06		19								3	6	1	6	1	1		32	3	69	27
	JVORN 97/3																				33
	ORN 12																				29
Ittre	ORN 10-3		12								3	4					6	47	1	72	29
	FM-80-2-1	2	8							2							3	2	?	17	?
	JVORN 97/01																				27
Rigenée	ORN 6(1)																			28	

Fig. 3. The absolute abundance of chitinozoans observed in the Orneau valley samples. Grey fields indicate barren samples. For sample details, see Appendix A.

to *Conochitina* sp. A have a cylindrical to claviform shape and are smooth. Their base is sometimes flat, and an invaginated depression is usually well developed. The basal margin is somewhat rounded. Maximum width of the chamber is at ca 1/3 of the total length from the base (Plate III: 1, 2). These specimens are comparable to *Pistillachitina elegans* (Eisenack), but are shorter, and do not possess the characteristic widened base of *P. elegans*. They are also similar to *Conochitina dolosa* Laufeld; however, *C. dolosa* is larger, and has a more rounded basal edge.

Ten samples from the Brutia Formation were examined, but only two yielded any useful chitinozoans (Fig. 3). In the mottled mudstone level of the Brutia Formation, in total 23 specimens of *Hercochitina* cf. *gamachiana* (Achab) were recovered from the samples JV88-17 and JVORN 97/11 (average size in JV88-17:  $L_p > 140 \mu\text{m}$ ,  $N = 17$ ;  $D_p = 84 \mu\text{m}$ ,  $N =$

17;  $D_c = 62 \mu\text{m}$ ,  $N = 13$ ), all are longitudinally incomplete (Plate III: 6, 8–11), and therefore placed in open nomenclature. The arrangement of the spiny ornamentation of these specimens in vertical rows (e.g. Plate III: 11) suggests that they belong within the genus *Hercochitina* rather than *Belonechitina* (see Paris et al., 1999). In the sample JV88-17, seven specimens of *Cyathochitina campanulaeformis* (Eisenack) (Plate III: 5, 7) were observed (average not possible to obtain, since the specimens were fragmented; typical measurements are  $L_p = 170 \mu\text{m}$ ;  $D_p = 120 \mu\text{m}$ ;  $D_c = 60 \mu\text{m}$ , where every measurement is from a different specimen).

#### 4.3. Dyle–Thyle valleys

Of the 17 investigated samples, 12 were fossiliferous (Figs. 2 and 4). Although more of the

FORMATIONS	Dyle - Thyle	Chitinozoan species															undetermined Chitinozoa	number of Chitinozoa/g rock	number of Chitinozoa/sample	sample weight (g)	
		<i>Spinachitina ?bulmani</i>	<i>Belonechitina</i> spp.	<i>Conochitina chydaea</i>	<i>Conochitina</i> spp.	<i>Cyathochitina</i> spp.	<i>Desmochitina</i> sp.	<i>Euconochitina</i> spp.	<i>Conochitina minnesotensis</i>	<i>Rhabdochitina</i> spp.	<i>Pistillachitina elegans</i>	<i>Lagenochitina</i> spp.	<i>Cyathochitina calix</i>	<i>Lagenochitina obeligitis</i>	<i>Belonechitina gr. micracantha</i>	<i>Euconochitina vulgaris</i>					<i>Eremochitina brevis</i>
Ittre	JV 10	2	2	1	8	3	1	3	3	3							40	2	66	30	
	JV 9		1		4	4			25		1						64	3	99	31	
Ittre/ Rigenée	AH99-17				4	15											7	2	26	12	
	AH99-18																			10	
Rigenée	JV 8																			32	
	AH98-346a				1			1			1						2	<1	5	30	
	JV 7		1	3	108	6			30			2	2				102	9	254	29	
	JV 6				9						1		3				30	1	43	31	
Tribotte	JV 5					1					2			1	1		14	1	19	31	
	AH99-15																			10	
	AH99-16																3	<1	3	11	
	JV 4																			38	
Abbaye de Villers	JV 3																			45	
	JV 2				1			6					11	2			5	1	25	28	
	AH99-12						1						7			2	4	1	14	10	
	JV 1				6			2					9			3	28	2	48	28	
	AH99-11				1	1											4	<1	6	33	

Fig. 4. 4 Absolute abundance of chitinozoans in the Dyle–Thyle valley samples. Grey fields indicate barren samples. For sample details, see Appendix A.

investigated samples were fossiliferous than in the Orneau and Senne–Senette valleys, the state of preservation of individual chitinozoans is comparable to that in the Orneau valley, with delicate details poorly preserved.

Chitinozoans identified at the base of the Abbey de Villers Formation (samples JV 1 and AH99-12) yielded five broken *Eremochitina brevis* Benoit and Taugourdeau with the oral part of the chamber missing (average in JV 1:  $D_p = 60 \mu\text{m}$ ,  $N = 3$ ; diameter of copula =  $18 \mu\text{m}$ ,  $N = 3$ ). *Lagenochitina obeligitis* Paris (average in JV 1:  $L_p = 166 \mu\text{m}$ ,  $N = 7$ ;  $D_p = 102 \mu\text{m}$ ,  $N = 9$ ;  $D_c = 48 \mu\text{m}$ ,  $N = 9$ ;  $L_p = 116 \mu\text{m}$ ,  $N = 6$ ) was also present in samples AH99-12 and JV 2 (Plate I: 4). Two specimens of *Euconochitina vulgaris* (Jenkins) were recovered from sample JV 2 (Plate I: 5);  $L = 100 \mu\text{m}$ ;  $D_c = 50 \mu\text{m}$ ;  $D_p = 95 \mu\text{m}$ ;  $L_p = 62 \mu\text{m}$ ;  $N = 1$ ).

In the Tribotte Formation, only a sample from the upper part of the formation (JV 5) yielded any specimens identifiable to the species level. This

sample contained a single specimen attributed to *Belonechitina gr. micracantha* (Eisenack) (Plate I: 12) and a single *Euconochitina vulgaris* (Jenkins).

In the Rigenée Formation, *Lagenochitina obeligitis* Paris was present with two specimens in sample JV 7. The same sample yielded poorly preserved smooth, rather wide (ca  $200 \mu\text{m}$ ) chitinozoans in great numbers. These are comparable to larger Conochitinae such as *Conochitina minnesotensis* Stauffer (Plate II: 2, 3, 4), and possibly *Rhabdochitina magna* Eisenack, but are here generally included in *Conochitina* spp. (Fig. 4). A few specimens attributed to *Cyathochitina calix* (Eisenack) are present in the formation (JV 6 and JV 7). Paris (1981) points out that Eisenack’s type *C. calix*-material raises taxonomic problems, and in a later paper (Paris, 1990), he uses a more limited definition of the species for his North Gondwana *Cyathochitina calix* Biozone. As the present specimens are few and flattened, we have not been able to use the definition of Paris (1981), but use instead Eisenack’s original description

FORMATIONS	Senne - Sennette	Taxonomy														undetermined Chitinozoa	number of Chitinozoa/g rock	number of Chitinozoa/sample	sample weight (g)								
		<i>Conochitina</i> spp.	<i>Cyathochitina</i> spp.	<i>Euconochitina</i> spp.	<i>Cyathochitina campanulaeformis</i>	<i>Conochitina minnesotensis</i>	<i>Desmochitina lecaniella</i>	<i>Desmochitina</i> spp.	<i>Belonechitina cf. robusta</i>	<i>Belonechitina</i> spp.	<i>Rhabdochitina</i> spp.	<i>Spinachitina ?bulmani</i>	<i>Conochitina chydaea</i>	<i>Rhabdochitina magna</i>	<i>Cyathochitina calix</i>					<i>Euconochitina vulgaris</i>	<i>Desmochitina ornensis</i>	<i>Conochitina pseudocarinata</i>	<i>Cyathochitina cf. dispar</i>	<i>Belonechitina gr. micracantha</i>	<i>Lagenochitina obeligitis</i>	? <i>Tanuchitina</i> spp.	
Bornival	JV98-001	3	1		1		1	4				2	15											100	3	127	49
	JV98-002	1			2			2	1			2	6											53	2	68	44
Ittre	JV98-004	2	2	1																			3	<1	8	46	
	JV98-003	8	3		3																		28	1	42	42	
	JV98-009	6				4	16	20															43	2	89	46	
	JV98-005	34	3			5	18		18	1	11	10	2										281	8	383	47	
	TD069																										11
	TD062																										11
	TD064																										11
	TD065																										12
Rigenée	JV99-005																										12
	TD059																										11
	JV98-006	4	5							1				1									15	1	26	45	
unnamed (Asquempont)	JV98-007												1										5	<1	6	46	
	JV99-003	42	5		3										5	58	10	5	2	1	5		36	15	172	11	
	JV99-002	3														33	7						9	5	54	12	
A. de Villers	JV99-001	10	3												42	19	6	3					15	8	98	12	
	JV99-006	6																81	2	2			20	9	111	12	

Fig. 5. Absolute abundance of chitinozoans in the Senne–Sennette valley samples. Grey fields indicate barren samples. For sample details, see Appendix A.

(Eisenack, 1931, 1962), which as a consequence gives a longer stratigraphic range of the species.

Two samples record the transition between the Rigenée and Ittre formations, but no biostratigraphically significant chitinozoans were recovered in the fossiliferous sample (AH99-17). A sample from the Ittre Formation (JV 10) yielded three specimens attributed to *Euconochitina* spp., and two specimens of *Spinachitina*, here referred to *S. ?bulmani* (Jansonius).

#### 4.4. Senne–Sennette valleys

Twelve of the 18 investigated samples were fossiliferous (Fig. 5), with the chitinozoans slightly better preserved than in the other two valleys. Probably as a consequence, the taxonomic diversity of the recovered assemblages appears to be somewhat higher than in the other valleys.

A sample belonging to the Abbaye de Villers Forma-

tion (JV99-006) yielded an assemblage with 81 specimens attributed to *Cyathochitina cf. dispar* Benoît and Taugourdeau (Plate I: 1–3; average size:  $L_p = 155 \mu\text{m}$ ,  $N = 12$ ;  $D_p = 96 \mu\text{m}$ ,  $N = 31$ ;  $D_c = 56 \mu\text{m}$ ,  $N = 22$ ;  $L_p = 105 \mu\text{m}$ ,  $N = 24$ ; vesicle wall thickness ca  $2 \mu\text{m}$ ). Two specimens in the same sample were attributed to *Lagenochitina obeligitis* Paris.

Three samples (JV99-001, 002 and 003) from the newly recognised, unnamed unit near Asquempont yielded an assemblage characterised by *Desmochitina ornensis* Paris (Plate I: 6, 7, 11), *Conochitina pseudocarinata* Paris (Plate I: 8), and to a lesser extent, *Cyathochitina cf. dispar* Benoît and Taugourdeau. Some specimens of *Belonechitina gr. micracantha* (Eisenack) (Plate I: 9, 10) are also present, as is a specimen of *Lagenochitina obeligitis* Paris. Specimens attributed to *D. ornensis* (average size in JV99-002:  $L_p = 96 \mu\text{m}$ ,  $N = 32$ ;  $D_p = 92 \mu\text{m}$ ,  $N = 31$ ;  $D_c = 52 \mu\text{m}$ ,  $N = 15$ ) are of two types, one treated as typical (compare Pl. 7: 13 in Paris, 1981) and

another as less typical (Pl. 7: 2 in Paris, 1981) by Paris (1981). Specimens of *C. pseudocarinata* Paris (average size in JV99-001:  $L_p > 142 \mu\text{m}$ ,  $N = 18$ ;  $D_p = 106 \mu\text{m}$ ,  $N = 23$ ;  $D_c = 55 \mu\text{m}$ ,  $N = 17$ ;  $L_p = 107 \mu\text{m}$ ,  $N = 24$ ), have a long neck, a conical chamber (triangular when flattened) and a poorly developed carina-like feature towards the base. They are comparable in size to the type-material from the base of the Pissot Formation in the Tanneries quarry, Domfront, Orne, France, which is of a middle Arenig age (Paris, 1981).

Two fossiliferous samples from the Rigenée Formation yielded *Cyathochitina calix* (Eisenack), but no other biostratigraphically useful taxa.

The sample JV98-005 from the lower part of the Ittre Formation yielded *Belonechitina* cf. *robusta* (Eisenack) (Plate II: 7, 8). Ten specimens attributed to *S. ?bulmani* (Jansonius) were also observed in the sample (Plate II: 11, 12; average:  $L_p = 149 \mu\text{m}$ ;  $D_p = 89 \mu\text{m}$ ;  $D_c = 47 \mu\text{m}$ ;  $N = 8$ ). Characteristic for the genus *Spinachitina* is a crown of spines developed directly at the basal edge (Laufeld, 1967; Paris et al., 1999). On our specimens, the spines are missing. Instead, faint scars are visible where the spines were once attached (Plate II: 11, 12).

In the upper part of the Ittre Formation, no biostratigraphically important taxa were recovered. A single specimen was uncertainly attributed to *Euconochitina* spp. (JV 98-004). Stratigraphically long-ranging taxa such as *Conochitina minnesotensis* Stauffer (Plate II: 5, 9) and *Desmochitina lecaniella* Laufeld (Plate II: 6) were also observed in the Ittre Formation, and so was a thick-walled *Conochitina* sp. (Plate II: 10).

Two samples from the Bornival Formation (JV98-002 and -001) yielded *Belonechitina* cf. *robusta* (Eisenack) (average in JV98-002:  $D_p = 73 \mu\text{m}$ ,  $N = 2$ ).

## 5. Age of the Brabant Massif units investigated herein

### 5.1. Relative ages

Since the formal lithostratigraphy of the Ordovician successions of the Brabant Massif is currently being revised (Verniers et al., 2001), the following discussion must be regarded as preliminary

concerning names and definitions of the stratigraphic units.

With their restudy of Ordovician graptolites from the Brabant Massif, Maletz and Servais (1998) provide the most recent independent age-control for several of the formations treated herein. Their study does not include the Dyle and Thyle valleys, because no graptolites or other macrofossils are observed above the lower Tremadocian top of the Mousty Formation (Herbosch and Lemonne, 2000).

The Abbaye de Villers Formation, the unnamed (Asquemont) unit and the Tribotte Formation are the oldest formations investigated herein (Fig. 2). These units were investigated in the Dyle–Thyle valleys and the Senne–Sennette valleys (Figs. 4 and 5).

In the basal third part of the Abbaye de Villers Formation in the Dyle–Thyle valleys, *Eremochitina brevis* Benoît and Taugourdeau was recovered (Fig. 4). The total stratigraphic range of *E. brevis* is inferred by Paris (1990) as part of the “middle” Arenig (Whitlandian pro parte), based on its co-occurrence with the trilobite *Nilobe* sp. and the presence of the graptolite *Didymograptus extensus* in the “Hamra Quartzite”, i.e. the upper part of the Oued Rharbi Member, El Arich el Megta Formation, Algerian Sahara (Benoît and Taugourdeau, 1961). This age-assignment is corroborated by graptolite ages from another *E. brevis* carrying unit, the Llandeyran Formation, Montagne Noire, France (Paris, 1990). *E. brevis* is also the main component of the Armorican Quartzite Formation of Brittany (Paris, 1990). Martin (1977) and Vanguetaine (in André et al., 1991) reported the presence of the acritarch genus *Frankea* Burmann from the middle and upper parts of the Abbaye de Villers Formation (sampling re-controlled by Herbosch, pers. commun., 2000). This acritarch genus is now considered to have its first appearance in the upper part of the *gibberulus* graptolite Biozone (uppermost middle Arenig) or in the *hirundo* Biozone (upper Arenig; Brocke et al., 1995). The chitinozoans are thus indicative of a middle Arenig age of deposition for the lower third of the Abbaye de Villers Formation, whereas the acritarchs in the middle and upper part of the formation suggest a latest middle or late Arenig age. Chitinozoans recovered in stratigraphically equivalent samples to those yielding *Frankea*, i.e. *Lagenochitina obeligitis* Paris and

*Euconochitina vulgaris* (Jenkins) broadly corroborate the late Arenig age, as both these chitinozoans appear to have a middle Arenig to lower Llanvirn stratigraphic range (Jenkins, 1967; Paris, 1981). The co-occurrence of *L. obeligeris* and specimens attributed to *Cyathochitina* cf. *dispar* (Benoît and Taugourdeau) in the middle and upper part of the Abbaye de Villers Formation in the Senne valley (Fig. 5) provides further evidence for a late Arenig age for the middle and upper part of the formation. The *Cyathochitina dispar* holotype is described from upper Arenig strata in Algeria (Benoît and Taugourdeau, 1961).

The chitinozoan assemblage recovered from the unnamed (Asquemont) unit in the Sennette valley is comparable to the middle to upper Arenig *Desmochitina ornensis* Biozone assemblage which Paris (1981, 1990) defined in the Armorican Massif. Paris (1990) assigned a middle Arenig age for his *D. ornensis* total-range Biozone, succeeding the slightly older middle Arenig total-range *Euconochitina brevis* chitinozoan Biozone (*E. brevis* is here observed in the lower third of the Abbaye de Villers Formation). As discussed above, geometrically judging from field observations, the unnamed unit can be situated stratigraphically in three positions: either below the Tribotte Formation, below the Abbaye de Villers Formation or as a lateral equivalent of the top of the Abbaye de Villers Formation. The palynological evidence supports a superposition of the Asquemont unit above the Abbaye de Villers Formation; however, this interpretation needs to be confirmed by further field evidence.

In the Tribotte Formation, a single recorded speci-

men of *Eremochitina vulgaris* (Jenkins) in the single fossiliferous sample (JV 5; Figs. 2 and 4) is broadly indicative of a middle Arenig to early Llanvirn (Paris, 1981) age. No other fossil data exists for the Tribotte Formation at present.

In the Thyle valley, acritarchs from the lower part of the Rigenée Formation suggest a late Arenig or younger age and a probable Llanvirn or younger age for the middle and upper parts of the unit (Servais, 1991). In the middle part of the Rigenée Formation in the Dyle–Thyle valleys (Fig. 4), the presence of a few *Lagenochitina obeligeris* Paris corroborate this age assignment (middle Arenig to early Llanvirn; Paris, 1981, 1996); and so do a few *Cyathochitina calix* (Eisenack) (early Llanvirn in Gondwana, Paris, 1996; late Arenig to early Caradoc in Baltica, Nölvak and Grahn, 1993). The latter species was also recovered from the Rigenée Formation in the Sennette valley.

In the Sennette valley, there is no significant difference in taxonomic composition of the chitinozoan assemblages between the Ittre Formation and an unnamed laminite member, situated low in the Bornival Formation. The presence of *Belonechitina* cf. *robusta* (Eisenack) in the laminite member (samples JV98-001 and 002) and in the lower part of the Ittre Formation (JV98-005) suggests a middle to late Caradoc (Burrellian to early Streffordian) age for the Ittre Formation and the lower Bornival Formation in the Sennette valley (*B. robusta* is the index species for a chitinozoan Biozone defined in North Gondwana by Paris, 1990). Chitinozoans attributed to *Spinachitina ?bulmani* (Jansonius) occur in the Ittre Formation in

## PLATE I

SEM photographs of selected Chitinozoa from the Abbaye de Villers, the unnamed (Asquemont) unit and the Tribotte Formation.

- 1 *Cyathochitina* cf. *dispar* (Benoît and Taugourdeau, 1961). Sample JV99-006, Abbaye de Villers Formation, Senne valley. × 300.
- 2 *Cyathochitina* cf. *dispar* (Benoît and Taugourdeau, 1961). Sample JV99-006, Abbaye de Villers Formation, Senne valley. × 300.
- 3 *Cyathochitina* cf. *dispar* (Benoît and Taugourdeau, 1961). Sample JV99-006, Abbaye de Villers Formation, Senne valley. × 300.
- 4 *Lagenochitina obeligeris* Paris, 1981. Sample JV 2, Abbaye de Villers Formation, Dyle–Thyle valley. × 220.
- 5 *Euconochitina vulgaris* (Jenkins, 1967). Sample JV 2, Abbaye de Villers Formation, Dyle–Thyle valley. × 550.
- 6 *Desmochitina ornensis* Paris, 1981. Sample JV99-001, SEM stub A, unnamed (Asquemont) unit, Sennette valley. × 400.
- 7 *Desmochitina ornensis* Paris, 1981. Sample JV99-001, SEM stub A, unnamed (Asquemont) unit, Sennette valley. × 550.
- 8 *Conochitina pseudocarinata* Paris, 1981. Sample JV99-001, SEM stub B, unnamed (Asquemont) unit, Sennette valley. × 300.
- 9 *Belonechitina* gr. *micracantha* (Eisenack, 1931). Detail of base of specimen showed in (10). × 600.
- 10 *Belonechitina* gr. *micracantha* (Eisenack, 1931). Sample JV99-001, SEM stub A, unnamed (Asquemont) unit, Sennette valley. × 240. Same specimen as in (9).
- 11 *Desmochitina ornensis* Paris, 1981. Sample JV99-003, unnamed (Asquemont) unit, Sennette valley. × 490.
- 12 *Belonechitina* gr. *micracantha* (Eisenack, 1931). Sample JV 5, Tribotte Formation, Dyle–Thyle valley. × 500.



PLATE I

all three valleys. This chitinozoan is of a limited value to biostratigraphy, as it has a long stratigraphic range, and because of the poor preservation of the Brabant Massif specimens, the specific determination is uncertain. However, specimens of *S. ?bulmani* were only observed in the Ittre Formation, and we use this observation as a stratigraphic marker (see Section 5.4).

From the Ittre Formation in the Sennette valley, Maletz and Servais (1998) reported a graptolite fauna biostratigraphically belonging to the *Nema-graptus gracilis* or the overlying *Diplograptus multidens* graptolite Zone with a preference for the *multidens* Zone. In age, the latter spans the latest Aurelucian to the late Burrellian, which roughly corresponds to the early middle Caradoc. For the Ittre Formation, we propose the age-span where stratigraphic data from chitinozoans and graptolites overlap; i.e. the *multidens* Zone (which approximates the Burrellian stage). Earlier, Martin and Rickards (1979) suggested a Caradoc age for part of the Ittre Formation, based on earlier data from graptolites, acritarchs and chitinozoans. In the Ittre Formation of the Orneau valley, *Belonechitina* cf. *robusta* (Eisenack) was also observed (Fig. 3), confirming the inferred Burrellian (to early Streffordian) age of the unit also in this area. In the succession attributed to the Ittre Formation in the Dyle–Thyle valleys, no *B. robusta* were recovered; only some specimens attributed to *Belonechitina* sp. The other chitinozoans found in this unit have long stratigraphic ranges, which do not contradict the suggested middle Caradoc (Burrellian) age for the Ittre Formation.

The chitinozoan content of both the Bornival and the Ittre formations are also very similar in the Orneau valley; e.g. *Belonechitina* cf. *robusta* (Eisenack) was observed in both units (Fig. 3).

Van Grootel and Verniers (1998) observed *Lagenochitina dalbyensis* (Laufeld) and *Belonechitina* (= *Kalochitina*) *hirsuta* (Laufeld) in the Bornival Formation in the Sennette valley. These two species are the index species of Baltoscandian chitinozoan Biozones (Nölvak and Grahn, 1993) in the Idavere substage, correlated with the lower part of the *multidens* graptolite Zone in the uppermost Costonian and lowermost Harnagian, roughly corresponding to the lower Burrellian (Paris, 1990). Our conclusion that both the Ittre and the Bornival formations probably have a Burrellian age is thus confirmed also in the outcrops in the Sennette valley south of the sections dealt with in this paper.

Van Grootel et al. (1997) assigned a preliminary age probably not older than the middle Pirgu (Cautleyan, early middle Ashgill) for the upper part of the Madot Formation. Van Grootel and Verniers (1998) suggested a late Vormsi or earliest Pirgu (late Streffordian to early Pusgillian, latest Caradoc to earliest Ashgill) age, based on the presence of *Tanuchitina bergstroemi* Laufeld, *Belonechitina robusta* (Eisenack), *Lagenochitina baltica* Eisenack and *Lagenochitina prussica* Eisenack. Our observation of the chitinozoan assemblage dominated by *L. baltica* Eisenack and *Conochitina* sp. A in sample JV88-P + 3 from the Madot Formation (Fig. 3) which indicates a late Burrellian to mid-Hirnantian

## PLATE II

SEM photographs of selected Chitinozoa from the unnamed (Asquemont) unit, Rigenée and Ittre formations.

- 1 *Desmochitina lecaniella* Laufeld, 1967. Sample JV98-005, Ittre Formation, Sennette valley. × 550. Same specimen as (6), showing detail of how aperture is linked to the succeeding vesicle.
- 2 *Conochitina minnesotensis* Stauffer, 1933. Sample JV 7, Rigenée Formation, Dyle–Thyle valley. × 130.
- 3 *Conochitina minnesotensis* Stauffer, 1933. Sample JV 7, Rigenée Formation, Dyle × Thyle valley. × 140. Same specimen as in (4).
- 4 *Conochitina minnesotensis* Stauffer, 1933. Same specimen as in (3), showing the oral tube and collarette. × 800.
- 5 *Conochitina minnesotensis* Stauffer, 1933. Sample JV98-001, Ittre Formation, Sennette valley. × 160.
- 6 *Desmochitina lecaniella* Laufeld, 1967. Sample JV98-005, Ittre Formation, Sennette valley. × 300. Same specimen as (1).
- 7 *Belonechitina* cf. *robusta* (Eisenack, 1959). Sample JV98-005, Ittre Formation, Sennette valley. × 170. Same specimen as (8).
- 8 *Belonechitina* cf. *robusta*. Same specimen as (7), showing details of worn, λ-shaped spiny ornamentation at base. × 1200.
- 9 *Conochitina* sp. Sample JV99-009, Ittre Formation, Sennette valley. × 170.
- 10 *Conochitina* sp. Sample JV98-004, Ittre Formation, Sennette valley. × 140.
- 11 *Spinachitina ?bulmani* (Jansonius, 1964). Sample JV99-005, Ittre Formation, Sennette valley. × 530. Same specimen as in (12).
- 12 *Spinachitina ?bulmani* (Jansonius, 1964). Same specimen as in (11), showing detail of structures at the basal edge, interpreted as degraded spines. × 2100.

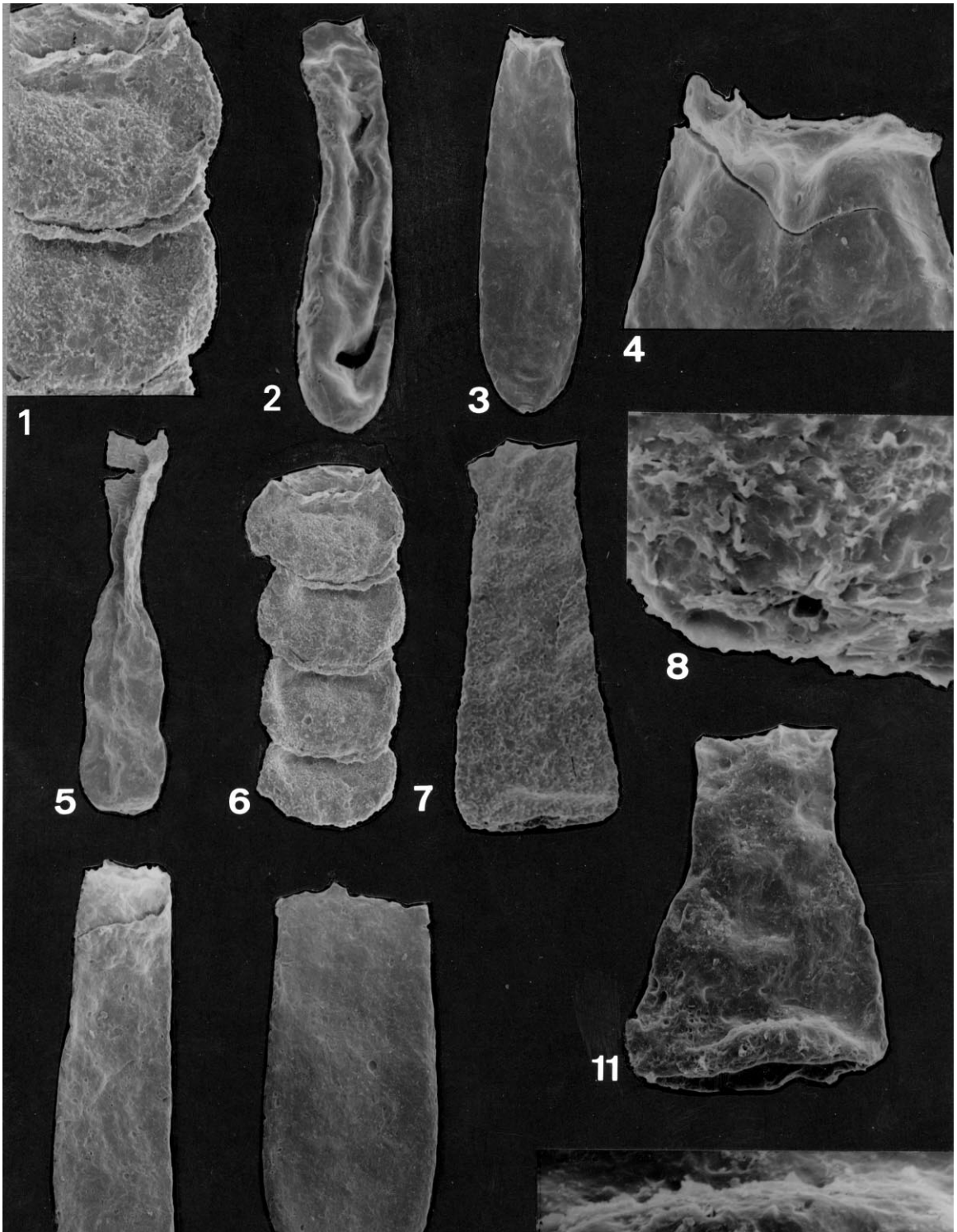


PLATE II

(Paris, 1990; Nölvak and Grahn, 1993) age, support the latter suggestion. Further evidence come from Regnéll (1951) who in his revision of the cystoid fauna of Belgium concluded that cystoid taxa from strata now regarded as belonging to the Huet Formation (or possibly the Madot Formation in a few cases) are indicative of a late Caradoc age.

Richter and Richter (1951) reported the presence of several trilobite taxa, indicative of an early Ashgill age, from the area of Grand-Manil (Orneau valley). Unfortunately, it is not stated in their paper if the trilobites were from the Huet or the Madot Formation. Our assumption, based on the microfossil data, is that the trilobites come from the Madot Formation. Macrofossils recovered from the Huet and Madot formations in the Sennette valley are presently being restudied for taxonomic and biostratigraphic purposes (for an earlier reference, see Maillieux, 1926).

In the mottled mudstone member low in the Brutia Formation in the Orneau valley, *Hercoclitina* cf. *gamachiana* (Achab) dominates the assemblage. This species indicates a middle to late Ashgill age, as it is hitherto reported from Estonian successions ascribed to Late Pirgu (Cautleyan–Rawtheyan, middle Ashgill) time (Nölvak, 1999) and from Hirnantian strata (late Ashgill) in Laurentia (Achab, 1989). Probable specimens of *H. gamachiana* were also reported from North Greenland by Grahn and Nøhr-Hansen (1989; attributed to *Hercoclitina crickmayi*?) in strata of a Richmondian (approximately Cautleyan, middle Ashgill) age. Grahn et al. (1994) illustrated a specimen they attributed to *Hercoclitina* sp. B in strata also

of an early Pirgu (middle Ashgill) age, which bears striking similarities to the specimens attributed to *H. cf. gamachiana* herein. A middle to upper Ashgill age is thus suggested for the mottled mudstone part of the Brutia Formation.

## 5.2. Correlation between the three valleys

Despite problems such as complex deformation, unknown contacts between several units, and limited outcrop areas, the relative positions of the different units within the Brabant Massif are now fairly well-established (e.g. Herbosch and Lemonne, 2000; Verniers et al., 2001). Thus, the identification of units outcropping in two or three valleys and supposed to be the same, can be tested using the biostratigraphic evidence available from the present study.

The chitinozoans of the Rigenée and Ittre formations could be investigated in all three valleys, the other units only in one or two valleys (Fig. 2). The Abbaye de Villers Formation was investigated in the Senne (see Appendix A; Fig. 2) and Dyle–Thyle valleys. Specimens of *L. obeligis* Paris were recovered from both localities. In the Dyle–Thyle and Senne–Sennette valleys, the units referred to as the Rigenée Formation have *C. calix* (Eisenack) in common. *Belonechitina* cf. *robusta* (Eisenack) was identified in the Ittre Formation in the Orneau and Sennette valleys, and *Belonechitina* sp. in the Dyle–Thyle valley. Specimens placed under open nomenclature as *Euconochitina* spp. were recovered from the Ittre

## PLATE III

SEM photographs of selected Chitinozoa from the Madot and Brutia Formations.

- 1 *Conochitina* sp. A. Same specimen as (2), showing the base. × 660.
- 2 *Conochitina* sp. A. Sample JV88-P + 3, Madot Formation, Orneau valley. × 250. Same specimen as in (1).
- 3 *Lagenochitina baltica* Eisenack, 1931. Sample JV88-P + 3, Madot Formation, Orneau valley. × 250. Same specimen as in (4).
- 4 *Lagenochitina baltica* Eisenack, 1931. Same specimen as in (3), showing the basal part of chamber and the granular surface, typical for this species. × 540.
- 5 *Cyathochitina campanulaeformis*. Sample JV88-17, SEM stub B, Brutia Formation, Orneau valley. × 360.
- 6 *Hercoclitina* cf. *gamachiana* (Achab, 1978). Sample JV88-17, SEM stub B, Brutia Formation, Orneau valley. × 400. Same specimen as in (11).
- 7 *Cyathochitina campanulaeformis*. Sample JV88-17, SEM stub D, Brutia Formation, Orneau valley. × 280.
- 8 *Hercoclitina* cf. *gamachiana* (Achab, 1978). Sample JVOrn 97/11, Brutia Formation, Orneau valley. × 340.
- 9 *Hercoclitina* cf. *gamachiana* (Achab, 1978). Sample JV88-17, SEM stub D, Brutia Formation, Orneau valley. × 280.
- 10 *Hercoclitina* cf. *gamachiana* (Achab, 1978). Sample JV88-17, SEM stub B, Brutia Formation, Orneau valley. × 420.
- 11 *Hercoclitina* cf. *gamachiana* (Achab, 1978). Same specimen as in (6), showing detail of surface. × 1150.

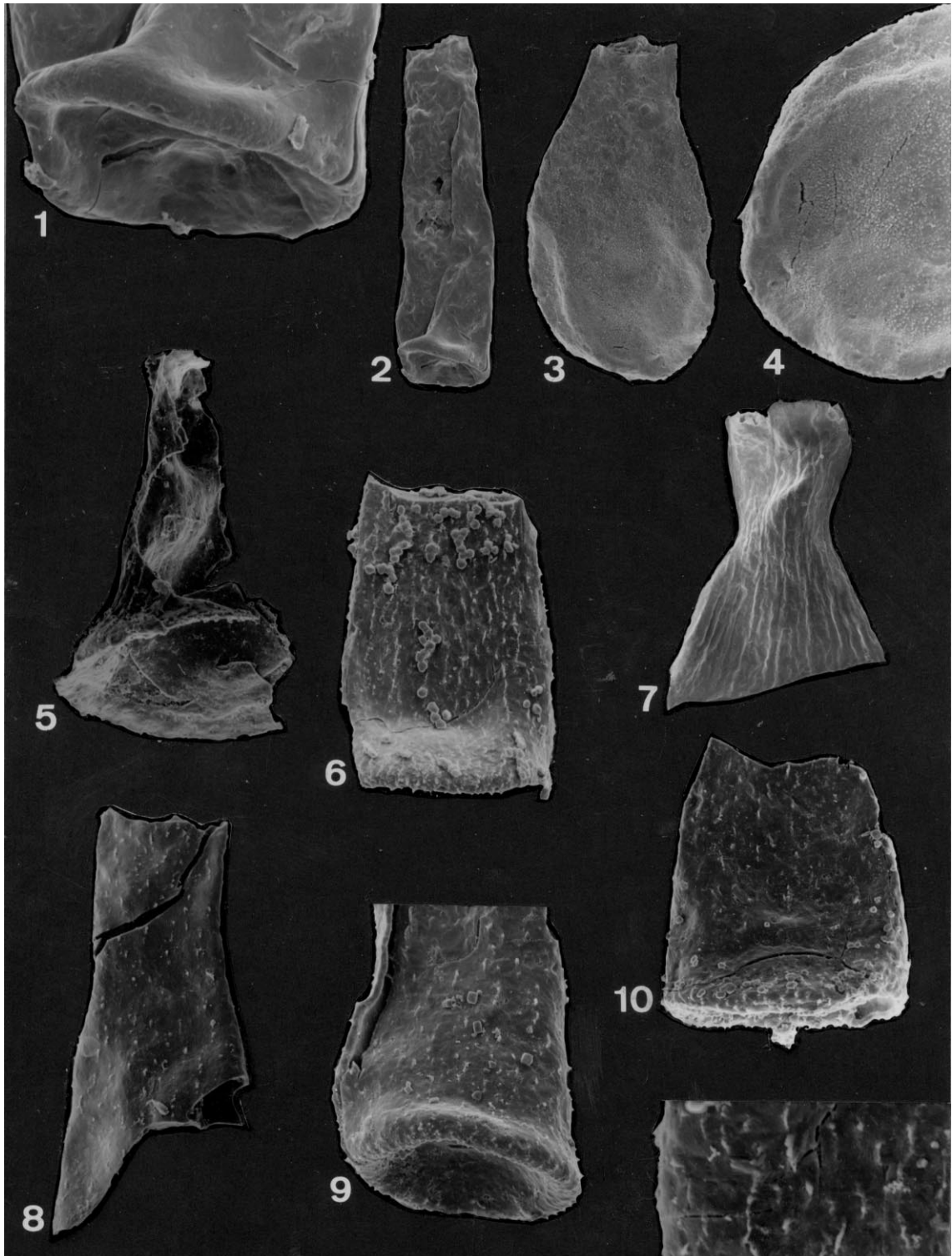


PLATE III

Formation in the Dyle–Thyle and Sennette valleys, *S. ?bulmani* (Jansonius) from all three areas. Keeping in mind that the chitinozoan data are often sparse, the lithostratigraphical correlations are corroborated by the present data.

### 5.3. Chitinozoan faunal changes in Avalonia through time

Because chitinozoan biogeographic differentiation was at its maximum in the Ordovician (e.g. Achab, 1988, 1991; Achab et al., 1992; Oulebsir and Paris, 1995; Paris, 1981, 1993), different Ordovician chitinozoan biozones have been established for North Gondwana (Paris, 1990), Baltoscandia (Nölvak and Grahn, 1993; Nölvak, 1999) and Laurentia (Achab, 1989). The Brabant Massif belonged to the Palaeozoic microcontinent Avalonia (Verniers and Van Grootel, 1991). Avalonia, in turn, was part of the high-latitude Gondwana palaeocontinent until it drifted off in the Middle Ordovician (late Arenig or Llanvirn) times (Prigmore et al., 1997; Cocks et al., 1997). Subsequently, Avalonia started to collide with middle-latitude Baltica probably in the Ashgill (Samuelsson et al., 2001), and with Laurentia in the Early Silurian (see references in Cocks et al., 1997; Prigmore et al., 1997).

Thus, as an a priori hypothesis, chitinozoan faunas preserved in the oldest rocks of Avalonia ought to be similar to the contemporary cold-water Gondwana faunas. In younger rocks on Avalonia, a successive incorporation of chitinozoans typical of middle latitudes as on Baltica and of the low latitude as on Laurentia ought to take place. This pattern is certainly true for the benthic macrofauna, where in the Caradoc epoch the Avalonian faunas started to mix with those of Baltica (Cocks and Fortey, 1990). In particular, generic faunal similarity of benthic ostracode faunas between southern Britain (Avalonia) and Baltoscandia (Baltica) is marked in the Caradoc and enhanced in the Ashgill (Vannier et al., 1989). Although planktonic micro-organisms have a mainly latitudinal distribution, Van Grootel et al. (1997) observed that Upper Ordovician chitinozoans of the Brabant Massif are very similar to those of Baltoscandia. Our results are consistent with the evidence from other more palaeobiogeographically reliable (benthic) fossil groups: the oldest strata (Abbaye de Villers Formation, the

Asquemont unit and the Tribotte Formation) yielded a typical North Gondwana chitinozoan fauna, different from the contemporaneous Baltoscandian fauna. This fauna include taxa such as *Eremochitina brevis* Benoît and Taugourdeau, *Lagenochitina obeligitis* Paris, *Conochitina pseudocarinata* Paris and *Desmochitina ornensis* Paris, all typical Gondwana taxa (e.g. Paris, 1981, 1990, 1996). Probably starting in the middle Caradoc Ittre or Bornival formations, an influx of chitinozoan species also common in Baltoscandia can be seen. Typical taxa known both from Gondwana and Baltoscandia found in the Brabant Massif units are evident especially in the Madot Formation, and includes e.g. *Lagenochitina prussica* Eisenack, *Tanuchitina bergstroemi* Laufeld (Van Grootel and Verniers, 1998), and *Lagenochitina baltica* Eisenack (Plate III: 3, 4). *Hercochitina* cf. *gamachiana* (Achab), present in the Brutia Formation, was first described in Laurentia (Achab, 1978), and might thus demonstrate a link between Baltica, Avalonia and Laurentia in the Ashgill.

The conclusions concerning the palaeogeography of the Brabant Massif based on chitinozoans are certainly speculative because they are based on data from few and comparably poorly preserved specimens. Nevertheless, the observed taxonomic differences can be explained as a consequence of the northward drift of Avalonia from Gondwana to Baltica and Laurentia. The chitinozoan evidence thus agrees with other faunal and geological evidence (e.g. Cocks and Fortey, 1982; Vannier et al., 1989).

### 5.4. A local chitinozoan biozonation of the Brabant Massif

The difference in taxonomic composition of the chitinozoan assemblages in the Brabant Massif units investigated herein is large. Thus, a local chitinozoan biozonation can be suggested for the Ordovician units of the Brabant Massif, mainly based on the findings herein. Earlier unpublished work confirms the suggested biozonation also for other areas within the massif (G. Van Grootel, pers. comm., 1999). For the compilation of this local biozonation, we incorporated unpublished data from Van Grootel (1995) and Van Grootel and Verniers (1998), and published data from Van Grootel et al. (1997).

Starting with the oldest assemblage, we suggest the following local chitinozoan biozonation for the Brabant Massif:

1. A zone characterised by the presence of *Eremochitina brevis* Benoît and Taugourdeau. The lower third of the Abbaye de Villers Formation falls within this zone. *Lagenochitina obeligis* Paris is also common.
2. The first appearance of *Cyathochitina* cf. *dispar* (Benoît and Taugourdeau) and *Euconochitina vulgaris* (Jenkins) defines the base of the second zone. The middle part of the Abbaye de Villers Formation falls within this zone.
3. A zone where *Desmochitina ornensis* Paris and *Conochitina pseudocarinata* Paris are the most characteristic components. The Asquempont unit falls within this zone. Other typical taxa include *L. obeligis*, *C. cf. dispar* and *E. vulgaris*.
4. A zone where *Cyathochitina calix* (Eisenack) is the most characteristic species is recognised in the Rigenée Formation. Large Conochitinae, attributed to *Conochitina minnesotensis* are also common.
5. A zone where *Spinachitina ?bulmani* (Jansonius) is the most discriminating chitinozoan species. *Belonechitina* cf. *robusta* (Eisenack) has its first occurrence in this zone, *C. minnesotensis* is still present. The Ittre Formation falls entirely within this zone.
6. *Lagenochitina dalbyensis* Laufeld and *Belonechitina hirsuta* (Laufeld), reported by Van Grootel and Verniers (1998) from the Bornival Formation, are the most characteristic taxa in this zone. *B. robusta* (referred to *B. cf. robusta* herein) is also a typical component.
7. The first appearance of *Lagenochitina baltica* Eisenack and *Lagenochitina prussica* Eisenack until the first appearance of *Tanuchitina bergstroemi* Laufeld constitute the seventh local chitinozoan zone. The first appearance of the earlier two taxa were observed in the Huet Formation by Van Grootel and Verniers (1998).
8. The very base of Unit I of the Lessines section (Dender valley), corresponding to a level low in the Fauquez Formation, belongs to the Balto-scandian *Armoricochitina reticulifera* chitinozoan Subzone (Van Grootel et al., 1997).

9. In the Fauquez Formation (except in its lowest beds), in the top of Unit I of the Lessines section and in the Madot Formation (Van Grootel and Verniers, 1998), specimens of *Tanuchitina bergstroemi* Laufeld were observed. In addition, *L. baltica*, *L. prussica* and *B. robusta* were observed by Van Grootel and Verniers (1998) to occur in the Madot Formation, specimens referred to *Conochitina* sp. A were also observed in the latter formation (this work).
10. The Harelbeke unit yielded *Spinachitina taugourdeau* (Van Grootel, 1995; Van Grootel et al., 1997).
11. In the lower part of the Brutia Formation, *Hercichitina* cf. *gamachiana* (Achab) is the dominant component of the assemblage.

Note that all parts of the Brabant Massif succession have not been studied up to now and as a consequence of future research a more refined biozonation is likely to be suggested.

## 6. Summary of the evidence for the relative ages of the post-Tremadoc Brabant Massif units

The chitinozoans in the Orneau, Dyle–Thyle and Senne–Sennette valleys yielded assemblages of low taxonomic diversity in a poor to moderate state of preservation. Despite these difficulties, the chitinozoans, together with stratigraphic data from other fossil groups, offered the opportunity to determine the relative ages of the Ordovician units in the Brabant Massif. For completeness, we have included the preliminary results by Van Grootel et al. (1997) and the unpublished results by Van Grootel (1995) and Van Grootel and Verniers (1998) here (Fig. 6):

1. The lower third of the *Abbaye de Villers Formation* (Dyle–Thyle): a Whitlandian pro parte (middle Arenig) age, based on the presence of *Eremochitina brevis* Benoît and Taugourdeau.
2. The middle and upper part of the *Abbaye de Villers Formation* (Dyle–Thyle and Senne): a late Arenig age, based on the presence of the acritarch *Frankea* Burmann (Martin, 1977; André et al., 1991; Brocke et al., 1995)

- supported by the chitinozoans *Lagenochitina obelgis* Paris, *Euconochitina vulgaris* (Jenkins) and *Cyathochitina* cf. *dispar* (Benoît and Taugourdeau).
3. *The unnamed (Asquemont) unit* (Sennette): a middle Arenig age, based on the presence of *Desmochitina ornensis* Paris.
  4. *Tribotte Formation* (Dyle–Thyle): a middle Arenig to early Llanvirn age range, as suggested by the presence of *Euconochitina vulgaris* (Jenkins).
  5. *Rigenée Formation* (Dyle–Thyle and Sennette): a late Arenig or younger age for the lower part and a probable Llanvirn or younger age for the middle and upper part of the unit (acritarchs; Servais, 1991; André et al., 1991). The presence of *Lagenochitina obelgis* Paris and *Cyathochitina calix* (Eisenack) corroborate the suggested ages. Graptolites belonging to the *Didymograptus artus* or *Didymograptus purchisoni* Biozone confirm the Aberiddian (Llanvirn) age (Maletz and Servais, 1998).
  6. *Ittre Formation* (Orneau, Dyle–Thyle and Sennette): a Burrellian (middle Caradoc) age for the entire Ittre Formation, based on *Belonechitina* cf. *robusta* (Eisenack) in agreement with the graptolite data indicating a *Diplograptus multidens* Biozone or possibly *Nemagraptus gracilis* Zone, belonging approximately to the Burrellian (Maletz and Servais, 1998).
  7. *Bornival Formation* (Orneau and Sennette): a Burrellian (middle Caradoc) age, based on *Lagenochitina dalbyensis* (Laufeld) and *Belonechitina hirsuta* (Laufeld) (Van Grootel and Verniers, 1998), supported by the presence of *Belonechitina* cf. *robusta* (Eisenack) observed by us.
  8. *Huet Formation* (Sennette): a latest Oandu (early Cheneyan, late middle Caradoc) age based on the presence of *Lagenochitina baltica* Eisenack, *Lagenochitina prussica* Eisenack and *Belonechitina robusta* (Eisenack) (Van Grootel et al., 1997; Van Grootel and Verniers, 1998). Cystoids are indicative of a late Caradoc age (Regnéll, 1951).
  9. *Fauquez Formation* (Sennette) yielded *Lagenochitina baltica* Eisenack, *Lagenochitina prussica* Eisenack, *Tanuchitina bergstroemi* Laufeld and *Belonechitina robusta* (Eisenack) (Van Grootel and Verniers, 1998) indicative of a late Vormsi to early Pirgu (corresponding to late Streffordian to early Pusgillian, latest Caradoc to earliest Ashgill) age. Maletz and Servais (1998) observed graptolites possibly belonging to the *Pleurograptus linearis* Biozone and the upper part of the *Dicranograptus clingani* Biozone that are indicative of a Streffordian (upper Caradoc) to early Pusgillian (early Ashgill) age in the Fauquez Formation. The chitinozoans thus corroborate the graptolite ages.
  10. *Madot Formation* (Sennette and Orneau): The unit is of a Late Vormsi or earliest Pirgu (late Streffordian to early Pusgillian, latest Caradoc to earliest Ashgill) age, based on the presence of *Tanuchitina bergstroemi* Laufeld, supported by the presence of *Lagenochitina baltica* Eisenack, *Lagenochitina prussica* Eisenack and *Belonechitina robusta* (Eisenack) (Van Grootel and Verniers, 1998). *L. baltica* was also observed in the sample treated by us. Trilobites, probably from the Madot Formation (Richter and Richter, 1951), are indicative of an early Ashgill age.
  11. In the *Harelbeke borehole* in Western Flanders, at depths of 123.71 and 124.45 m, respectively, *Spinachitina taugourdeau* (Eisenack) was identified by Van Grootel (1995). In Baltoscandia, Nölvak and Grahn (1993) established a *S. taugourdeau* Zone, assigned to the late Pirgu-earliest Porkuni time (late Rawtheyan-early Hirnantian, late Ashgill).
  12. *Mottled mudstone level of the Brutia Formation* (Orneau): A middle or upper Ashgill age is suggested, as *Hercochitina* cf. *gamachiana* (Achab) is present. In Baltica, a corresponding *Hercochitina* (= *Belonechitina*) *gamachiana* Biozone has recently been introduced by Nölvak (1999). His zone corresponds to the partial range of the index species between its first occurrence and the first appearance of *Spinachitina taugourdeau* (Eisenack), late Pirgu time (late Rawtheyan, late Ashgill). In the Brabant Massif, *H. cf. gamachiana* and *S. taugourdeau* have not been observed to co-occur, and hence the biostratigraphic relationships cannot be worked out, leaving the possibility open that

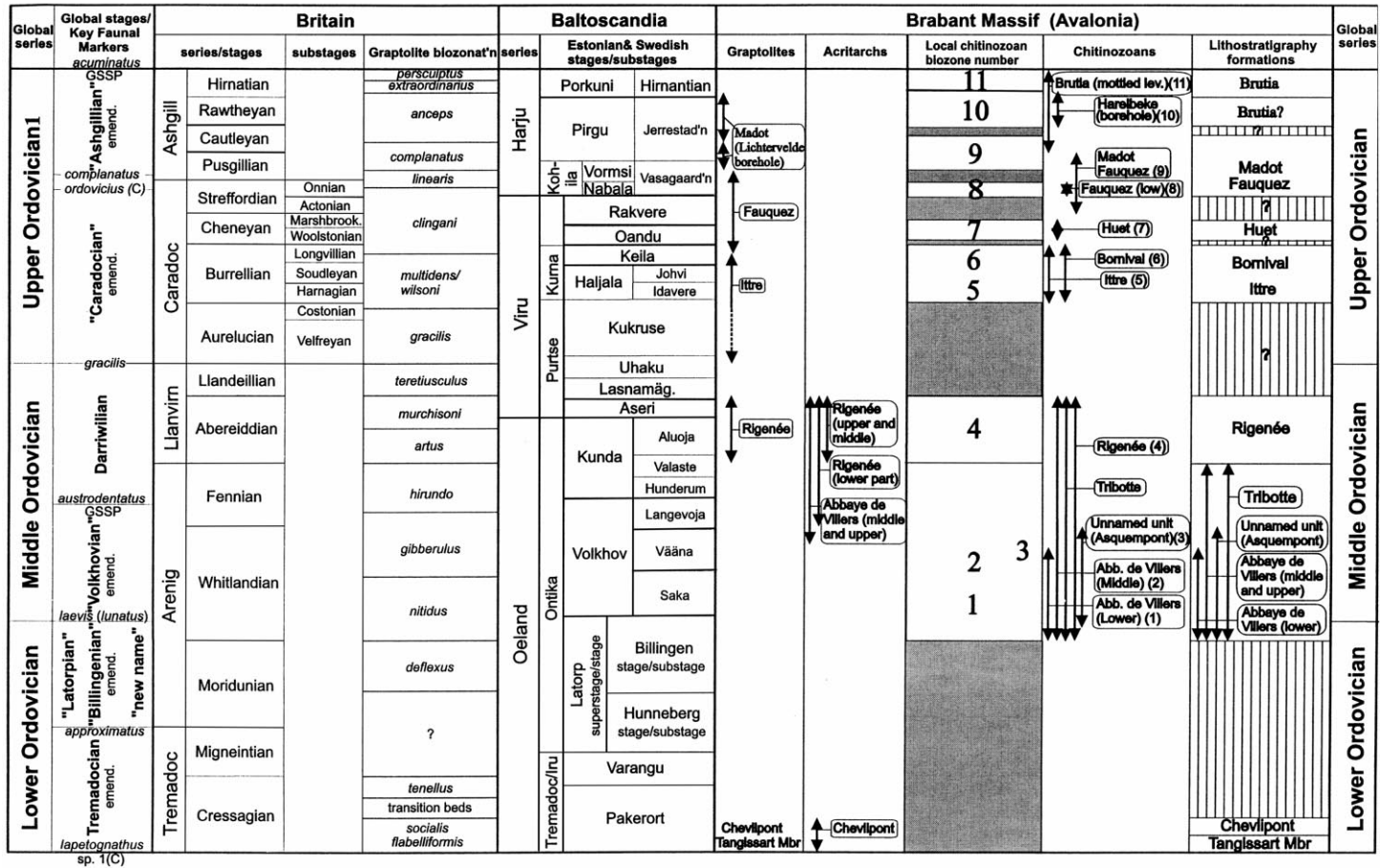


Fig. 6. Schematic correlation of the Ordovician Brabant Massif formations with chitinozoan, acritarch and graptolite biozonations and the global, British and Baltoscandian chronostratigraphy and British graptolite biozonation (after Fortey et al., 1995; Webby, 1998). Vertical hatching indicates hiatus, non-deposition, erosion or faulted contact. Arrows in biostratigraphy column indicate the range of the biozones versus the chronostratigraphy on the left. The number between brackets in the chitinozoan column is the number of the local biozonation. The Tangissart member is the top part of the Mousty Formation.

the Harelbeke unit might be younger than the mottled mudstone level in the Brutia Formation.

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### Appendix A. List of samples in stratigraphic order

A list of samples in stratigraphic order is given in the following table:

Sample	Lab preparation number	Formation	Valley	Location
ORN 6(1)	98-182	Rigenée	Orneau	City centre of Gembloux, Rue du Moulin; outcrop between houses 42 and 44. Lambert coordinates: km 173.020 ¥ 139.230
JVORN 97/01	98-183	Ittre	Orneau	City centre of Gembloux, School Institut St. Guibert, Place de l’Orneau, outcrop on the south side of playground under the wall between school and supermarket. Lambert coordinates: km 172.820 ¥ 138.970.
FM-80-2-1		Ittre	Orneau	Centre of Gembloux, temporary outcrop (1980) under a supermarket, between the Place de l’Orneau, rue Malaise and the rue Gustave Maset; collected by J. Verniers; prepared by Dr. Francine Martin in 1980; Lambert coordinates: km 138.950 ¥ 172.810.
ORN 10-3	98-221	Ittre	Orneau	Centre of Gembloux, temporary outcrop (1980) under a supermarket, between the Place de l’Orneau, rue Malaise and rue Gustave Maset; Lambert coordinates: km 172.810 ¥ 138.925
ORN 12	98-185	Bornival	Orneau	Gembloux, rue Lucien Petit, 100 m S of the northern end of the street; outcrop on NW side of road; Lambert coordinates: km 172.575 ¥ 138.700.
JVORN 97/03	98-186	Bornival	Orneau	Gembloux, rue de la Chapelle, southeast of St Adèle Chapel, northside of road, 1 m east of house N° 7; Lambert coordinates: km 172.895 ¥ 138.555.

## Appendix A (continued)

Sample	Lab preparation number	Formation	Valley	Location
JVORN 97/06	98-187	Bornival	Orneau	Gembloux, rue La Vôte, sample from rocky ridge 12 m east of house N° 7; Lambert coordinates: km 172.905 ¥ 138.550.
JV88-GFI	98-188	Huet	Orneau	Abandoned quarry, behind house where “grauwacke fossilifère” of Grand-Manil was excavated, Huet Formation; Lambert coordinates: around km 172.200 ¥ 138.150.
JV88-GFS	98-189	Madot	Orneau	Tri à la Vigne, Grand-Manil, Gembloux; temporary excavation in 1988 for the construction of a house; bryozoan- and brachiopod-rich mudstone of the Madot Formation, at 8.5–11.5 m below the base of the porphyroid bed at the top of the formation; BGS Archive number 143E142; Lambert coordinates: km 172.189 ¥ 138.103.
JV88-P-1	99-190, 99-377	Madot	Orneau	Tri à la Vigne, Grand-Manil, Gembloux; temporary excavation in 1988 for construction of a house; between 0 and 10 cm below the porphyroid bed in the Madot Formation; Lambert coordinates: km 172.204 ¥ 138.098.
JV88-P + 3	99-375	Madot	Orneau	As JV88-P-1; 0–5 cm above the 80 cm thick porphyroid, in a fossiliferous porphyroid 85 cm thick, Madot Formation; Lambert coordinates: km 172.206 ¥ 138.097.
JV88-P + 7		Brutia (basal part)	Orneau	As JV88-P-1; 0.10 m above the top of fossiliferous porphyroid; Lambert coordinates: km 172.208 ¥ 138.096.
JV88-P + 8	99-374	Brutia (basal part)	Orneau	As JV88-P-1; 0.50 m above the top of fossiliferous porphyroid; Lambert coordinates: km 172.208 ¥ 138.096.
JV88-P + 10	99-373	Brutia	Orneau	As JV-88-P-1; 2.90 m above the top fossiliferous porphyroid; Lambert coordinates: km 172.211 ¥ 138.095.
JV88-P + 10'	99-372	Brutia	Orneau	As JV88-P-1; 4.05 m above the top fossiliferous porphyroid; Lambert coordinates: km 172.213 ¥ 138.093.
JV88-P + 12	99-371	Brutia	Orneau	As JV88-P-1; 6.25 m above the top fossiliferous porphyroid; Lambert coordinates: km 172.201 ¥ 138.091.
JV88-P + 13	99-370	Brutia	Orneau	As JV88-P-1; 7.25 m above the top fossiliferous porphyroid; Lambert coordinates: km 172.204 ¥ 138.090.
JV88-P + 15	99-369	Brutia	Orneau	As JV88-P-1; 9.4 m above the top fossiliferous porphyroid, about 1 m NW of the streetside; Lambert coordinates: km 172.207 ¥ 138.089.
JV88-P + 16	99-368	Brutia	Orneau	As JV88-P-1; 16.4 m above the top fossiliferous porphyroid; Lambert coordinates: km 172.197 ¥ 138.077.
JV88-17	99-378	Brutia (mottled mudstone member)	Orneau	Tri à la Vigne, Grand-Manil, Gembloux; south east talud of rue de la Treille, dark grey mottles in grey mudstone, at about 17–18 m above the top fossiliferous porphyroid; Lambert coordinates: km 172.240 ¥ 138.100.
	99-386			
	99-387			

## Appendix A (continued)

Sample	Lab preparation number	Formation	Valley	Location
JVORN97/11	98-223	Brutia (mottled mudstone member)	Orneau	Tri à la Vigne, Grand-Manil, Gembloux; in temporary excavation on northern talud, rue de la Treille, 1.5 m west of cherry tree at about 22.5 m above the top fossiliferous porphyroid; Lambert coordinates: km 172.245 ¥ 138.080.
AH99-11	98-244 99-388	Abbaye de Villers (lower third part)	Dyle–Thyle	Road Porte de Bruxelles to Laroche; 8 m N of JV 1 and lowermost sample of the formation in the outcrops. Lambert coordinates: km 161.413 ¥ 142.601.
JV 1	99-397 98-209	Abbaye de Villers (lower third part)	Dyle–Thyle	380 m SSW of Chevlipont Mill, 430 m NNE of the Porte de Bruxelles; Lambert coordinates: km 161.412 ¥ 142.593.
AH99-12	98-289 99-389	Abbaye de Villers (lower third part)	Dyle–Thyle	road Porte de Bruxelles to Laroche; 12 m S and above of JV1. Lambert coordinates: km 161.407 ¥ 142.581.
JV 2	98-210	Abbaye de Villers (middle third part)	Dyle–Thyle	Outcrop close to railway, km 38.750, north–east of the ruins of the abbey. Lambert coordinates: km 161.505 ¥ 142.450.
JV 3	98-290 99-211	Abbaye de Villers (uppermost part)	Dyle–Thyle	Railway outcrop, km 38.853. Lambert coordinates: km 161.490 ¥ 142.320.
JV 4	99-394 99-212	Tribotte	Dyle–Thyle	Base of the formation. Lambert coordinates: km 161.120 ¥ 141.240.
JV 5	99-395 98-213	Tribotte	Dyle–Thyle	Uppermost part of the formation. Lambert coordinates: km 160.875 ¥ 140.075.
AH99-16	99-291 99-391	Tribotte	Dyle–Thyle	85 m N of crossing leading to the sunken road of Rigenée, in the east flank of the road in forest; high in the clayey part of the formation.; Lambert coordinates: km 160.830 ¥ 140.155.
AH99-15	99-390	Tribotte	Dyle–Thyle	Old quarry behind and east of the Hollers watermill; high in the clayey part of the formation. Lambert coordinates: km 161.430 ¥ 140.440.
JV 6	98-214	Rigenée	Dyle–Thyle	5–10 m above sample JV 5; lowermost part of the formation. Lambert coordinates: km 160.900 ¥ 140.055.
JV 7	98-215	Rigenée	Dyle–Thyle	Middle part of the formation. Lambert coordinates: km 160.785 ¥ 139.910.
AH98-346a	98-220	Rigenée	Dyle–Thyle	Outcrop in the river La Falise, south of the bridge, Pont Labinia, Baisy Thy. Middle or upper part of formation. Lambert coordinates: km 157.710 ¥ 142.720.
JV 8	98-216	Rigenée	Dyle–Thyle	Top of formation (possibly lower part of Ittre Formation). Lambert coordinates: km 160.800 ¥ 139.720.
AH99-18	99-393	Ittre–Rigenée transition	Dyle–Thyle	At +1.5 m from a tree growing on the outcrop of well. Lambert coordinates: km 160.800 ¥ 139.695.
AH99-17	99-392	Ittre–Rigenée transition	Dyle–Thyle	Possibly basal Ittre Formation; outcrop of well at –2 m from tree growing on the outcrop (15 m S of sample JV8). Lambert coordinates: km 160.800 ¥ 139.705.

## Appendix A (continued)

Sample	Lab preparation number	Formation	Valley	Location
JV 9	98-217	Ittre	Dyle–Thyle	Base of formation. Lambert coordinates: km 160.805 ¥ 139.645.
JV 10	98-218	Ittre	Dyle–Thyle	Uppermost part of the formation in this outcrop area. Lambert coordinates: km 160.810 ¥ 139.520.
JV99-006	99-460	Abbaye de Villers	Senne	Quenast station, outcrop south side, at km 3.777, at +1 m above ground; Lambert coordinates: km 135.905 ¥ 151.160.
JV99-001	99-446	unnamed (Asquempont unit)	Sennette	Charleroi–Brussels canal, Asquempont section, east side, km 40.0925 at +1 m above canal road; Lambert coordinates: km 140.837 ¥ 147.694.
JV99-002	99-447	unnamed (Asquempont unit)	Sennette	Charleroi–Brussels canal, Asquempont section, east side, km 40.0991, at +1 m above canal road; Lambert coordinates: km 140.838 ¥ 147.702.
JV99-003	99-458	Unnamed (Asquempont unit)	Sennette	Charleroi–Brussels canal, Asquempont section, east side, km 40.1075 at +1 m above canal road; Lambert coordinates: km 140.840 ¥ 147.710.
JV98-007	98-235	Rigenée	Sennette	Charleroi–Brussels canal, Asquempont section east side, km 39.752 at +3.5 m above canal road; Lambert coordinates: km 140.655 ¥ 147.408.
JV98-006	98-234	Rigenée	Sennette	Charleroi–Brussels canal, Asquempont section east side, km 39.765 at +1.2 m above canal road; Lambert coordinates: km 140.665 ¥ 147.420.
TD059	99-381	Rigenée	Sennette	Charleroi–Brussels canal, Asquempont section, km 39.6935; Lambert coordinates: km 140.610 ¥ 147.362.
JV99-005	99-459	Ittre/basal	Sennette	Unused old canal, west of Asquempont bridge (“brief 29”; 513 m along northern side of canal from its eastern end, in volcanic layers at the base of the Ittre Formation); Lambert coordinates: km 140.320 ¥ 148.160.
TD065	99-384	Ittre (basal)	Sennette	cf. JV99-001; km 39.676, in the 5 m thick volcanic layers at the base of the Ittre Formations; Lambert coordinates: km 140.602 ¥ 147.352.
TD064	99-383	Ittre	Sennette	cf. JV99-001, km 39.6595, at 1 m above ground level; Lambert coordinates: km 140.590 ¥ 147.340.
TD062	99-382	Ittre	Sennette	cf. JV99-001, km 39.623, at 1 m above ground level; Lambert coordinates: km 140.560 ¥ 147.320.
TD069	99-385	Ittre	Sennette	cf. JV99-001, km 39.587, at 80 cm above ground level; Lambert coordinates: km 140.534 ¥ 147.292.
JV98-002	98-230	Bornival (laminite member)	Sennette	cf. JV99-001, km 39.313, at +2 m above canal road; Lambert coordinates: km 140.365 ¥ 147.065.
JV98-001	98-229	Bornival (laminite member)	Sennette	cf. JV99-001, km 39.247, at +1 m above canal road; Lambert coordinates: km 140.342 ¥ 147.022.
JV98-005	98-233	Ittre	Sennette	cf. JV99-001, km 39.460, at +1.5 m above canal road; Lambert coordinates: km 140.448 ¥ 147.200.

## Appendix A (continued)

Sample	Lab preparation number	Formation	Valley	Location
JV98-009	98-236	Ittre	Sennette	cf. JV99-001, km 39.484, at +5 m above canal road; Lambert coordinates: km 140.460 Y 147.222.
JV98-003	98-231	Ittre	Sennette	cf. JV99-001, km 39.515, at +1 m above canal road; Lambert coordinates: km 140.485 Y 147.245.
JV98-004	98-232	Ittre	Sennette	cf. JV99-001, km 39.549, at +1.6 to +1.9 m above canal road; Lambert coordinates: km 140.498 Y 147.292.

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