GEOLOGICA BELGICA (2005) 8/4: 145-159.

CHITINOZOAN BIOZONATION AND NEW LITHOSTRATIGRAPHICAL DATA IN THE UPPER ORDOVICIAN OF THE FAUQUEZ AND ASQUEMPONT AREAS (BRABANT MASSIF, BELGIUM)

Jan VANMEIRHAEGHE[1], Annelies STORME[1], Koen VAN NOTEN[1,2], Geert VAN GROOTEL & Jacques VERNIERS[1]

(3 figures, 2 tables, 3 plates)

1. Palaeontology Research Unit, Ghent University, Krijgslaan 281/S8, B-9000 Gent, Belgium, E-mail: Jan.Vanmeirhaeghe@UGent.be.

2. Present address: Structural Geology & Tectonics Group, Katholieke Universiteit Leuven, Redingenstraat 16, B-3000 Leuven, Belgium.

ABSTRACT. A chitinozoan biozonation is established for the Upper Ordovician rocks of the Sennette valley in the Fauquez area and the Asquempont area, revising the existing chitinozoan biozonation of the Brabant Massif. The chitinozoans of five formations (the Ittre, Bornival, Huet, Fauquez and Madot formations) are studied from 70 samples. The chitinozoan biozonation is correlated with Baltoscandia and the Avalonian Upper Ordovician type sections in the U.K. This correlation provides an accurate dating of the studied formations. A megaslumping event, affecting a part of the Ittre and Bornival Formation and causing the overturning of a pile of sediments estimated at minimum 200 m thick, may be placed in the mid Oandu (Cheneyan, middle Caradoc, early “Stage 6”). The volcanic rocks in the Fauquez area, formally thought to be restricted to the Ashgill, are confined to the late Caradoc - early Ashgill timespan. In addition to this, this paper presents new lithostratigraphical data on the Ittre Formation and the lower member of the Bornival Formation.

KEYWORDS. Avalonia, biostratigraphy, Brabant Massif, correlation, chitinozoans, lithostratigraphy, Sennette valley, Upper Ordovician

1. Introduction

The Upper Ordovician rocks of the Sennette valley in the area around and to the north of the hamlet of Fauquez are among the most complete successions of this stratigraphical interval in Belgium (Fig. 1). Outcrops situated to the north of the Fauquez area, in the southern Asquempont area, contain the deposits of the Ittre and Bornival formations, which are supposed to contain a megaslump (Debacker *et al.*, 2001). In the Fauquez area, there are the macrofossil-bearing greenish-grey mudstones, siltstones and sandstones of the Huet Formation, the dark grey to black graptolitic shales of the Fauquez Formation and the silt- to mudstones of the Madot Formation, containing two major volcanic or volcano-sedimentary levels and some macrofossiliferous levels. Whereas the lithostratigraphy and the structural geology of the area are well known (Verniers *et al.*, this volume), the biostratigraphical knowledge is restricted to a few macrofauna-bearing sites (see references in Verniers *et al.*, this volume) and preliminary acritarch (Martin, 1968; Martin & Rickards, 1979) and chitinozoan studies (Van Grootel & Verniers, 1998; Samuelsson & Verniers, 2000). The present study is undertaken to date the Upper Ordovician rocks of the Sennette valley in more detail, by means of a detailed chitinozoan study from 70 samples.

2. Study area

The study area is situated around and to the north of the hamlet of Fauquez, on the territory of both Ittre and Ronquières (see also Verniers *et al.*, this volume). The study area is the same as that of Verniers *et al.* (this volume), but is extended to the north with outcrops along the eastern slope of the Brussels-Charleroi canal, from km 39.175 to km 39.700 (Fig. 1). All locations of samples or boundaries are marked in kilometres along the canal, as marked on the IGNB topographic map of 1983.

3. Lithostratigraphy

For an extensive litho- and biostratigraphical overview of the southern Asquempont and the Fauquez areas concerning the upper members of the Bornival Formation and the Huet, Fauquez and Madot formations, we refer to Verniers *et al.* (this volume). As our paper also provides new lithostratigraphical information on the Ittre Formation (collected by AS) and the lower member of the Bornival Formation (collected by KVN), these units are discussed below. They crop out in their type sections in the southern Asquempont area (Debacker, 2001), along the east side of the Brussels-Charleroi canal to the north of Fauquez, from approximately km 39.690 to km 39.246 (Fig. 1). Neither the base nor the top of both the Ittre Formation and the lower member of the Bornival Formation were ever observed.

According to literature, the Ittre Formation consists of an alternation of light grey fine-grained cross-laminated sandstone, medium grey parallel laminated siltstone and dark grey mudstone, interpreted respectively as the Tc-, Td-, and Te-intervals of the Bouma (1962) turbidite sequence (Servais, 1991; Verniers *et al.*, 2001; Debacker 2001; Debacker *et al.*, 2001, 2003). Its thickness is estimated at >180 m (Debacker *et al.*, 2001). The bedding planes are sharp (Verniers *et al.*, ibid.). Servais (1991) mentioned the presence of some turbidites interstratified in a mainly dark pelite sequence. According to this author, these deposits are base cut-out Tcde sequences in the terminology of Bouma (1962) and he interpreted them as distal turbidites.

Our observations confirm the presence of Tc-, Td- and Te-intervals in some parts of the Ittre Formation. However, in the traditional belief, the Tc-intervals of the Ittre Formation are often more than 5 cm thick (Verniers *et al.*, 2001), whereas our observations confirm this only for two sections in the lower part of the Ittre Formation (zone with normal polarity, with an exceptionally thick Tc-interval of up to 60 cm thickness in between km 39.659 and km 39.658) and the uppermost (observed) 30 m of the formation. This type of turbidites corresponds to the medium-grained turbidites *sensu* Reading (1986). In the rest of the Ittre

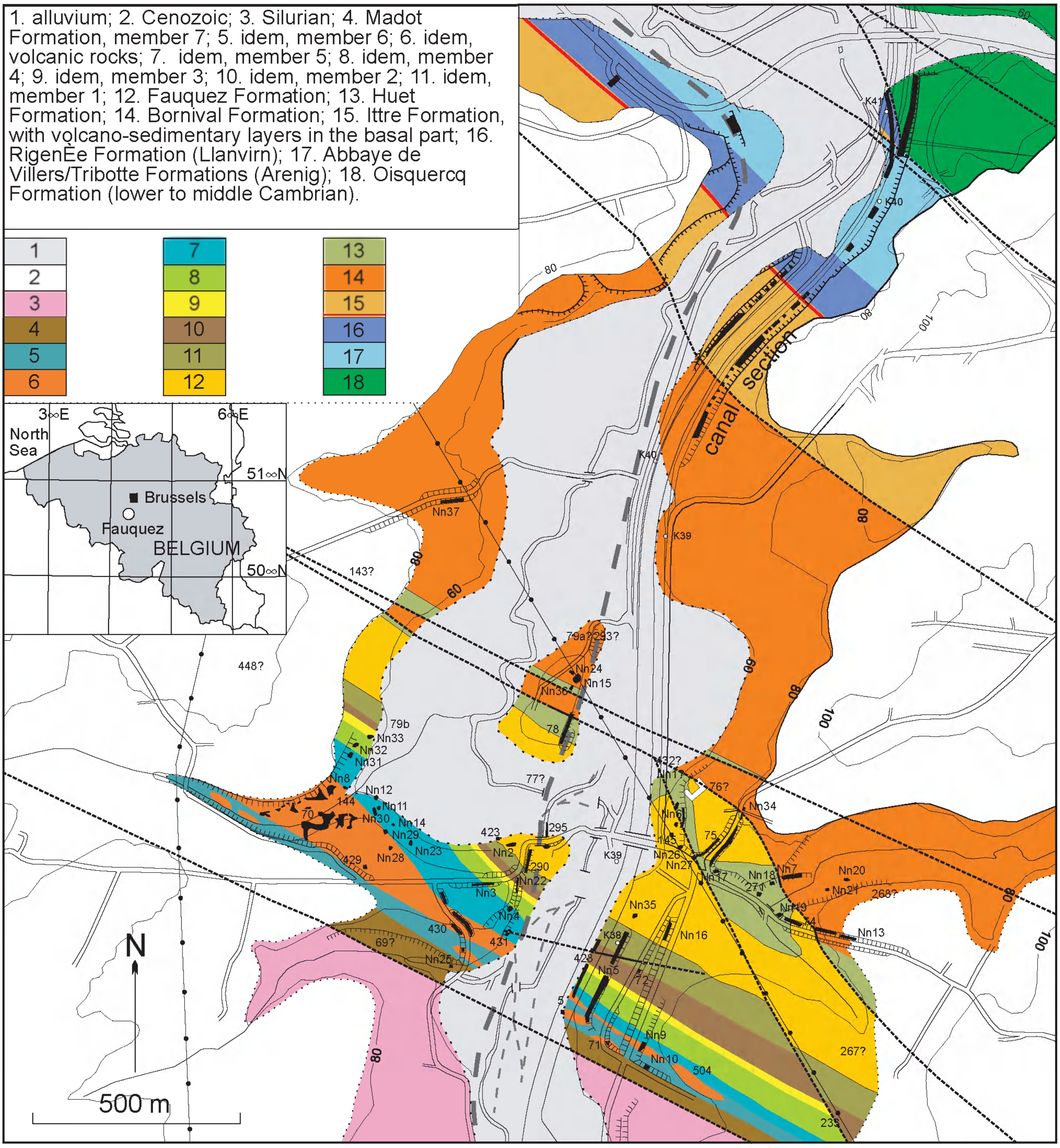

Figure 1. Geological map of the Lower Palaeozoic of the Fauquez and Asquempont areas with location of the outcrops. Compiled and modified from Debacker (2001) and Verniers *et al.* (this volume) for the southern part, and Debacker (2001) and Debacker *et al.* (2003) for the northern part.

Formation, Tc-intervals are mostly thinner than 2 cm or absent (Storme, 2004) and the turbidites resemble the fine-grained turbidites *sensu* Stow (in Reading, 1986).

In the basal part of the Ittre Formation, from km 39.691 to km 39.671, volcanosedimentary layers occur intercalated in between siliciclastics (Corin, 1963; Debacker *et al.*, 2003). The base of the Ittre Formation is considered to occur between km 39.690 and km 39.700 (Debacker, 2001).

A pronounced post-cleavage deformation zone occurs around km 39.400, apparently coinciding with the limit between the Ittre Formation and the lower member of the Bornival Formation (Debacker *et al.*, 2003). Probably this deformation and the juxtapostion of both units is fault-related (Debacker *et al.*, 2003).

The lower member of the Bornival Formation crops out from km 39.318 to 39.246, but Van Noten (2004) observed rocks of this member in the overgrown part of the talus as far as km 39.210. This implies that the thickness of the lower member of the Bornival Formation is now estimated at minimum 116 m, in contrast to the >95 m estimate of Verniers *et al.* (2001). In the literature, the lower member of the Bornival Formation is described as a centrimetric alternation of light to medium grey fine micaceous sandstone to siltstone and dark grey to black mudstone with abundant silt grains distributed throughout (Debacker, 2001; Debacker *et al.*, 2003; Verniers *et al.*, 2001, this volume). Our observations point to the relative abundance of the silt-dominated laminae (mostly 1 to 4 cm thick). The homogenous mudstone laminae are in most cases very thin (<1 cm). Verniers *et al.* (2001)

describe occasional very fine-grained sandstone beds, laminated or obliquely stratified and never more than 5 cm in thickness. Although obliquely stratified fine-grained sandstone beds sometimes occur, the thickest fine-grained sandstone beds of the Bornival Formation are well–sorted, homogeneous and have sharp bedding planes. The mean thickness of these beds is approximately 5 cm, the thickest bed being 10 cm thick. The sediments of the lower member of the Bornival Formation contain pronounced small-scale soft-sediment deformation of biogenic and non-biogenic origin (Debacker, 2001; Debacker *et al.*, 2003). According to Verniers *et al.* (2001), the bedding planes are rarely sharp and mostly gradual. New observations, however, show that in zones without soft-sediment deformations, sharp bedding planes do occur. The sediments of the Bornival Formation are heavily bioturbated fine-grained turbidites *sensu* Stow (in Reading, 1986) (cf. Debacker *et al.*, 2003), pelagites and/or contourites. A profound study of the sedimentology is necessary to determine the exact nature of the sediments.

The sediments of the Ittre Formation differ clearly from those of the lower member of the Bornival Formation. The fine-grained sandstone beds of the Ittre Formation display cross-laminated bedding, whereas in the lower member of the Bornival Formation, cross-lamination is mostly obscured by soft-sediment deformation; the thickest fine-grained sandstone beds of the lower member of the Bornival Formation are homogeneous and structureless. The Ittre Formation contains pluridecimetric beds of homogeneous mudstone, whereas this type of sediment generally is restricted to sub-centimetric laminae in the lower member of the Bornival Formation. The sharp bedding planes of the Ittre Formation contrast with the often vague bedding planes of the lower member of the Bornival Formation. Soft-sediment deformations are not as abundant in the Ittre Formation as in the lower member of the Bornival Formation, where they occur frequently. Moreover, most soft-sediment deformations in the Ittre Formation are of non-biogenic origin, while bioturbations are common in the lower member of the Bornival Formation.

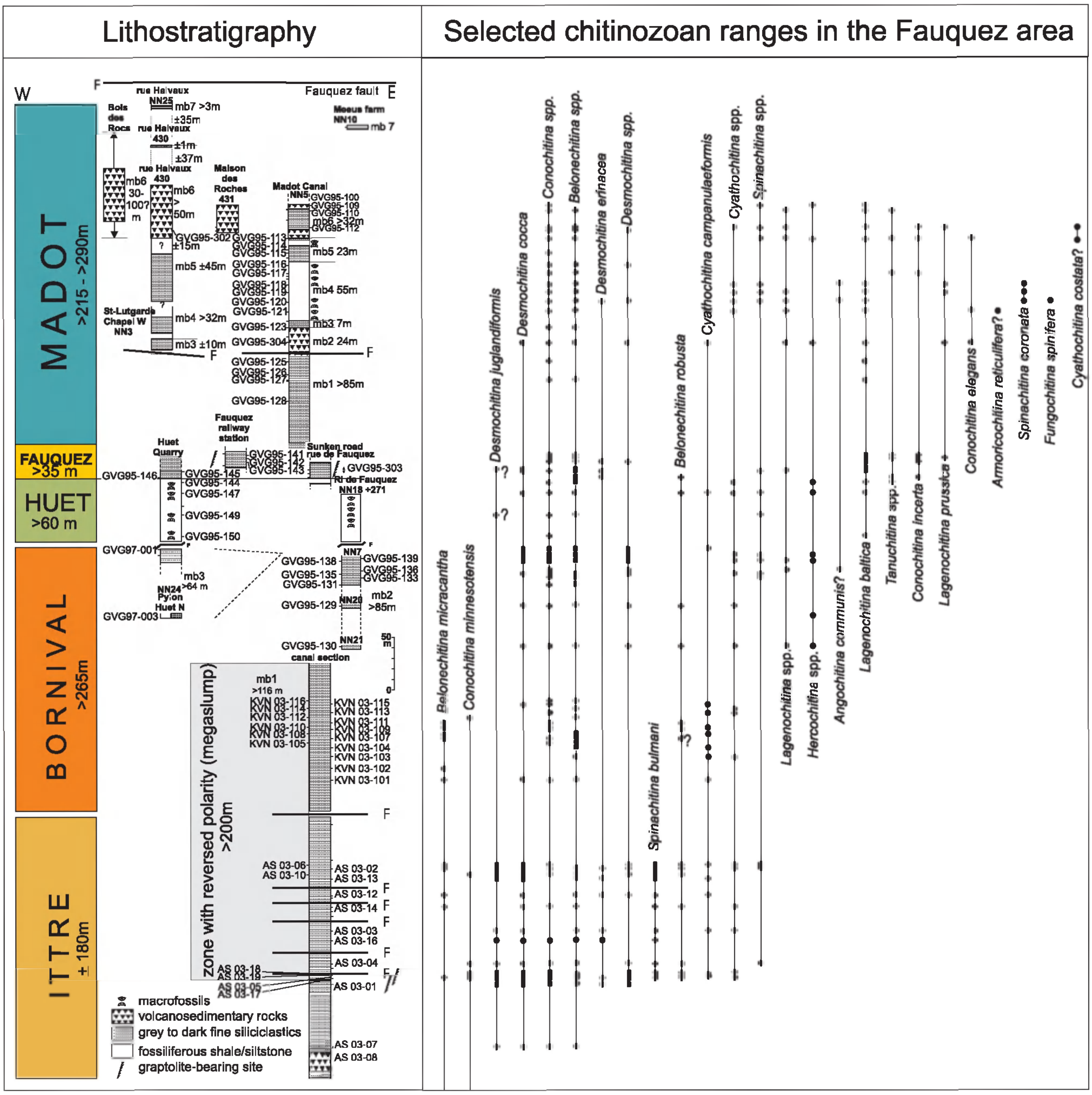

Figure 2. Lithostratigraphy, position of the samples, and chitinozoan ranges in the investigated formations. Lithologs modified from Van Grootel *et al.* (1998), except for the Ittre Formation and the lower member of the Bornival Formation.

The differences between the lower and the other members of the Bornival Formation are distinct. In the middle member of the Bornival Formation, mudstone beds are thicker (up to 10 cm) than in the lower member (mostly sub-centimetric). The centimetric lamination of the lower member is absent here and beds are commonly thicker. Also the homogeneous fine-grained sandstone beds do not occur in the middle member. In the upper, finer-grained member, only a faint lamination is observed, caused by the varying amount of fine silt grains in the very dark grey to black shale (Verniers *et al.*, 2001).

On the basis of structural and sedimentary features, Debacker *et al.* (2001, 2003) interpret the overturning of a + 200 m thick interval containing a large part of the Ittre Formation and the lower member of the Bornival Formation in the southern Asquempont area as a result of a megaslumping event.

4. Chitinozoan results

4.1. Sample processing and state of preservation

FORMATION	MEMBER	SAMPLE NUMBER	*Desmochitina juglandiformis*	*Desmochitina cocca*	*Belonechitina* spp.	*Conochitina* spp.	*Desmochitina erinacea*	*Desmochitina* spp.	*Conochitina minnesotensis*	*Belonechitina robusta*	*Spinachitina bulmani*	*Cyathochitina* spp.	*Belonechitina micracantha*	*Cyathochitina campanulaeformis*	*Spinachitina* spp.	*Conochitina* sp.1	*Laufeldochitina* spp.	*Conochitina* sp. 2	*Cyathochitina* sp. 1	*Hercochitina* sp. 1	*Lagenochitina* spp.	*Angochitina communis*?	Undetermined chitinozoans	Total number of chitinozoans	Sample weight (g)	Chitinozoans/ g rock
BORNIVAL	Mb 3	GVG 97-001		2	3	5		1						1		3							34	49	37.3	1,3
		GVG 97-003		2	4	4		1				1			3	5	1	3		4			10	38	39.1	1,0
	Mb2	GVG 95-139				4																	26	30	39.7	0,8
		GVG 95-138		6	7	11		3				1			5					1	1		12	47	31.8	1,5
		GVG 95-136				2		1													1	1	14	19	35.0	0.5
		GVG 95-135		2	4	12		3				5			3								52	81	36.3	2.2
		GVG 95-133			2	2									2								8	14	?	?
		GVG 95-131			2	3																	17	22	65.3	0.3
		GVG 95-129		1	1	6		1		1		2											35	47	?	?
		GVG 95-130		5	1	12		6		4								7	1	1?	1		54	92	33.4	2.8
	Mb1	KVN 03-116			1	2																	25	28	16.7	16.5
		KVN 03-115		2		1								1									24	28	15.8	1.8
		KVN 03-114			1							1											32	34	15.6	2.2
		KVN 03-113				3						2		1			1						52	59	15.7	3.8
		KVN 03-112			2				12														125	139	15.8	8.8
		KVN 03-111			1	5				1			1										62	70	15.3	4.6
		KVN 03-110				1							5	3		1							16	26	15.3	1.7
		KVN 03-109				4				6						1							28	39	15.9	2.5
		KVN 03-108			3								8	1									24	36	16.0	2.3
		KVN 03-107			3	5				1?			5										68	82	15.2	5.4
		KVN 03-105			2	3										2							13	20	15.2	1.3
		KVN 03-104			1									1									12	14	15.1	0.9
		KVN 03-103			1							1		1									12	15	15.1	1.0
		KVN 03-102											3										14	17	15.1	1.1
		KVN 03-101		3	4	10							9	1									71	98	35.7	2.7
ITTRE		AS 03-06	1	39		16		4		34	12	2	32	3	21								88	252	15.2	16.6
		AS 03-02	1	66	1	2	25	8		5	3	2	2		6								235	356	15.1	23.6
		AS 03-10	7	70	9	19		6	3	10	6												178	310	16.1	19.3
		AS 03-13	1	11	7		3				1			1									54	78	8.1	9.6
		AS 03-12		28	1		35	6			14		1	5									50	140	14.1	10.0
		AS 03-14		10	14	12				1	7	2	1										106	153	18.7	8.2
		AS 03-03	2	19	1		16				3	2		1									123	167	15.1	11.0
		AS 03-16	2	4	12	2	3				1												122	146	7.9	18.6
		AS 03-04	4	11	13	2		2	5	12	2				3								82	136	15.2	9.0
		AS 03-18	28	93		5		69	1	1	5	4											44	251	17.0	14.7
		AS 03-19		10	3	8								3									57	91	14.5	6.3
		AS 03-05	3	61	18	13			2	17	24			7									111	256	14.6	17.6
		AS 03-17	18	70	20	15	1	22	3	7	17	3	1										106	283	8.0	35.2
		AS 03-01	4	8	1	3	1	3															34	54	15.1	3.5
		AS 03-07	1	2	2	2																	16	23	18.4	1.3

Table 1. Chitinozoan absolute abundance in samples from the Ittre and the Bornival formations. Sample weight and chitinozoan abundance/g rock are indicated on the right. Samples from the zone with inversed polarity are indicated in grey.

HUET				FAUQUEZ						MADOT																				FORMATION
										Mb1				Mb2	Mb3	Mb4						Mb5			Mb6					MEMBER
GVG 95-150	GVG 95-149	GVG 95-147	GVG 95-144	GVG 95-146	GVG 95-145	GVG 95-303	GVG 95-143	GVG 95-142	GVG 95-141	GVG 95-128	GVG 95-127	GVG 95-126	GVG 95-125	GVG 95-304	GVG 95-123	GVG 95-121	GVG 95-120	GVG 95-119	GVG 95-118	GVG 95-117	GVG 95-116	GVG 95-115	GVG 95-114	GVG 95-113	GVG 95-302	GVG 95-112	GVG 95-110	GVG 95-109	GVG 95-100	SAMPLE NUMBER
8		81	30		50	20	33	11	10		17		1	50		27	7	50	48					31		25	1	25		*Lagenochitina baltica*
5	13																													*Conochitina* sp. 3
	2	5	2		3		3	7	5		3		2	6	1	4	2	9	2	5	2	1		7	2	5	9	2		*Conochitina* spp.
	3	5	18	1	4	2	4	3	2		4			5	1	3	7	4	4	3	1			17	1	8	2			*Belonechitina* spp.
	1					1																								*D. juglandiformis*?
							1							1			1				2				1					*Desmochitina* spp.
	1	4			1												4	2	1					1		1		1		*Spinachitina* spp.
		1	1											1										1				2		*Hercochitina* spp.
		5		1																										*Belonechitina robusta*
		1			3	1								2																*Desmochitina cocca*
		1												1																*Cy. campanulaeformis*
		2																												*Conochitina* sp. 2
		2	1													1	1									2				*Cyathochitina* spp.
			1?	1				4	4											1				2			3			*Tanuchitina* spp.
				1			9	50	4											3				12		5				*Conochitina incerta*
				4	11		1										1													*Desmochitina erinacea*
					1									3		14	1	1						1		5	1			*Lagenochitina* spp.
								2						1				4	12							5				*Lagenochitina prussica*
														1		1								1						*Conochitina elegans*
																1														*Laufeldochitina* spp.
																1														*A.. reticulifera*?
																1	4	1												*Euconochitina* spp
																	2		1											*Angochitina communis*?
																	1													*F. spinifera*
																	2	10	1											*Spinachitina coronata*
																	6	2?	1											*Cyathochitina* sp. 1
																					2							21		*Conochitina* sp.4
																								1		2				*Cyathochitina costata*?
16	53	131	28	13	114	26	65	75	21	4	46		71	37	2	17	12	19	11	40	8	13		144	3	35	53	57		undetermined
29	73	238	81	21	186	50	116	152	46	4	70	0	74	107	4	69	51	102	81	52	15	14	0	218	7	93	69	108	0	Chitinozoans/sample
?	?	36.3	28.1	34.1	40.2	?	?	37.4	39.8	?	38.8	41.5	43.0	?	37.6	36.0	69.4	41.0	36.1	39.6	32.4	75.8	28.7	78.4	?	35.0	39.2	39.9	?	Sample weight (g)
?	?	6.6	31.3	0.6	4.6	?	?	205.7	45.2	?	1.8	0	1.7	?	0.1	1.9	22.7	12.4	22.4	34.3	0.2	0.2	0	6.1	?	17.7	8.8	2.7	0	Chitinozoans/ g rock

Table 2. Chitinozoan absolute abundance in samples from the Huet, Fauquez and Madot formations. Sample weight and chitinozoan abundance/g rock are indicated on the right. The underlined values are calculated from the number of chitinozoans from the partially picked out residu.

Chitinozoans were studied from 70 samples in the study area (see Tabs. 1 and 2), of which 15 samples were taken from the Ittre Formation, 25 from the Bornival Formation (15 from member 1; 8 from member 2; 2 from member 3), 4 from the Huet Formation, 6 from the Fauquez Formation and 20 from the Madot Formation (4 from member 1; 1 from member 2; 1 from member 1; 6 from member 4; 3 from member 5; 5 from member 6). Forty from the seventy samples were taken by Van Grootel during 1995 and 1997 and are indicated with prefix GVG. Seventeen GVG samples were already preliminarily studied by Van Grootel & Verniers (1998), but are now restudied, allowing new determinations. The other 23 GVG samples were studied for the first time in this work. In addition, 30 new samples, indicated with prefix AS and KVN, were taken in 2003. Three out of seventy samples proved to be barren. From the 67 productive samples, a total of 5970 chitinozoans was studied. The chitinozoans are poorly to moderately well preserved and the assemblages are fairly diverse. The mean concentration is 11.5 chitinozoans/ g rock, with a maximum of 205.7 chitinozoans/ g rock in GVG 95-142 (Fauquez Formation), which is surprisingly high for the Brabant Massif. The chitinozoans were extracted from the samples using standard palynological techniques (Paris, 1981) and then handpicked and mounted on slides for Scanning Electron Microscope (JEOL 6400) study.

4.2. Chitinozoan data (Fig. 2)

The chitinozoan assemblage of the Ittre Formation is characterised by the presence of *Desmochitina juglandiformis*, *Desmochitina cocca*, *Belonechitina micracantha*, *Conochitina* spp., *Belonechitina* spp. and *Desmochitina* spp.. *Desmochitina erinacea* first occurs in the top of the zone with normal polarity. The oldest strata involved in the megaslump contain the same chitinozoan assemblage, complemented by *Conochitina minnesotensis*, *Cyathochitina campanulaeformis*, *Belonechitina robusta*, *Spinachitina bulmani*, *Spinachitina* spp. and *Cyathochitina* spp.

The specimens of *D. juglandiformis* reported in this study (Pl. I, photos A-D) correspond closely to the type material of Laufeld (1967) and the description of Paris (1981). However, the typical wrinkled outer layer of this species, present in the holotype, is detached. This preservation state is well-known and illustrated by Paris (1981, Pl. 17, figs 8, 12 and 13).

The chitinozoan content of the lower member of the Bornival Formation, also comprised in the megaslump, only slightly differs from that of the Ittre Formation. Whereas the *Desmochitina* genus is well represented in the Ittre Formation, *Desmochitina* spp. only occur sporadically and in small numbers in the Bornival Formation (see Tab. 1). *C. minnesotensis* has its highest occurrence in member 1 of the Bornival Formation. Also note the presence of *Angochitina communis*? (one single specimen) and the occurrence of a few *Lagenochitina* spp. (but not *L. baltica*, *L. prussica* or *L. dalbyensis*) in the upper part (member 2) of the Bornival Formation.

Most of the (long-ranging) species from the Bornival Formation range into the Huet Formation. *Lagenochitina baltica* starts to occur in the basalmost sample of the Huet Formation, whereas *Tanuchitina* spp. have their lowest occurrence at the top of the Huet Formation.

The holotype of *L. baltica* (Eisenack, 1931) seems to have a longer neck than our specimens (see Pl. 2, A-C). However, the neck of our specimens is trimmed, and they are identified as *L. baltica* by the size, the shape and the typical ornamentation.

In the Fauquez Formation, we note the occurrence of *Lagenochitina prussica* and *Conochitina incerta* and the disappearance of *Belonechitina robusta*. Apart from that, the assemblage does not change significantly in comparison to that of the Huet Formation.

The same species are encountered in the Madot Formation. *Desmochitina cocca* and *Cyathochitina campanulaeformis* have their last occurrence in member 2 of the Madot Formation and so does *D. erinacea* in member 4. *Conochitina elegans* has its lowermost occurrence in member 2 of the Madot Formation. More important for biostratigraphical correlation is the occurrence of *Armoricochitina reticulifera*? in GVG 95-121 and the occurrence of *Fungochitina spinifera* and *Spinachitina coronata* in a level somewhat higher. The latter species are restricted to member 4. In member 6, *Cyathochitina costata*?, another biostratigraphically important species, occurs.

The specimen identified here as *F. spinifera* (Pl. 3, H and M) clearly has spines, just as the neotype designed by Paris *et al.* (1999). *Saharochitina fungiformis*, a species very similar to *F. spinifera* but with a smooth wall, was the former index species of the *F. spinifera* Biozone, at that time called the *F. fungiformis* Biozone. However, the two species have a slightly different range (Nõlvak, in press). One must thus be careful in correlating the ranges of these species.

4.3. Biozonation (Figs 2 & 3)

4.3.1. Spinachitina cervicornis Biozone

a) This study: The Baltoscandian *Spinachitina cervicornis* Biozone, defined by the total range of the index species by Nõlvak & Grahn (1993), is recognised in the study area not by the index fossil itself, but by the presence of *Desmochitina juglandiformis*. The range of the latter species coincides with the major part of the *S. cervicornis* Biozone in Baltoscandia (Nõlvak & Grahn, 1993). Characteristic co-occurring species of the *S. cervicornis* Biozone in Baltoscandia, such as *Belonechitina robusta* and *Belonechitina micracantha*, are also found in this study. However, *Spinachitina multiradiata*, known to co-occur in this biozone in Baltoscandia, is not recognised in our samples. Based on the presence of *D. juglandiformis*, the *S. cervicornis* Biozone is recognised in the Ittre Formation, from AS 03-07 to AS 03-06. The doubtful and sole occurrences of *D. juglandiformis*? in the Huet (GVG 95-149) and the Fauquez formations (GVG 95-303) are not included in this biozone.

b) Other studies: On Avalonia, *D. juglandiformis* is reported from the Belgian Condroz Inlier, from the Vitrival–Bruyère Formation in Faulx-les-Tombes (Vanmeirhaeghe, submitted). Furthermore, in the Avalonian Whitland section (U.K.), the species is found from the lower part of the *clingani* Biozone over the *miserabilis – morrisi* interval into the *Normalograptus* proliferation interval (Vandenbroucke, pers. comm., 2004). In the samples from the Shelve Inlier, comprising the type Caradoc section of the Onny Valley, Shropshire, U.K. (Avalonia), neither *D. juglandiformis* nor *S. cervicornis* are recognised (Jenkins, 1967). Ancilletta (1997) reported new observations from the Onny Valley and found an assemblage comprising *B. robusta*, *D. cocca*, *S. bulmani* and *C. minnesotensis*, all of which also occur in the Ittre and Bornival formations (except for *S. bulmani* that is restricted to the Ittre Formation), in the Harnage Shales, the Chatwall Flags and the Chatwall Sandstone. *S. bulmani* and *B. robusta* occur even higher, respectively into the Acton Scott Group and the Onny Shales (Ancilletta, 1997).

D. juglandiformis and *B. robusta* are also found in northern Gondwana (the former only in southern Spain) in the *B. robusta* Biozone (Paris, 1990). In the GSSP candidate section for the base of "Stage 6" in Hartfell Score, Scotland (Laurentia), *D. juglandiformis* was recovered together with *B.* aff. *robusta* from the upper part of the *wilsoni* Biozone to the lower part of the *clingani* Biozone (Zalasiewicz *et al.*, 2004). With the Laurentian biozonation (Achab, 1989; Webby *et al.*, 2004), this study has the occurrence of *B. robusta* and *S. bulmani* in common. The former occurs on Laurentia in the *Conochitina hirsuta* / *Lagenochitina* sp. A. Biozone and

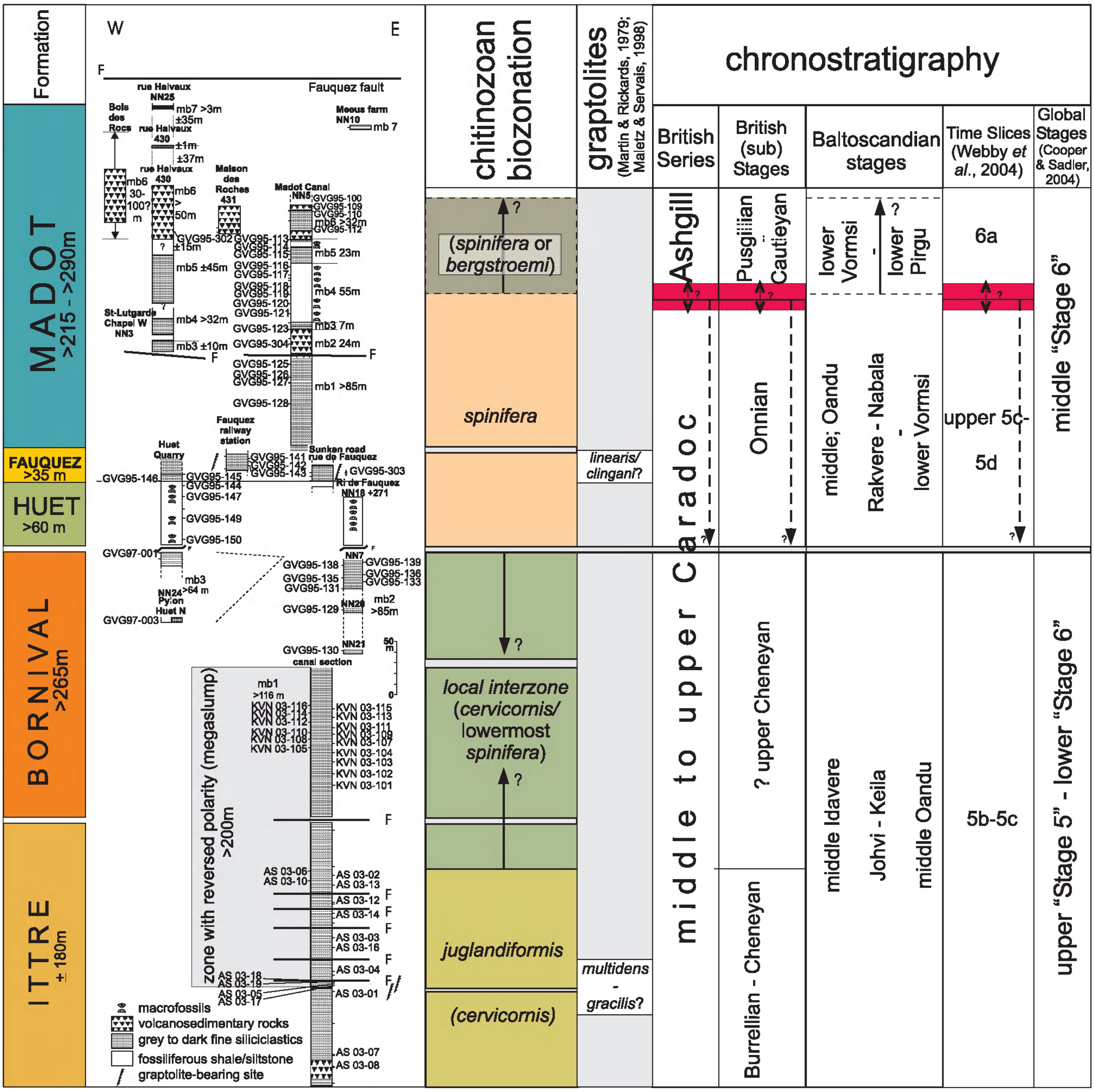

Figure 3. Lithostratigraphy, position of the samples, biozonation and chronostratigraphy of the investigated formations. Correlation of the British and Baltoscandian Stages according to Webby *et al.* (2004) for the Burrellian-Cheneyan interval. The red rectangle indicates the most probable interval in which the Caradoc-Ashgill boundary is situated.

the *Conochitina primitiva* / *Spinachitina* sp. A Biozone, while the latter occurs in the *Conochitina* sp. 2 / *Conochitina pygmaea* / *Hercochitina cristata* Biozone and higher.

4.3.2. Local interzone

Because of the lack of any index species in the Bornival Formation, a local interzone is defined between the last (certain) occurrence of *D. juglandiformis* and the first occurrence of *Lagenochitina baltica* (Figs 2 & 3). This local interzone is correlated with a part of the Baltoscandian *S. cervicornis* Biozone or the lowermost part of the *F. spinifera* Biozone, characteristically without *L. baltica* in Baltoscandia.

4.3.3. *Fungochitina spinifera* Biozone

a) This study: The Baltoscandian *Fungochitina spinifera* Biozone corresponds to what was formerly known as the *Fungochitina fungiformis* Biozone, defined by Nõlvak & Grahn (1993) (Nõlvak, 2005; see also above). It is a total range zone, recognised in this study from GVG 95-150 (basal Huet Formation), extending certainly to GVG 95-120 (member 4; Madot Formation), but possibly to GVG 95-112 (member 6; Madot Formation; Figs 2 & 3) or even higher, as *Tanuchitina bergstroemi*, the index species of the overlying Baltoscandian chitinozoan biozone, is not found to occur in our samples.

The first occurrence of *Lagenochitina baltica* indicates the presence of the lower part of the *F. spinifera* Biozone in the study area. In Baltoscandia, *L. baltica* occurs slightly higher than the index species, from which we can infer the probable absence of the basalmost part of the biozone. *F. spinifera* itself is recorded only from one sample (one specimen in GVG 95-120, member 4 of the Madot Formation). Characteristic co-occurring species reported from this biozone in Baltoscandia, that are also recognised in this study, are *Armoricochitina reticulifera*?, *Cyathochitina* *costata*?, *Spinachitina coronata*, *Lagenochitina prussica* and *Conochitina incerta*. The determination of the former two species is uncertain because of their fragmentary preservation.

The *C. angusta* Subbiozone is possibly also present by the occurrence of *C. incerta* in the Fauquez Formation, as the latter species starts to occur in the *C. angusta* Subbiozone (lower to middle part of the *spinifera* Biozone) in Baltoscandia. *C. angusta* itself is, however, not recovered from our samples.

In Baltoscandia, the *A. reticulifera* Subbiozone, known from the middle part of the *F. spinifera* Biozone, overlies the *C. angusta* Subbiozone (Nõlvak & Grahn, 1993). On this palaeocontinent, *C. costata* and *L. prussica* have their first occurrence together with *A. reticulifera* (Nõlvak & Grahn, 1993), whereas in the present study, *Lagenochitina prussica* first occurs in member 2 of the Madot Formation, *A. reticulifera*? is present in the lower part of member 4 and *C. costata*? occurs only in member 6. The exact position of the *A. reticulifera* Subbiozone in the study area is hence uncertain, but may range from member 2 to a level between GVG 95-121 and GVG 95-120 in member 4 of the Madot Formation. As the upper boundary of the *A. reticulifera* Subbiozone is placed below the first occurrence of *S. coronata* in Baltoscandia (Nõlvak & Grahn, 1993), it is in this study rather well constrained. *S. coronata*, present in member 4 of the Madot Formation, is reported in Baltoscandia from the upper part of the *F. spinifera* Biozone and from the lower part of the overlying *T. bergstroemi* Biozone (Nõlvak & Grahn, 1993).

b) Other studies: The first occurrences of *L. baltica* and *L. prussica* were observed at the base of the Huet Formation in a preliminary study by Van Grootel & Verniers (1998), leading to the definition of local chitinozoan biozone 7 by Samuelsson & Verniers (2000). The samples studied in the former paper were restudied herein, revealing the occurrence of *L. prussica* only at a higher level, i.e. in the Fauquez Formation. In the Brabant Massif, the *A. reticulifera* Subbiozone was recognised from the very base of Unit I of the Lessines borehole (Van Grootel, 1995; Van Grootel *et al.*, 1997), corresponding to a level low in the Fauquez Formation (Samuelsson & Verniers, 2000). In Faulx-les-Tombes, Condroz Inlier, Belgium, the presence of the *F. spinifera* Biozone is deduced from the occurrence of *Lagenochitina baltica* and *Conochitina incerta*? in the uppermost strata of the Vitrival-Bruyère Formation and the lower part of the Bois de Presles Member of the Fosses Formation (Vanmeirhaeghe, submitted). Elsewhere on Avalonia, in the type Ashgill Area, Cautley District, U.K., the presence of the *F. spinifera* Biozone was inferred by the presence of *S. fungiformis*, accompanied with *Conochitina elegans*, *C. incerta*?, *S. coronata*, *L. baltica* and *Tanuchitina* spp. (Vandenbroucke *et al.*, in press). Furthermore, Van Nieuwenhove *et al.* (submitted) showed that the *spinifera* Biozone is present in the Greenscoe section, Southern Lake District, U.K., in the *superbus* conodont Biozone. In the upper Caradoc Cardigan (U.K.) section, its possible presence in the *clingani-morrisi* to *linearis* graptolite Biozones is inferred from a.o. the occurrence of *Conochitina elegans*, *S. coronata*?, *L. baltica*, *L. prussica*, *A. reticulifera* and *Tanuchitina* spp. (Vandenbroucke, pers. comm., 2004).

Jenkins (1967) studied chitinozoans from the Onny River Valley, Shropshire, U.K. (Avalonia), and reported *L. baltica* (without *F. spinifera*) from strata as low as the Costonian (lower Caradoc). The specimens determined as *L. baltica* (Jenkins, 1967, Pl. 73, figs 6-7) are, however, not convincing as the typical ornamentation cannot be seen.

The only species found in common with the Laurentian biozonation (Achab, 1989; Webby *et al.*, 2004) is *L. baltica*, reported from the *Cyathochitina vaurealensis* Biozone on this palaeocontinent (Achab, 1989).

4.3.4. *Tanuchitina bergstroemi* Biozone

a) This study: It is possible that also a part of the Baltoscandian *T. bergstroemi* Biozone, a total range zone, can be correlated with the studied sections. Characteristic co-occurring species as *L. baltica*, *L. prussica*, *C. incerta* and *S. coronata* are found in our samples. Furthermore, many specimens of *Tanuchitina* spp., not determinable to the species level as a consequence of their fragmentary state of preservation, occur from the top of the Huet Formation onwards (starting from GVG 95-144; see Tab. 2 and Fig. 2). If present, the base of the *T. bergstroemi* Biozone must be placed above GVG 95-120, member 4 of the Madot Formation, because *F. spinifera* still occurs in GVG 95-120. Preferably, it is placed in the range of *S. coronata*, which is present from GVG 95-120 to GVG 95-118 (see Tab. 2 and Fig. 2) in this study, as *T. bergstroemi* has its first occurrence in the range of *S. coronata* in Baltoscandia (Nõlvak & Grahn, 1993). The occurrence of *C. costata*?, in Baltoscandia restricted to the *F. spinifera* Biozone (Nõlvak & Grahn, 1993), must then be regarded as due to reworking or an erroneous determination (because of the fragmentary preservation). The top of the *T. bergstroemi* Biozone, marked by the first occurrence of *C. rugata* on Avalonia (Vandenbroucke *et al.*, in press, Vanmeirhaeghe, submitted) is not observed in this study.

b) Other studies: In the Brabant Massif, *T. bergstroemi* was reported from the Fauquez Formation (Van Grootel & Verniers, 1998) and the top of Unit I in the Lessines borehole (Van Grootel, 1995). The samples from the former study were restudied by us and we prefer to determine them as *Tanuchitina* spp., as only fragments of the specimens are preserved and a specific determination is impossible. In the Condroz Inlier, the species was reported from the Bois de Presles Member of the Fosses Formation, both from the Puagne Inlier (Vanmeirhaeghe & Verniers, 2004) and Faulx-les-Tombes (Vanmeirhaeghe, submitted). Elsewhere on Avalonia, *T. bergstroemi*? was found in the *linearis* graptolite biozone in Cardigan U.K. (Vandenbroucke, pers. comm. , 2004); *T. bergstroemi* occurs in the Cautley Mudstones Formation in the type Ashgill area, U.K. (Vandenbroucke *et al.*, in press).

5. Age assignment (Fig. 3)

Correlation with the Baltoscandian biozonation (Nõlvak & Grahn, 1993) can be done by means of two (or three if we can accept the presence of the *T. bergstroemi* Biozone) biozones. Correlation with the biozonation of the type Ashgill area and Pus Gill type section on Avalonia (Vandenbroucke *et al.*, in press) is clear by the recognition of one and possibly two biozones. Correlations with Laurentia and northern Gondwana can be done by the presence of *D. juglandiformis* and to a lesser extent with *B. robusta*.

In correlations with Baltoscandia, we prefer to use the Baltoscandian Stage terms, followed by the equivalent British Stages, according to the correlation scheme of Webby *et al.* (2004). In correlations with the biozonations proposed in Webby *et al.* (2004), we refer to the Time Slices (TS) of Webby *et al.* (2004), followed by their equivalent British Stage, according to Webby *et al.* (2004). In correlations with (candidate) GSSP's of the Ordovician Stages, the current terminology of the Ordovician Time Scale (Cooper & Sadler, 2004) is used. An overview of the correlation with different chronostratigraphical schemes is given in Fig. 3.

Ittre Formation. The Ittre Formation can be dated as late Idavere to mid Oandu (Burrellian to Cheneyan, Webby *et al.*, 2004) by correlation with the Baltoscandian chitinozoan biozonation. On Avalonia, a chitinozoan assemblage quite similar to that of the Ittre Formation is found in the Harnagian to Soudleyan (Burrellian) interval in the Onny Valley, type Caradoc area, U.K. (Ancilletta, 1997) and in the upper

Caradoc of the Whitland section, U.K. (Vandenbroucke, pers. comm., 2004). Correlation with Laurentia corroborates this age assignment: in the GSSP candidate section for the base of "Stage 6" in Hartfell Score, Scotland (Laurentia), *D. juglandiformis* was recovered from the upper part of the *wilsoni* Biozone to the lower part of the *clingani* Biozone (Zalasiewicz *et al.*, 2004) (upper "Stage 5" to lower "Stage 6", roughly Burrellian-Cheneyan). *B. robusta* occurs on Laurentia in TS 5a to 5b, corresponding to the Aurelucian to Burrellian Stages (Webby *et al.*, 2004). Correlation with northern Gondwana is less straightforward. Paris (1999) places the *B. robusta* Biozone (in which *D. juglandiformis* is found, see above) from the middle Cheneyan to the middle Streffordian. However, Webby *et al.* (2004) correlate it with the upper TS 5c to lower TS 5d, roughly corresponding to the British Streffordian Stage.

The other palaeontological data of the Ittre Formation corroborate the dating as Burrellian to Cheneyan. Legrand (1967, p. 39) mentioned the presence of *Nemagraptus gracilis*. Two graptolite-bearing levels were described by Martin & Rickards (1979), who considered them as belonging to the *Nemagraptus gracilis* or *Diplograptus multidens* Zone. The same authors described acritarchs and chitinozoans from the Ittre Formation in this section and assigned an Upper Ordovician (post-Llanvirn Ordovician) age to the assemblage. Later on, Maletz & Servais (1998) collected new material from the site of Martin & Rickards (1979), restudied the latter authors's collection and attributed the fauna also to the *N. gracilis* or the *D. multidens* Zone, with a preference for the latter zone, by the presence of *Climacograptus bicornis*. Our chitinozoan data also point to a correlation with the *D. multidens* Biozone (roughly Burrellian, Webby *et al.*, 2004), certainly for the lower and middle (known) part of the Ittre Formation. For the upper part, the youngest possible age is however the mid Oandu (late Cheneyan, early "Stage 6", *D. clingani* Biozone). This is not in contrast to the graptolite data, as the uppermost fertile chitinozoan-bearing sample is situated + 60 m stratigraphically higher than the uppermost graptolite-bearing site. The latter point itself is situated at a level + 100 m stratigraphically lower than the uppermost known strata of the Ittre Formation.

Samuelsson & Verniers (2000) studied the chitinozoans of the Ittre Formation from the Brussels-Charleroi canal section as well as from other localities and found *Belonechitina* cf. *robusta* and *Spinachitina ?bulmani*. Combining all palaeontological data, a Burrellian age for the formation was deduced (Samuelsson & Verniers, ibid.). However, the new chitinozoan evidence, as well as the other palaeontological data do not allow such a precise dating.

Bornival Formation. The possible local interzone of the Bornival Formation is mid Oandu (late Cheneyan) in age or somewhat earlier. The lack of *D. juglandiformis* and *L. baltica* in the Bornival Formation argues for a position high in the *S. cervicornis* Biozone or very low in the *F. spinifera* Biozone. As mentioned above, *L. baltica* is not present in the lowermost *F. spinifera* Biozone in Baltoscandia.

Acritarchs from member 1 of the Bornival Formation were described by Martin & Rickards (1979), who inferred a ?late Arenig to Llanvirn age for it. Chitinozoans from all three members were studied by Van Grootel & Verniers (1998) and Samuelsson & Verniers (2000), who mention the presence of *Lagenochitina dalbyensis*, *Belonechitina hirsuta* and *Belonechitina* cf. *robusta*. These authors (ibid.) deduced a Burrellian age for the Bornival Formation. Bearing in mind the conclusions drawn in the previous paragraph and the fact that the determinations of *L. dalbyensis* and possibly also *B. hirsuta* (which we determine as *A. communis?*) are not confirmed in this study, a mid Oandu (late Cheneyan) age is suggested for the Bornival Formation. As this age is deduced in the absence of the index species, it remains speculative.

The megaslumping, affecting the upper part of the Ittre Formation and the lower member of the Bornival Formation (Debacker *et al.*, 2001) occurred before the deposition of member 2 and may thus have taken place during the mid Oandu (late Cheneyan).

Huet, Fauquez and Madot formations. In the Fauquez area, the *F. spinifera* Biozone is recognised in the Huet, the Fauquez and in the lower part of the Madot Formation. The *F. spinifera* Biozone corresponds in Baltoscandia to the late Oandu – early Vormsi time (formerly supposed to be late Caradoc; Nõlvak & Grahn, 1993). Vandenbroucke *et al.* (in press) recently showed that the *F. fungiformis* Biozone (which is renamed *F. spinifera*; Nõlvak, 2005) is present on Avalonia in the graptolite-bearing Pus Gill and the type Ashgill area sections (U.K.) from the upper part of the Onnian (uppermost Caradoc) to the basal part of the Cautleyan (lower Ashgill), thus crossing the Caradoc-Ashgill boundary.

S. coronata ranges in Baltoscandia from the upper part of the *F. spinifera* Biozone trough the *T. bergstroemi* Biozone to the top of the *Conochitina rugata* Biozone (Nõlvak & Grahn, 1993). On Avalonia, *S. coronata?* has been reported from the Onnian (uppermost Caradoc) of the Pus Gill Section (U.K.) and the Pusgillian of the Cautley District, type Ashgill area, U.K. (Vandenbroucke *et al.*, in press). Certainly in Baltoscandia and probably also on Avalonia, the species' range thus comprises the Caradoc-Ashgill boundary. In our dataset, *S. coronata* is restricted to only 3 samples (GVG 95-120, GVG 95-119 and GVG 95-118) in member 4 of the Madot Formation and hence the Caradoc-Ashgill boundary could be placed there. However, we consider this argument not convincing enough to exclude a lower position of this boundary in the Huet or Fauquez formation.

Huet Formation. Maillieux (1926) described corals, cystoids, crinoids, bryozoans, brachiopods, gastropods, cephalopods and trilobites from the Huet quarry and indicated a Caradoc to Ashgill age. The cystoids were further studied by Regnell (1951), who inferred an upper Caradoc age for the rocks of the Huet Formation. Chitinozoans were studied by Van Grootel *et al.* (1997), Van Grootel & Verniers (1998) and Samuelsson & Verniers (2000). According to the latter authors, a late mid Caradoc age must be attributed by the presence of *Belonechitina robusta*, *Lagenochitina baltica* and *Lagenochitina prussica*. We, however, cannot confirm the presence of *L. prussica* in the Huet Formation. Instead, our data argue for an Onnian (latest Caradoc) age for the Huet Formation, in agreement to most macrofossil-based age assignments, but an age as young as the earliest Cautleyan remains possible.

Fauquez Formation. Many graptolite finds were done in the Fauquez Formation. According to Elles in Maillieux (1930), graptolites from the Sennette valley belong to the *clingani* or *linearis* Zone. Bulman (1950) restudied these graptolites and indicated the most probable presence of the *P. linearis* Biozone. Maletz & Servais (1998) critically reviewed the old collections and sampled for new graptolite material in the Fauquez Formation and concluded that the fauna may belong to the *P. linearis* Zone or possibly also to the upper part of the *D. clingani* Zone (upper Caradoc to lowermost Ashgill). Earlier chitinozoan studies mentioned the presence of *L. baltica*, *L. prussica*, *T. bergstroemi* and *B. robusta* in the Fauquez Formation (Van Grootel & Verniers, 1998; Samuelsson & Verniers, 2000). These samples were, however, restudied by us and we cannot confirm the presence of *T. bergstroemi* in them. Combining all data, we can deduce an Onnian age (latest Caradoc) for the Fauquez Formation, but an age as young as the earliest Cautleyan remains possible.

Madot Formation. Despite some Ashgill trilobites, determined by Richter & Richter (1951), but of which the origin from the Madot Formation is uncertain, most of the macrofauna collected from the Madot Formation is not studied yet in detail. Acritarch studies by Martin & Rickards (1979) indicate a broad Caradoc to Llandovery interval. The chitinozoans from the Madot Formation were studied by Van Grootel & Verniers (1998) and Samuelsson & Verniers (2000). By the presence of *L. baltica*, *L. prussica*, *T. bergstroemi* and *B. robusta*, they deduced late Vormsi to earliest Pirgu age (late Streffordian to early Pusgillian, latest Caradoc to earliest Ashgill) for the formation. In the present study, *T. bergstroemi* and *B. robusta* were not recovered from the samples of the Madot Formation. Based on the correlation of the *F. spinifera* and possibly also of the *T. bergstroemi* Biozones with the type Ashgill area (Vandenbroucke *et al.*, in press) and assuming that the range of *S. coronata* in our samples includes the Caradoc-Ashgill boundary as it is the case in the type Ashgill area and on Baltoscandia, we propose an Onnian (latest Caradoc) age for the lower part of the Madot Formation (member 1, member 2, member 3 and member 4 pro parte) and a Pusgillian to Cautleyan age (early to mid Ashgill) for the upper part (member 4 pro parte, member 5, member 6 and member 7).

As such, the volcanosedimentary deposits of member 2 can be dated as late Caradoc (Onnian), whereas those of member 4, member 5 and member 6 can be dated as early to mid Ashgill (Pusgillian-Cautleyan). This contrasts with the traditional belief of Legrand (1967), who regarded all volcanosedimentary rocks in the Brabant Massif as having an Ashgill age. Van Grootel *et al.* (1997) saw the peak of the extrusive volcanism in the early Ashgill; our data include the possibility to date the earliest important episode of volcanism as latest Caradoc.

6. Conclusions

New lithological observations in the Ittre Formation and the lower member of the Bornival Formation allowed a better description of the lithology of these units. The Ittre Formation contains medium-grained base-cut turbidites of the Bouma-type (Tcde intervals) and sediments resembling the fine-grained turbidites of Stow. The Bornival Formation contains heavily bioturbated fine-grained turbidites *sensu* Stow (in Reading, 1986) (cf. Debacker *et al.*, 2003), pelagites and/or contourites. The lower member of the Bornival Formation has a minimum thickness of 116 m.

Five Upper Ordovician formations of the Brabant Massif are dated by correlation of the chitinozoan assemblages with the biozonations of Baltoscandia (Nõlvak & Grahn, 1993) and Avalonia (Ancilletta, 1997; Vandenbroucke *et al.*, in press). The Ittre Formation, formerly supposed to be Burrellian (mid Caradoc) (Samuelsson & Verniers, 2000) in age, is shown to have a late Idavere to mid Oandu (Burrellian to Cheneyan) age. The Bornival Formation possibly has a mid Oandu (late Cheneyan age or earlier, opposed to the formerly deduced Burrellian age (Samuelsson & Verniers, 2000). Hence, the megaslumping, affecting the upper part of the Ittre Formation and the lower member of the Bornival Formation, is deduced to have taken place during the mid Oandu (late Cheneyan) or earlier. The chitinozoan assemblage of the Ittre and Bornival formations does not differ much and the Ittre Formation is assigned to the *S. cervicornis* Biozone by the presence of *D. juglandiformis*. Noteworthy is the abundant occurrences of *Desmochitina* species in the Ittre Formation, whereas this genus is almost absent in the overlying Bornival Formation (see Tab. 1).

The Huet Formation contains a strongly different chitinozoan assemblage as compared to the underlying formations. This suggests that a part of the stratigraphical record is missing due to a hiatus or faulting. The Huet, Fauquez and Madot Formation are correlated with the *F. spinifera* biozone and are all deposited during the latest Onnian (latest Caradoc) to earliest Cautleyan (early Ashgill) timespan. Assuming that the range of *S. coronata* comprises the Caradoc-Ashgill boundary, as it is the case in the type Ashgill area and on Baltoscandia, the Huet Formation itself and the overlying Fauquez Formation can be dated as Onnian (latest Caradoc). This differs slightly from the former dating by Samuelsson & Verniers (2000), who deduced a late Caradoc age for the Huet Formation and a latest Caradoc to earliest Ashgill age for the Fauquez Formation. From the former assumption, an Onnian age (latest Caradoc) for the lower part of the Madot Formation (member 1, member 2, member 3 and member 4 pro parte) and a Pusgillian to Cautleyan (early to mid Ashgill) age for the upper part (member 4 pro parte, member 5, member 6 and member 7) can be deduced. The volcanosedimentary deposits of member 2 could hence be dated as Onnian (latest Caradoc), whereas the volcanosedimentary layers of member 4, member 5 and member 6 could be dated as early to mid Ashgill (Pusgillian-Cautleyan). The Huet, Fauquez and Madot formations contain (a part of) the *F. spinifera* Biozone. Possibly the *T. bergstroemi* Biozone is present in the upper part (upper part of member 4 and higher) of the Madot Formation.

7. Acknowledgements

We acknowledge reviewers Florentin Paris and Timothy Debacker for their useful comments. The authors like to express their sincere thanks to Sabine Van Cauwenberghe for help with the sample processing. Thijs Vandenbroucke is thanked for sharing his knowledge on Upper Ordovician chitinozoans and discussions.

The first author acknowledges the financial support of the Bijzonder Onderzoeksfonds of the Ghent University. We acknowledge the financial support of the Fund for Scientific Research (Flanders) projects G.0094.01 and G.0271.05. This work is a contribution to the IGCP 503 project (Ordovician Palaeogeography and Palaeoclimate).

References

ACHAB, A., 1989. Ordovician chitinozoan zonation of Quebec and western Newfoundland. *Journal of Paleontology*, 63 (1): 14-24.

ANCILLETTA, A., 1997. *New observations of chitinozoan associations from Caradoc Type Section, Onny Valley, Shropshire.* Unpublished M.Sc., Université de Liège.

BOUMA, A.H., 1962. *Sedimentology of some flysch deposits.* Elsevier, Amsterdam, 168 pp.

BULMAN, O. M. B., 1950. On some ordovician graptolite assemblages of Belgium. *Bulletin de l'Institut Royal des Sciences naturelles de Belgique*, 26(5): 1-8.

COOPER, R.A. & SADLER, P.M., 2004. The Ordovician Period. In Gradstein, F., Ogg, J. & Smith, A. (eds) *A Geologic Time Scale 2004.* Cambridge University Press, Cambridge, 165-187.

CORIN, F., 1963. Sur les roches éruptives de la tranchée d'Hasquempont, canal de Charleroi. *Bulletin de la Société belge de Géologie*, 72: 94-98.

DEBACKER, T., 2001. *Palaeozoic deformation of the Brabant Massif within eastern Avalonia: how, when and why?* Unpublished Ph.D. Thesis, Ghent University.

DEBACKER, T., SINTUBIN, M. & VERNIERS, J., 2001. Large-scale slumping deduced from structural and sedimentological features in the Lower Palaeozoic Anglo-Brabant fold belt, Belgium. *Journal of the Geological Society of London*, 158: 341-352.

DEBACKER, T.N., HERBOSCH, A., SINTUBIN, M. & VERNIERS, J., 2003. Palaeozoic deformation history of the Asquempont-Virginal area (Brabant Massif, Belgium): large-scale slumping, low-angle extensional detachment development (the Asquempont Fault redefined) and normal faulting (the Nieuwpoort-Asquempont fault zone). *Memoirs of the Geological Survey of Belgium*, 49: 1-30.

EISENACK, A., 1931. Neue Mikrofossilien des baltischen Silurs I. *Palaeontologische Zeitschrift* 13 (1-4): 74-118.

JENKINS, W.A.M., 1967. Ordovician Chitinozoa from Shropshire. *Palaeontology*, 10 (3): 436-488.

LAUFELD, S., 1967. Caradocian Chitinozoan from Dalarna, Sweden. *Geologiska Föreningens i Stockholm Förhandlingar*, 89: 275-349.

LEGRAND, R., 1967. Ronquières, documents géologiques. *Mémoires pour servir à l'Explication des Cartes Géologiques et Minières de Belgique*, 6: 1-60.

MAILLIEUX, E., 1926. Remarques sur l'Ordovicien de la Belgique. *Bulletin de la Société belge de Géologie, Paléontologie et Hydrologie*, 36: 67-85.

MAILLIEUX, E., 1930. Observations nouvelles sur le Silurien de Belgique. *Bulletin du Musée Royal d'Histoire naturelle de Belgique*, 6(15): 1-8.

MALETZ, J. & SERVAIS, T., 1998. Upper Ordovician graptolites from the Brabant Massif, Belgium. *Geobios*, 31(1): 21-37.

MARTIN, F., 1968. Les acritarches de l'Ordovicien et du Silurien belge. Détermination et valeur stratigraphique. *Mémoires de l'Institut Royal des Sciences naturelles de Belgique*, 160: 1-176.

MARTIN, F. & RICKARDS, B., 1979. Acritarches, chitinozoaires et graptolithes ordoviciens et siluriens de la vallée de la Sennette (Massif du Brabant, Belgique). *Annales de la Société géologique de Belgique*, 102: 181-197.

NÕLVAK, J., 2005. Some improvements to the Ordovician chitinozoan biozoantion scheme of Baltoscandia. In Sheehan, P.M. & Servais, T. (eds), *Abstracts for the Second International Symosium of IGCP 503 on Ordovician Palaeogeography and Palaeoclimate.* Insight, A Milwaukee Public Museum Series in Natural History, 2: 23-24.

NÕLVAK, J. (in press). Distribution of Ordovician chitinozoans. In Põldvere, A. (ed.), *Mehikoorma (421) drill core.* Estonian Geological Sections, 6.

NÕLVAK, J. & GRAHN, Y., 1993. Ordovician chitinozoan zones from Baltoscandia. *Review of palaeobotany and palynology*, 79: 245-269.

PARIS, F., 1981. Les Chitinozoaires dans le Paléozoïque du Sud-Ouest de l'Europe (Cadre géologique – Etude systématique – Biostratigraphie). *Mémoires de la Société géologique et minéralogique de Bretagne*, 26(412): 1-496.

PARIS, F., 1990. The Ordovician chitinozoan biozones of the nortern Gondwana domain. *Review of Palaeobotany and Palynology*, 66: 181-209.

PARIS, F., 1999. Palaeobiodiversification of Ordovician chitinozoans from northern Gondwana. 8th ISOS, *Acta Universitatis Carolinae - Geologica*, 43 (1/2): 283-286.

PARIS, F., GRAHN, Y., NESTOR, V. & LAKOVA I., 1999. A revised chitinozoan classification. *Journal of Paleontology*, 73 (4): 549-570.

REGNELL, G., 1951. Revision of the Caradocian-Ashgillian cystoid fauna of Belgium with notes on isolated pelmatozoan stem fragments. *Mémoires de l'Institut Royal des Sciences Naturelles de Belgique*, 120: 1-47.

RICHTER, E. & RICHTER, R., 1951. Trilobiten von Ashgill-Alter aus dem massif du Brabant (Grand-Manil). *Bulletin de l'Institut Royal des Sciences naturelles de Belgique*, 27 (16): 1-6.

SAMUELSSON, J. & VERNIERS, J., 2000. Ordovician chitinozoan biozonation of the Brabant Massif, Belgium. *Review of Palaeobotany and Palynology*, 113: 105-129.

SERVAIS, T., 1991. Discovery of turbiditical levels in the Late Ordovician of the Sennette Valley (Brabant Massif, Belgium). *Annales de la Société Géologique de Belgique*, 114: 247-251.

STORME, A., 2004. *Lithostratigrafie en biostratigrafie met Chitinozoa van de Formatie van Ittre (Caradoc) in haar typelokaliteit in de Sennettevallei (Massief van Brabant).* Unpublished M. Sc. Thesis, Palaeontology Research Unit, Ghent University.

STOW, D.A.V., 1986. Deep clastic seas. In Reading, H.G., (ed.), *Sedimentary Environments and Facies.* Blackwell Scientific Publications, Oxford, 399-444.

VANDENBROUCKE, T.R.A., RICKARDS, R.B. & VERNIERS, J. (in press). Upper Ordovician Chitinozoan biostratigraphy from the type Ashgill Area (Cautley district) and the Pus Gill section (Dufton district, Cross Fell Inlier), Cumbria, Northern England. *Geological Magazine.*

VAN GROOTEL, G., 1995. *Project VLA93-3.5.1.: Microfossielen Eindverslag.* Laboratorium voor Paleontologie, Universiteit Gent, Gent, 36pp.

VAN GROOTEL, G., VERNIERS, J., GEERKENS, B., LADURON, D., VERHAEREN, M., HERTOGEN, J. & DE VOS, W., 1997. Timing of magmatism, foreland basin development, metamorphism and inversion in the Anglo-Brabant fold belt. *Geological Magazine*, 134(5): 607-616.

VAN GROOTEL, G. & VERNIERS, J., 1998. *Project NAT/96-3.3. Micropaleontologie en biostratigrafie van het Ordovicium. Eindverslag.* Unpublished report to the Belgian Geological Survey. Laboratorium voor Paleontologie, Universiteit Gent, Gent, 103pp.

VANMEIRHAEGHE, J. (submitted). Chitinozoan biostratigraphy and dating of the Upper Ordovician of Faulx-les-Tombes (central Condroz Inlier, Belgium). *Review of Palaeobotany and Palynology.*

VANMEIRHAEGHE, J. & VERNIERS, J., 2004. Chitinozoan bio- and lithostratigraphical study of the Ashgill Fosses and Génicot Formations (Condroz Inlier, Belgium). *Review of Palaeobotany and Palynology*, 130: 241-267.

VAN NIEUWENHOVE, N., VANDENBROUCKE, T.R.A. & VERNIERS, J. (submitted). Chitinozoan biostratigraphy of the Upper Ordovician Greenscoe-roadcutting, Southern Lake District, U.K. *Review of Palaeobotany and Palynology.*

VAN NOTEN, K., 2004. *Lithostratigrafie en biostratigrafie met Chitinozoa van de Formatie van Bornival (Caradoc) in haar typegebied in de Sennettevallei (Massief van Brabant).* Unpublished M.Sc. Thesis, Palaeontology Research Unit, Ghent University.

VERNIERS, J., HERBOSCH, A., VANGUESTAINE, M., GEUKENS, F., DELCAMBRE, B., PINGOT, J.L., BELLANGER, I., HENNEBERT, M., DEBACKER, T., SINTUBIN, M. & DE VOS, W., 2001. Cambrian – Ordovician – Silurian lithostratigraphic units (Belgium). *Geologica Belgica*, 4/1-2: 1-28.

VERNIERS, J., VAN GROOTEL, G. & DEBACKER, T. (this volume). The Upper Ordovician lithostratigraphy and structural architecture of the Fauquez area (Brabant Massif, Belgium). *Geologica Belgica.*

WEBBY, B.D., COOPER, R.A., BERGSTRÖM, S.M. & PARIS, F., 2004. Stratigraphic Framework and Time Slices. In Webby, B.D., Paris, F., Droser, M.L., & Percival I.G. (eds). *The Great Ordovician Biodiversification Event.* Columbia University Press, New York, 41-47.

ZALASIEWICZ, J., RUSHTON, A., VANDENBROUCKE, T. & VERNIERS, J., 2004. *Submission of Hartfell Score (south Scotland) as a GSSP for the base of the middle stage of the Upper Ordovician Series.* ISOS website, December 2004.

Manuscript received on 01.12.2004 and accepted for publication on 15.11.2005.

APPENDIX: Sample localities

Sample number	Formation and member (mb.)	Outcrop	Location
AS 03-01	Ittre	Brussels-Charleroi canal section	km 39.5962, at 2.0 m above towpath level
AS 03-02	Ittre	Brussels-Charleroi canal section	km 39.5396, at 3.0 m above towpath level
AS 03-03	Ittre	Brussels-Charleroi canal section	km 39.5048, at 1.5 m above towpath level
AS 03-04	Ittre	Brussels-Charleroi canal section	km 39.4863, at 1.5 m above towpath level
AS 03-05	Ittre	Brussels-Charleroi canal section	km 39.4659, at 2.0 m above towpath level
AS 03-06	Ittre	Brussels-Charleroi canal section	km 39.5440, at 1.5 m above towpath level
AS 03-07	Ittre	Brussels-Charleroi canal section	km 39.6585, at 0.5 m above towpath level
AS 03-10	Ittre	Brussels-Charleroi canal section	km 39.5340, at 3.2 m above towpath level
AS 03-12	Ittre	Brussels-Charleroi canal section	km 39.5215, at 1.0 m above towpath level
AS 03-13	Ittre	Brussels-Charleroi canal section	km 39.5310, at 7.5 m above towpath level
AS 03-14	Ittre	Brussels-Charleroi canal section	km 39.5180, at 3.1 m above towpath level
AS 03-16	Ittre	Brussels-Charleroi canal section	km 39.4955, at 4.2 m above towpath level
AS 03-17	Ittre	Brussels-Charleroi canal section	km 39.4640, at 4.3 m above towpath level
AS 03-18	Ittre	Brussels-Charleroi canal section	km 39.3990, at 1.7 m above towpath level
AS 03-19	Ittre	Brussels-Charleroi canal section	km 39.4160, at 1.0 m above towpath level
KVN 03-101	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.362, at 1.5 m above towpath level
KVN 03-102	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.346, at 1.8 m above towpath level
KVN 03-103	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.331, at 1.2 m above towpath level
KVN 03-104	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.321, at 1.2 m above towpath level
KVN 03-105	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.310, at 5.3 m above towpath level
KVN 03-107	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.307, at 3.4 m above towpath level
KVN 03-108	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.302, at 3.4 m above towpath level
KVN 03-109	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.295, at 2.1 m above towpath level
KVN 03-110	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.2955, at 0.8 m above towpath level
KVN 03-111	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.288, at 1.0 m above towpath level
KVN 03-112	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.280, at 4.8 m above towpath level
KVN 03-113	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.2715, at 4.2 m above towpath level
KVN 03-114	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.266, at 3.4 m above towpath level
KVN 03-115	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.2615, at 3.7 m above towpath level
KVN 03-116	Bornival, mb. 1	Brussels-Charleroi canal section	km 39.258, at 1.7 m above towpath level
GVG 95-100	Madot, mb. 6	Brussels-Charleroi canal section	km 37.792, between canal and rue Madot
GVG 95-109	Madot, mb. 6	Brussels-Charleroi canal section	km 37.8000, at 2.5 m above towpath level
GVG 95-110	Madot, mb. 6	Brussels-Charleroi canal section	km 37.8020, at 4.5 m above towpath level
GVG 95-112	Madot, mb. 6	Brussels-Charleroi canal section	km 37.8200, at 5.0 m above towpath level
GVG 95-113	Madot, mb. 5	Brussels-Charleroi canal section	km 37.8300, at 5.0 m above towpath level
GVG 95-114	Madot, mb. 5	Brussels-Charleroi canal section	km 37.8440, at 5.0 m above towpath level
GVG 95-115	Madot, mb. 5	Brussels-Charleroi canal section	km 37.8530, at 6.0 m above towpath level
GVG 95-116	Madot, mb. 4	Brussels-Charleroi canal section	km 37.8605, at 6.0 m above towpath level
GVG 95-117	Madot, mb. 4	Brussels-Charleroi canal section	km 37.8700, at 3.0 m above towpath level
GVG 95-118	Madot, mb. 4	Brussels-Charleroi canal section	km 37.8825, at 3.5 m above towpath level
GVG 95-119	Madot, mb. 4	Brussels-Charleroi canal section	km 37.8900, at 3.5 m above towpath level
GVG 95-120	Madot, mb. 4	Brussels-Charleroi canal section	km 37.9000, at 3.5 m above towpath level
GVG 95-121	Madot, mb. 4	Brussels-Charleroi canal section	km 37.9100, at 1.0 m above towpath level
GVG 95-123	Madot, mb. 3	Brussels-Charleroi canal section	km 37.9270, at 1.5 m above towpath level
GVG 95-125	Madot, mb. 1	Brussels-Charleroi canal section	km 37.9800, at 2.5 m above towpath level
GVG 95-126	Madot, mb. 1	Brussels-Charleroi canal section	km 37.9940, at 2.5 m above towpath level
GVG 95-127	Madot, mb. 1	Brussels-Charleroi canal section	km 37.9995, at 2.5 m above towpath level
GVG 95-128	Madot, mb. 1	Brussels-Charleroi canal section	km 38.0220, at 3.5 m above towpath level
GVG 95-129	Bornival, mb. 2	Ri de Fauquez, NN20	left bank, 135 m N of bridge
GVG 95-130	Bornival, mb. 2	Ri de Fauquez, NN20	left bank, 185 m N of bridge
GVG 95-131	Bornival, mb. 2	Ri de Fauquez, NN20	At F4
GVG 95-133	Bornival, mb. 2	Ri de Fauquez, NN20	GVG 95-131 + 7 m
GVG 95-135	Bornival, mb. 2	Ri de Fauquez, NN20	GVG 95-131 + 11 m
GVG 95-136	Bornival, mb. 2	Ri de Fauquez, NN20	GVG 95-131 + 13.5 m
GVG 95-138	Bornival, mb. 2	Ri de Fauquez, NN20	GVG 95-131 + 21.3 m
GVG 95-139	Bornival, mb. 2	Ri de Fauquez, NN20	GVG 95-131 + 24.2 m
GVG 95-141	Fauquez	Fauquez railway station	11 m N of smallanticline
GVG 95-142	Fauquez	Fauquez railway station	7m N of small anticline
GVG 95-143	Fauquez	Fauquez railway station	centre of small anticline
GVG 95-144	Huet	Huet quarry	Km 10.9012
GVG 95-145	Fauquez	Huet quarry	Km 10.913
GVG 95-146	Fauquez	Huet quarry	Km 10.906
GVG 95-147	Huet	Huet quarry	Km 10.887
GVG 95-149	Huet	Huet quarry	Km 10.862
GVG 95-150	Huet	Huet quarry	Km 10.8495
GVG 95-302	Madot, mb. 6	Fauquez, Maison des Roches	11.2 m SSW of house
GVG 95-303	Fauquez	south of Rue de Fauquez, along the Rue des Tilleuls	at 1.5 m above the road in N flanc, 32 m NW of the corner with the Rue de Bornival, and 1.40 m east of fault.
GVG 95-304	Madot, mb. 2	Brussels-Charleroi canal section	km 37.971-37.925, 11 m S of pole 1440
GVG 97-001	Bornival, mb. 3	Huet quarry	km 10.8346 (0.6 m N of fault)
GVG 97-003	Bornival, mb. 3	Huet quarry	km 10.822 (13 m N of fault)

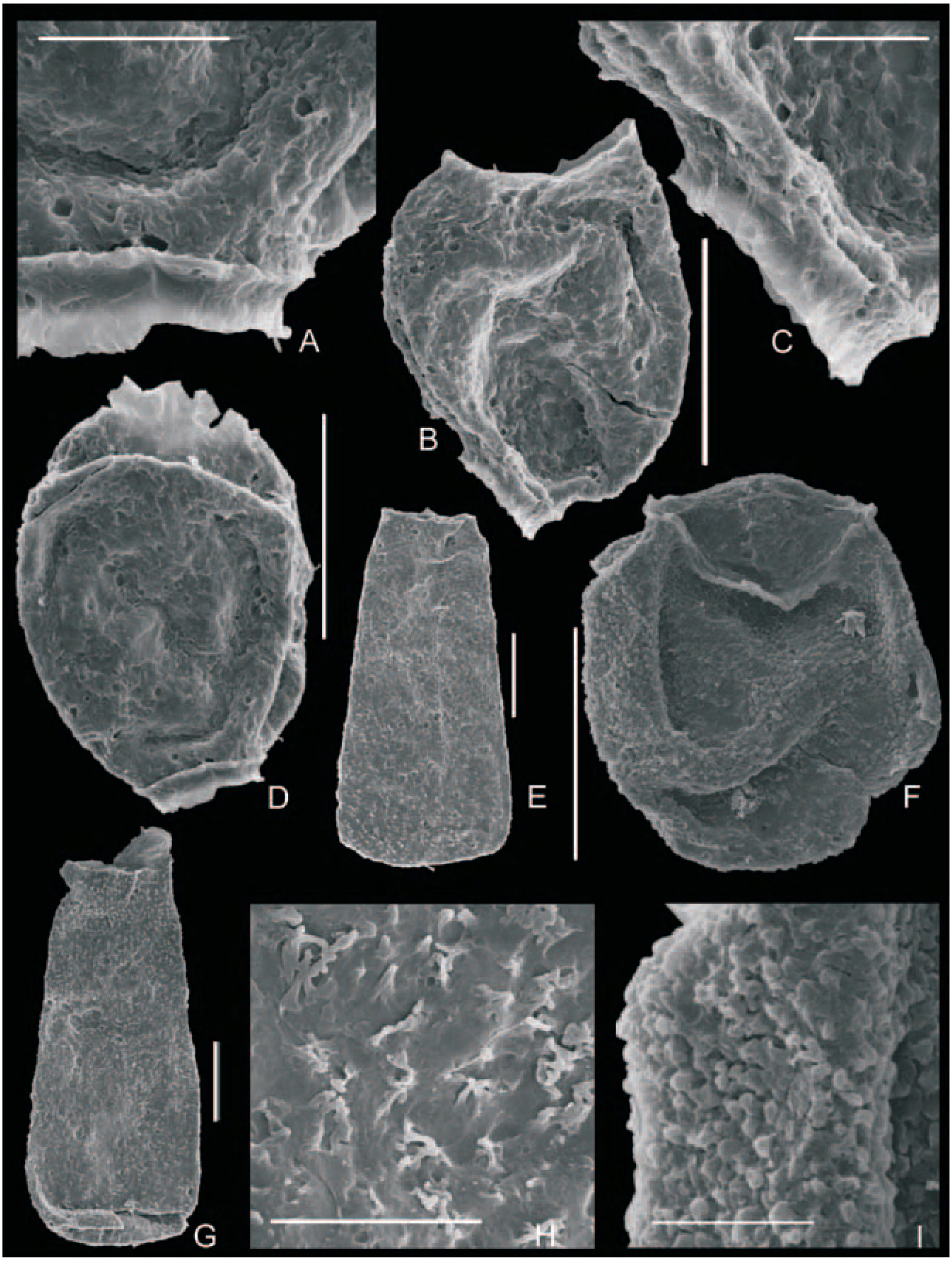

Plate 1. SEM photographs of chitinozoans from the Ittre Formation. Scale bars on complete specimen photographs represent 50 μm. Scale bars on detail photographs represent 10 μm.

A. Desmochitina juglandiformis. AS 03-04, Ittre Formation. Same specimen as D. Detail of the operculum. – *B. Desmochitina juglandiformis.* AS 03-04, Ittre Formation. L: 95; Dp: 60. – *C. Desmochitina juglandiformis.* AS 03-04, Ittre Formation. Same specimen as B. Detail of the operculum. – *D. Desmochitina juglandiformis.* AS 03-04, Ittre Formation. L: 80; Dp: 60. – *E. Belonechitina robusta.* AS 03-05, Ittre Formation. L: 220; Dp: 110; Dc: 65. – *F. Desmochitina erinacea.* AS 03-03, Ittre Formation. L: 85; Dp: 80. – G. *Belonechitina robusta.* AS 03-05, Ittre Formation. L: 270; Dp: 105; Dc: 60. – *H. Belonechitina robusta.* AS 03-05, Ittre Formation. Same specimen as G. Detail of the multirooted spines. Spine length approximately 3 μm. – *I. Desmochitina erinacea.* AS 03-03, Ittre Formation. Same specimen as F. Detail of the ornamentation.

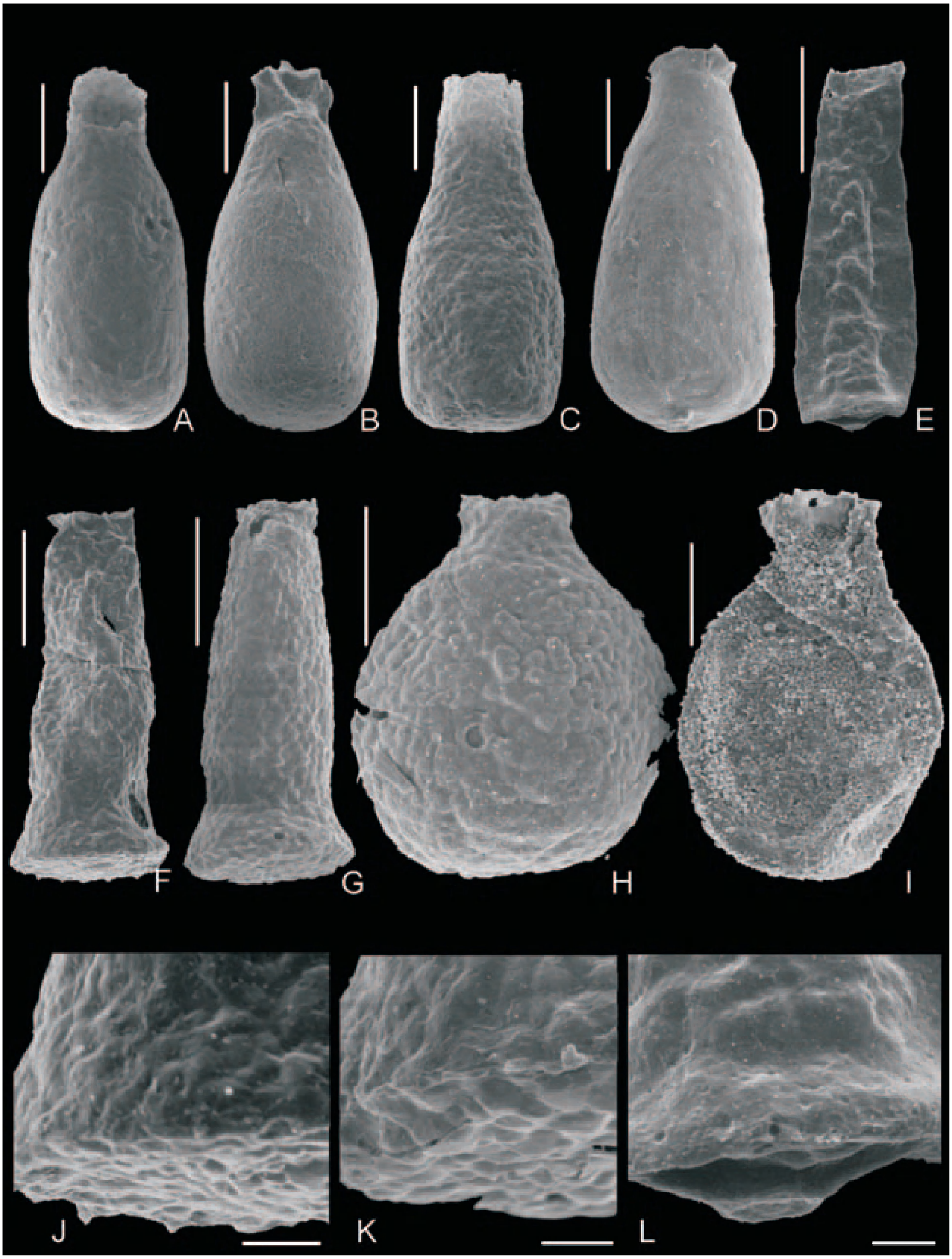

Plate 2. SEM photographs of chitinozoans from the Fauquez and Madot formations. Scale bars on complete specimen photographs represent 50 μm. Scale bars on detail photographs represent 10 μm.
A. *Lagenochitina baltica*. GVG 95-121, Madot Formation, member 4. L: 210; Dp: 90; Dc: 45. – *B. Lagenochitina baltica*?. GVG 95-112, Madot Formation, member 6. L: 210; Dp: 90; Dc: 45. L: 205; Dp: 95; Dc: 45. – *C. Lagenochitina baltica*. GVG 95-119, Madot Formation, member 4. L: 210; Dp: 90; Dc: 50. – *D. Lagenochitina* sp. GVG 95-304, Madot Formation, member 2. L: 205; Dp: 95; Dc: 45. – *E. Conochitina incerta*? GVG 95-142. Fauquez Formation. L: 300; Dp: 100; Dc: 65. – *F. Spinachitina coronata*. GVG 95-120. Madot Formation, member 4. L: 165; Dp: 60; Dc 35. – G. *Spinachitina coronata*. GVG 95-120. Madot Formation, member 4. L: 150; Dp: 65; Dc: 35. – *H. Lagenochitina prussica*. GVG 95-304. Madot Formation, member 2. L: 140; Dp: 100; Dc: 40. – *I. Lagenochitina prussica*? GVG 95-143. Fauquez Formation. L: 195; Dp: 130; Dc: 50. – *J. Spinachitina coronata*. GVG 95-120. Madot Formation, member 4. Same specimen as F. Detail of the basal spines. *K. Spinachitina coronata*. GVG 95-120. Madot Formation, member 4. Same specimen as G. Detail of the basal spines. – *L. Conochitina incerta*? GVG 95-142. Fauquez Formation. Same specimen as E. detail of the base.

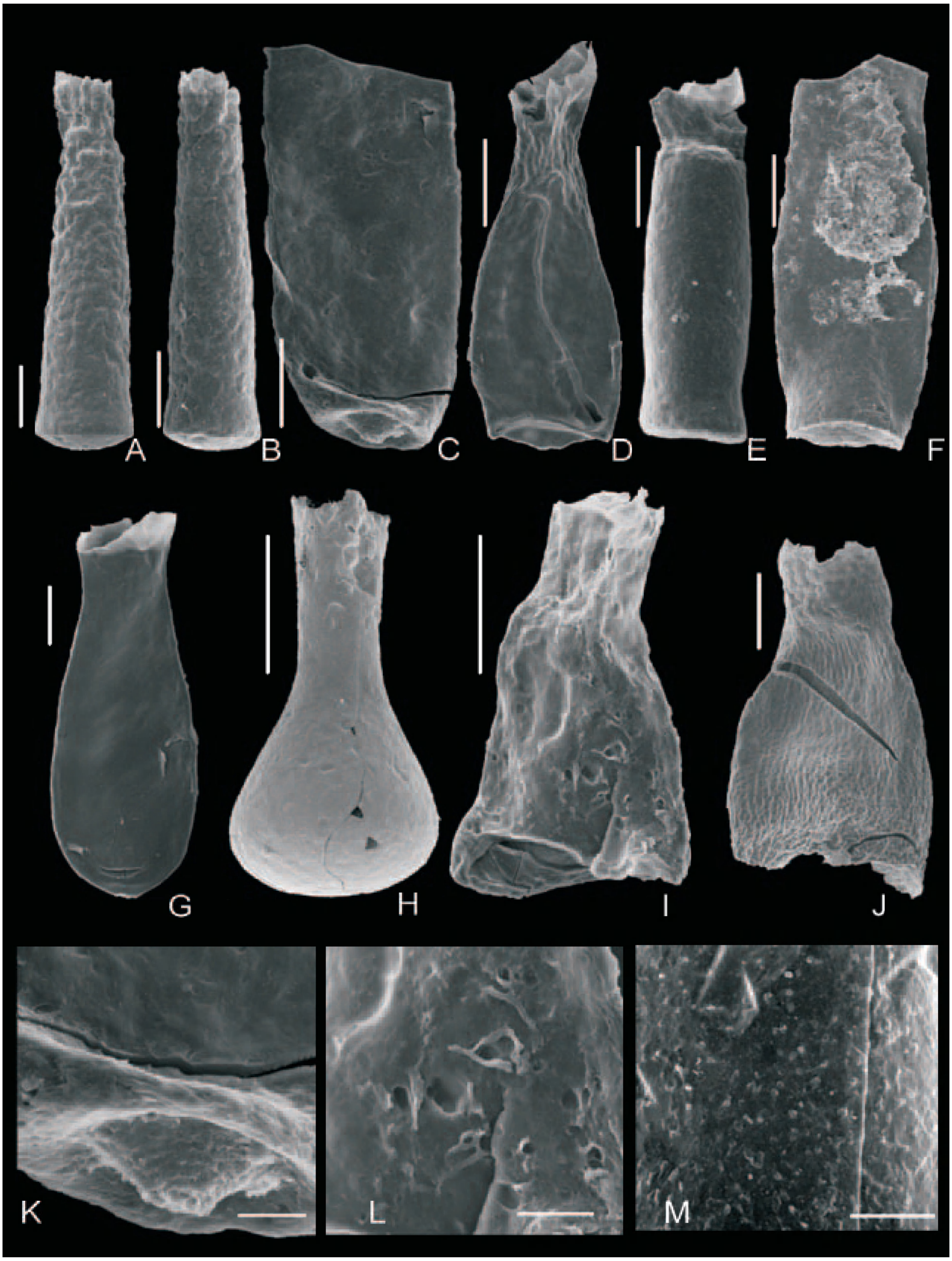

Plate 3. SEM photographs of chitinozoans from the Fauquez and Madot formations. Scale bars on complete specimen photographs represent 50 μm. Scale bars on detail photographs represent 10 μm.

A. Conochitina incerta. GVG 95-142, Fauquez Formation. L: 300; Dp: 70; Dc: 45. – *B. Conochitina incerta*. GVG 95-142, Fauquez Formation. L: 250; Dp: 60; Dc: 40. – *C. Conochitina incerta*? GVG 95-112, Madot Formation, member 6. L: 220; Dp: 100. – *D. Tanuchitina* sp. GVG 95-112, Madot Formation, member 6. L: 230; Dp: 90; Dc: 40. – *E. Conochitina elegans*. GVG 95-113, Madot Formation, member 5. L: 240; Dp: 70; Dc: 55. – *F. Tanuchitina* sp. GVG 95-142, Fauquez Formation L: 280; Db: 85; Dp: 110. – *G. Conochitina* sp. 4. GVG 95-116, Madot Formation, member 4. L: 290; Dp: 105; Dc: 65. – *H. Fungochitina spinifera*. GVG 95-120, Madot Formation, member 4. L: 150; Dp: 75; Dc: 30. – *I. Angochitina communis*? GVG 95-118, Madot Formation, member 4. L: 150; Dp: 80; Dc: 35. – *J. Armoricochitina reticulifera*? GVG 95-121, Madot Formation, member 4. L: 240; Dp: 140; Dc: 80. – *K. Conochitina incerta*? GVG 95-112, Madot Formation, member 6. Same specimen as C. Detail of the base. – *L. Angochitina communis*? GVG 95-118, Madot Formation, member 4. Same specimen as I. Detail of the multirooted spines. Spine length approximately 10 μm. – *M. Fungochitina spinifera*. GVG 95-120, Madot Formation, member 4. Detail of the ornamentation.