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New chitinozoans from the historical type area of the Hirnantian Stage and additional key sections in the Wye Valley, Wales, UK

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The type locality for several core elements of the *Hirnantia* brachiopod fauna is a small disused quarry on the western slopes of Cwm Hirnant. There, the Hirnant Limestone Member of the Foel-y-Ddinas Mudstone Formation yields a new, well-preserved chitinozoan assemblage, attributed to the *Spinachitina taugourdeaui* Biozone. This allows tight correlation with the Hirnantian of Baltica and Laurentia and neatly ties the chitinozoan zonation with the classical brachiopod fauna. Nearby, the chitinozoan assemblage from the Caradoc Cymerig Limestone Member at Gelli-grîn belongs to the *Spinachitina cervicornis* Biozone?, and is identical to that recovered from the Burrellian in the Onny Valley, Welsh Borderland. A Silurian assemblage higher up section, discovered in the Cwm-yr-Aethnen Formation, is attributed to the globally recognized *Eisenackitina dolioliformis* Biozone. Attempts to integrate the chitinozoan and graptolite biozonation, in the central Welsh Rhayader area, were less successful.

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1. INTRODUCTION

The term ‘Hirnantian’ has a long history. Originally introduced by Bancroft (1933) to name the highest Ordovician beds in the Bala area of North Wales, it was formally attributed regional stage status in the Ashgill Series by Ingham and Wright (1970). More recently it has been elevated to an international stage in the global stratigraphical chart and designated the uppermost stage of the Upper Ordovician Series (Finney 2004; IUGS). A GSSP (global boundary stratotype section and point) for the stage has since been defined in Wangjiawan, China (Chen *et al*. 2004, 2006), its base defined by the FAD (first appearance datum) of the graptolite *Normalograptus extraordinarius*.

Vandenbroucke *et al.* (2005) attempted a chitinozoan biozonation for the Ashgill in its type area at Cautley, northern England. Successful for the Pusgillian-Rawtheyan part of the section, the Hirnantian only yielded chitinozoans doubtfully identifiable to biozone level. In order to complete the biozonal scheme for the Ashgill in its Anglo-Welsh type area, additional sections were sought in (1) the type area for the Hirnantian, (2) the immediate surrounding area and (3) in the Rhayader area, in the Wye and Claerwen valleys where good graptolite control exists for the upper Hirnantian stratigraphy. This paper details the subsequent results.

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2. CHITINOZOAN BIOSTRATIGRAPHY IN CWM HIRNANT

2.1. Geological setting and previous work

Cwm Hirnant, south of the Welsh town of Bala (Figure 1 A–B), gives its name to the short but important Hirnantian Stage and is the type locality for two of the core species of the *Hirnantia* fauna, namely *Hirnantia sagittifera* (M'Coy) and *Eostropheodonta hirnantensis* (M'Coy). The global importance of the *Hirnantia* fauna has been widely recognized (for an overview see Rong and Harper 1988; Rong *et al*. 2002). The fauna was originally described from mudstones and limestones at Cwm Hirnant (Elles 1922, 1923). Rushton *et al.* (2000) provided an overview of the research history of the strata and their fauna, from the attribution of the beds to the top of the 'Bala Group' by Sedgwick (1845) up to the most recent interpretations. An important contribution to the understanding of the stratigraphical position of the section was made by Bassett *et al.* (1966) and this is still used as the standard guide for the area (and references therein).

The site itself (Figure 1B) is a small abandoned quarry [SH 951 296] on the western slopes of Cwm Hirnant, due west of Cwm-yr-Aethnen Farm now in ruins. It is not to be confused with the larger, more recent roadside quarry, also due west of the farm, that is lower in the topography and east of the small quarry. In the new quarry, exposure is poor but the lithology can be observed in the scree. The beds exposed in the old quarry are the Hirnant Limestone Member of the Foel-y-Ddinas Mudstone Formation and mudstones of the same formation; the rocks dip ESE at 75° (Rushton *et al*. 2000). Bassett *et al.* (1966, p. 254) provided the following measured section through 22.5 m of the Foel-y-Ddinas Mudstone Formation in the small quarry in ascending order:

Unfossiliferous cleaved blue mudstone	0.9 m (3 ft)
Gap	1.5 m (5 ft)
Fossiliferous cleaved blue mudstones	13.7 m (45 ft)
Cleaved mudstones and silty mudstones with fossils	1.5 m (5 ft)
Lenticular, oolitic limestone (Hirnant Limestone)	1.8 m (6 ft)
Silty dark blue mudstones and siltstones	3.1 m (10 ft)

The distinctive, dark-coloured limestone is pisolitic and possibly originally oolitic, containing ellipsoidal, 1–3 mm sized grains flattened in the plane of cleavage and set in a black, carbon-rich, crystalline matrix. It has been interpreted as a channel-fill sediment into which shells were washed (Brenchley and Cullen 1984) during a sea level lowstand associated with the important Hirnantian glacial event. *Hirnantia sagittifera* and *Eostropheodonta hirnantensis* are the most common fossils found. These brachiopods, together with other fossils, have also been recovered from the mudstones (Bassett *et al*. 1966).

2.2. Sampling

Samples from the Cwm Hirnant quarry were collected from the mudstones of the Foel-y-Ddinas Mudstone Formation and from the Hirnant Limestone Member (Figure 1B); the exact localities are described in the Appendix. In addition, samples have been collected from the neighbouring Bwlch-yr-Hwch section [SH 9501 3034 – 9532 3010], which straddles the boundary between the Moelfryn and Foel-y-Ddinas formations, but where we did not observe the Hirnant Limestone Member (Figure 1B).

In order better to tie in the Hirnantian sections stratigraphically, samples have also been collected from a Silurian exposure [SH 955 301] in the Cwm-yr-Aethnen Shales Formation, close to the Bwlch-yr-Hwch section (JH 05-003), from a Rawtheyan section at Rhiwlas, through the Rhiwlas Limestone Member of the Moelfryn Formation [SH 923 369], shown in Figure 1C, described by Bassett *et al.* (1966) and Rushton *et al.* (2000), and from the old quarry at Gelli-grîn [SH 945 341], where the Cymerig Limestone Member of the Gelli-grîn Formation (Caradoc) crops out at about 300 m south–west of the Gelli-grîn farm (Figure 1D). All localities were described in detail by Bassett *et al.* (1966). At Rhiwlas, only the upper part (3.6 m) of the Rhiwlas Limestone Member of the Moelfryn

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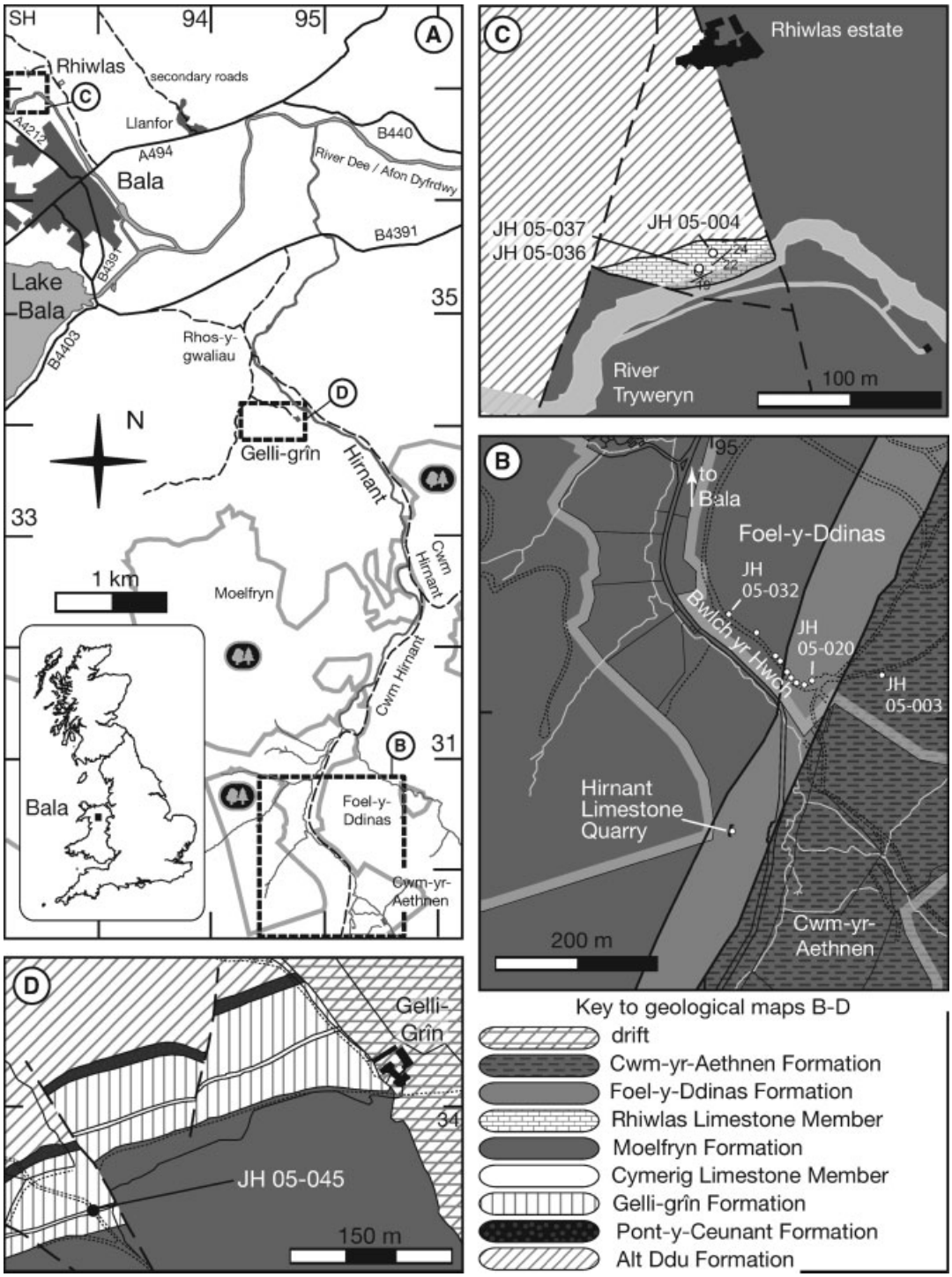

Figure 1. Location of the sections studied in the area around Bala. **A**—Generalized overview of the Bala area, with indication of the localities. **B**—Detailed geological map showing the Hirnant Limestone Quarry and the Bwlch-yr-Hwch section. **C**—Detailed geological map of the Rhiwlas area. **D**—Detailed geological map of the Gelli-grîn area. The geological maps show the sample localities and are after Bassett *et al.* (1966). For the stratigraphical relations between the units, see Figure 2.

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Formation has been observed (Bassett *et al*. 1966) and sampled, and not the contacts with the over- and underlying mudstones. At Gelli-grîn, sample JH 05-045 was collected from the top part of the Cymerig Limestone Member, taking into account its subdivision by Bassett *et al.* (1966, p. 241). Figure 2 shows the sections studied vis-à-vis the Bala/Arenig column of the Fortey *et al.* (2000) Ordovician correlation chart of the British Isles. All samples have

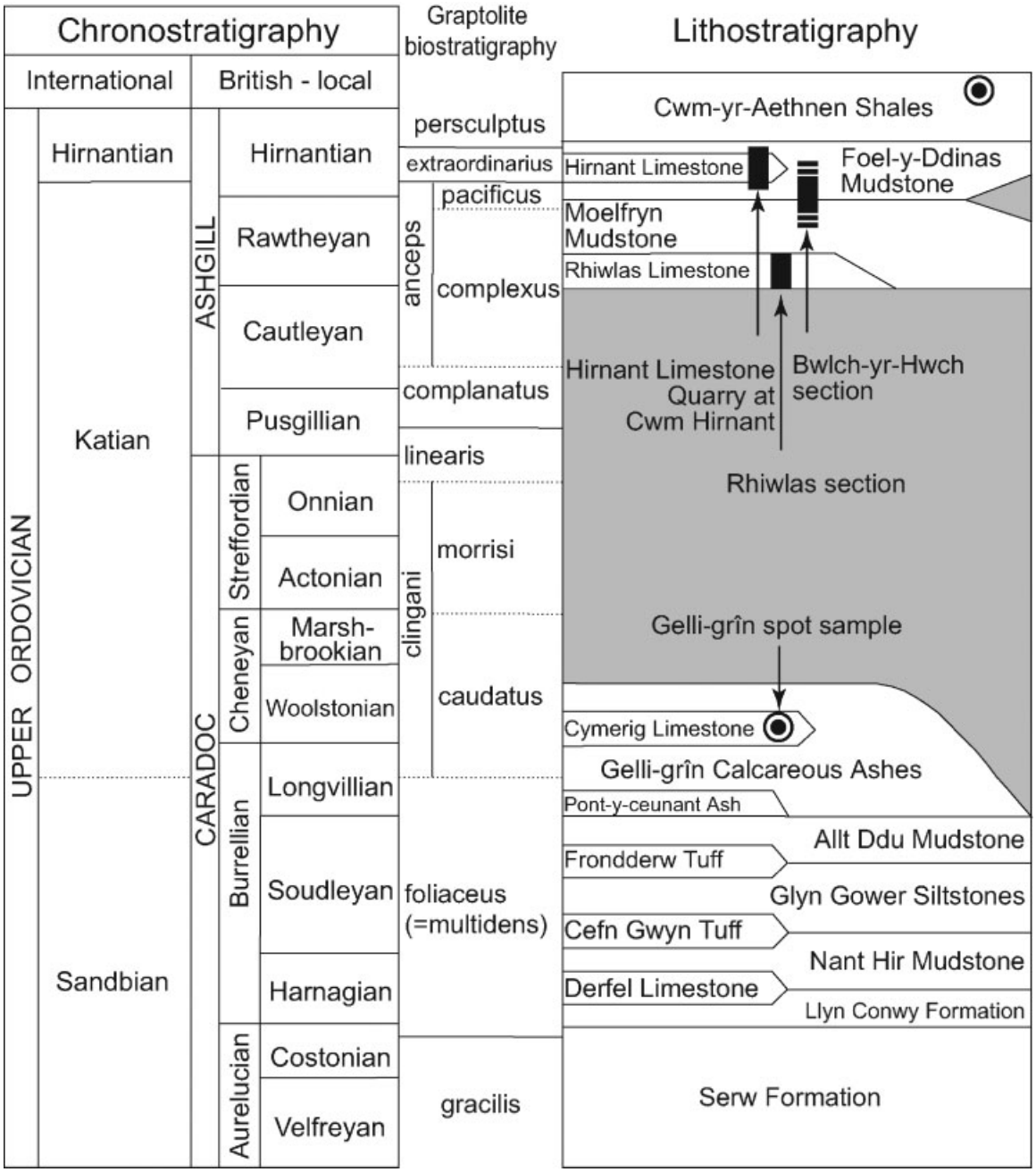

Figure 2. Upper part of the Bala/Arenig column of Fortey *et al.* (2000), showing the stratigraphical position of the sections studied and the spot samples.

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been treated according to standard palynological techniques (Paris 1981), although unusually large samples of limestone were used (up to 1.8 kg).

2.3. Chitinozoan results

The four samples dissolved from the mudstone facies of the Foel-y-Ddinas Mudstone Formation were completely barren of chitinozoans or yielded only unidentifiable specimens, but interesting material was recovered from the Hirnant Limestone Member (Table 1, Figure 3). Although not rich, especially when the relatively large amount of dissolved rock is considered (Table 1), the fauna is quite diverse and the specimens are particularly well preserved. Samples from the Hirnant Limestone Member yielded *Belonechitina* sp. 11 (*sensu* Vandenbroucke in press), *Belonechitina* sp. 12 (*sensu* Vandenbroucke in press), *Belonechitina wesenbergensis*, *Belonechitina* spp., *Conochitina* sp., *Cyathochitina campanulaeformis* (group), *Cyathochitina kuckersiana*, *Cyathochitina* spp., *Conochitina* sp., *Desmochitina minor*, *Hercochitina* cf. *gamachiana*, *Hercochitina* spp., *Lagenochitina* aff. *baltica*, *Lagenochitina* spp., *Spinachitina taugourdeaui*, *Spinachitina* sp. 5 (*sensu* Vandenbroucke in press), *Spinachitina* spp., *Tanuchitina* sp., and also a number of most probably reworked Caradoc and Ashgill specimens (of *Angochitina* ?*communis*, *Conochitina* ?*rugata*, *Desmochitina juglandiformis* and *Tanuchitina* cf. *bergstroemi*).

The samples collected from the Bwlch-yr-Hwch section yielded specimens belonging to the same genera as cited above (Table 2), although only a few specimens were identifiable to species level.

The three samples from the Rhiwlas Limestone Member at Rhiwlas (JH 05-004, 05-036 and 05-037) were barren of chitinozoans (amounts of rock dissolved, respectively, were 20.41, 354.35 and 31.44 g).

The Silurian sample from the Cwm-yr-Aethnen Shales Formation, JH 05-003 (44.58 g), yielded 1056 specimens of *Eisenackitina dolioliformis*, 30 specimens of *Cyathochitina kuckersiana* or *Cyathochitina* spp., 30 specimens of *Ancyrochitina* ?*ancyrea*, 1 *Conochitina* specimen, 35 specimens of unidentifiable chitinozoans and 4 scolecodonts.

The Caradoc sample of the Cymerig Limestone Member (JH 05-045, 67.2 g) yielded 119 specimens of *Spinachitina multiradiata*, 12 other *Spinachitina* spp., 23 specimens of *Desmochitina erinacea*, 2 specimens of *C. campanulaeformis*, 2 other *Cyathochitina*, 1 *Conochitina* specimen and 70 specimens of unidentifiable chitinozoans.

A full systematic review of the chitinozoans from, amongst others, the Cwm Hirnant area is given by Vandenbroucke (in press). A selection of species is shown in Figure 7.

2.4. Interpretation

In the Hirnant Limestone Quarry, the presence of the index species *Spinachitina taugourdeaui* allows the recognition of the eponymous biozone, defined in the upper Pirgu–lowermost Porkuni stages of Baltoscandia (Nõlvak and Grahn 1993) and in the uppermost Ordovician of Laurentia (Achab 1989). The *S. taugourdeaui* Biozone has thus been attributed a Hirnantian age (Achab 1989) and, in other publications, a late Rawtheyan to Hirnantian age (Soufiane *et al*. 1999; Soufiane and Achab 2000). The latest correlation charts of Webby *et al.* (2004) place the *S. taugourdeaui* Biozone in the upper part of the 6c timeslice (now timeslice VII in Achab and Paris 2007), correlated with the *Normalograptus persculptus* graptolite Biozone. Melchin *et al.* (2003) and Melchin and Holmden (2006) correlated the *S. taugourdeaui* Biozone with the lower *N. persculptus* Biozone (in the upper Hirnantian). In their latest revision of the bio- and chronostratigraphy of Estonia, Nõlvak *et al.* (2006, figure 1) placed the *S. taugourdeaui* Biozone in the lower Porkuni Stage (the lower part of the 6c timeslice), correlated with the *Normalograptus extraordinarius* graptolite Biozone. We would like to remark, however, that the Welsh specimens are morphologically closer to the Baltoscandian ones than to the Laurentian specimens (see Vandenbroucke in press). At the time of writing, no chitinozoans have been reported from the Hirnantian Stage of the new GSSP in Wangjiawan, so no direct correlation based on chitinozoans can be drawn between the Hirnant section and the new stratotype section.

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Table 1. Numerical results of the chitinozoan study in the Hirnant Limestone Quarry at Cwm Hirnant in North Wales

	TVDB 04-012	TVDB 04-010	JH 05-007	TVDB 04-005	JH 05-009	JH 05-010	JH 05-011	JH 05-012	JH 05-015	TVDB 04-007	JH 05-013	JH 05-014	TVDB 04-008	TVDB 04-009
Chitinozoa indet.			32	6	10	20	31	4			3	1	10	2
Angochitina ?communis			2 Rem											
Belonechitina sp. 11			3			10	3			2				
Belonechitina sp. 12			7	3	1	13								
Belonechitina wesenbergensis			2			1	2	1	1					
Belonechitina spp.			13		3	1		2						
Conochitina ?rugata			1 Rem			1 Rem								
Conochitina spp.			9	5	2	4	1			3		1		
Cyathochitina campanulaeformis			11		5	10								
Cyathochitina kuckersiana			4			7		2						
Cyathochitina spp.			15	1	3	28	6	1	1		1			
Desmochitina juglandiformis			1 Rem											
Desmochitina minor			2		1	3								
Hercochitina cf. *gamachiana*			16			14	13		1	2	1			
Lagenochitina aff. *baltica*			1	1			2				1			
Spinachitina taugourdeaui			10			16	1							
Spinachitina ?taugourdeaui			5			5		2						
Spinachitina sp. 5			6											
Spinachitina spp.			19	6	3	13	4	2						
Tanuchitina cf. *bergstroemi*			2 Rem?											
Hercochitina spp.					1	1	1							
Cyathochitina campanulaeformis group				4										
Tanuchitina spp.			1		1					1				
Lagenochitina spp.						1	1							
Total number of chitinozoans	0	0	162	26	30	148	65	14	3	8	6	2	10	2
Amount of dissolved rock (g)	15.71	16.36	1809.15	285.67	344.04	332.41	217.98	21.79	31.31	43.03	35.71	28.4	15.79	15.80

'Rem.' is shortform for 'interpreted as reworked specimens'.

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Hercochitina gamachiana ranges through its eponymous biozone and the *S. taugourdeaui* Biozone in Laurentia (Achab 1989); the species has, however, not been recognized unambiguously in any of the Anglo-Welsh sections. *Belonechitina* sp. 11 has some correlation potential (see below). Specimens of a granulate *Lagenochitina* species, resembling *Lagenochitina baltica* in its ornamentation, occur aberrantly high in the stratigraphy, if it is indeed the species suggested; it has been placed within open nomenclature due to its atypical shape (see Vandenbroucke in press). A number of species, equally aberrantly high in the stratigraphy, are interpreted as reworked (see above and Table 1).

The sample from the Cwm-yr-Aethnen Shales Formation (JH 05-003) belongs to the *Eisenackitina dolioliformis* Biozone, which is a globally recognized chitinozoan biozone of Aeronian-Telychian (Llandovery, early Silurian) age (Verniers *et al*. 1995).

The sample of the Cymerig Limestone Member yielded nicely preserved specimens of *Spinachitina multiradiata*, which are identical to those that have been recovered from the Smeathen Wood, Glenburrell and Horderley Sandstone formations, of Burrellian age, from the Onny Valley (type Caradoc area, Welsh Borderland, England;

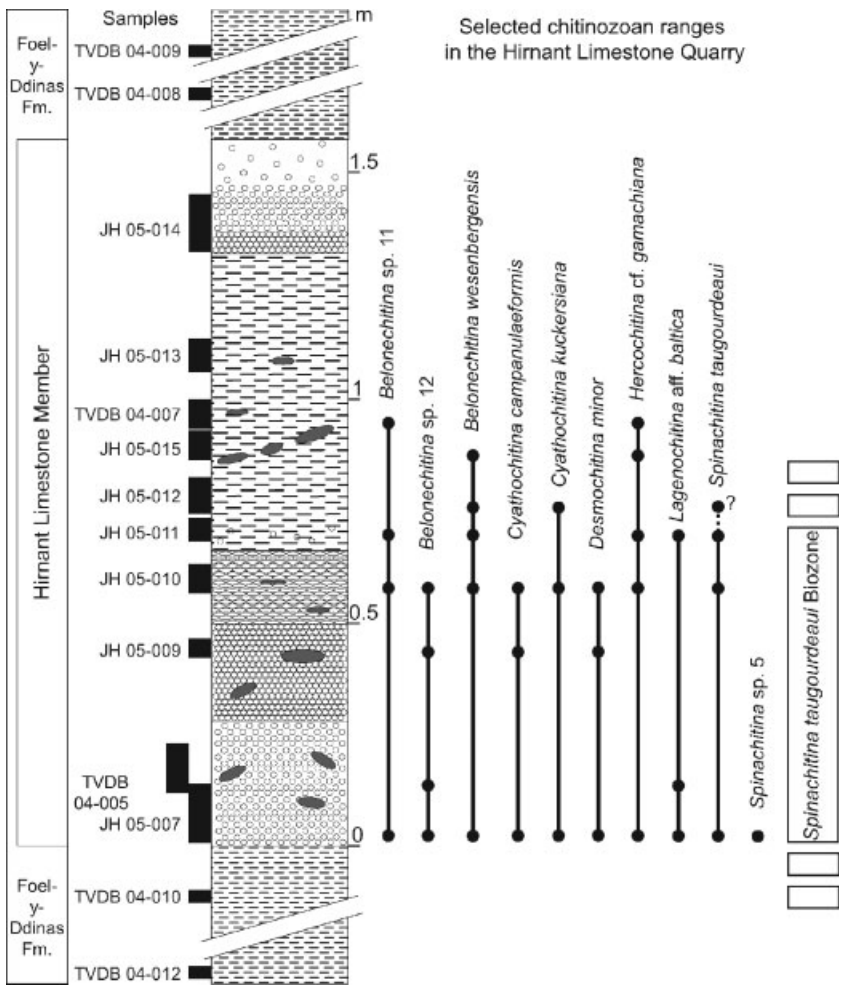

Figure 3. Selected, biostratigraphically interesting chitinozoan ranges in the Hirnant Limestone Quarry set against the newly measured lithostratigraphical log.

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Table 2. Numerical results of the chitinozoan samples collected from the Bwlch-yr-Hwch section at Cwm Hirnant in North Wales

Chitinozoan results from the Blwch-yr-Hwch section	JH05-020	JH05-021	JH05-022	JH05-023	JH05-024	JH05-025	JH05-026	JH05-030	JH05-032
Chitinozoans indet.	34	79	84	6	23	12	31	2	4
Spinachitina spp.		4	3		3				
Cyathochitina campanulaeformis	1		2						
Cyathochitina spp.	1	9	4		2		3	26	
Belonechitina ? sp. 11								4	
Belonechitina spp.	2	4	5		2	4	3	2	1
Tanuchitina spp.	0								1
Hercochitina spp.		9	13		4	1	1	5	1
Lagenochitina spp.								1	
Conochitina spp.			22			10			
Total number of chitinozoans	38	105	133	6	34	27	38	40	7
Sample weight (in gram)	38.06	40.69	120.14	51.16	35.72	79.37	46.79	33.45	42.85

Vandenbroucke *et al*., in press). The lithostratigraphical successions can therefore be correlated. However, in the Onny Valley, it is at present uncertain where the base of the *Spinachitina cervicornis* Biozone ought to be drawn exactly, and the interval below the Alternata Limestone Formation (which comprises *S. multiradiata*) has only been tentatively assigned to the *S. cervicornis* Biozone (Vandenbroucke *et al*., in press); this means that the correlation drawn has little additional importance as regards refining the age of the Cymerig Limestone, which is late Longvillian according to Bassett *et al.* (1966) and early Woolstonian according to Fortey *et al.* (2000).

3. CHITINOZOAN BIOSTRATIGRAPHY IN THE WYE VALLEY - RHAYADER AREA

3.1. Introduction, geological setting and previous work

The following paragraphs describe the chitinozoan biostratigraphy through an upper Ashgill–lower Silurian section along the River Wye, near Rhayader in central Wales (Figure 4A–B). The earliest geological research dates back to Murchison (1839) and the region has been subsequently studied in great detail. Davies *et al.* (1997, pp. 4–5) provided a detailed overview of the research history in the BGS memoir accompanying the 1/50 000 Llanilar (178) and Rhayader (179) geological sheets and this is considered the main source reference for this region.

The region is sedimentologically and structurally complex. The part of the stratigraphical column studied is summarized following Davies *et al.* (1997, p. 3). The lower and middle Ashgill, bioturbated mudstones in the area represent an oxygenated, turbiditic slope-apron facies, with local turbidite conglomerate and sandstone bodies. Towards the glacial sea-level lowstand(s) at the end of the Ashgill, the instability of these systems increased further with widespread slumping. The latest Ashgill and early Llandovery postglacial rise of the sea-level introduced anoxic bottom conditions and allowed graptolites to be preserved in laminated hemipelagites between the turbidite units. The graptolite succession from the area has been described by Zalasiewicz and Tunnicliff (1994), Davies *et al.* (1997) and Blackett *et al.* (in press). Two sections through more or less the same stratigraphical interval have been studied in the area: a section in the Cerrig Gwynion Quarry (Figure 4B) and a roadside section in the

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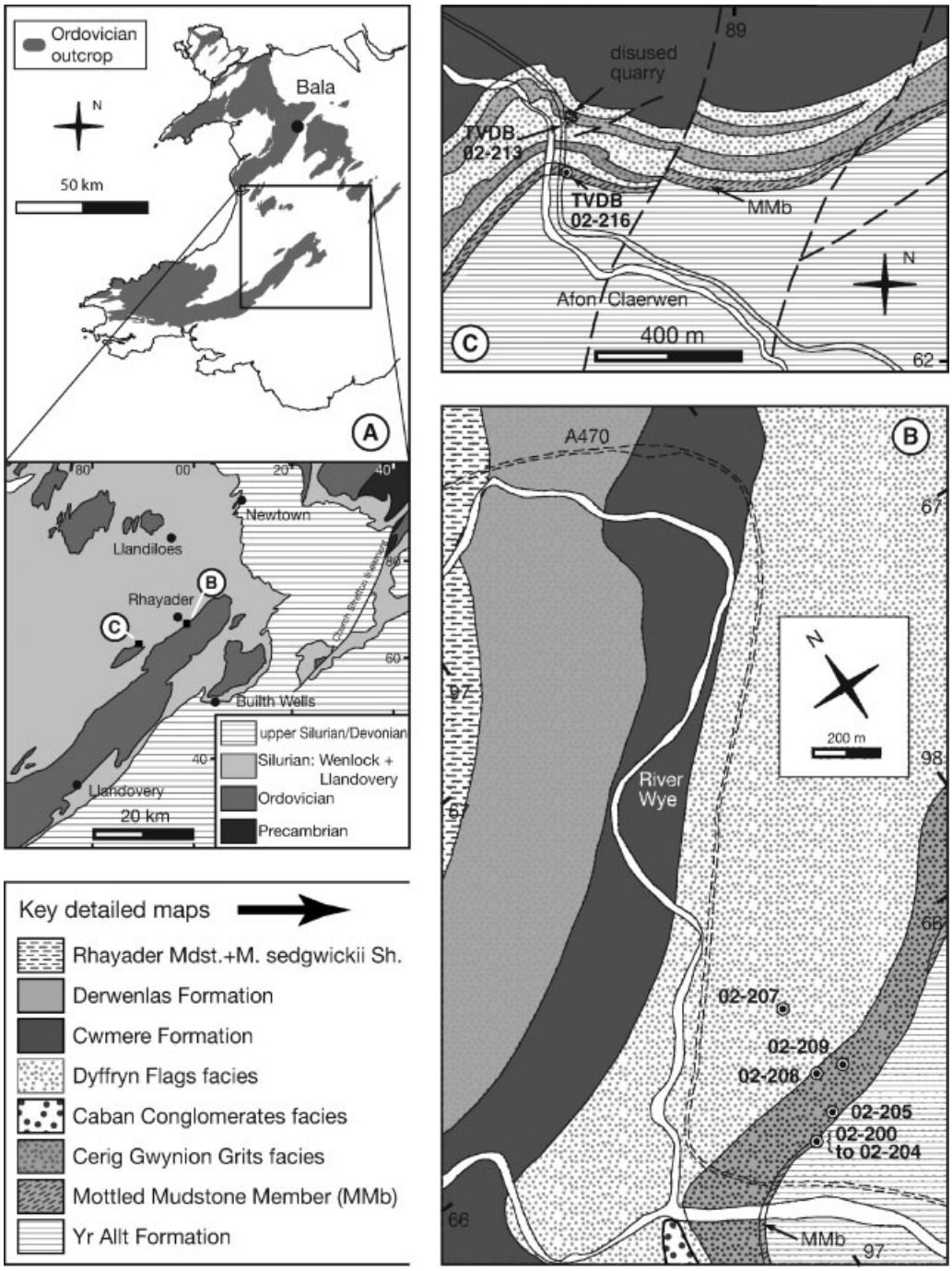

Figure 4. Location of the sections studied in the Rhayader area. **A**—Generalized geological map of the area, with indication of the sections. **B**—Geological map showing the Cerrig Gwynion Quarry and the samples taken. **C**—Detailed geological map of the Claerwen river section and the collected samples. All maps are taken from Davies *et al.* (1997), with the exception of the general map of Wales, which is modified after Bettley *et al.* (2001) and Williams *et al.* (1972). The stratigraphical relations of the units are detailed in the text and Figure 5 and are summarized as follows, from bottom to top: the Yr Allt Formation; the Mottled Mudstone Member of the Cwmere Formation including the *persculptus* bands; higher strata of the Cwmere Formation are separated from the lower unit by lenses of the Caban Conglomerate Formation (i.e. the Cerig Gwynion facies, Dyffryn Flags facies, Caban Conglomerate facies); Derwenlas and higher formations.

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Claerwen Valley (Figure 4C). Their description is drawn from Zalasiewicz and Tunnicliff (1994) and Davies *et al.* (1997).

3.1.1. The Cerrig Gwynion Quarry

The disused Cerrig Gwynion Quarry [SN 969 656] exposes a section through the Hirnantian and lower Llandovery strata of the region. A detailed sedimentological column is shown in Davies *et al.* (1997, figure 20, p. 99) and its position is shown on a facies architecture diagram (Davies *et al.* 1997, figure 19, p. 98, 'Section A'). In ascending order, the following lithostratigraphical units are exposed:

- The Yr Allt Formation: dark grey mudstone, deposited as slump units and turbidites during the Hirnantian glacio-eustatic regressions.
- Cwmere Formation/Mottled Mudstone Member: in general, the mudstone formation is composed mainly of mudstone turbidites and hemipelagites. In the Cerrig Gwynion Quarry, the basal 'Mottled Mudstone Member' of the formation is exposed, in which the hemipelagites are predominately burrowed (oxic facies). Only 5.8 m of the member are locally exposed. It contains two, closely spaced, thin units of anoxic, laminated hemipelagite, the *persculptus* bands, with abundant *N. persculptus* Biozone graptolites. The whole member is considered to belong to this graptolite biozone. Higher strata of the Cwmere Formation do not directly overlie the Mottled Mudstone Member, as the formation interdigitates with the Caban Conglomerate Formation and tongues of coarse-grained intercalations separate the lower and higher strata of the Cwmere Formation.
- Caban Conglomerate Formation/Cerig Gwynion facies: between the late Hirnantian and early Telychian, coarse grained (conglomerate and sand) turbidites intertongued with the contemporaneous mud-dominated slope apron sediments. From the five facies recognized within the Caban Conglomerate Formation, the lowermost Cerig Gwynion Grits facies and the Dyffryn Flags facies are the most important units in this study. The Cerig Gwynion Grits facies consists of medium- to thick-bedded turbiditic sandstones with subordinate thin-bedded sandstones and mudstones, and scattered hemipelagites, mostly laminated. The entire sequence of the Cerig Gwynion Grits is attributed to the *N. persculptus* Biozone.
- Caban Conglomerate Formation/Dyffryn Flags facies: in the Cerrig Gwynion Quarry, the stacked, thin-bedded, turbiditic, sandstone/mudstone couplets of the Dyffryn Flags Facies overlie the Cerig Gwynion Grits with a gradational contact. The graptolite faunas in the lower part of the formation also belong to the *N. persculptus* Biozone; 40 m above the base of the sequence, *Akidograptus acuminatus* Biozone graptolites have been recovered (Zalasiewicz and Tunnicliff 1994; Davies *et al*. 1997), marking the base of the Silurian System. Higher up in the section, above the interval studied, the Dyffryn Flags facies grades up into the mudstones of the Cwmere Formation.

3.1.2. Claerwen valley

Along the Afon Claerwen, the same stratigraphical succession can be observed, with the only difference being that the Cerig Gwynion Grits are developed as two tongues, separated by muddy deposits of the Dyffryn Flags facies. The facies architecture of the Caban Conglomerate Formation and associated formations is illustrated in Davies *et al.* (1997, figure 19, p. 98).

3.2. Sampling

Eleven samples from the upper part of the Hirnantian and the lower Silurian were taken during the field season in the summer of 2002, mainly re-sampling the graptolite localities mentioned in Davies *et al.* (1997) and Zalasiewicz and Tunnicliff (1994) in order to accurately position our samples against known graptolite occurrences. The localities are illustrated in Figure 4B–C and listed in detail in the Appendix.

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Table 3. Numerical results of the chitinozoan study in the Cerrig Gwynion Quarry section and Claerwen Valley section in the central Welsh Rhayader area

Chitinozoan results from the Rhayadar area	Cerrig Gwynion Quarry									Claerwen Valley	
	TVDB 02-200	TVDB 02-201	TVDB 02-202	TVDB 02-203	TVDB 02-204	TVDB 02-205	TVDB 02-209	TVDB 02-208	TVDB 02-207	TVDB 02-213	TVDB 02-216
Chitinozoa indet.	18	3	5			8	1	2	3	5	1
Belonechitina spp.	1	1	1								
Belonechitina sp. 11	8										
Cyathochitina spp.	3					9	6	7	14	7	
Desmochitina aff. *erinacea*	3	1									
Lagenochitina spp.	1	1						1			
?Siphonochitina spp.	1										
Saharochitina spp.	3						3				
Spinachitina sp. aff. *oulebsiri*	6?		24				6				
Spinachitina spp.	2										
Hercochitina spp.		1							1		
Spinachitina bulmani		1									
Rhabdochitina spp.			1				1				
Desmochitina minor						2					
Ancyrochitina spp.						7?	10	115	58	3?	
Conochitina spp.							1	1			
Euconochitina spp.							4				
Cyathochitina campanulaeformis group								58	32		
Cyathochitina kuckersiana								2			
Spinachitina ?*fragilis*								1			
Hercochitina aff. *gamachiana*										1	
Total number of chitinozoans	46	8	31	0	0	26	32	187	108	16	1
Amount of dissolved rock (g)	15.57	15.47	15.59	15.16	15.90	15.43	15.10	15.58	15.32	15.66	15.48

3.3. Chitinozoan results

The chitinozoan results from the Claerwen Valley were rather poor (Table 3). Sample TVDB 02-213 only yielded specimens barely identifiable to the genus level, and one *Hercochitina* aff. *gamachiana*. The other sample, 02-216, was practically barren.

Samples from the Cerrig Gwynion Quarry (Table 3) were generally more productive and yielded a more or less workable chitinozoan fauna. The lowermost TVDB 02-200 sample contains *Belonechitina* sp. 11, *Desmochitina* aff. *erinacea*, possibly *Spinachitina* sp. aff. *oulebsiri* and quite a few specimens that are not identified to the species level, but definitely belong to other genera than the ones mentioned. In addition to some of the above, sample TVDB 02-201 yielded *Spinachitina bulmani* and *Hercochitina* spp. and TVDB 02-202, from the '*persculptus* band', yielded *Spinachitina* sp. aff. *oulebsiri*. The samples from the upper part of the Mottled Mudstone Member, TVDB 02-203 and 02-204 were barren of chitinozoans. The samples from the Cerig Gwynion Grits and Dyffryn Flags facies of the Caban Conglomerate Formation (TVDB 02-205 to 02-207) mainly yielded *Cyathochitina* spp. and *Ancyrochitina* spp. More accurately identified Cyathochitininae are represented in samples TVDB 02-208 and 02-207 by the *Cyathochitina campanulaeformis* group in both samples, and by *C. kuckersiana* in the lowest of the pair. In addition, sample TVDB 02-209 yielded *Spinachitina* sp. aff. *oulebsiri*, and sample TVDB 02-208 yielded *Spinachitina* ?*fragilis*. The chitinozoan ranges are shown in Figure 5.

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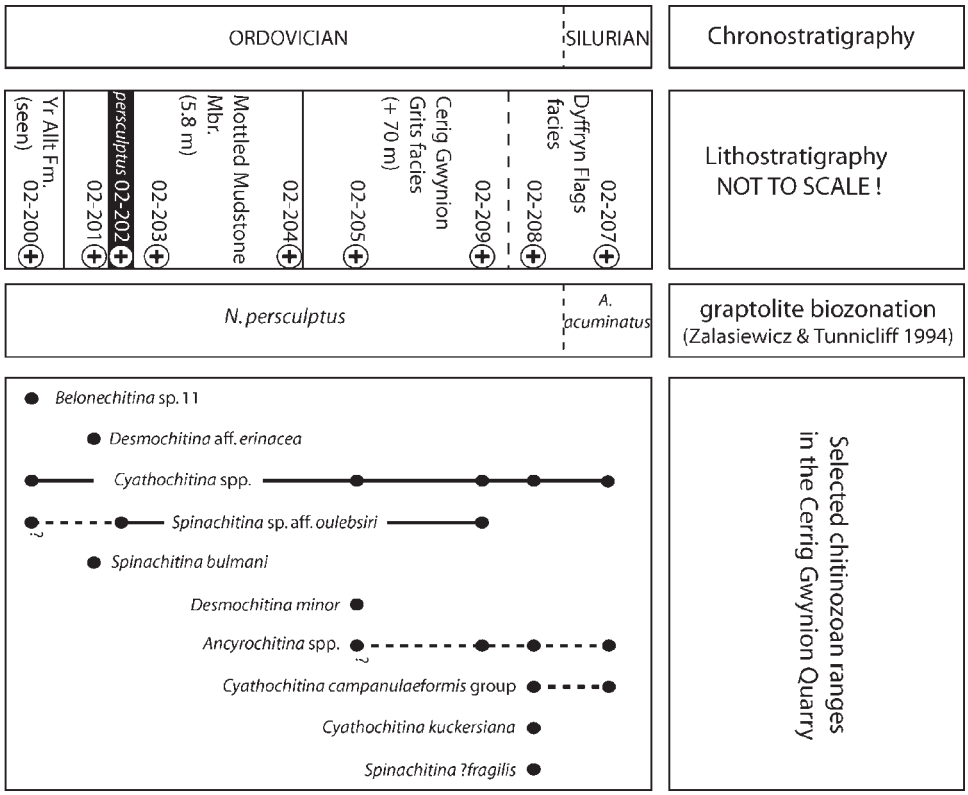

Figure 5. Range chart of chitinozoan species in the Cerrig Gwynion Quarry. Lithostratigraphical column not to scale and modified after Davies *et al.* (1997).

3.4. Interpretation

The chitinozoan data set is not extensive enough to establish a chitinozoan biozonation of the section. However, some interesting species occurrences are highlighted below and may be correlated with comparable occurrences in several other sections.

Belonechitina sp. 11 also occurs in the Hirnantian of the type Ashgill of the Cautley district (Ingham's 1966 Zone 8; Vandenbroucke *et al*. 2005) and in the Hirnant Limestone Member of the Bala area (see above). The species might thus prove to become a stratigraphically important species in the Hirnantian, once an extensive enough assemblage is recovered in order to define formally the species.

Spinachitina sp. aff. *oulebsiri* was reported by Paris *et al.* (2000), together with the holotype of *Spinachitina oulebsiri*, from the uppermost Ordovician in the northeastern Algerian Sahara. These authors considered the species to represent an 'early stage of the *Spinachitina fragilis* lineage, i.e. latest Hirnantian in age'. *S. fragilis* is the index fossil for the lowermost global Silurian biozone (Verniers *et al*. 1995), and one specimen very similar to this index fossil occurs, aberrantly, in the topmost sample from the *N. persculptus* Biozone, immediately below the base of the Silurian. As there is an evolutionary lineage within the *Spinachitina* genus around the base of the Silurian, and as only one, doubtful identification is made, this low occurrence is not really considered a problem.

Many *Cyathochitina* spp. are recognized in the upper part of the Cerrig Gwynion Quarry section, as was expected; the genus is common in the Ordovician and abundant, sometimes even dominant, in the lower biozones of

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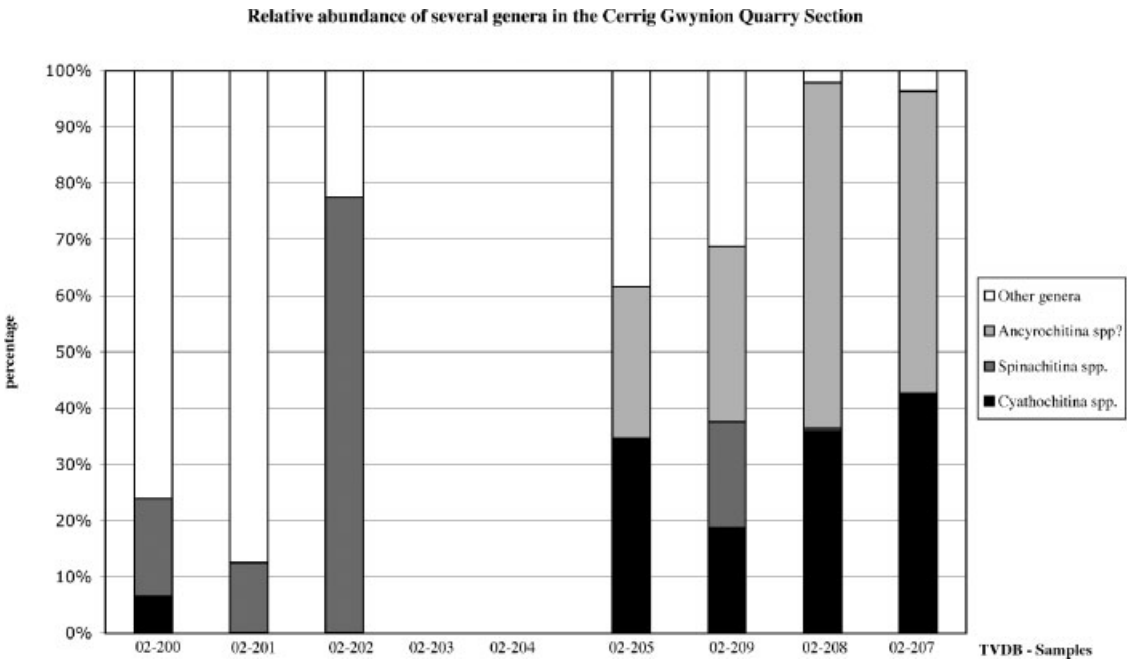

Figure 6. The relative abundance of the genera *Ancyrochitina*, *Cyathochitina* and *Spinachitina* in the Cerrig Gwynion Quarry section. The pattern of dominance of the first two genera, co-occurring with several species of less abundant *Spinachitina*, is in accordance with the late-Ordovician–early Silurian age proposed for the age of the section sampled.

the Silurian (Verniers *et al*. 1995). Likewise, *Ancyrochitina* spp. is abundant in the uppermost Ordovician and remains an important group in the Silurian (Verniers and Vandenbroucke 2006). The dominance of both genera towards the top of the Ordovician is illustrated in Figure 6. The pattern of dominance of the *Cyathochitina* and *Ancyrochitina* genera, co-occurring with several species of less abundant *Spinachitina*, is in accordance with the late Ordovician–early Silurian age proposed for the section sampled. The same pattern has been recorded from other sections bracketing the boundary between the two systems, such as the Lönstorp-1 drill core (unpublished data) and the Dob's Linn GSSP (Verniers and Vandenbroucke 2006).

4. CONCLUSIONS

In the Cwm Hirnant Quarry, samples from the pisolitic Hirnant Limestone Member yield surprisingly well-preserved chitinozoans, belonging to the *Spinachitina taugourdeaui* Biozone. This not only allows correlation of the type Hirnantian with sections in the Baltic region and North America, but also provides a very rigid link between the *Hirnantia* fauna (in its type section) and the *S. taugourdeaui* Biozone, co-occurring at Cwm Hirnant.

Loosely bracketing the section above, the chitinozoan assemblage from the Caradoc Cymerig Limestone Member at Gelli-grîn belongs to the *Spinachitina cervicornis* Biozone?, while a Silurian assemblage higher up section from the Cwm-yr-Aethnen Formation is attributed to the global *Eisenackitina dolioliformis* Biozone.

Eleven samples from the Ordovician–Silurian transition and mainly from the *persculptus* graptolite Biozone in the Rhayader area (Wye and Claerwen valleys) do not provide a detailed biozonation, but a chitinozoan fauna dominated by *Cyathochitina* spp. and *Ancyrochitina* spp., together with a few *Spinachitina* specimens is characteristic of the levels immediately below and above the Ordovician–Silurian boundary. Tentative correlations between the Rhayader area, the Cautley district and the Bala area are suggested, using the occurrence of *Belonechitina* sp. 11.

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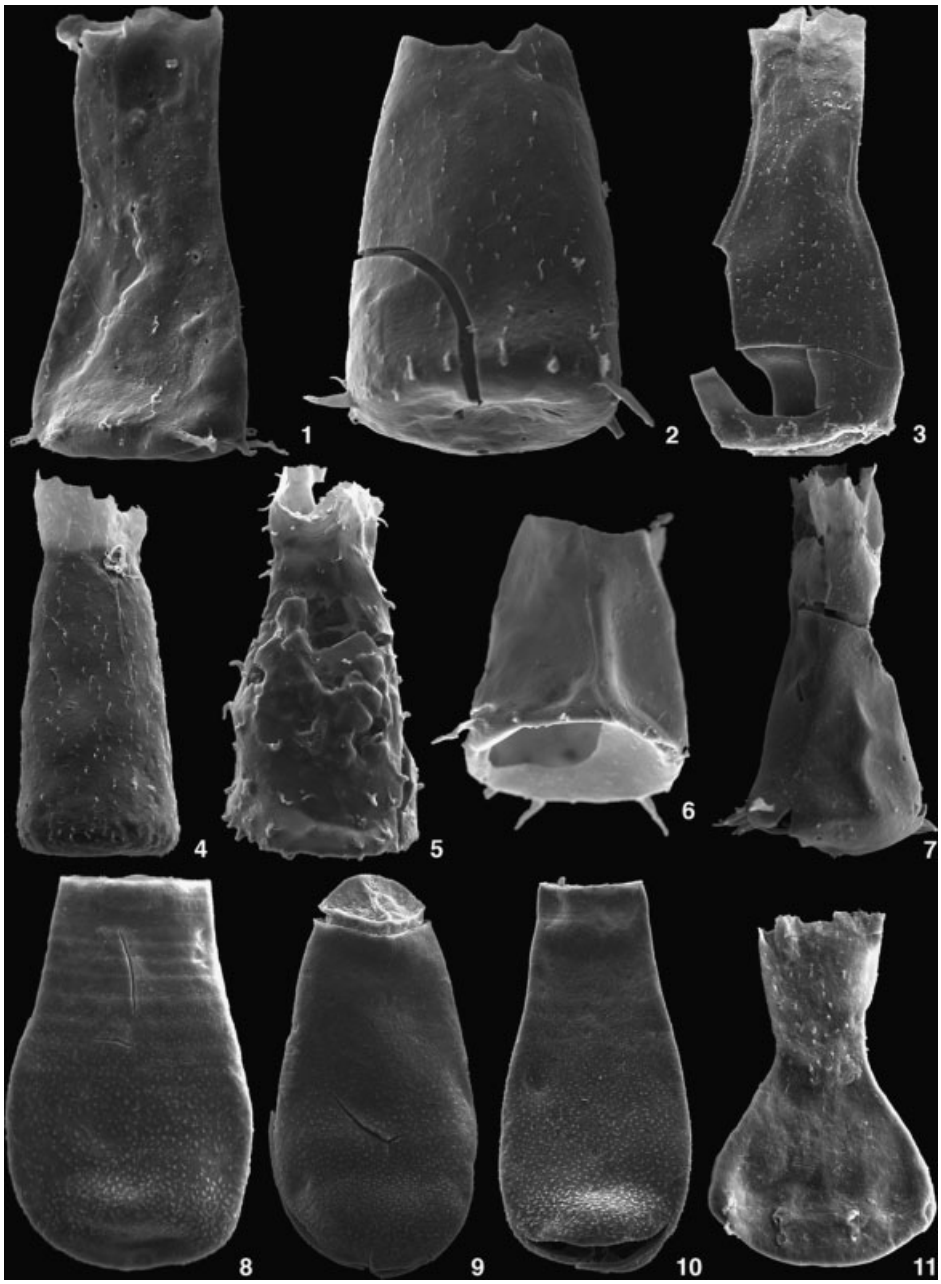

Figure 7. 1–3. *Spinachitina taugourdeaui*. 1, 165 × 80 × 50, sample JH 05-010, Hirnant Limestone Quarry, Hirnant Limestone Member. 2, 140 × 90 × 60, sample JH 05-010, Hirnant Limestone Quarry, Hirnant Limestone Member. 3, 150 × 75 × 45, sample JH 05-010, Hirnant Limestone Quarry, Hirnant Limestone Member. Figures 4–5. *Hercochitina* cf. *gamachiana*. 4, 140 × 60 × 35, sample JH 05-010, Hirnant Limestone Quarry, Hirnant Limestone Member. 5, 140 × 70 × 35, sample JH 05-007, Hirnant Limestone Quarry, Hirnant Limestone Member. Figures 6–7. *Spinachitina multiradiata*. 6, 90 × 60, sample JH 05-045, Gelli-grîn, Cymerig Limestone Member 6, 140 × 80, sample JH 05-045, Gelli-grîn, Cymerig Limestone Member. Figures 8–10. *Eisenackitina dolioliformis*. 8. 200 × 140 × 90, sample JH 05-003, near Cwm-yr-Aethnen, Cwm-yr-Aethnen Formation. 9. 260 × 130 × 90, sample JH 05-003, near Cwm-yr-Aethnen, Cwm-yr-Aethnen Formation. 10. 280 × 150 × 105, sample JH 05-003, near Cwm-yr-Aethnen, Cwm-yr-Aethnen Formation. Figure 11. *Ancyrochitina* ?*ancyrea*. 125 × 80 × 75, sample JH 05-003, near Cwm-yr-Aethnen, Cwm-yr-Aethnen Formation. All measurements are given in microns as L × Dp × Dc × Dc or Dp × Dc. For abbreviations, see Paris (1981): L = total length, Dp = chamber diameter, Dc = diameter of oral tube. The specimens and samples are stored at the Research Unit Palaeontology of Ghent University in Belgium.

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5. APPENDIX

5.1. Sample localities, Wye Valley: Cerrig Gwynion Quarry (near Rhayader, central Wales)

TVDB 02-200: Exposure in Cerrig Gwynion Quarry, 510 m at 120° from Glyn Farm, which is 2 km S of Rhayader, Powys; little below CGQ 3 of Zalasiewicz (Davies *et al*. 1997) [SN 9710 6559]. Stratigraphically in the Yr Allt Formation, ±2 m below the '*persculptus* band'.

TVDB 02-201: Exposure in Cerrig Gwynion Quarry, 510 m at 120° from Glyn Farm, which is 2 km S of Rhayader, Powys; between CGQ 3 and CGQ 4 of Zalasiewicz (Davies *et al*. 1997) [SN 9710 6559]. Stratigraphically in the Mottled Mudstone Member of the Cwmere Formation (or immediately below it, which is not always obvious in the field), 50–45 cm below the '*persculptus* band'.

TVDB 02-202: Exposure in Cerrig Gwynion Quarry, 510 m at 120° from Glyn Farm, which is 2 km S of Rhayader, Powys; CGQ 4 of Zalasiewicz (Davies *et al*. 1997) [SN 9710 6559]. Stratigraphically in the anoxic '*persculptus* band', low in the Mottled Mudstone Member of the Cwmere Formation.

TVDB 02-203: Exposure in Cerrig Gwynion Quarry, 510 m at 120° from Glyn Farm, which is 2 km S of Rhayader, Powys; little above CGQ 4 of Zalasiewicz (Davies *et al*. 1997) [SN 9710 6559]. Stratigraphically in the Mottled Mudstone Member of the Cwmere Formation 70–75 cm above sample TVDB 02-202 of the '*persculptus* band'.

TVDB 02-204: Exposure in Cerrig Gwynion Quarry, a few metres away from the same locality as above [SN 9710 6559]; stratigraphically in the Mottled Mudstone Member of the Cwmere Formation, immediately below a ±35 cm thick sandstone of the Cerig Gwynion Grits Facies of the Caban Conglomerate Formation.

TVDB 02-205: Exposure (talus) on the E side of Cerrig Gwynion Quarry, 550 m at 113° from Glyn Farm, which is 2 km S of Rhayader, Powys; CGQ 5 of Zalasiewicz (Davies *et al*. 1997) [SN 9718 6564]. Stratigraphically ±5 m above the base of the Cerig Gwynion Grits Facies of the Caban Conglomerate Formation.

TVDB 02-207: Trackside exposure in Cerrig Gwynion Quarry, 600 m at 078° from Glyn Farm, which is 2 km S of Rhayader, Powys; ± CGQ 2 of Zalasiewicz (Davies *et al*. 1997) [SN 9723 6597]. Stratigraphically ±40 m above the top of the Cerig Gwynion Grits Facies of the Caban Conglomerate Formation; in the Dyffryn Flags facies of the same formation.

TVDB 02-208: Trackside exposure in Cerrig Gwynion Quarry, 570 m at 097° from Glyn Farm, which is 2 km S of Rhayader, Powys; CGQ 1 of Zalasiewicz (Davies *et al*. 1997) [SN 9722 6597]. Stratigraphically ±5 to 10 m

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above the top of the Cerig Gwynion Grits Facies of the Caban Conglomerate Formation; low in the Dyffryn Flags facies of the same formation.

TVDB 02-209: Face in Cerrig Gwynion Quarry, 640 m at 099° from Glyn Farm, which is 2 km S of Rhayader, Powys; CGQ 7 of Zalasiewicz (Davies *et al*. 1997) [SN 9729 6575]. Stratigraphically ±10–15 m below the top of the Cerig Gwynion Grits Facies of the Caban Conglomerate Formation.

5.2. Sample localities, Claerwen Valley

TVDB 02-213: S edge of a small disused quarry on the E side of the road along Afon Claerwen, leading to the Claerwen reservoir, 420 m at 123° from Ciloerwynt Farm, which is 10 km SW of Rhayader, Powys [SN 8855 6268]. Jan Zalasiewicz field locality 18 on the (SN85Se map). P5 on figure 21 of Davies *et al.* (1997, p. 100). *N. persculptus* Biozone. The sample contains hemipelagites from the Dyffryn Flags facies, at about 1 m below the base of the 'upper leaf' of the Cerig Gwynion Grits Facies of the Caban Conglomerate Formation.

TVDB 02-216: Small road side exposure (2 m long, 0.5 m high) on the E side of the road along Afon Claerwen, leading to the Claerwen reservoir, 142 paces south along the road from TVDB 02-213. Mottled Mudstone Member of the Cwmere Formation.

5.3. Sample localities, Cwm Hirnant quarry

The samples were collected from a small abandoned quarry [SH 951 296] on the western slopes of Cwm Hirnant, due west of the Cwm-yr-Aethnen Farm.

TVDB 04-012: Mudstone of the Foel-y-Ddinas Mudstone Formation at 2.46 m below the base of the Hirnant Limestone Member.

TVDB 04-010: Mudstone of the Foel-y-Ddinas Mudstone Formation taken 10–13 cm below the base of the Hirnant Limestone Member.

JH 05-007: Hirnant Limestone Member of the Foel-y-Ddinas Mudstone Formation, collected 2–15 cm above the base of the Hirnant Limestone Member.

TVDB 04-005: Hirnant Limestone Member of the Foel-y-Ddinas Mudstone Formation, collected 12–23 cm above the base of the Hirnant Limestone Member.

JH 05-009: Hirnant Limestone Member of the Foel-y-Ddinas Mudstone Formation, collected 44–48 cm above the base of the Hirnant Limestone Member.

JH 05-010: Hirnant Limestone Member of the Foel-y-Ddinas Mudstone Formation, collected 59–63 cm above the base of the Hirnant Limestone Member.

JH 05-011: Hirnant Limestone Member of the Foel-y-Ddinas Mudstone Formation, collected 68–72 cm above the base of the Hirnant Limestone Member

JH 05-012: Hirnant Limestone Member of the Foel-y-Ddinas Mudstone Formation, collected 73–83 cm above the base of the Hirnant Limestone Member.

JH 05-015: Hirnant Limestone Member of the Foel-y-Ddinas Mudstone Formation, collected 80–90 cm above the base of the Hirnant Limestone Member.

TVDB 04-007: Hirnant Limestone Member of the Foel-y-Ddinas Mudstone Formation, collected 90–100 cm above the base of the Hirnant Limestone Member; the lithology seems more muddy than observed in sample TVDB 04-005.

JH 05-013: Hirnant Limestone Member of the Foel-y-Ddinas Mudstone Formation, collected 106–116 cm above the base of the Hirnant Limestone Member.

JH 05-014: Hirnant Limestone Member of the Foel-y-Ddinas Mudstone Formation, collected 132–152 cm above the base of the Hirnant Limestone Member.

TVDB 04-008: mudstone of the Foel-y-Ddinas Mudstone Formation at 2 m above the base of the Hirnant Limestone Member which is 1.8 m thick at this locality.

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TVDB 04-009: mudstone of the Foel-y-Ddinas Mudstone Formation at 63–73 cm above sample TVDB 04-008 m.

5.4. Sample localities, Bwlch-yr-Hwch section [SH 9501 3034–9532 3010]

The samples were collected along the southern part of the track surrounding the Foel-y-Ddinas hill, indicated as Bwlch-yr-Hwch on the 1:25000 OS map.

JH 05-032: Mudstone of the Moelfryn Formation, [SH 9502 3030], 90.2 m north–west, along the track, of JH 05-030.

JH 05-030: Mudstone of the Moelfryn Formation, 87.1 m north–west, along the track, of JH 05-026.

JH 05-026: Mudstone of the Moelfryn Formation, 24–25 m north–west, along the track, of JH 05-025.

JH 05-025: Mudstone of the Moelfryn Formation, 20 m north–west, along the track, of JH 05-024.

JH 05-024: Mudstone of the Foel-y-Ddinas Mudstone Formation, 20 m north–west, along the track, of JH 05-023.

JH 05-023: Mudstone of the Foel-y-Ddinas Mudstone Formation, 20 m north–west, along the track, of JH 05-022.

JH 05-022: Mudstone of the Foel-y-Ddinas Mudstone Formation, 20 m west, along the track, of JH 05-021.

JH 05-021: Mudstone of the Foel-y-Ddinas Mudstone Formation, 20 m west, along the track, of JH 05-020.

JH 05-020: Mudstone of the Foel-y-Ddinas Mudstone Formation at the eastern end of the Bwlch-yr-Hwch section [SH 9532 3010], at the western end of the old quarry, where the bedding planes are nicely exposed.

5.5. Spot sample localities, Bala area

JH 05-045: Limestone of the Cymerig Limestone Member of the Gelli-grîn Formation, taken from the nodular bed near the top of the member, collected at the abandoned quarry [SH 945 341] at 304 m south–west of Gelli-grîn Farm, about 3 km south–east of the town of Bala.

JH 05-003: Cwm-yr-Aethnen Formation, due north of Cwm-yr-Aethnen Farm, 200 m east of the quarry at the east end of the Bwlch-yr-Hwch section, along the track leading east from the same quarry [SH 955 301].

Scientific editing by Dave Harper.

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