

Integrated Upper Ordovician graptolite–chitinozoan biostratigraphy of the Cardigan and Whitland areas, southwest Wales

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Abstract – To help calibrate the emerging Upper Ordovician chitinozoan biozonation with the graptolite biozonation in the Anglo-Welsh, historical type basin, the graptolite-bearing Caradoc–Ashgill successions between Fishguard and Cardigan, and at Whitland, SW Wales, have been collected for chitinozoans. In the Cardigan district, finds of *Armoricochitina reticulifera* within strata referred to the *clingani* graptolite Biozone (*morrissi* Subzone), together with accessory species, indicate the *Fungochitina spinifera* chitinozoan Biozone, known from several Ordovician sections in northern England that span the base of the Ashgill Series. *Tanuchitina ?bergstroemi*, eponymous of the succeeding chitinozoan biozone, has tentatively been recovered from strata of *Pleurograptus linearis* graptolite Biozone age in the Cardigan area. The *T. ?bergstroemi* Biozone can also be correlated with the type Ashgill Series of northern England. Chitinozoans suggest that the widespread Welsh Basin anoxic–oxic transition at the base of the Nantmel Mudstones Formation in Wales, traditionally equated with the Caradoc–Ashgill boundary, is of Cautleyan (or younger Ashgill) age in the Cardigan area. In the broadly time-equivalent, graptolite-rich Whitland section, also in SW Wales, two Baltoscandian chitinozoan biozones and a subzone have been recognized (again using accessory species), namely the *Spinachitina cervicornis* Biozone?, the *Fungochitina spinifera* Biozone and the *Armoricochitina reticulifera* Subzone. The new chitinozoan data provide a more precise means of correlation between the Whitland and Cardigan successions and suggest that the *Normalograptus* proliferation interval of the Whitland section is at least partly attributable to the *Dicellograptus morrissi* Subzone of the *Dicranograptus clingani* Biozone, rather than equating with the overlying *Pleurograptus linearis* Biozone.

Keywords: chitinozoans, graptolites, Ordovician, biostratigraphy, Wales.

1. Introduction

Recent years have witnessed an ongoing effort to establish an Upper Ordovician chitinozoan biozonation in England and Wales, based on material from the type sections for the Caradoc and Ashgill series (Vandenbroucke, Rickards & Verniers, 2005; Vandenbroucke *et al.* 2008). This has been particularly successful in the Cautley (type Ashgill) district in northern England and in establishing the relationship between the chitinozoan scheme and the British chronostratigraphical framework for the Late Ordovician. However, it has so far failed to provide a precise tie between the biozonal schemes for chitinozoans and graptolites, the latter being still the main biostratigraphical reference group (together with the conodonts) for the Ordovician System; this is an important gap, not least because of the current uncertainties regarding the graptolite

biozonal age of chronostratigraphical boundaries in this time interval (cf. Rickards, 2002, 2004). In seeking to address this problem, this paper evaluates the chitinozoan biostratigraphy of key graptolite-bearing, Late Ordovician (Caradoc and Ashgill) successions in the Cardigan and Whitland areas of SW Wales (Fig. 1). This is viewed as an essential step towards providing an integrated chitinozoan and graptolite biozonation for the Late Ordovician that can be applied across the British Lower Palaeozoic, as the latter fossil group occurs only sporadically in the chitinozoan-bearing sections in northern England.

2. Geological setting

This paper deals with two separate study areas: (1) the Cardigan area in SW Wales, between Fishguard in north Pembrokeshire and Cardigan in south Ceredigion, and (2) the Whitland–Meidrim area that lies to the east, in Carmarthenshire (Fig. 1).

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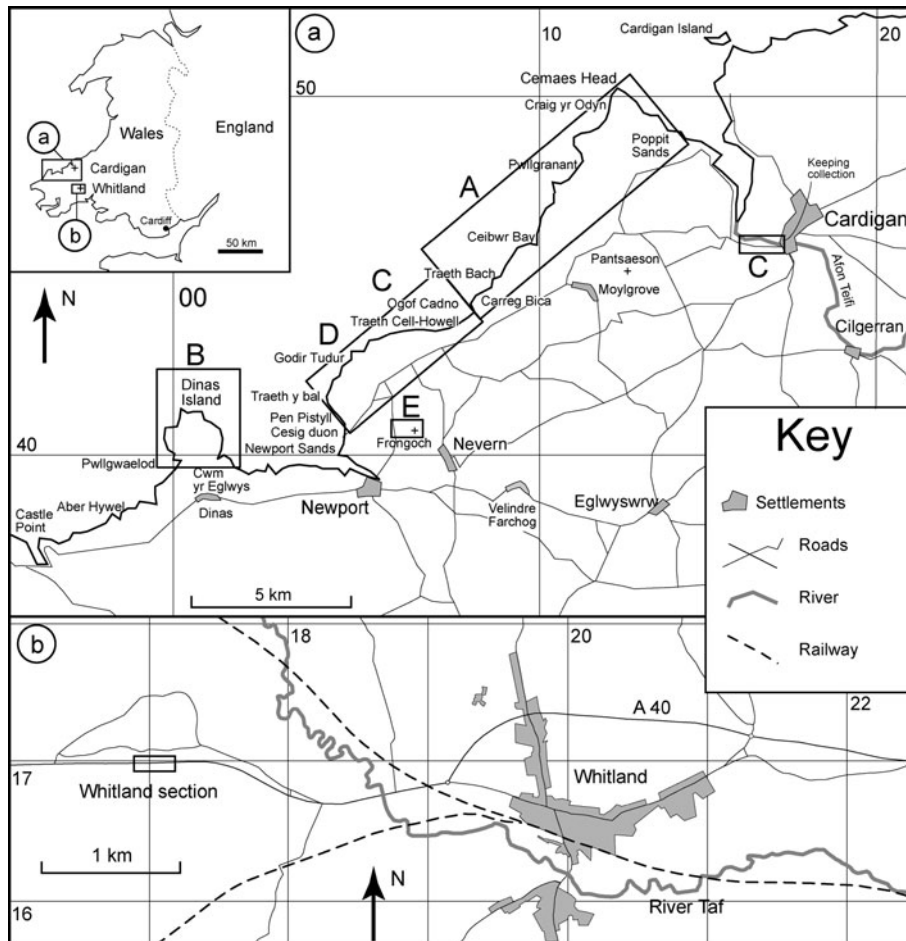


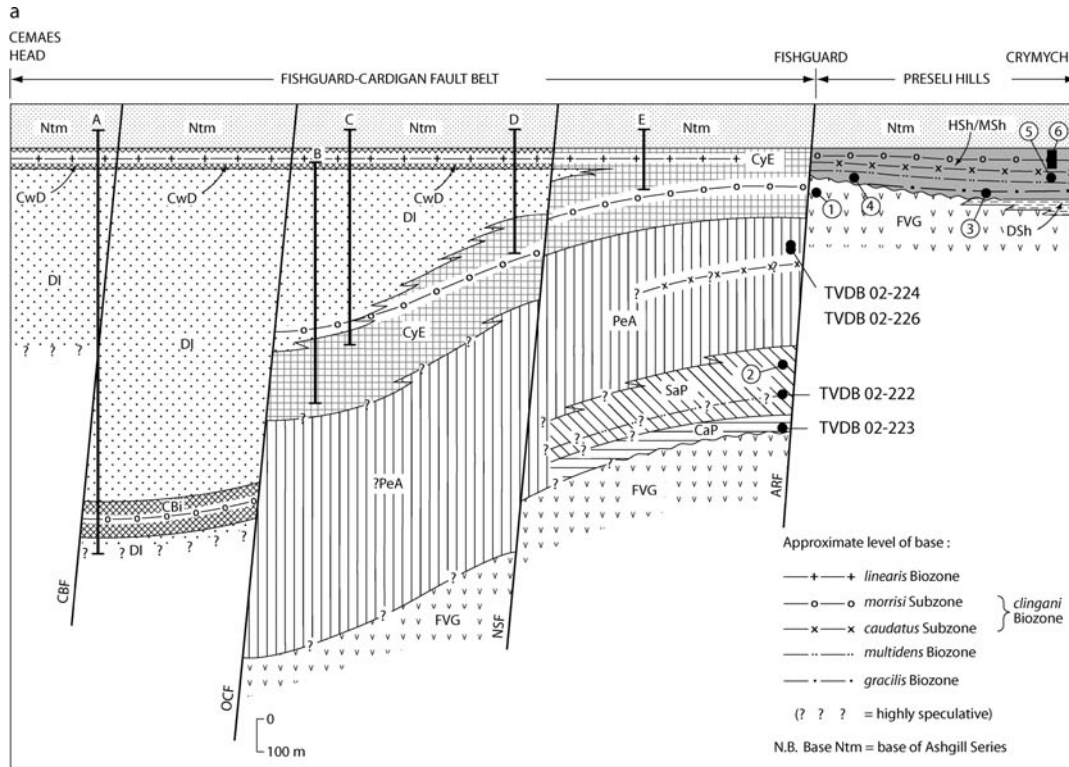
Figure 1. (a) Location of the principal sections (A to E) studied in the Cardigan area (after Williams *et al.* 2003; UK National Grid SN) (b) Location of the Whitland section (UK National Grid SN).

2.a. The Cardigan area

The following overview of the stratigraphy and facies architecture of the up to 1.3 km thick succession in the Cardigan district is based on the recent revision by Davies *et al.* (2003). The exposed formations display abrupt changes in facies and thickness across the ENE–WSW-trending faults of the Fishguard–Cardigan Fault Belt (Fig. 2), which played an important role during both the accumulation and deformation of the sediments. The Caradoc strata are spectacularly exposed in the coastal cliffs in the area, in contrast to smaller and poorly exposed inland outcrops. Several of the localities described are only accessible by boat. The succession contrasts markedly with coeval sequences developed in the Preseli Hills to the south and elsewhere in South Wales (see below).

In the Cardigan area, the Penyraber Mudstone Formation is the lowest sedimentary Caradoc formation and rests unconformably on the Llanvirn Fishguard Volcanic Group. It consists mainly of grey mudstones, with the exception of the coarser sediments of the basal Castle Point Member. In the overlying Saddle Point Member, allochthonous rafts of various volcanic and sedimentary lithologies can be recognized in the

mudstones. These two members are succeeded by turbiditic, silty mudstone with occasional burrows, deposited in a weakly oxic setting. The overlying Cwm-yr-Eglwys Mudstone Formation comprises turbiditic mudstones, associated thin beds of siltstone and sandstone, and laminated hemipelagites; the latter are indicative of deposition beneath anoxic bottom waters. The Cwm-yr-Eglwys Mudstone Formation forms the top of the Caradoc succession south of the Newport Sands Fault, but passes laterally into the Dinas Island Formation north of the fault. The latter is a sandstone-dominated turbidite sequence, spectacularly exposed in the cliffs and incorporating several, often local, mudstone units of which only two have been given formal ‘member’ status. The Cwm Degwel Mudstone Member at the top of the formation is the only one to have been correlated between the major cliff sections. Anoxic bottom water conditions persisted, as can be concluded from the presence of laminated hemipelagites throughout the formation. Both the Cwm Degwel Member to the north of the Newport Sands Fault, and the Cwm-yr-Eglwys Mudstone to the south are sharply overlain by oxic, strongly burrow-mottled facies characteristic of the widely recognized Nantmel



Legend for a, b

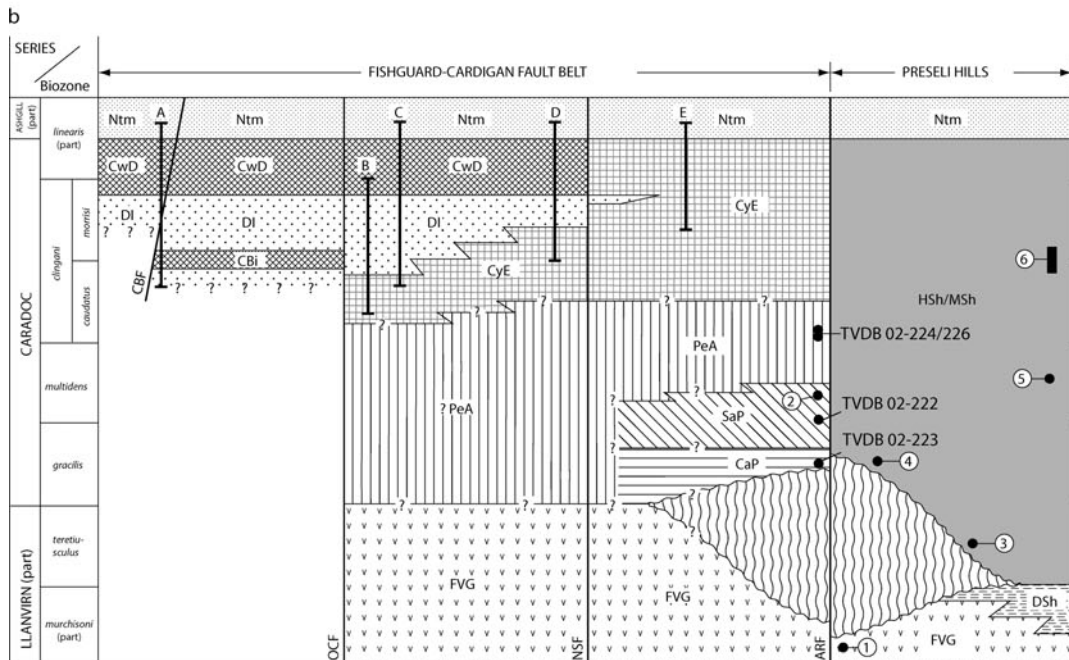
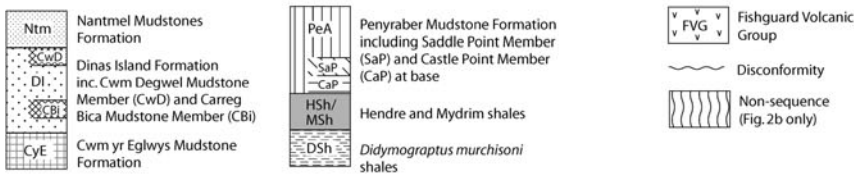


Figure 2. (a) Lithostratigraphy and facies architecture of the Caradoc succession in the Cardigan area (from Williams *et al.* 2003). The position of the sections studied (A to E) and several sample localities (TVDB) referred to in the text are indicated. Locality 1 yields *murchisoni* Biozone graptolites (Lowman & Bloxam, 1981). The other localities 2–6 are explained in the text. (b) The chronostratigraphical version of (a). Abbreviations: ARF – Aber Richard Fault; CBF – Ceibwr Bay Fault; NSF – Newport Sands Fault; OCF – Ogof Cadno Fault.

Mudstones Formation. Throughout central Wales, the abrupt change from anoxic to oxic facies at the base of the latter formation has been taken as a proxy for the Caradoc/Ashgill boundary (Davies *et al.* 1997, 2003; Fortey *et al.* 2000).

In the Preseli Hills, south of the Fishguard–Cardigan Fault Belt, a late Llanvirn to Caradoc succession of black, graptolitic mudstones is equivalent to the Hendre Shales and Mydrim Shales of South Wales and is overlain by the oxic Nantmel Mudstones. The contrasting succession straddling the Fishguard–Cardigan Fault Belt formed within a fault-controlled trough in which, initially, there was much non-graptolitic oxic marine deposition (Penyraber Mudstone Formation) and which subsequently confined the sand-prone facies of the Dinas Island Formation (Davies *et al.* 2003, p. 9, Fig. 4), whereas, to the south of the fault belt, black graptolitic mudstone deposition was allowed to proceed uninterrupted throughout the Late Ordovician. However, these abrupt changes in facies and sequence may additionally (or instead) record juxtaposing of once widely separated facies belts by strike-slip faulting (Williams *et al.* 2003).

2.b. Whitland and Meidrim

Fortey *et al.* (2000, p. 16) describe the central south Wales area as probably having ‘the most complete Ordovician succession of any part of Britain’, hence two stratigraphically consecutive sections through the same lithostratigraphical succession were selected for this study: the Meidrim village section and Whitland road cutting. The Meidrim (formerly Mydrim) area was selected to study the *Nemagraptus gracilis* Biozone–*Diplograptus foliaceus* Biozone transition (Bettley, Fortey & Siveter, 2001), and the Whitland section because of its Caradoc–Ashgill boundary succession and its recently revised graptolite biostratigraphy (Zalasiewicz, Rushton & Owen, 1995). The lithological succession of these two areas comprises, in ascending order: the Hendre Shales (250 m), Mydrim Limestone (40 m), Mydrim Shales (150 m) and Shoeshook Limestone (70+ m) formations. Due to disappointing results in the Meidrim area (none of the nine dissolved samples from the upper part of the Hendre Shales to the lower part of the Mydrim Shales yielded identifiable species), no further attempt has been made to integrate the section in this study (see T. R. A. Vandenbroucke, unpub. Ph.D. thesis, Ghent Univ. 2005).

The Whitland section [SN 1697 1699–1713 1698] is a recent road cutting along the A40, 3 km west of Whitland. The bulk of the strata exposed are laminated grey graptolitic mudstones and silty mudstones of the Mydrim Shales, formerly called the Dicranograptus Shales (Zalasiewicz, Rushton & Owen, 1995). The mudstones are thought to have been deposited under dysaerobic bottom conditions. Towards the upper part, they become paler, and less distinctly laminated; thin

beds of limestone appear in the uppermost part forming a transition into the overlying Shoeshook Limestone, which is sparsely shelly.

In attempting to calibrate UK chitinozoan and graptolite biozonal schemes, this paper will also address outstanding biostratigraphical issues in the South Wales Late Ordovician by seeking to:

- (1) gain a better insight into the relationships between chitinozoans and graptolites in the Welsh basin during the Caradoc–Ashgill;
- (2) determine the age of the oldest Caradoc strata disconformably overlying the Fishguard Volcanic Group in the Cardigan district;
- (3) determine the age of the anoxic to oxic transition at the base of the Nantmel Mudstones Formation, currently taken to equate with the base of the Ashgill Series;
- (4) evaluate the stratigraphical level attributed to the ‘*Normalograptus* proliferation interval’ in the Whitland section;
- (5) enable more precise correlation between the Upper Ordovician rocks of SW Wales and the Ordovician sequences of northern England.

3. Graptolite biostratigraphy

A detailed assessment of the graptolite biostratigraphy of the Cardigan area by Williams *et al.* (2003) produced the following conclusions.

- (1) The Castle Point Member post-dates mudstones near the top of the Fishguard Volcanic Group, which contain *Didymograptus murchisoni* Biozone graptolites.
- (2) A black mudstone raft [SM 990 385] (Fig. 2, locality 2) in the Saddle Point Member gives a maximum age referable to the *Diplograptus multidentis* Biozone.
- (3) The Cwm-Yr-Eglwys Mudstone Formation south of the Newport Sands Fault includes both the *Dicranograptus clingani* and *Pleurograptus linearis* biozones of the Caradoc. *P. linearis* itself is not known from Wales, but *Climacograptus tubuliferus* is taken as diagnostic of the *P. linearis* Biozone; this represents the first definite record of the biozone in Wales.
- (4) North of the Newport Sands Fault, the Cwm-Yr-Eglwys Mudstone Formation is partly replaced by the Dinas Island Formation and confined to the *D. clingani* Biozone, more precisely the *Ensignraptus caudatus* Subzone at Dinas Island, but also including the higher *Dicellograptus morrisoni* Subzone at Newport Sands. To the north of the Ogof Cadno Fault, the base of the Dinas Island Formation lies within the *E. caudatus* Subzone as the *caudatus–morrisoni* boundary occurs in the middle part of the Carreg

Bica Mudstone Member; south of the fault, the base of the Dinas Island Formation lies within the *D. morrisi* Subzone. The presence of probable *C. tubuliferus* near the top of the Dinas Island Formation (Cwm Degwel Mudstone) suggests that this part of the formation may range into the *P. linearis* Biozone.

- (5) South of the Fishguard–Cardigan Fault Belt, the black mudstone succession of the Preseli Hills has yielded graptolites from several localities, indicative of the *Hustedograptus teretiusculus* Biozone at Pen-cnwc Bach [SM 124 375] (Fig. 2, locality 3), the *Nemagraptus gracilis* Biozone at Felindre Farchog [SM 0975 3870] (Fig. 2, locality 4), and the *D. multidentis* and *D. clingani* biozones at Crymych [SM 183 388] (Fig. 2, localities 5 and 6).

Zalasiewicz, Rushton & Owen (1995, Fig. 3) recognized three assemblages of graptolites in the measured section at Whitland, listed in ascending order:

- (1) *Dicranograptus clingani* Biozone (lower part), between 12.5 and 27 m above the base of the section;
- (2) *miserabilis*–*morrisi* interval, between 27 and 39 m above the base of the section;
- (3) *Normalograptus* proliferation interval, between 39 and 57 m above the base of the section.

The *Dicranograptus clingani* levels (the lower part and the *morrisi* interval) can easily be correlated with other levels with a comparable fauna (with Cardigan, but also with, for example, Hartfell Score, Scotland), but the upper levels of the Whitland section are more problematic. The incoming of *Normalograptus* forms was tentatively correlated with the base of the *Pleurograptus linearis* Biozone by Zalasiewicz, Rushton & Owen (1995). However, in Whitland the typical forms characterizing the *P. linearis* Biozone, such as leptograptids or pleurograptids, are absent, while in other upper Caradoc sections, the aforementioned ‘*Normalograptus* proliferation’ assemblages have not been recovered. Williams *et al.* (2003) explain the late Caradoc faunal contrast between Cardigan and Whitland in terms of graptolite ecology: up to the mid-*clingani* level, an offshore, open marine, ‘graptolite-friendly’ biotope existed in both areas, giving rise to highly diverse graptolite faunas. In the late Caradoc, cooling and falling global sea-levels were responsible for the shallowing of the shelf in Whitland, establishing an inshore, graptolite biotope of ‘cratonic invaders’ of the low diversity, *Normalograptus* proliferation fauna. In Cardigan, however, the offshore, open marine ‘graptolite-friendly’ biotope persisted due to the local development of a deep marine trough (Davies *et al.* 2003).

In addition to graptolite fauna, a shelly fauna was obtained from the lower levels of the Sholeshook Limestone between 58.5 and 65 m above the base of the section. It is characteristic of the late Pusgillian and early Cautleyan in Wales and northern England (Price, 1984; Zalasiewicz, Rushton & Owen, 1995). Price published several papers on the trilobite fauna and age of the Sholeshook Limestone, dating the base of the formation to the early Cautleyan and its youngest levels to the early Rawtheyan (Price, 1973, 1977, 1980, 1984). His conclusions were drawn prior to the finds of Zalasiewicz, Rushton & Owen (1995), and there is now evidence from the shelly fauna that the base of the Sholeshook Limestone in Whitland might be a little older than in other localities. Fortey *et al.* (2000) considered the Sholeshook Limestone as late Pusgillian–largely Cautleyan in age, and the topmost strata are dated to the early Rawtheyan. Zalasiewicz, Rushton & Owen (1995) re-examined graptolites from the Sholeshook Limestone, originally reported by Strahan *et al.* (1914) and assigned to their local *Orthograptus truncatus* Biozone; these graptolites are better referable to *Orthograptus abbreviatus*, indicative of the *Dicellograptus anceps* Biozone (that is, Rawtheyan).

4. Sampling for chitinozoans

Collections made by Williams *et al.* (2003) are stored at the British Geological Survey in Keyworth, Nottingham, and have been resampled as part of this study. This permits a precise correlation between the graptolites and chitinozoans recovered. The sub-sampled levels are from the Williams *et al.* (2003) sections A to E, which are indicated on our Figures 1 to 3 and their Figures 3 to 7. The Williams *et al.* (2003) sample numbers and the corresponding TVDB chitinozoan sample numbers are shown in Figures 4 and 5 and in the Appendix. A sub-sample from the graptolite sample at Aber Howel was also obtained (Fig. 2, locality 2, TVDB 02-185). Samples from the Whitland section were obtained during 2002. Close correlation with the graptolite levels was possible as the markings (denoting metres above the base of the section) for the graptolite study by Zalasiewicz, Rushton & Owen (1995) were still visible on the rock face. Additional samples from the Cardigan area, collected during a Ludlow Research Group meeting in 2003, have been collected from:

- (1) Castle Point (TVDB 02-223) and Saddle Point (TVDB 02-222) and their eponymous lithological members (see location on Fig. 2a);
- (2) Parrog [SN 049 397], along the coast between Newport and Dinas Island: oxic, mottled Penyraber Mudstone Formation (TVDB 02-224) with phosphatic nodules (TVDB 02-226);

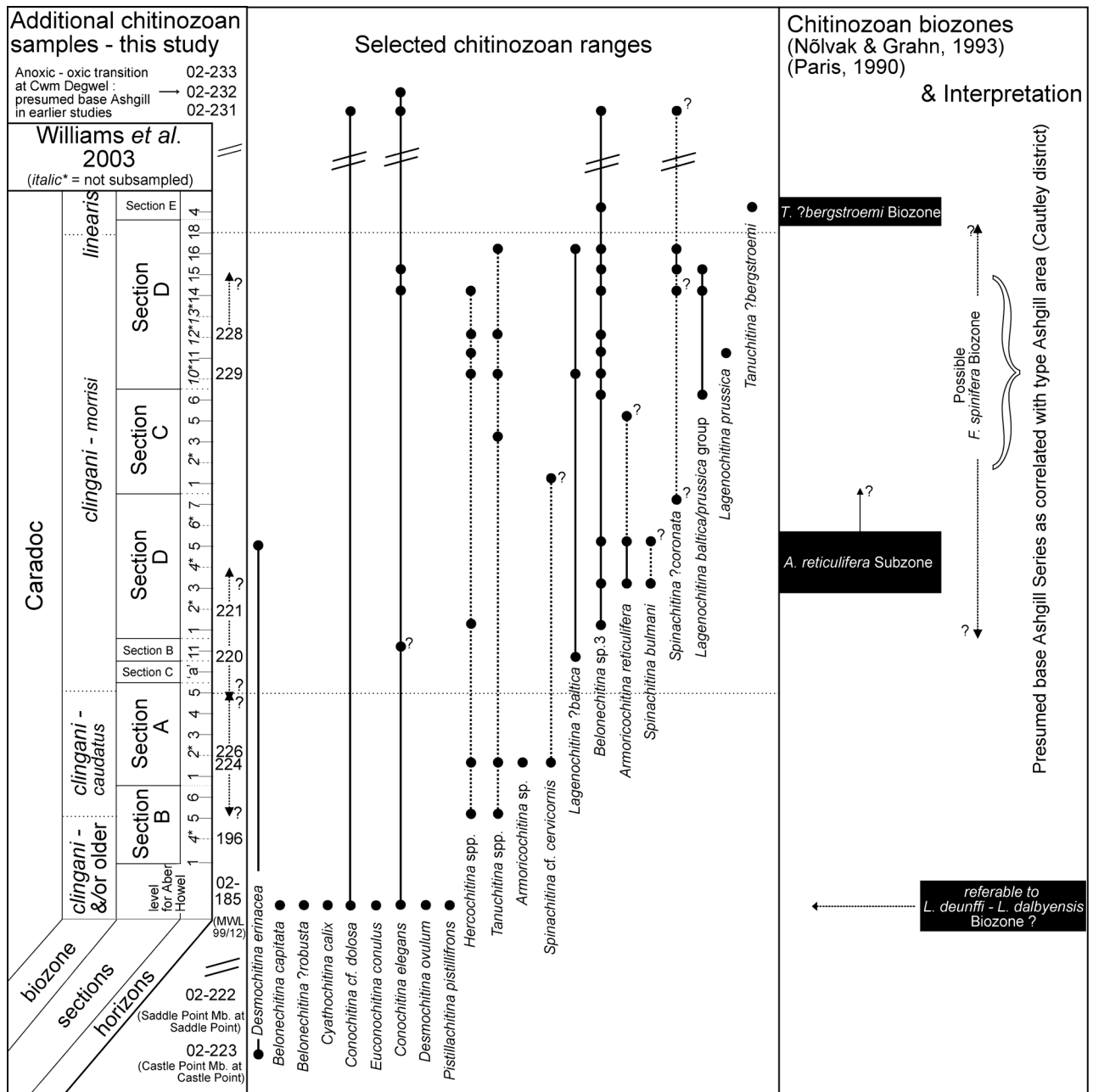


Figure 3. Composite range chart of chitinozoan species in the Cardigan area; the reconstruction of the succession is based on Williams *et al.* (2003, p. 557) and is not to scale. The TVDB sample numbers corresponding to the sub-sampled levels from Williams *et al.* (2003) are shown in Figures 4, 5 and in the Appendix. The precise stratigraphical position of some of the additional samples collected on the Ludlow Research Group (LRG) field trip is uncertain (modified after Williams *et al.* 2003).

- (3) Section D, Newport Sands, *D. clingingi* Biozone (TVDB 02-229), locality 10 of Williams *et al.* (2003);
- (4) Section E, Frongoch quarry, *D. clingingi* Biozone (TVDB 02-228), close to locality 2 of Williams *et al.* (2003);
- (5) Cwm Degwel [SN 1635 4540], at the transition from the anoxic Dinas Island Formation lithology into the grey, mottled Nantmel Mudstone Formation, at the assumed base of the Ashgill; TVDB 02-231, 02-232 and 02-233 respectively

at about 1 m below, at the facies transition, and 1 m above it;

- (6) Preseli Hills, Crymych [SM 183 338], *D. clingingi* Biozone (Fig. 2, locality 6; TVDB 02-221).

All sample localities are described in the Appendix; the samples are deposited at the Research Unit Palaeontology of Ghent University. In total, thirty-six samples from the Cardigan area and twenty samples from the Whitland road cutting were treated according to standard palynological techniques (Paris, 1981).

Chitinozoan results from the Cardigan area Sections A - E (Williams <i>et al.</i> 2003)	SECTION B Dinas Island					SECTION A Ogof Cadno				SECTION C Traeth Cell-Howel/Cardigan						SECTION D Newport Sands								SECTION E Frongoch		
	TVDB 02-195 / B1	TVDB 02-196 / B3	TVDB 02-186 / B5	TVDB 02-187 / B6	TVDB 02-197 / B11	TVDB 02-199 / A1	TVDB 02-180 / A3	TVDB 02-182 / A4	TVDB 02-181 / A5	TVDB 02-189 / C'a	TVDB 02-192 / C1	TVDB 02-193 / C3	TVDB 02-194 / C5	TVDB 02-183 / C6	TVDB 02-191 / D1	TVDB 02-175 / D3	TVDB 02-176 / D5	TVDB 02-190 / D7	TVDB 02-229	TVDB 02-177 / D11	TVDB 02-179 / D14	TVDB 02-178 / D15	TVDB 02-188 / D16	TVDB 02-198 / D18	TVDB 02-228	TVDB 02-184 / E4
<i>Chitinozoa</i> indet.		12	48	13	7	5				6	13	13	32		13	34	97	1	21	38	37	83	39	18	32	115
<i>Belonechitina</i> spp.	1		4	1	5						2	4			2		5		10	8	6	14	1	3	12	9
<i>Conochitina</i> spp.	8	6	8	6		3	1	1				1	4	10		24	1	17	5		6	9	11	12	1	
<i>Cyathochitina</i> spp.			15							1			12	5	2		7	3	4	12	9	6			6	6
<i>Hercochitina</i> spp.			11											4					6	1	1				5	2
<i>Tanuchitina</i> spp.			2										4?						1			3	1		1	
<i>Conochitina elegans</i>					4?																10	15				
<i>Spinachitina cf. cervicornis</i>										1?																
<i>Armoricochitina reticulifera</i>												4?														
<i>Belonechitina</i> sp. 3													14	17	1	21		7	1	8	11	31	1		11	9
<i>Lagenochitina baltica / prussica</i> group													1								1	2				
<i>Rhabdochitina</i> spp.													30			3					2				2	2
<i>Desmochitina minor</i>														1	2											1
<i>Spinachitina bulmani</i>															5	5?										
<i>Spinachitina</i> spp.																2									6	3
<i>Desmochitina erinacea</i>																5										
<i>Spinachitina ?coronata</i>																	1?			10?	80	30				
<i>Lagenochitina ?baltica</i>																			35				2			
<i>Lagenochitina prussica</i>																				3						
<i>Tanuchitina ?bergstroemi</i>																										77
scolecodonts																						X			X	
total number of chitinozoans	9	18	88	20	16	8	1	1	0	0	8	18	22	97	52	53	262	10	100	60	87	223	119	33	87	225
amount of dissolved rock (g)	15.17	15.57	15.62	14.95	15.05	15.49	15.40	14.84	14.79	15.38	15.78	15.43	15.16	15.20	15.28	14.57	42.65	15.05	22.92	14.53	15.43	15.06	15.36	15.61	21.81	14.93

Figure 4. Numerical results from sections A to E as mentioned in Williams *et al.* (2003). The residue of all samples has been completely picked and investigated.

Chitinozoan results from additional inland and coastal localities in the Cardigan area	Castle pt.	Saddle pt.	Aber Howel	Parrog		Crymych Preseli Hills		Cwm Degwel		
	TVDB 02-223	TVDB 02-222	TVDB 02-185 MWL99/12	TVDB 02-224	TVDB 02-226	TVDB 02-220	TVDB 02-221	TVDB 02-231	TVDB 02-232	TVDB 02-233
<i>Chitinozoa</i> indet.		5	57	12	3	5	7	46	4	6
<i>Desmochitina erinacea</i>	1									
<i>Belonechitina</i> spp.		2			1			7		
<i>Belonechitina capitata</i>			4							
<i>Belonechitina ?robusta</i>			6							
<i>Desmochitina minor</i>			2							
<i>Desmochitina ovulum</i>			3							
<i>Conochitina cf. dolosa</i>			21					3		
<i>Conochitina elegans</i>			11					81	2	
<i>Cyathochitina calix</i>			17							
<i>Cyathochitina</i> spp.			2	1			4			3
<i>Euconochitina conulus</i>			11							
<i>Lagenochitina</i> spp.			1							
<i>Pistillachitina pistillifrons</i>			4							
<i>Rhabdochitina</i> spp.			7							
<i>Armoricochitina</i> sp.				1						
<i>Conochitina</i> spp.				7			1	6		1
<i>Hercochitina</i> spp.				6						
<i>Spinachitina cf. cervicornis</i>				2						
<i>Tanuchitina</i> spp.				1						
<i>Lagenochitina ?baltica</i>						23				
<i>Belonechitina</i> sp. 3								2		
<i>Spinachitina ?coronata</i>								16?		
<i>Spinachitina</i> spp.									1	1
scolecodonts	X		X							
ostracodes								X		
total number of chitinozoans	1	7	146	30	4	28	12	161	7	11
amount of dissolved rock (g)	22.89	22.09	15.29	23.79	29.06	18.74	17.78	19.30	20.34	22.79

Figure 5. Numerical results from samples from inland and coastal localities in the Cardigan district, in addition to the samples from sections A to E as mentioned in Williams *et al.* (2003) and shown in Figure 4. The residue of all samples has been completely picked and investigated.

5. Chitinozoan results

The results of the chitinozoan analysis are presented in Figures 4, 5 and 6. The first of these figures shows the results from sections A to E (as defined in Williams *et al.* 2003) and the second figure shows the numerical results from several additional samples in the Cardigan area. The corresponding chitinozoan ranges are plotted on a composite stratigraphy (Fig. 3) that was constructed by Williams *et al.* (2003, p. 557) using key lithostratigraphical and graptolite data. In general, chitinozoan preservation is poor and yields were disappointing, but some levels yielded stratigraphically useful assemblages. Figure 6 quantitatively shows the results from the Whitland section as raw data. Figure 7 gives the range chart and the interpretation at the right hand side, described in section 6. Chitinozoans were recovered in sufficient quantities from the section but are not very well preserved and are commonly pyritized. A full systematic review of the chitinozoans from the study areas is contained in a Palaeontographical Society Monograph (Vandenbroucke, in press *b*). Some additional remarks are listed below.

In Cardigan, the chitinozoan morphospecies *Lagenochitina baltica* and *Lagenochitina prussica* are

combined, as distinction between them is often difficult. This group is recorded from sections C and D. *Tanuchitina ?bergstroemi* is reported only as fragments, but in considerable numbers, from section E. *Spinachitina ?coronata* has been recognized only provisionally in the lower half of the Whitland section but is identified with more certainty higher up in the section (see Fig. 6 for exact distribution). *Belonechitina* sp. 4, observed in several Whitland samples, is morphologically close to *Belonechitina* sp. 3 from the Cardigan area, although the poor preservation hampers formal synonymy.

6. Chitinozoan biostratigraphy

6.a. Cardigan area biozonation

Although not very well preserved or rich, the chitinozoan assemblages from several levels have good potential for biozonation and correlation, mainly with the Scandinavian chitinozoan biozonation (Nölvak & Grahn, 1993).

- (1) Interval possibly referable to the *Lagenochitina deunffi* to *Lagenochitina dalbyensis* Biozone?. At Aber Howel (Sample 02-185), the chitinozoan

Chitinozoan results from the Whitland Road Cutting	TVDB 02-138	TVDB 02-136	TVDB 02-134	TVDB 02-132	TVDB 02-130	TVDB 02-128	TVDB 03-118	TVDB 02-120	TVDB 02-122	TVDB 02-123	TVDB 02-124	TVDB 02-125	TVDB 02-126	TVDB 02-114	TVDB 02-113	TVDB 02-110	TVDB 02-141	TVDB 02-142	TVDB 02-143	TVDB 02-144
<i>Chitinozoa</i> indet.	163	56	33	28	85	26	22	28	32	51	28	26	85	20	94	45		3		15
<i>Belonechitina</i> spp.	35	13	3	12	41	6		4	4	11	28	18	24		6			1		
<i>Calpichitina</i> sp.	1																			
<i>Conochitina</i> spp.	3				7	4	2	3	6	4	25	37	5	3	4	8	1		1	1
<i>Conochitina elegans</i>	12		1		18	3	1	1	7	16	10	17	17	2	12					
<i>Conochitina</i> ? <i>incerta</i>	5			1	1				1	3	12	14	1							
<i>Cyathochitina</i> spp.	8	13	4	7	9	10	1	4	3	6	6	3	4	1	15	2	2			
<i>Cyathochitina campanulaeformis</i>	1		3																	
<i>Desmochitina erinacea</i>	12			9	5	1	6	2							2					
<i>Desmochitina juglandiformis</i>	6			1	14	1+2?			2	9	4	2				1?		2?		
<i>Desmochitina minor</i>	9	2		7	23	8	6	5	3	6	2	3	19	1	11	3		2	2	
<i>Desmochitina ovulum</i>	11				3	5		5		7	3	1	8		1	1		1		4
<i>Lagenochitina</i> ? <i>baltica</i>	1																2			
<i>Rhabdochitina</i> spp.	21	5	8		12	1	6	2	1	25	11	17	17	4	2			1		
<i>Saharochitina</i> spp.	8				1		1									2?				1
<i>Spinachitina</i> spp.	23	6	3	4	3			4	2	9	2	1	2		3					
<i>Spinachitina</i> cf. <i>cervicornis</i>	14			2																
<i>Spinachitina</i> ? <i>coronata</i>	9?			2?	19?	2?		4?	8	2	10	6	19+15?	7	4?	4				
<i>Belonechitina</i> sp. 4			310	54	13															
<i>Cyathochitina</i> ? <i>jenkinsi</i>	2			1							4?	1								
<i>Tanuchitina</i> spp.			5	4							1		1?		1?	1?				3
<i>Fungochitina</i> aff. <i>actonica</i>				2																
<i>Lagenochitina</i> spp.				1	1					2	1		2							
<i>Angochitina</i> ? <i>communis</i>					8			1?												
<i>Hercochitina</i> spp.					20					3	2	4	2		3					
<i>Saharochitina</i> <i>fungiformis</i>								2	1	2	1?	1+1?		1+6?						
<i>Armoricochitina reticulifera</i>									1+2?		2?	3?		1?	1?	1?				
? <i>Acanthochitina</i> spp.										4										
<i>Ancyrochitina</i> spp.										1										
<i>Cyathochitina</i> sp. 4										3	2?		14							
<i>Belonechitina</i> sp. 5										3										
<i>Lagenochitina baltica</i>										6	1	19	2	17	1	1		1	5	60
<i>Cyathochitina kuckersiana</i>											1	1	1		1					
<i>Acanthochitina latebrosa</i>												2	2							
<i>Calpichitina complanata</i>													3					1	2	1
<i>Desmochitina</i> cf. <i>nodosa</i>													1			1				
scolecodonts			X			X			X	X	X	X	X		X					
total number of chitinozoans	342	95	372 *	134	284	69	45	65	73	173	155	173	244	63	161	70	5	12	10	85
amount of dissolved rock (g)	15.11	16.15	14.98	14.83	15.50	15.73	15.16	14.85	15.36	15.46	18.76	18.74	15.79	15.95	15.29	115.32	152.49	156.79	153.75	154.10

Figure 6. Numerical results of the chitinozoan study in the Whitland section. * – about one-half of the residue picked.

fauna has, as its main constituents, *Belonechitina capitata*, *Belonechitina? robusta*, *Conochitina* cf. *dolosa*, *Conochitina conulus*, *Conochitina elegans*, *Cyathochitina calix* and *Pistillachitina pistillifrons* and is very similar to the northern Gondwanan assemblage shown in Henry *et al.* (1974). Paris (1990) established a formal biozonation for northern Gondwana and showed that *P. pistillifrons* has a short range within the *Lagenochitina deunffi* to *Lagenochitina dalbyensis* biozonal interval (Paris, 1990, fig. 4, p. 189).

- (2) *Armoricochitina reticulifera* chitinozoan Subzone of the *Fungochitina spinifera* chitinozoan Biozone. In sections C and D, the presence of *Spinachitina* ?*coronata*, *Lagenochitina* ?*baltica*, *Lagenochitina prussica* and *Armoricochitina reticulifera* are taken as indicative of the *Fungochitina spinifera* chitinozoan Biozone (Nölvak & Grahn, 1993; Nölvak, 2005), although the index fossil itself has not been recovered. The recovery of *A. reticulifera* also allows the local recognition of the eponymous Baltoscandic chitinozoan subzone (Nölvak & Grahn, 1993) (Fig. 3).
- (3) *Tanuchitina* ?*bergstroemi* Biozone. Higher in the Cardigan stratigraphy, *Tanuchitina* ?*bergstroemi*, a form close to the index fossil of the eponymous

Baltoscandic chitinozoan biozone, has been identified tentatively from an isolated locality at Frongoch [SN 0749 4108]. There, it occurs at the level of the *Pleurograptus linearis* graptolite Biozone. Records of this chitinozoan species, though abundant, are all fragmentary, hence the open nomenclature and the caution needed in using this occurrence for correlation.

6.b. Whitland section biozonation

The chitinozoan biozonation in the Whitland section remains tentative as index fossils are rare. Further study ought to increase the accuracy of the boundaries drawn and the biozones defined. Nevertheless, the following biozones have been recognized in the Whitland section (Fig. 7).

- (1) *Spinachitina cervicornis* Biozone?. The biozone has only tentatively been recognized because the index fossil has been provisionally identified as *Spinachitina* cf. *cervicornis* (occurring only in low numbers and in the lowermost part of the section). However, well-preserved specimens of *Desmochitina juglandiformis* have been recovered from several levels. *D. juglandiformis* is characteristic of the *Spinachitina cervicornis*

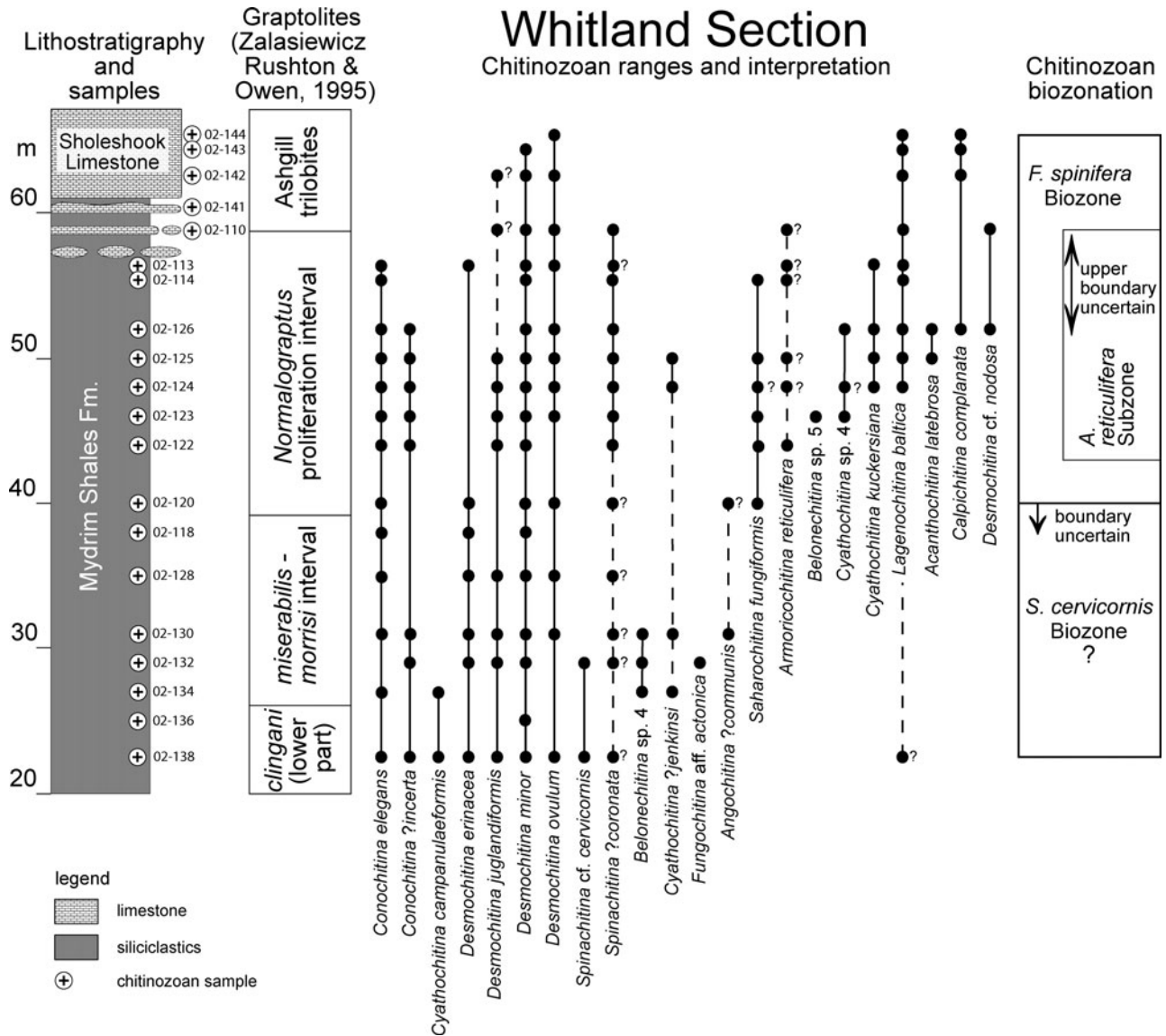


Figure 7. Range chart of chitinozoan species and chitinozoan biozonation in the Whitland road cutting. Lithostratigraphical column modified after Zalasiewicz, Rushton & Owen (1995).

Biozone in Baltoscandia, where both species have more or less the same short range (Nölvak & Grahn, 1993, p. 261). The occurrence of *D. juglandiformis* and to a lesser extent *S. cf. cervicornis* has therefore been used to identify the *Spinachitina cervicornis* Biozone? from the base of the sampled section up to the incoming of the index fossils of the overlying biozone.

- (2) *Fungochitina spinifera* Biozone. For the history of this biozone we refer to the study dealing with the Cautley district (Vandenbroucke, Rickards & Verniers, 2005). As in the type Ashgill area, *Saharochitina fungiformis* is taken as the local index fossil of the biozone, but the same preservation problems as in the Cautley district have to be considered. It was recognized from sample 02-120, at the base of the *Normalograptus* proliferation interval, upwards. However, only

a few specimens (7+8?) have been recovered. The presence of abundant (108) and easily recognizable *Lagenochitina ballica* specimens adds to the validation of the biozone, as *L. ballica* is considered a characteristic species, occurring slightly above the base of the original *Fungochitina fungiformis* Biozone in Nölvak & Grahn (1993). The single specimen questionably attributed to *L. ballica* (Fig. 7), aberrantly found at the base of the section, is not attributed any biostratigraphical value.

- (3) *Armoricochitina reticulifera* Subzone. The subzone was defined by Nölvak & Grahn (1993) in Baltoscandia as corresponding to the total range of the index fossil, a definition applied here also. However, only one specimen has been positively identified; the remaining ten specimens are doubtful and hence kept in open

nomenclature. The stratigraphical attribution of the biozone thus has to be treated with caution, although it helps to confirm the presence of the *Fungochitina spinifera* Biozone in the section. The first occurrences of *A. reticulifera* and *Lagenochitina baltica* appear to be inverted in comparison with their FADs given by Nölvak & Grahn (1993).

7. Correlations and significance of the chitinozoan biozonation

In general, the chitinozoan stratigraphy supports the established graptolite biozonation, but there are potentially important implications for the age of the base of the Nantmel Mudstones Formation and the biostratigraphical position of the *Normalograptus* proliferation interval. The recognition of the Baltoscandic biozones leads, cautiously, to a reasonably accurate correlation with the Baltic chitinozoan scheme (Nölvak & Grahn, 1993), with certain levels from the Gondwanan biozonation (Paris, 1990), and with several assemblages from northern England (Vandenbroucke, Rickards & Verniers, 2005).

7.a. Early Caradoc

The lowermost assemblage of interest has been recovered from strata assigned to the *Diplograptus multidentis* Biozone by Williams *et al.* (2003) at Aber Howel. The chitinozoan fauna (see Sections 5 and 6.a), comparable to Gondwanan assemblages including *P. pistillifrons* (Henry *et al.* 1974; Paris, 1990), is possibly indicative of the *Lagenochitina deunffi*–*Lagenochitina dalbyensis* biozonal interval. Paris dated the range of *P. pistillifrons* to the Costonian–earliest Harnagian and placed the two chitinozoan biozones in the upper part of the *N. gracilis* and the lower part of the *D. multidentis* graptolite biozones. The other chitinozoan species present tend to restrict the age assignment only to a (early) Caradoc age (Nölvak & Grahn, 1993). Chitinozoan correlations with Gondwana are thus consistent with the age and biozonal assignment suggested by Williams *et al.* (2003). Definite biozone attribution of the level remains impossible due to the lack of zonal index fossils.

7.b. Mid- to late Caradoc

In the Southern Uplands of Scotland, *Desmochitina juglandiformis* has been used in the Hartfell Score section to attribute the levels spanning the base of the *Ensigraptus caudatus* Subzone to the *Spinachitina cervicornis* Biozone or the *Belonechitina robusta* Biozone on Gondwana (J. A. Zalasiewicz *et al.* unpub. data, 2004: <http://www.ordovician.cn>). Finds from Whitland do not contradict this: *D. juglandiformis* ranges upwards from the lowermost Whitland sample, the base of the *E. caudatus* Subzone being situated

below this level. The *Spinachitina cervicornis* Biozone is reported from the pre-Onnian strata in the Onny Valley (Vandenbroucke *et al.* 2008), although there it was recognized by its index species, while *D. juglandiformis* has not been observed.

7.c. Late Caradoc–early Ashgill

Within the Welsh Basin, interesting ties between the Cardigan and Whitland areas can be recognized (Fig. 8). Even given the minor uncertainties concerning its exact stratigraphical extent (see Section 6.b and Fig. 8), the *Fungochitina spinifera* Biozone–*Armoricochitina reticulifera* Subzone combination in the *Normalograptus* proliferation interval of the Whitland section can easily be linked with the same chitinozoan assemblages in the Cardigan area, where it is present in the Dinas Island and Cwm-Yr-Eglwys Mudstone formations in sections C and D. However, at the latter localities, the chitinozoan assemblages are associated with graptolites of the *Dicellograptus morrisoni* Subzone of the *Dicranograptus clingani* Biozone (Williams *et al.* 2003). The latter graptolite–chitinozoan link is considered stable, as *A. reticulifera* and *D. morrisoni* graptolites are known to co-occur in the North Cliff Trench at Dob's Linn, Scotland (Verniers & Vandenbroucke, 2006). Hence, rocks containing the reduced diversity *Normalograptus* graptolite assemblage at Whitland appear to correlate, at least in part, with rocks yielding *D. morrisoni* faunas in the Cardigan area. This indicates that the 'Normalograptus proliferation interval' cannot correlate directly with the *Pleurograptus linearis* Biozone as proposed by Zalasiewicz, Rushton & Owen (1995). However, comparable *Fungochitina spinifera* Biozone chitinozoan assemblages, present in sections in northern England, are assigned an age of late Onnian to early Cautleyan. This is according to data from the Onnian and Pusgillian of Pus Gill (Cross Fell Inlier), the Pusgillian to lowermost Cautleyan of the Type Ashgill area (north of Sedbergh: Zalasiewicz, Rushton & Owen, 1995) and the Greenscoe road cutting in the Lake District (Van Nieuwenhove, Vandenbroucke & Verniers, 2006). Hence, in the Whitland section, the continuation of the *F. spinifera* Biozone into the Shoeshook Limestone also supports the late Pusgillian/early Cautleyan dating of the lower part of this division suggested by the associated trilobites (Zalasiewicz, Rushton & Owen, 1995 and based on Price, 1984). Taken together, these data suggest that (only) the upper part of the 'Normalograptus proliferation interval' might still correlate with the lower part of the *linearis* Biozone.

Four specimens of *Acanthochitina latebrosa*, as defined in the Onny Shales Formation of the Onny Valley (of Onnian age), occur in samples 02-125 and 02-126. This means that correlation between these parts of the section at Whitland and the Onny Valley might

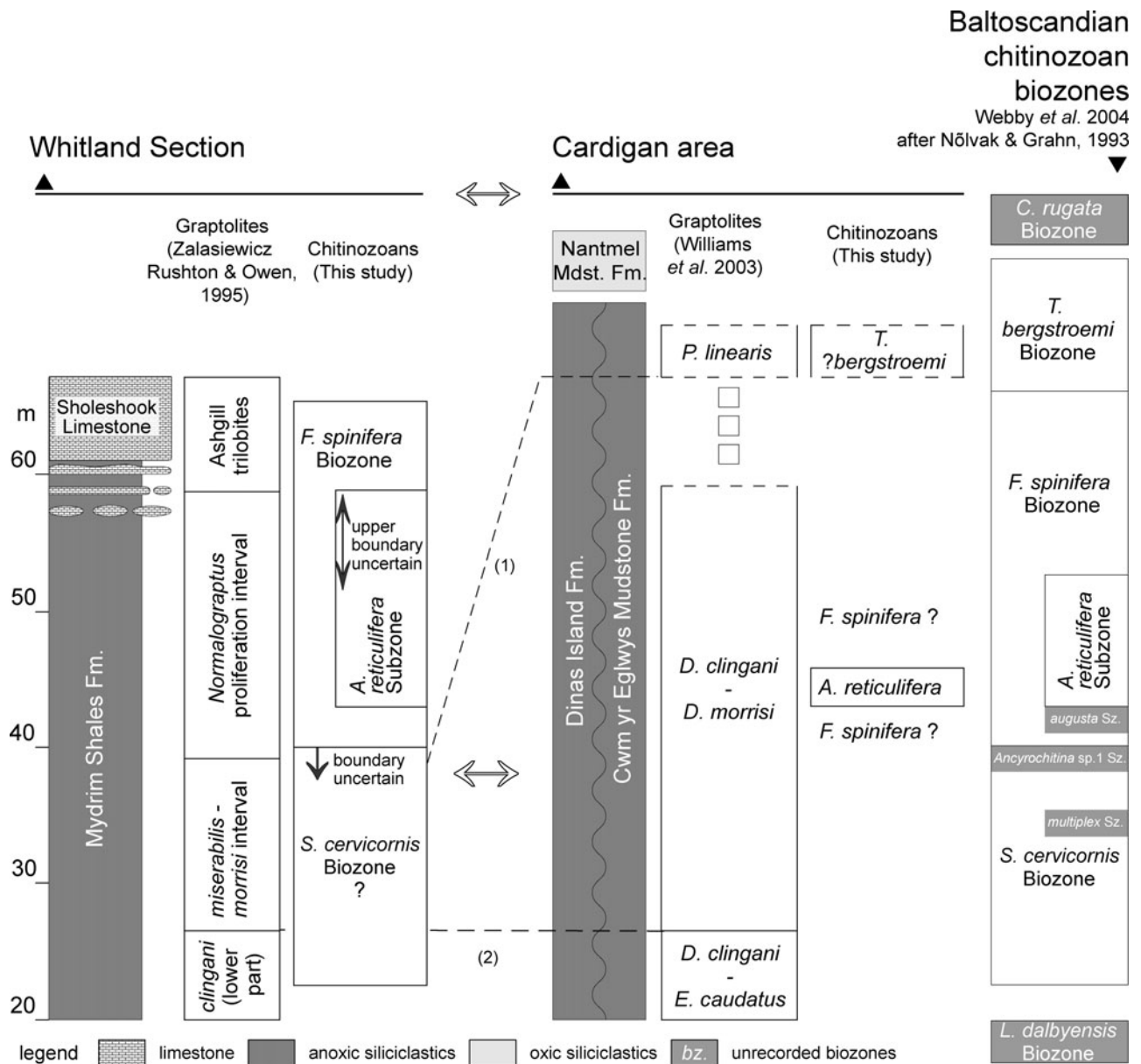


Figure 8. Correlation of the Whitland section with the Cardigan area using chitinozoans (most of the horizontal correlations) and graptolites (dashed line 2). One of the graptolite ties (dashed line (1) on the figure) suggested by Zalasiewicz, Rushton & Owen (1995) causes rather substantial discrepancies between the chitinozoan biozones of the two areas. It is therefore suggested that the correlation between the two areas using the *Fungochitina spinifera* Biozone/*Armoricochitina reticulifera* Subzone might be more accurate. This involves the correlation of the (lower) *Normalograptus* proliferation interval with levels of the *Dicellograptus morrisi* Subzone of the *Dicranograptus clingani* Biozone. Given that the *Pleurograptus linearis* graptolites are from an isolated locality at Frongoch [SN 0749 4108], there is some flexibility in the exact stratigraphical position of this biozone's boundary with the preceding biozone. The Baltoscandian chitinozoan biozonation is given at the right hand side of the figure as a reference.

be possible, although this would only be based on a small percentage of specimens in common, while the bulk of the assemblages in Whitland and the Onny Valley are rather different and hard to correlate. For a full discussion on the correlation potential, we refer to Vandenbroucke (in press *a*).

7.d. Ashgill

Taken at face value, the abundant chitinozoan fragments tentatively assigned to the index fossil *T.*

?bergstroemi at Frongoch carry implications, since they suggest a correlation with post-*spinifera* Biozone Cautleyan rocks in the Cautley type area (Vandenbroucke, Rickards & Verniers, 2005). Admittedly, in the Cautley district, rare specimens comparable to *T. bergstroemi* are found at the top of the *F. spinifera* Biozone, of Cautleyan age (Vandenbroucke, Rickards & Verniers, 2005); however, this is stratigraphically immediately below the appearance of true *T. bergstroemi* at the base of the eponymous biozone. If the presence of *T. bergstroemi* can be confirmed in the Cardigan area,

its association with *P. linearis* Biozone graptolites at Frongoch would also lend support to the findings of Rickards (2002, 2004), that is, that this biozone ranges into the Cautleyan and younger rocks. Such chitinozoan-based correlation would also imply that the anoxic–oxic transition which defines the base of the Nantmel Mudstones Formation, previously taken as the Caradoc–Ashgill boundary in the Cardigan area, and throughout mid-Wales, is in fact Cautleyan or younger in age; the true base of the Ashgill would hence be lower in the rock succession than suggested previously. It would also follow, contrary to current thinking (Fortey *et al.* 2000), that the base of the Nantmel Mudstones Formation in the basin is younger than the base of the shelfal Shoeshook Limestone at Whitland. Given these implications, confirmation of the presence of *T. ?bergstroemi* at Frongoch, and in equivalent strata elsewhere, should be viewed as an urgent requirement.

One significant implication of these results is that the Caradoc–Ashgill boundary in Wales (and in the Southern Uplands of Scotland) might lie within continuously graptolite-bearing strata. Locating this level more precisely would not only aid regional correlation, it would help constrain whether or not marked palaeoenvironmental changes (the anoxic to oxic switch at the base of the Nantmel Mudstones Formation; the switch to limestone deposition represented by the Shoeshook Limestone) were synchronous, thus helping assess their significance for early Palaeozoic climate evolution (Page *et al.* 2007).

8. Conclusions

Palynological analysis of rock samples collected for graptolites from the Cardigan and Whitland areas of SW Wales provides the following stratigraphical results from chitinozoans.

- (1) At Aber Howel, low in the Caradoc rock succession at Cardigan, the chitinozoan fauna has *P. pistillifrons* that indicates the Costonian–earliest Harnagian, and thus the chitinozoan correlations confirm the age and biozonal assignment of *D. multidentis* suggested by Williams *et al.* (2003) from the graptolites.
- (2) Finds of the subzonal index fossil *Armoricochitina reticulifera* within the Newport Sands section (*clingani* graptolite Biozone, *morrissi* Subzone) together with *Spinachitina? coronata*, *Lagenochitina ?baltica* and *Lagenochitina prussica*, indicate the *F. spinifera* chitinozoan Biozone, known from several sections in northern England where it spans the lower boundary of the Ashgill Series.
- (3) The link between the *Armoricochitina reticulifera* chitinozoan Subzone and the *D. morrissi* graptolite Subzone confirms the findings of

Verniers & Vandenbroucke (2006) at Dob's Linn, Scotland.

- (4) Fragmentary chitinozoans suggestive of the *T. ?bergstroemi* chitinozoan Biozone, from a level within the *Pleurograptus linearis* graptolite Biozone, indicate that upper parts of the Cwm-yr-Eglwys Mudstone Formation might correlate with strata of Cautleyan age in the type Ashgill area. If confirmed, this would imply that the widespread Welsh Basin anoxic–oxic transition at the base of the Nantmel Mudstones Formation is also Cautleyan (or younger) in age, and that the Caradoc–Ashgill boundary must lie at a lower level within the Cwm-yr-Eglwys or Dinas Island formations.
- (5) Chitinozoans from the Whitland road cutting allow recognition of two Baltoscandian biozones and a subzone, mainly by using accessory species rather than the index fossils. From bottom to top, the following biozones are present: *Spinachitina cervicornis* Biozone?, *Fungochitina spinifera* Biozone and *Armoricochitina reticulifera* Subzone.
- (6) Comparison of the Whitland assemblages with those of the Cardigan area suggests that at least the lower part of the *Normalograptus* proliferation interval of the Whitland section might better be attributed to the *Dicellograptus morrissi* Subzone of the *Dicranograptus clingani* Biozone rather than to the *Pleurograptus linearis* Biozone as previously suggested.

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Appendix 1. Sample localities

Cardigan–Fishguard area

Cardigan area: sub-samples Williams *et al.* (2003) collection

For each sample sub-sampled from the BGS collections the sample labels of the Williams *et al.* (2003) paper (A.* to E.*), the BGS field labels (e.g. 99/16 or boat*) and BGS storage labels (MWL/Tray) are indicated, together with the TVDB – sub sample label.

Section A (see Fig. 2): Ogof Cadno to Cemaes Head

- A.1: scree, base of cliff, fault zone S of Ogof Cadno [SN 0917 4399]
Boat 3; MWL 1034-1047/Tray 25903; TVDB 02-199
- A.3: top of cliff at Carreg Bica/Ceibwr [SN 0926 4420]
C.2; MWL 629–650/Tray 25512; TVDB 02-180
- A.4: Traeth Bach, S side of bay, foot of cliff/Ceibwr [SN 1014 4506]

- C.3; MWL 737-750/Tray 25513; TVDB 02-182
 A.5: Traeth Bach, near end of headland, S side of bay/Ceibwr [SN 1012 4508]
 C.1; MWL 651-735/Tray 25512; TVDB 02-181

Section B (see Fig. 2): Dinas Island

- B.1: S side of bay at Cwm-yr-Eglwys [SN 0155 4004]
 99/1; MWL 2103-2148; TVDB 02-195
 B.3: N side of small embayment at Pwllgwaelod [SN 4035 3995]
 2001/6; MWL 5298-5304; TVDB 0196
 B.5: centre of small bay just SE of Catch y Mitsiwr [SN 0026 4022]
 99/15; MWL 2757-2782; TVDB 02-186
 B.6: crags at top of cliff to the E of Catch y Mitsiwr [SN 0024 4025]
 2001/1; MWL 5227-5249; TVDB 02-187
 B.11: scree from near centre of bay Aber Pensidan [SN 0011 4075]
 99/18; MWL 2817-2831; TVDB 02-197

Section C (see Fig. 2): Treath Cell-Howel to Cardigan (Afon Teifi)

- C.'a': S of Ogof Cadno, scar 2/3 from the top of the cliff [SN 0905 4380]
 SPT/MW/97/4; MWL 955-963/Tray 25902; TVDB 02-189
 C.1: S bank just east of river bend [SN 1712 4602]
 PT 10; MWL 5200-5226; TVDB 02-192
 C.3: S bank, 60 paces downstream from effluent outflow [SN 1696 4600]
 PT7; MWL 824-834, 879-890/Tray 25902; TVDB 02-193
 C.5: S bank, 60 paces downstream from C4 [SN 1687 4598]
 (C4: opposite rocky cliff on N bank)
 PT 9; MWL 807-812/Tray 25514; TVDB 02-194
 C.6: at small bridge over tributary on the Afon Teifi [SN 1755 4605]
 'Keeping locality'; MWL 858-878/Tray 25515 & MWL 981-1007/Tray 25903; TVDB 02-183

Section D (see Fig. 2): Newport Sands

- D.1: shoreline exposure at high water mark [SN 0543 4067]
 P4; MWL 2192-2202 & 5305-5327; TVDB 02-191
 D.3: cave at high water mark on shoreline [SN 0539 4080]
 P1; MWL 388-428/Tray 25509; TVDB 02-175
 D.5: shoreline exposure on large reef [SN 0540 4088]
 P3; MWL 439-455/Tray 25508; TVDB 02-176
 D.7: shoreline exposure, at base of cliff [SN 0542 4099]
 N7; MWL 466-482/Tray 25508; TVDB 02-190
 D.11: shoreline exposure, about 3 m of Pen Pistyll [SN 0538 4111]
 N1; MWL 483-531/Tray 25508&25509; TVDB 02-177
 D.14: 39 paces N of Pen Pistyll [SN 0535 4118]
 N4; MWL 576-596 & MWL 906-941/Tray 25510, 25511 & 25902; TVDB 02-179
 D.15: shoreline exposure, 12 paces N of Pen Pistyll [SN 0535 4118]
 N2; MWL 540-545/Tray 25510; TVDB 02-178

- D.16: 49 paces N of Pen Pistyll [SN 0535 4118]
 N5; MWL 597-615/Tray 2551; TVDB 02-188
 D.18: Traeth y Bâl, at base of cliff on N side of bay [SN 0525 4225]
 boat 1; MWL 1008-1023/Tray 25903; TVDB 02-198

Section E (see Fig. 2): Frongoch

- E.4: steam bed, 52 paces upstream from old stone bridge [SN 0749 4108]
 99/8; MWL 2246-2272; TVDB 02-184
Aber Howel; 99/12; MWL 2414-2468; TVDB 02-185 [SM 9905 3852]

Cardigan area: Field collection 2002

- TVDB 02-220: Crymych, Preseli Hills [SM 185 339]; blacks shales of the Mydrim Shales Formation, more or less at the *E. caudatus*-*D. morrisi* transition in the *D. clingani* Biozone (Fig. 2, locality 6); sample at 1/3 of the outcrop length from the eastern margin of the outcrop, and 2/3 of the outcrop length from the bridge in the W.
 TVDB 02-221: Crymych, Preseli Hills [SM 185 339]; blacks shales of the Mydrim Shales Formation, in the upper *D. clingani* Biozone (*D. morrisi*) (Fig. 2, locality 6); sample at 0.5m east of the bridge at the western margin of the outcrop.
 TVDB 02-222: Saddle Point, Fishguard foreshore, mudstone (matrix?) of the Saddle Point Member of the Penyraber Mudstones Formation, stratigraphically below rafts with *D. multidentis* fauna at another locality.
 TVDB 02-223: Castle Point [SM 962 377], at the basal disconformity of the sedimentary succession on the Fishguard Volcanic Group; sample in the Castle Point Member of the Penyraber Mudstones Formation, stratigraphically 2 m above the top of the volcanics (or less possibly a large siltstone clast in the volcanics).
 TVDB 02-224: Parrog [SN 0459 3977] along the shore between Newport and Dinas Island; sample in the oxic, mottled Penyraber Mudstone Formation at 45 to 50 cm above a 15 cm thick, obvious quartz vein, exactly at the site of a small hollow under the path on top of the low cliff.
 TVDB 02-226: Parrog [SN 0459 3977] along the shore between Newport and Dinas Island; sample is a phosphatic nodule taken in the mottled Penyraber Mudstone Formation at about 0.5 to 1 m higher in the stratigraphy than TVDB 02-224, 5 paces more to the E
 TVDB 02-228: Frongoch quarry; [SN 0759 4098]; Cwm-Yr-Eglwys Mudstones Formation, in between Locality 1 and 2, but closer to locality 2 in section E of Williams *et al.* (2003), both near the W end of the Quarry, see Fig. 2; *D. clingani* Biozone.
 TVDB 02-229: Newport Sands section (Section D); [SN 0538 4111]; locality D.10 of Williams *et al.* (2003), about 4 m S of Pen Pistyll on shoreline; *D. clingani* Biozone; 60-67 cm under a 11.5 cm thick sandstone layer in the Dinas Island Formation.
 TVDB 02-231: Cwm Degwel [SN 1635 4540], at the transition from the anoxic Dinas Island Formation lithology into the grey, mottled Nantmel Mudstones Formation, or at the assumed base of the Ashgill; at ± 1 m below the facies transition.
 TVDB 02-232: Cwm Degwel [SN 1635 4540], at the transition from the anoxic Dinas Island Formation lithology

into the grey, mottled Nantmel Mudstones Formation, or at the assumed base of the Ashgill; at the facies transition. TVDB 02-233: Cwm Degwel [SN 1635 4540], at the transition from the anoxic Dinas Island Formation lithology into the grey, mottled Nantmel Mudstones Formation, or at the assumed base of the Ashgill; ± 1 m above the facies transition.

Whitland Road Cutting

The Whitland section [SN 1697 1599–1713 1598] is a road cutting along the A40, 3 km west of Whitland in southern Wales

TVDB 02-138: eastern part of the outcrop, about 22.3 m above the base of the section, 4.8 m east of the TVDB 02-136 locality. Mydrim Shales Formation.
 TVDB 02-136: eastern part of the outcrop, 25 m above the base of the section. Mydrim Shales Formation.
 TVDB 02-134: eastern part of the outcrop, 27 m above the base of the section. Mydrim Shales Formation.
 TVDB 02-132: eastern part of the outcrop, 29 m above the base of the section (2 m below the '31 m mark' of Zalasiewicz, Rushton & Owen (1995), which is still visible on the rock face). Mydrim Shales Formation.
 TVDB 02-130: eastern part of the outcrop, 31 m above the base of the section, at the '31 m mark' of Zalasiewicz, Rushton & Owen (1995), which is still visible on the rock face. Mydrim Shales Formation.
 TVDB 02-128: eastern part of the outcrop, 35 m above the base of the section (2 m below the '37 m mark' of Zalasiewicz, Rushton & Owen (1995), which is still visible on the rock face). Mydrim Shales Formation.
 TVDB 02-118: eastern part of the outcrop, 38 m above the base of the section, at the '38 m mark' of Zalasiewicz, Rushton & Owen (1995), which is still visible on the rock face. Mydrim Shales Formation.
 TVDB 02-120: eastern part of the outcrop, 40 m above the base of the section, at the '40 m mark' of Zalasiewicz, Rushton & Owen (1995), which is still visible on the rock face. Mydrim Shales Formation.

TVDB 02-122: eastern part of the outcrop, 44 m above the base of the section (between the '42 and 48 m marks' of Zalasiewicz, Rushton & Owen (1995), which are still visible on the rock face). Mydrim Shales Formation.
 TVDB 02-123: eastern part of the outcrop, 46 m above the base of the section. Mydrim Shales Formation.
 TVDB 02-124: eastern part of the outcrop, 48 m above the base of the section. Mydrim Shales Formation.
 TVDB 02-125: eastern part of the outcrop, 50 m above the base of the section. Mydrim Shales Formation.
 TVDB 02-126: eastern part of the outcrop, 52 m above the base of the section. Mydrim Shales Formation.
 TVDB 02-114: western part of the outcrop, 2.97 m to 3.00 m below the limestone layer described in TVDB 02-110; about 55 m above the base of the section. Mydrim Shales Formation.
 TVDB 02-113: western part of the outcrop, 1.93 m to 1.98 m below the limestone layer described in TVDB 02-110; about 56 m above the base of the section. Mydrim Shales Formation.
 TVDB 02-110: western part of the outcrop, 58 m above the base of the section, in the lowest, continuous, clearly observable limestone layer of the Shoeshook Limestone Formation, indicated as the one which yielded 'Ashgill trilobites' (R. Fortey, pers. comm. 2002); see Zalasiewicz, Rushton & Owen (1995).
 TVDB 02-141: western part of the outcrop, stratigraphically 2 m above TVDB 02-110 or 60 m above the base of the section; 42 paces east of the western edge of the road cutting. Shoeshook Limestone Formation.
 TVDB 02-142: western part of the outcrop; stratigraphically 4 m above TVDB 02-110 or 62 m above the base of the section; 42 paces east of the western edge of the road cutting. Shoeshook Limestone Formation.
 TVDB 02-143: western part of the outcrop; stratigraphically about 2 m above TVDB 02-142 or about 64 m above the base of the section; 42 paces east of the western edge of the road cutting. Shoeshook Limestone Formation.
 TVDB 02-144: western part of the outcrop; stratigraphically 2.75 to 2.95 m above TVDB 02-142 or about 65 m above the base of the section; 44 paces east of the western edge of the road cutting. Shoeshook Limestone Formation.