

Chitinozoan biostratigraphy of the Upper Ordovician *D. clingani* and *P. linearis* graptolite biozones on the Island of Bornholm, Denmark

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ABSTRACT: The last decade saw a revival of the debate on the exact stratigraphical position of the Upper Ordovician *P. linearis* graptolite biozone. Chitinozoan biostratigraphy can be useful to help address this question. Here, we provide a high-resolution chitinozoan biostratigraphy through the *Dicellograptus* Shale Formation at Vasagård on the Island of Bornholm (Denmark), which recently also was subject to a thorough revision of its graptolite fauna, representing the *Dicellograptus folicaceus*, *Dicranograptus clingani* and *Pleurograptus linearis* biozones. We have identified close to 9000 individual chitinozoan vesicles from 26 samples through the upper c. 9m of the *Dicellograptus* Shale Formation. The *Spinachitina cervicornis*, *Fungochitina spinifera* and *Tanuchitina bergstroemi* chitinozoan biozones are identified, and their boundaries carefully calibrated against the revised graptolite biostratigraphy. A correlation with the chitinozoan biozonation in the British Cautley district, which has a predominantly Baltoscandian, mid-latitude signature and is well-correlated with the graptolite and shelly fauna biozones described from the historical type region, is established.

Keywords: Caradoc, Ashgill, Katian, Upper Ordovician, biostratigraphy, correlations, chitinozoans, graptolites.

INTRODUCTION

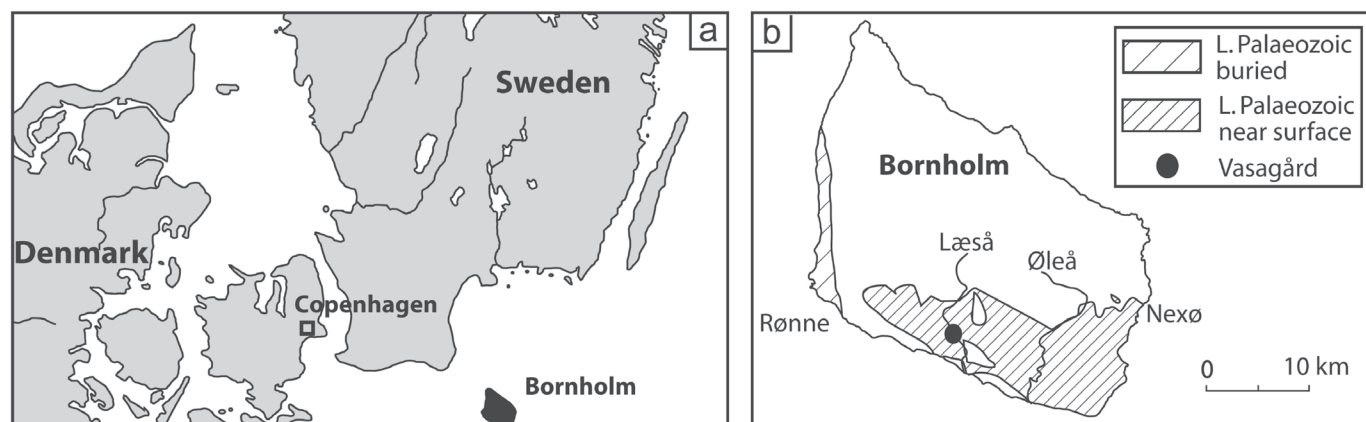
Graptolites of the *Pleurograptus linearis* Biozone have long been known to straddle the boundary between the British Caradoc and Ashgill series (C/A, Katian, Upper Ordovician), based, amongst other observations, on studies of the geology and shelly faunas of the classic Girvan area in southern Scotland (Ingham 1966; Ingham and Wright 1970). However, in key sections of northern England, notably in the type Cautleyan-Rawtheyan area, some of the same graptolites have been observed to range into the Rawtheyan (middle to upper Ashgill) by Rickards (2002; 2004). This has created considerable confusion with regard to local correlation around the C/A boundary. However, the implications are larger than those of the local correlation predicament: in response to an increasing demand for higher-resolved Ordovician stratigraphies the '*P. linearis*' Zone has been suggested as one of the new global 'Stage Slices' for the Upper Ordovician (Bergström et al. 2009). In addition, there is some confusion as to the validity of the age revision of the *P. linearis* Zone, as it was shown in its original upper Caradoc-lower Ashgill position by Zalasiewicz et al. (2009), in their revision of the graptolite biostratigraphy of the British Isles.

The graptolite slabs of the type Cautleyan-Rawtheyan area also yielded chitinozoan microfossils, with a Baltoscandian-Avalonian 'mid-palaeolatitude' signature (Vandenbroucke, Rickards and Verniers 2005). In an attempt to shed light on the confusing correlation issue summarized above, we are investigating other sections with *P. linearis* graptolite faunas, and where we expect to find chitinozoans similar to those of Vandenbroucke, Rickards and Verniers (2005). The Vasagård section on Bornholm, Denmark (text-fig. 1), is such a section with

a well-described graptolite fauna (Hadding 1915; Bruvo 2005), and high-resolution chitinozoan biostratigraphy through this section forms the subject of this paper. Preliminary chitinozoan data (7 species from 4 sampled levels) have previously been described (Grahn and Nõlvak 2007) and the current study aims to complete, refine and calibrate the chitinozoan biostratigraphy against the newly revised graptolite biostratigraphy (Bruvo 2005). Our objective, at this moment, is to add high-resolution data from a key section to the discussion, rather than trying to solve the complex correlation problem at hand in a single paper.

Geological setting and lithostratigraphy of the Upper Ordovician of Bornholm

The small Danish island of Bornholm is located within the extensively faulted Fennoscandian Border Zone, forming the boundary between the stable basement of the Baltica craton and the subsiding Norwegian-Danish Basin (Berthelsen 1992). The southern part of the island comprises a mosaic of small fault-bounded successions of Lower Palaeozoic and Mesozoic sediments, including a comparatively thin Ordovician succession, with a maximum thickness of about 50m. Upper Ordovician strata, assigned to the *Dicellograptus* Shale and the Lindegård Mudstone formations, are locally exposed in the small rivulets Læså and Risebæk (text-fig. 2). The instructive exposures at Vasagård, Læså, investigated in this paper, are classical in Danish geology. The *Dicellograptus* Shale and the Lindegård Mudstone at this site have been discussed and described by Ravn (1899), Hadding (1915), Funkquist (1919), Poulsen (1936), Gry (1948), Kielan (1959), Poulsen (1966), Bergström and Nilsson (1974), Bjerreskov and Stouge (1985) and Grahn and Nõlvak (2007).



TEXT-FIGURE 1
Localization and general geology of Bornholm

We here use the traditional lithostratigraphic name for the *Dicellograptus* Shale, instead of the more recent designations Sularp Shale, Mossen Formation and Fjäckå Shale (see e.g. Grahn and Nölvak 2007). The Mossen and Fjäckå shales were originally defined in central Sweden as two thin tongues of black shale that undoubtedly represent incursions of the *Dicellograptus* Shale onto the carbonate platform, associated with prominent sea level rises (e.g., Wærn et al. 1948; Nielsen 2004). The thin shales are also known from various other Swedish districts as well as from East Baltica (e.g., Männil 1966; Hints and Meidla 1997). However, in the distal facies belt in Scania-Bornholm there is no obvious lithologic difference between the amalgamated Mossen and Fjäckå Shales and attempts at distinction solely rely on palaeontological criteria. Despite their modern naming they are thus ‘topostratigraphical’ units in the sense of Jaanusson (1976), whereas the *Dicellograptus* Shale, albeit inappropriately named, is a true lithostratigraphic unit. The Sularp Shale refers to the lower part of the traditional *Dicellograptus* Shale, being characterized by numerous bentonite beds (Lindström 1953). Although this unit is also recognisable on Bornholm (see, e.g., Funkquist 1919; Bergström and Nilsson 1974), we will here use the traditional ‘*Dicellograptus* Shale’ for the whole set of strata, awaiting a full revision of the local Ordovician lithostratigraphy. The typical *Dicellograptus* Shale is a black, well-laminated shale, rich in pyrite and with abundant graptolites and tiny inarticulate brachiopods.

The Lindegård Mudstone (name introduced by Glimberg 1961) has traditionally been referred to as the Tretaspis Shale or Jerrestad Formation on Bornholm (see Poulsen 1966). Only the lowermost 3.5m of the unit is exposed at Vasagård; other exposures on Bornholm are insignificant. The formation is 16–21m thick in water wells and scientific drillings in the Øleå area some 8 km east of the Læså (Poulsen 1978; Pedersen 1989; Pedersen and Klitten 1990). The Lindegård Mudstone also includes the uppermost Ordovician strata traditionally assigned to the Brachiopod Beds, Dalmanitina Beds or, lately, Tommarp Mudstone in Scania, but this upper part of the unit is not exposed on Bornholm. The Lindegård Mudstone is lighter coloured than the *Dicellograptus* Shale, intensively bioturbated and contains fairly common shelly fossils, notably trilobites (Ravn 1899; Poulsen 1936; Kielan 1959) whereas graptolites are rare.

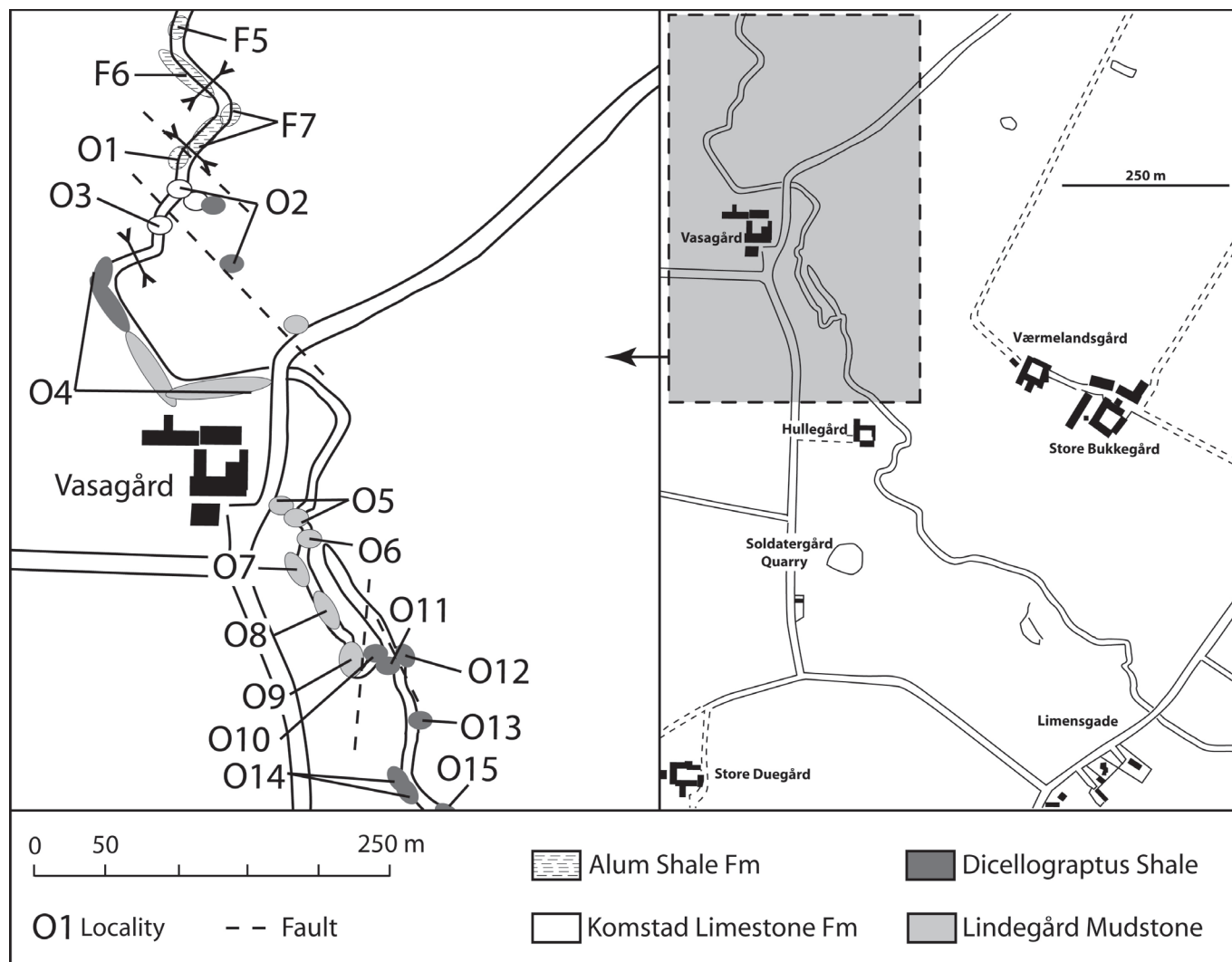
Graptolite and shelly fauna biostratigraphy at Vasagård

In Scandinavia, the lower part of the Upper Ordovician is virtually continuously graptolitic only in the Scania-Bornholm

area, i.e., in the Scanian confacies belt *sensu* Jaanusson (1976; also see e.g., Bergström et al. 1999; Pålsson 1996, 2001). The corresponding strata are only in part graptolitic in the Oslo area (Williams and Bruton 1983; Harper et al. 1984), and throughout most of Sweden and the east Baltic area dominated by limestones with a shelly fauna, only interrupted by the thin Mossen (*D. clingani* Biozone) and Fjäckå (*P. linearis* Biozone) shales (e.g., Wærn et al. 1948; Jaanusson 1982; Hints and Meidla 1997). The overlying strata attributed to the Upper Ordovician *D. complanatus* Biozone are sparsely graptolitic in Scania-Bornholm (Glimberg 1961; Poulsen 1966) whereas the *D. anceps* and *N. extraordinarius* equivalent intervals are non-graptolitic throughout Baltoscandia.

The upper 9m of the *Dicellograptus* Shale Formation, well-exposed in the up to 6m high and c. 200m long section along the Læså at Vasagård (loc O4, text-fig. 2), are mostly highly graptolitic. The strata tilt c. 10 degrees south. A zonation was established by Hadding (1915), in ascending order comprising the *Climacograptus rugosus*, *Amplexograptus vasae*, *Dicranograptus clingani* and *Climacograptus styloideus* biozones. The underlying poorly fossiliferous strata, c. 2m thick in the Læså area, were assigned to the *Nemagraptus gracilis* Biozone by Poulsen (1936). Poulsen (1966) suggested to abandon the local zonation introduced by Hadding (1915) and instead he assigned the *Climacograptus rugosus* and *Amplexograptus vasae* interval to the *Diplograptus multidens* Biozone and revised the *C. styloideus* Zone to the *Pleurograptus linearis* Zone. Bergström and Nilsson (1974), based on correlation of bentonite beds, indicated that the basal part of the *Dicellograptus* Shale of Bornholm most likely correlates with the *D. multidens* Biozone [now *D. foliaceus* Biozone, see Hughes 1989] and suggested that the *Nemagraptus gracilis* Zone is absent.

Bruvo (2005) recently undertook a modern restudy of the Vasagård section with extensive bed-by-bed collection of graptolites. She collected more than 7000 specimens, of which c. 4000 could be determined at species level (17 species recorded) and c. 3000 only at generic level. The graptolites are preserved as flattened and coalified organic films. The basal part of the sampled section, 0.7m thick, only yielded the long-ranging *Pseudoclimacograptus rugosus* and *Corynoides calicularis*. The absence of *D. clingani* in combination with correlation of bentonite beds (cf. Bergström and Nilsson 1974) is taken to indicate a correlation with the *D. foliaceus* Zone. *D. clingani* appears above a thin phosphoritic conglomerate at 8.1m below top of the *Dicellograptus* Shale and is indicative of the *D. clingani*



TEXT-FIGURE 2

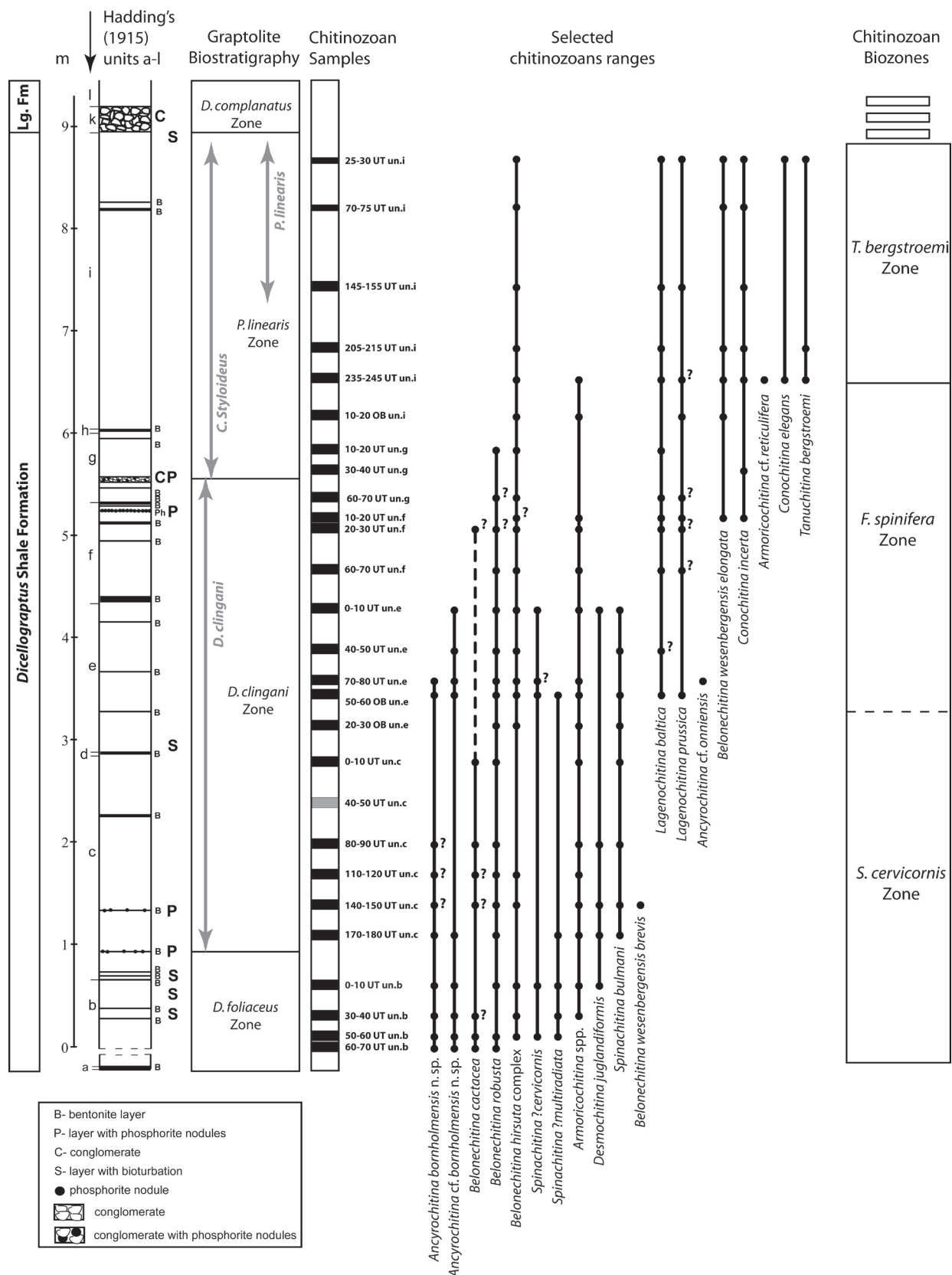
A. Map of the Vasagård area; B. Detailed map Vasagård with the localisation of the section and of the fossils localities.

Zone, which ranges up to another thin phosphoritic conglomerate at 3.5m below top of the *Dicellograptus* Shale. The upper 2.5m of the *D. clingani* Zone – largely corresponding to the *D. clingani* Zone *sensu* Hadding (1915) – are rich in graptolites including *D. clingani*, *Archiclimacograptus vasa*, *A. compactus* and several other species. *A. compactus* is only known from the upper half of the *D. clingani* Zone in Scandinavia and Great Britain (Elles and Wood 1907; Hadding 1915; Nilsson 1977; Williams and Bruton 1983) whereas *A. vasa* is a local Scandinavian species, also restricted to the *D. clingani* Zone (Hadding 1915; Nilsson 1977). The revised zonation (Bruvo 2005) shows that most of the *C. rugosus* Zone and the *A. vasa* Zone *sensu* Hadding (1915) represent the *D. clingani* Zone in modern terminology; he just did not find *D. clingani* below his *D. clingani* Zone. The overlying *P. linearis* Zone is rich in graptolites, dominated by *Climacograptus styloideus*, but several other species also occur. The boundary between the *D. clingani* / *P. linearis* zones is defined by the disappearance of *D. clingani* and the concomitant appearance of *C. styloideus*. This boundary, marked by a 5cm thick phosphoritic conglomerate, is located slightly lower in the section than originally indicated by Hadding (1915). It should be noted that *P. linearis* itself is sparsely occurring only in the upper half of the zone, 0.2–1.65m below top of the *Dicellograptus* Shale Formation.

The Lindegård Mudstone, unconformably overlying the *Dicellograptus* Shale, contains a fairly rich shelly fauna, and the lower part of the unit exposed at Vasagård seems to represent mainly the *Staurocephalus clavifrons* trilobite Zone, with its basalmost part possibly representing the *Eodindymene pulchra* trilobite Zone (Kielan 1959). *S. clavifrons* occurs in the *Phillipsinella parabola* Zone in Great Britain (of Cautleyan-Rawtheyan age; Ingham 1966) and *P. parabola* has also been found on Bornholm (Kielan 1959; Poulsen 1966). Rare graptolites, recorded c. 3.5m above the base of the unit (Poulsen 1936), represent *D. complanatus* (see Skoglund 1963), but, in general, the Lindegård Mudstone is non-graptolitic. The upper part of the unit generally is assumed to correspond in age to the *D. anceps*, *N. extraordinarius* and basalmost part of the *N. persculptus* biozones, but no graptolites have so far been recorded in the few cored wells available from Bornholm (Koren and Bjerreskov 1997; unpubl.). In fact, the *D. anceps* and *N. extraordinarius* intervals are non-graptolitic throughout Baltoscandia.

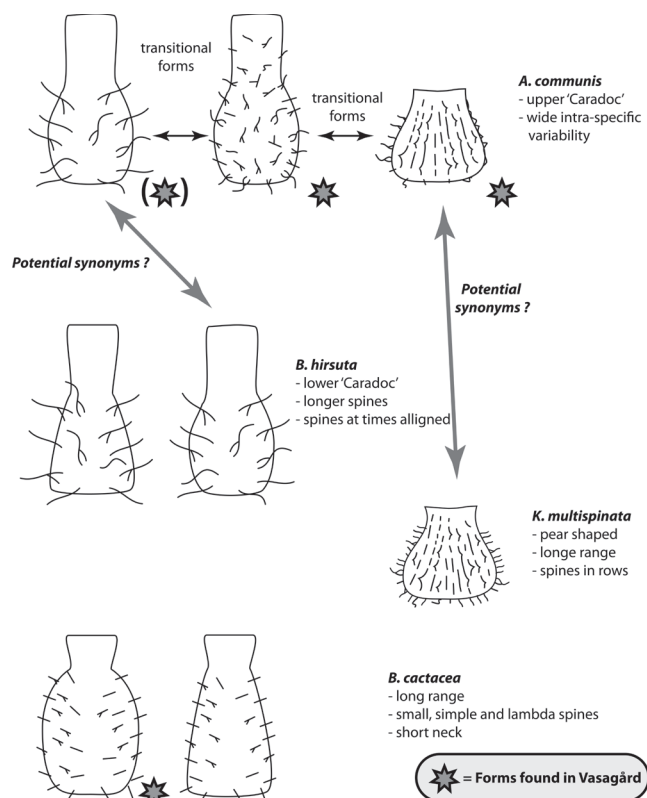
METHODS

The graptolite fauna was sampled by Bruvo (2005) from the *Dicellograptus* Shale at Vasagård, Bornholm, in 10 cm intervals throughout the outcrop. Subsamples for chitinozoan



TEXT-FIGURE 3

Sampled section and selected chitinozoan ranges. The *Dicellograptus* Shale is in total 11m thick at Vasagård, Læså, of which the lower 2m, rich in bentonites, can only be reached by excavation (Funkquist 1919). Its upper part is rich in graptolites, first studied in detail by Hadding (1915). The Vasagård section has recently been reinvestigated by Bruvo (2005). The exposed succession represents in ascending order the uppermost part of the *Dicellograptus foliaceus* Zone (>0.7m), the *Dicranograptus clingani* Zone (4.6m) and the *Pleurograptus linearis* Zone (3.5m). The underlying bentonite-rich level (c. 2m at Vasagård) was correlated with the *D. foliaceus* Zone by Bergström and Nilsson (1974) and this zone is thus close to 3m thick at Vasagård. Lg.Fm= Lindegård Mudstone Formation.



TEXT-FIGURE 4

Inter and intra-specific morphological variation of Upper Ordovician small spiny chitinozoans, and suggested potential synonymies.

micropalaeontology were taken at the same time by ATN. Six supplementary samples were also obtained from the exposed lower part of the Lindegård Mudstone at the less weathered sections slightly downstream from Vasagård (locs O4 and O7, text-fig. 2). The thickness of the interval hidden between the main exposure and the exposures downstream was calculated using levelling. The samples were labelled in the field using the unit designations a-i introduced by Hadding (1915); see text-fig. 4 for details. These nine informal subunits refer to lithological differences that, albeit subtle, are fairly easily recognisable in the field. Subsampling of the graptolite collections ensures very accurate calibration between the graptolite and chitinozoan biozonation. The micropalaeontology samples were chemically treated with HCl-HF-HCl at 80°C, according to standard palynological methods (Paris 1981) at the micropalaeontology lab of Ghent University (Department of Geology). Sample weights were between 10 and 17 g. Chitinozoans were handpicked from the organic residue and mounted on slides for study with the Scanning Electron Microscope (Jeol 6400 at Ghent University and FEI Quanta 200 at the University of Lille 1) or normal optical light microscopy. The material is permanently stored in the palaeontological collections of University of Lille 1, and the repository references are from USTL 2792 to USTL 2855.

RESULTS

The quantitative results of the palynological analyses of the samples from the *Dicellograptus* shale Fm. are shown in Table 1. In total, 8851 chitinozoans were handpicked from 26 samples. Of these, 8427 specimens were photographed and identified using SEM. The remaining 424 were counted using a

stereomicroscope, at magnification of x150, their identification aided by SEM imaging of other specimens of the same sample. Forty-three taxa were identified (and over half of these to the species level). A selection of stratigraphically diagnostic species, and their ranges through the section are shown in text-fig. 3. In contrast, the 6 samples from the overlying Lindegård Mudstone Formation yielded almost no chitinozoans. Sample VI_45-53 yielded 7 unidentifiable chitinozoans, 8 granulated specimens of the *Lagenochitina baltica* / *Lagenochitina prussica* group and 1 specimen of the genus *Belonechitina*. Samples VI_82-94, VI_163-170, VI_235-240, VII_0.30 and VII_0.85-0.90 were all barren of chitinozoans.

SYSTEMATIC PALEONTOLOGY

Here, we only discuss new species, species in open nomenclature, groupings of species, and other taxa where ambiguity could exist as to their taxonomical significance. For information on all the other taxa listed in Table 1, we refer to the published literature, e.g., Grahn and Nölvak (2007; 2010) or Vandenbroucke (2008a) and references therein. We follow the chitinozoan classification of Paris et al. (1999). The Bornholm chitinozoans are illustrated in Plates 1-5.

Incertae sedis Group CHITINOZOA Eisenack 1931
Order PROSOMATIFERA Eisenack 1972
Family CONOCHITINIDAE Eisenack 1931 emend. Paris 1981
Subfamily CONOCHITININAE Paris 1981
Genus CONOCHITINA Eisenack 1931 emend. Paris et al. 1999

Conochitina incerta Eisenack 1962

Description: See Vandenbroucke (2008a).

Discussion: These specimens have a very sharp basal margin, which could also be interpreted as a very short carina, and are therefore very close to the genus *Tanuchitina*. In the Vasagård section, however, they are much less elongate, and have a much more pronounced neck-chamber differentiation than the only, very slender species of *Tanuchitina* present, *Tanuchitina bergstroemi*.

Subfamily TANUCHITININAE Paris 1981
Genus TANUCHITINA Jansonius 1964 emend. Paris et al. 1999

Tanuchitina spp.

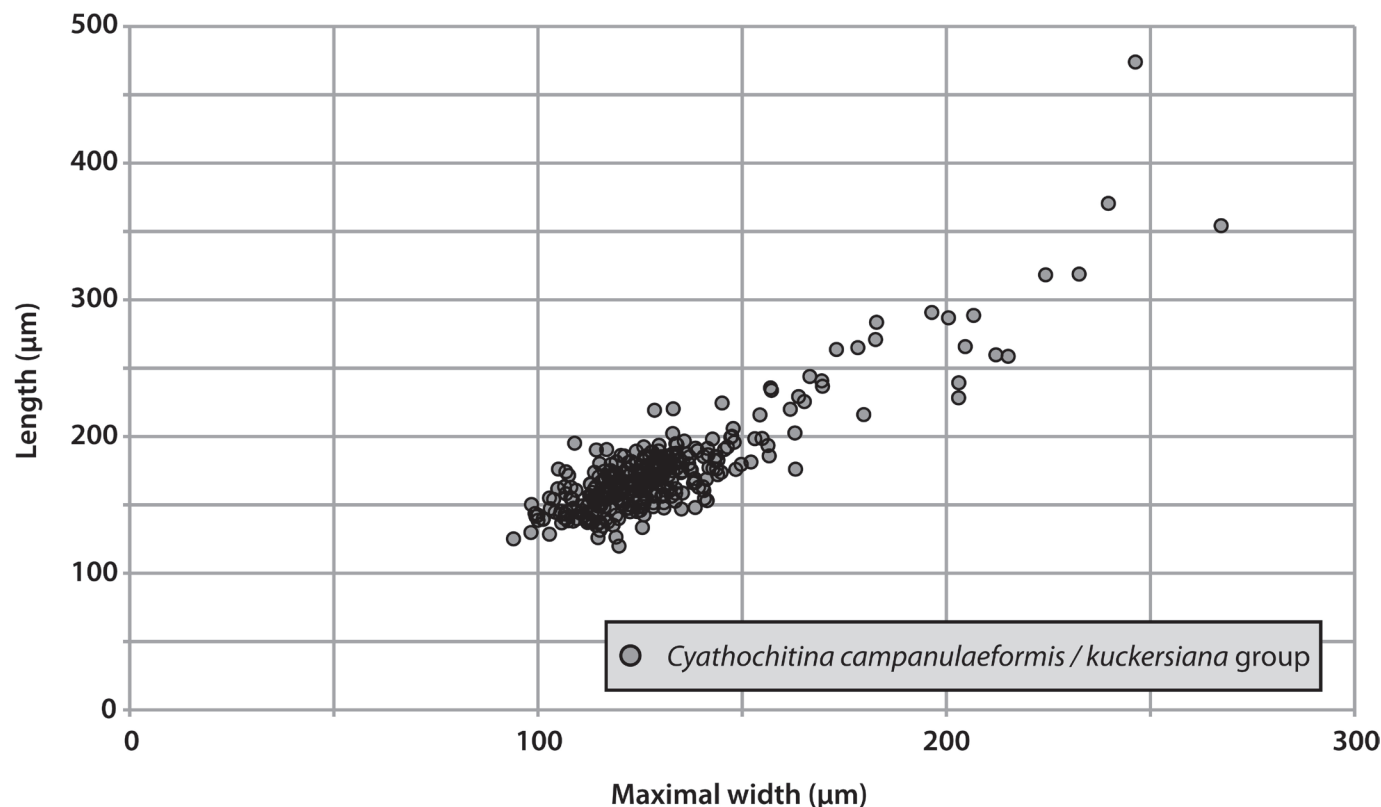
Description: “*Tanuchitina* spp.” predominantly groups basal fragments with a very sharp basal edge or a carina, which can belong to either *Tanuchitina bergstroemi* or *Conochitina incerta*.

Subfamily BELONECHITININAE Paris 1981
Genus BELONECHITINA Jansonius 1964

Belonechitina hirsuta complex (Laufeld 1967)

Description: This groups small cylindro-conical to trapezoid, spiny specimens otherwise attributed to *Belonechitina hirsuta* or *Angochitina communis*.

Discussion: The morphological similarity between a number of spiny, small species, including *Angochitina communis* (Jenkins 1967), *Belonechitina hirsuta* (Laufeld 1967) and *Kalochitina multispinata* (Jansonius 1964), and the systematic confusion associated with this, is discussed in detail by Vandenbroucke (2008a, p. 75-76), and only summarized herein (text-fig. 4). In their revision of the chitinozoans from the Onny Valley chitinozoans, Vandenbroucke et al. (2009) re-studied the type



TEXT-FIGURE 5

Length-Width plot of the *Cyathochitina campanulaeformis-kuckersiana* group (334 specimens). This shows that the short, bell-shaped *Cyathochitina* specimens illustrated in Plate 3, n, o, p and included in the aforementioned group, cannot be considered a separate species based on their length and width.

stratum for *Angochitina communis* (Onnia Beds Formation). They found specimens of *Angochitina communis* as defined by Jenkins (1967), with an ovoid chamber and slender simple and wishbone spines that are evenly distributed over the whole vesicle. Alongside these specimens, in the same assemblages, they also found forms with a slightly more trapezoid to pear-shaped chamber, a shorter neck and more, smaller and aligned spines. The former form is very close to *Belonechitina hirsuta*, while the latter resembles *Kalochitina multispinata*. Nevertheless, the two forms from the Onny Valley were not separated into discrete species, as all transitional forms were present. Vandenbroucke et al. (2009) considered the two forms to be end-members of a morphological spectrum (also see Vandenbroucke 2008a, p. 75–76), and attributed all the specimens to *Angochitina communis*, typified by substantial intra-specific variability. Studying the type assemblage, they retained *A. communis* as a name, hereby ignoring the suggestion by Jenkins (1969). Pouille et al. (2013) followed the same reasoning when they named their stratigraphically isolated assemblages from the Borenshult-I core in Sweden, that displayed a quasi-identical degree of morphological variability.

Here, the situation is slightly different. The assemblages recovered also display an important morphological variability (text-fig. 4), comparable to that described above. In addition, they are also spread throughout the stratigraphy. The assemblages, and their imperfect preservation, however, do not allow us to identify morphologically evolutionary trends. It is clear that a systematical revision of these taxa is an urgent requirement.

Until such a revision (which would necessarily include a re-study of the *B. hirsuta* type material), we have grouped all the small spiny chitinozoans into the *B. hirsuta* complex (when grouping we do follow the nomenclature suggestions of Jenkins 1969).

The specimens in this complex differ from those of *Belonechitina cactacea*, which have much shorter neck, ovoid-conical chamber and smaller simple or wish-bone shaped spines (text-fig. 4).

***Belonechitina* sp. A**

Description: Slender, cylindrical to cylindro-conical *Belonechitina* species with numerous, very small, simple spines spread over the vesicle, and with a rounded basal margin.

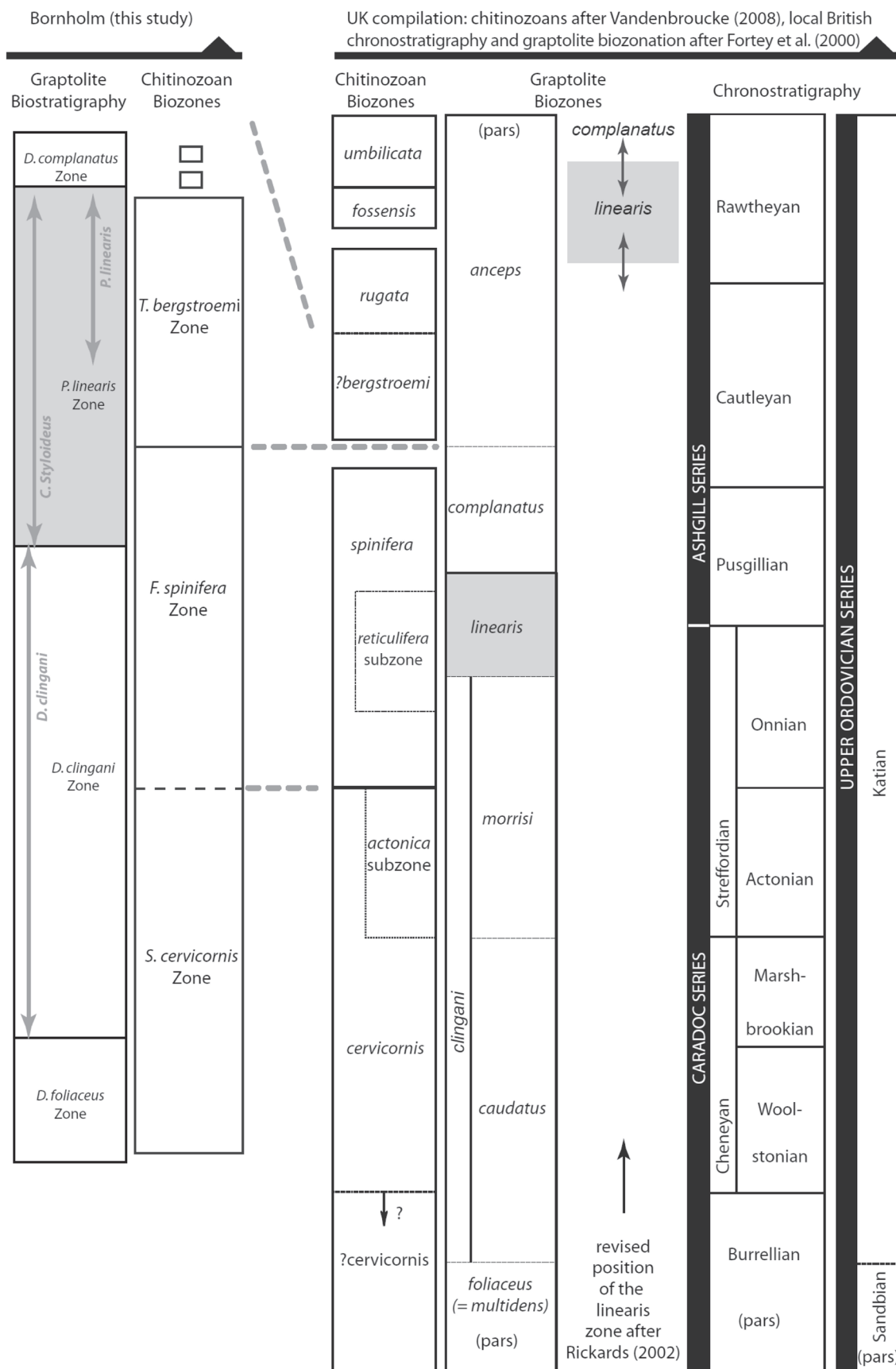
Subfamily SPINACHITININAE Paris 1981

Genus SPINACHITINA Schallreuter 1963

Spinachitina* ?*multiradiata (Eisenack 1959), ***Spinachitina* ?*cervicornis*** (Eisenack 1931), ***Spinachitina bulmani*** (Jansonius 1964)

Description: See holotype descriptions and Vandenbroucke (2008a).

Discussion: Within the studied section, the three species for *Spinachitina* are distinguished as follows: *S. ?multiradiata* has a crown of simple spines, a cylindrical neck, a pronounced flexure and a conical body; the flanks can be concave. *S. bulmani* also has a crown of simple spines, but has a much more slender and



TEXT-FIGURE 6

Correlation diagram showing the Vasagård chitinozoan and graptolite biozones, correlated with those of the Cautley District in the UK (Vandenbroucke, Richards and Verniers 2005).

TABLE 1

Quantitative chitinozoan results from the Vasagård section through the *Dicellograptus* Shale Formation.

	Un B 60-70 UT	Un B 50-60 UT	Un B 30-40 UT	Un B 0-10 UT	Un C 170-180 UT	Un C 140-150 UT	Un C 110-120 UT	Un C 80-90 UT	Un C 0-10 UT	Un E 20-30 OB	Un E 50-60 OB	Un E 70-80 UT	Un E 40-50 UT	Un E 0-10 UT	Un F 60-70 UT	Un F 20-30 UT	Un F 10-20 UT	Un G 60-70 UT	Un G 30-40 UT	Un G 10-20 UT	Un I 10-20 OB	Un I 235-245 UT	Un I 205-215 UT	Un I 145-155 UT	Un I 70-75 Ut	Un I 25-30 UT
Chitinozoan indet.	8	3	16	10	9	4	1	16	40	4	24	17	6	18	23	22	3	8	10	7	32 + 19*	34	14 + 23*	3 + 29*	12 + 78*	5 + 48*
<i>Ancyrochitina bornholmensis</i> n. sp.	50	357	145	32	4	1 ?	1 ?	1 ?	0	0	3	4 ?	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ancyrochitina cf. bornholmensis</i> n. sp.	8	118	18	5	2	0	0	0	0	0	7	2	1	4	0	0	0	0	0	0	0	0	0	0	0	0
<i>Belonechitina cactaea</i>	7	2	9 ?	0	0	3 ?	13 ?	29	1	0	0	0	0	0	0	1 ?	0	0	0	0	0	0	0	0	0	0
<i>Belonechitina robusta</i>	2	11	0	106	114	13	30	31	36	1#	5 + 1#	6	38	10	46	11 ?	0	88 ?	0	28	0	0	0	0	0	0
<i>Belonechitina</i> sp. A	3	3	4	0	0	0	1	0	0	0	19 + 13#	20	2	1	0	0	0	0	0	3 ?	0	0	0	0	0	0
<i>Belonechitina</i> spp.	1	0	1	1	5	0	0	0	0	1	0	0	1	2	2	0	15	0	0	6	14 + 5*	22	0	4 + 2*	0	0
<i>Conochitina</i> spp.	6	3	10	17	4	1	0	16	27	0	0	3	8	2	15	0	1	17	2	0	4 + 4*	6	0	0	24 + 2*	17
<i>Cyathochitina campanulaeformis/luckersiana</i> group	27	47	41	208	102	14	42	735	513	227	450	70	173	159	215	158	10	33	0	45	55 + 11*	16	2	8 + 12*	0	3 + 2*
<i>Desmochitina minor</i>	5	0	17	20	0	9	2	5	0	0	0	1	76	60	0	0	1	0	1	11	5	3	0	1*	0	1*
<i>Saharochitina</i> sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Desmochitina</i> sp. 1	2	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Belonechitina hirsuta</i> complex	5	28	1	0	2	2 + 2 ?	0	0	1 + 4#	18 + 16#	164	8	49	1	91	3 ?	11	0	36	27 + 8*	6	3	7 + 10*	2 + 2*	13 + 1*	
<i>Pogonochitina?</i> sp. 1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Spinachitina ?cervicornis</i>	4	0	2	0	0	0	0	0	0	0	1	2 ?	0	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Spinachitina ?multiradiata</i>	25	7	49	5	0	1	0	0	0	0	3 + 2 #	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ancyrochitina</i> spp.	1	0	0	0	0	0	0	2	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Amorochitina</i> spp.	1	12	4	2	3	50	2	37 + 11 #	7 + 4 #	2	0	12	2	2	1	0	0	0	0	0	1	8	0	0	0	0
<i>Desmochitina juglandiformis</i>	10	44	3 (?)	11	0	7	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
<i>Herocochitina</i> spp.	2	1	0	2	0	0	0	0	0	1#	0	0	0	3	0	0	0	0	0	0	4	0	0	0	0	0
<i>Bursachitina</i> spp.	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Spinachitina bulmani</i>	9	54	0	17	5	3	5 + 6#	0	10	167	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Belonechitina wesenbergensis</i> brevis	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Rhabdochitina</i> spp.	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
<i>Spinachitina</i> sp.	1	0	0	0	6	0	2	6	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Eucenochitina</i> sp.	98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Lagenochitina baltica</i>	117 + 16 #	0	17	0	221	230	1	2	0	116	0	6	29 + 11*	1 + 1*	0	2 + 2*										
<i>Lagenochitina prussica</i>	2 + 4 #	0	0	2 ?	9 ?	7	1 ?	0	0	1 + 3*	17	0	3 + 1*	0	30 + 11*											
<i>Lagenochitina</i> sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ancyrochitina cf. onniensis</i>	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Desmochitina ovulum</i>	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0
<i>Eisenachitina</i> spp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Desmochitina erinacea</i>	1	0	0	13	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	7	0	0	0	0
<i>Belonechitina wesenbergensis</i> elongata	16	0	0	0	0	14	21	14 + 2*	0	12 + 32*	10 + 1*															
<i>Conochitina incerta</i>	119	0	11	0	0	17	35 + 3*	22 + 14*	15 + 36*	16 + 9*																
<i>Spinachitina</i> sp. 1	3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Conochitina elegans</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Tanuchitina</i> spp.	11	32 + 10*	0	0	0	11 + 6*																				
<i>Tanuchitina bergstoerni</i>	109	12	0	0	0	7																				
<i>Amorochitina cf. reticulifera</i>	12	0	0	0	0	0																				
<i>Angochitina</i> sp. A	1	0	0	0	0	0																				
<i>Rhabdochitina gracilis</i>	6	1 + 1*	0	0	0	0																				
<i>Belonechitina micrantha</i>	61 + 24*																									
TOTAL	118	581	316	509	262	124	98	907	731	288	754	307	346	495	525	539	163	160	41	271	216	285	199	120	215	281

Key: # = particularly nice specimens picked and photographed from the part of the residue that was not systematically picked // * = identified using optical stereomicroscope (all other specimens were identified using SEM)

elongate form (*S. bulmani sensu* Achab 1977 a, b) with much less pronounced flexure (see discussion on *S. bulmani* with more and less pronounced flexure in Vandenbroucke, Verniers and Clarkson 2003, p. 127). *S. ?cervicornis* is closer to *S. ?multiradiata* in overall form, but bears more complex, comb-like spines, here

often broken and preserved as vertically elongated spine-bases. The imperfect preservation state explains the open nomenclature.

S. ?multiradiata is more ‘cylindro-conical’ and elongate than the rather stocky *A. bornholmensis* n. sp., and its chamber does not have the typical bell-shape of the new species. The difference, however,

PLATE 1

Illustrations of chitinozoans from Vasagård. Dimensions are in micrometer, Vesicle length × maximal diameter.

a-p: *Ancyrochitina bornholmensis* n. sp.

a Sample unB 60-70 UT, specimen Vasagård_800, 118×75;

b Sample unB 60-70 UT, specimen Vasagård_830, 103×80;

c Sample unB 60-70 UT, specimen Vasagård_797, 102×81;

d Sample unB 60-70 UT, specimen Vasagård_849, 103×84;

e Sample unB 60-70 UT, specimen Vasagård_845, 107×79;

f Sample unB 60-70 UT, specimen Vasagård_864, 126×99;

g Sample unB 50-60 UT, specimen 314, 103×71;

h Sample unB 60-70 UT, specimen Vasagård_853, 103×72;

i Sample unB 50-60 UT, specimen 290, 113×84;

j Sample unB 50-60 UT, specimen 109, 111×76;

k Sample unB 30-40 UT, specimen 251, 114×91;

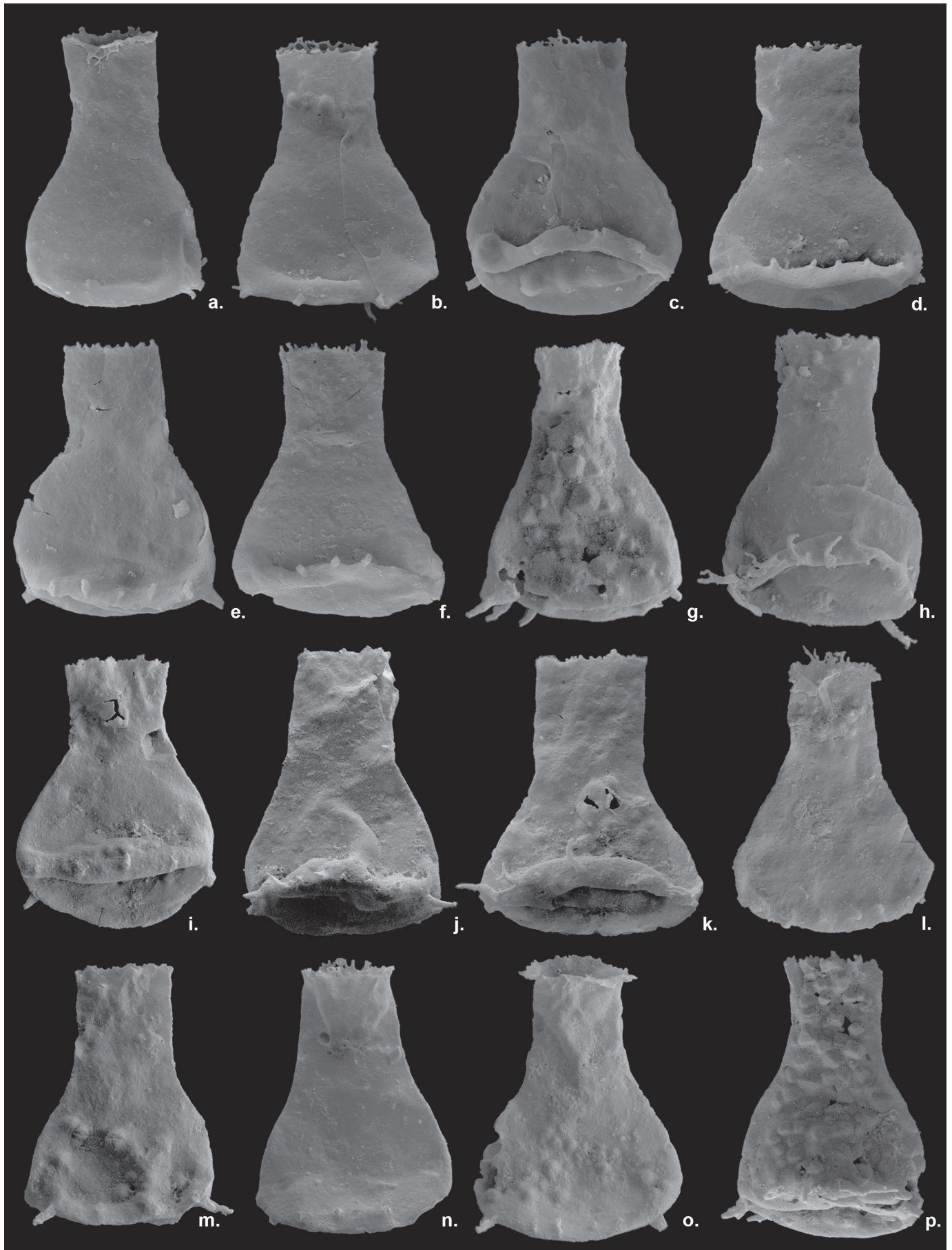
l Sample unB 60-70 UT, specimen Vasagård_879, 124×91;

m Sample unB 30-40 UT, specimen 118, 109×77;

n Sample unB 50-60 UT, specimen 353, 105×77;

o Sample unB 50-60 UT, specimen 508, 123×91;

p Sample unB 50-60 UT, specimen 073, 120×78



between these two species can be subtle, witness of which are the 'transition' forms labeled as *A. cf. bornholmensis* n. sp.

Family LAGENOCHITINIDAE Eisenack 1931 emend. Paris 1981

Subfamily CYATHOCHITININAE Paris 1981

Genus CYATHOCHITINA Eisenack 1955b emend. Paris et al. 1999

Cyathochitina campanulaeformis - *kuckersiana* group

Description: The *Cyathochitina campanulaeformis*-*kuckersiana* group contains well-identified specimens of *Cyathochitina campanulaeformis* (Plate 3, 1, m), well-identified specimens of *Cyathochitina kuckersiana* (Plate 3, k), intermediate forms between these two species, less well-preserved forms that could be attributed either of these two species, and a group of short, bell-shaped *Cyathochitina* specimens illustrated in Plate 3, n, o, p. The dimensions of the latter, short specimens at first sight seem quite different from *Cy. campanulaeformis* or *Cy. kuckersiana*, though, when these are plot on a length-width (L-Dp) diagram (e.g. *Cyathochitina* specimens of sample Un E 50-60 OB in text-fig. 5), a continuous point cloud illustrates many transition forms and a uniform distribution of L/Dp throughout the whole assemblage. The short, bell-shaped end members (Plate 3, n, o, p) have not been split off as a separate species.

Discussion: In relatively rare instances it was possible to well-identify individuals of *Cyathochitina campanulaeformis* or *Cy. kuckersiana* (Plate 3, k, l, m). Nevertheless, these are not represented as such in Table 1 and text-figure 3 as the stratigraphical value of these species is quasi identical.

Subfamily ANGOCHITININAE Paris 1981

Genus ANGOCHITINA Eisenack 1931

Angochitina sp. A

Description: *Angochitina* species with a cylindrical, relatively short neck, ovoid chamber and basal remnants of very well-developed ornamentation. One single specimen, with broken large spines has been recovered from sample UnI 235-245 UT, and has been kept in open nomenclature.

Discussion: The specimen recovered bears some resemblance to *Angochitina* n. sp. A of Grahn and Nölvak (2010, pl. 1, figs F-G).

Subfamily ANCYROCHITININAE Paris 1981

Genus ANCYROCHITINA Eisenack 1955a

Ancyrochitina bornholmensis Vandenbroucke and Nölvak n. sp. Plate 1, figures a–p

Ancyrochitina. n. sp. 1, NÖLVAK 1999, not-illustrated [new subzone]. – NÖLVAK 2001, (Valga 10), not-illustrated [faunal log] . – NÖLVAK 2003, (Ruhnu 500), not-illustrated [faunal log] . – WEBBY et al. 2004, not-illustrated [biozonal scheme] . – NÖLVAK 2005, (Mehi-koorma), not-illustrated [faunal log]

?*Ancyrochitina* sp., GRAHN and NÖLVAK 2007, fig. 11 A-B. – GRAHN and NÖLVAK 2010, pl. 1, figs A, B. – POUILLE et al. 2013, pl. 1, 16

Diagnosis: Small *Ancyrochitina* with a bell-shaped chamber, a fringed aperture and relatively simple appendices.

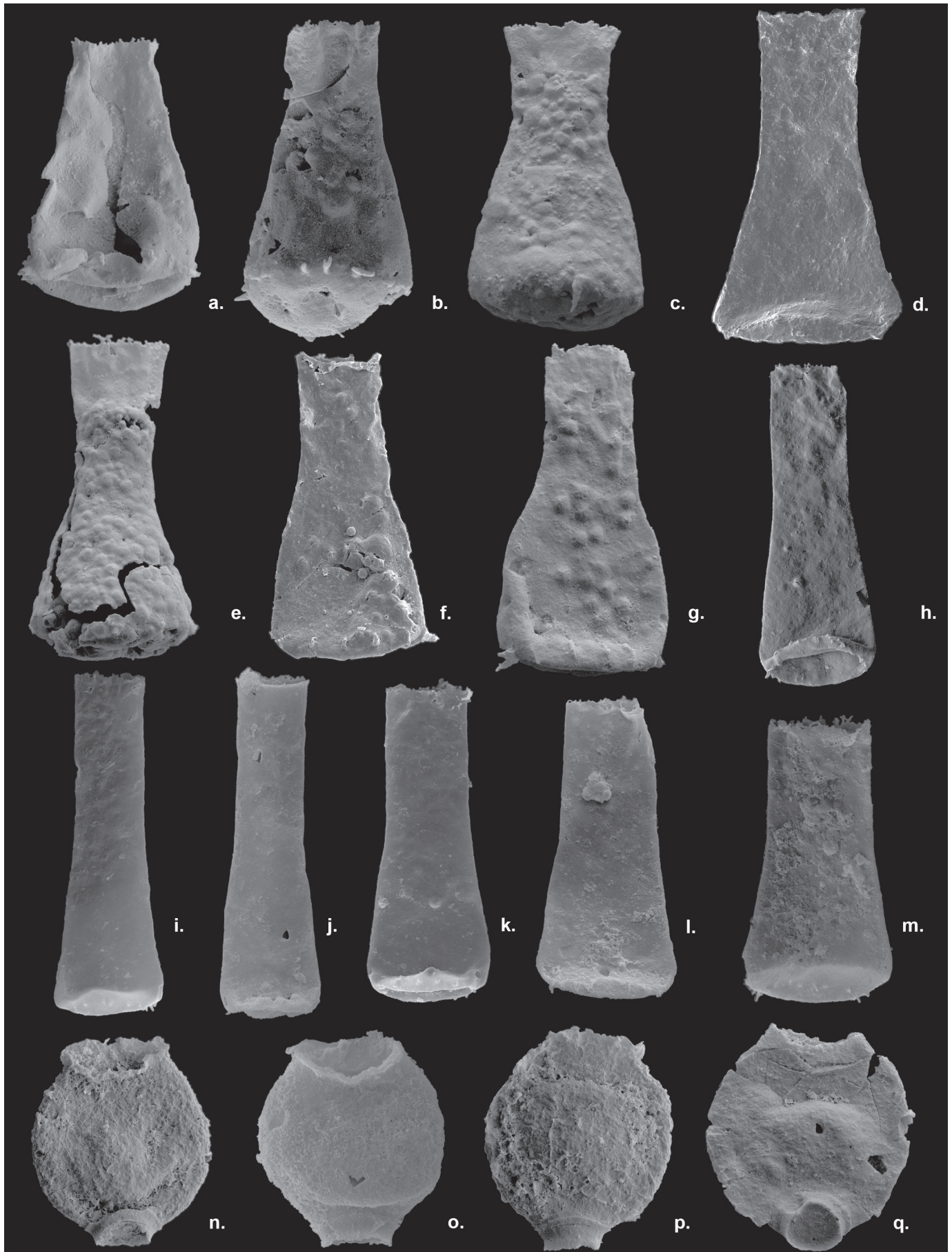
Holotype: Specimen Vasagård-0849, Plate 1, d. (Sample UnB 60-70 UT; slides filed in a series with Lille 1 Repository catalogue numbers USTL 2792 to USTL 2855)

Dimensions of the holotype: L: 103µm; Dp: 84µm

PLATE 2

Illustrations of chitinozoans from Vasagård. Dimensions are in micrometer, Vesicle length × maximal diameter.

- | | | | |
|---|---|-----------------------|--|
| a | <i>Ancyrochitina cf. bornholmensis</i> n. sp., sample unB 50-60 UT, specimen 547, 111×72; | Vasagård_073, 265×85; | |
| b | <i>Ancyrochitina cf. bornholmensis</i> n. sp., sample unB 50-60 UT, specimen 012, 139×72; | j | <i>Spinachitina bulmani</i> , sample unE 0-10 UT, specimen Vasagård_047, 227×78; |
| c | <i>Ancyrochitina cf. bornholmensis</i> n. sp., sample unB 50-60 UT, specimen 574, 117×69; | k | <i>Spinachitina bulmani</i> , sample unE 0-10 UT, specimen Vasagård_090, 200×80; |
| d | <i>Spinachitina ?multiradiata</i> , sample unB 0-10 UT, specimen Bornholm_5048, 160×90; | l | <i>Spinachitina bulmani</i> , sample unE 0-10 UT, specimen Vasagård_060, 174×82; |
| e | <i>Spinachitina ?multiradiata</i> , sample unB 50-60 UT, specimen 222, 128×64; | m | <i>Spinachitina bulmani</i> , sample unE 0-10 UT, specimen Vasagård_527, 145×79; |
| f | <i>Spinachitina ?cervicornis</i> , sample unB 0-10 UT, specimen Bornholm_5825, 250×140; | n | <i>Desmochitina juglandiformis</i> , sample unC 140-150 UT, specimen 080, 128×111; |
| g | <i>Spinachitina ?cervicornis</i> , sample unB 50-60 UT, specimen 558, 145×75; | o | <i>Desmochitina juglandiformis</i> , sample unE 0-10 UT, specimen Vasagård_078, 95×87; |
| h | <i>Spinachitina bulmani</i> , sample unC 140-150 UT, specimen 055, 214×78; | p | <i>Desmochitina juglandiformis</i> , sample unC 140-150 UT, specimen 012, 138×116; |
| i | <i>Spinachitina bulmani</i> , sample unE 0-10 UT, specimen | q | <i>Desmochitina juglandiformis</i> , sample unC 140-150 UT, specimen 116, 119×117 |



Dimensions of figured specimens: L: 102µm minimum, 112µm average, 126µm maximum; Dp: 71µm minimum, 82µm average, 99µm maximum (Plate 1, 16 specimens)

Description: Short species of *Ancyrochitina*, with a cylindrical neck, well-identified flexure, a bell-shaped chamber with convex flanks and a rounded basal margin. The basal margin bears a crown of (here, often broken) rather simple appendices, that can bifurcate once or twice. The test wall is unornamented. The aperture has a fringed collarete.

Discussion: The new species is identical to the taxon '*Ancyrochitina*. n. sp. 1' of J. Nölvak in a series of publications (Nölvak 1999; 2001; 2003; 2005) from the Mossen Formation in Estonian and Latvia. Nölvak (1999) originally intended to define a holotype from the lower Mossen Formation.

The new species might be identical to *Ancyrochitina* sp. from Grahn and Nölvak (2007), and to *Ancyrochitina* sp. 1 from Grahn and Nölvak (2010), which both are recorded from Sweden and from slightly younger strata. Grahn and Nölvak (2010, p. 48) explained that their Swedish *Ancyrochitina* sp. (1) "probably is not conspecific with" *Ancyrochitina*. n. sp. 1, used as a biostratigraphical index of a subzone in the biostratigraphic framework for the East Baltic (Estonia) by Nölvak (1999), at the top of the *S. cervicornis* zone. Grahn and Nölvak (2010, p. 48)

also mentioned that their suggested non-synonymy "requires further study to establish". Here, we cannot solve this ambiguity. In the Gotska Sandön section (N of Gotland), the records of *Ancyrochitina* sp. 1 from the Slandrom Fm. (Grahn and Nölvak 2010, their figure 20) are questionable. First identified as *Spinachitina multiradiata* (cf. Grahn 1982, his figures 7 and 16 Q, R), these specimens were only later named *Ancyrochitina* sp. 1. However, the original identification seems more in line with the criteria used in the current paper. Moreover, South Swedish specimens of the taxon are generally rare, and poorly preserved (Grahn and Nölvak 2010, p. 48). We suggest that the presence of *Ancyrochitina* (as *A. sp. 1* in Grahn and Nölvak 2010, their figure 29) in the Slandrom Formation remains a matter of discussion. In addition, the occurrence of *Ancyrochitina* sp. (Grahn and Nölvak 2007, fig. 11 A, D, identical to specimens shown in Grahn and Nölvak 2010, pl. 1 A, B) is from beds in the Röstånga core that are poorly constrained, attributed to the Fjäckå Formation by Grahn and Nölvak (2007), and revised to the Lindegård Mudstone Formation by Grahn and Nölvak (2010).

Here, we are suggesting that Estonian and West Latvian (previously un-illustrated or unpublished) specimens of *Ancyrochitina*. n. sp. 1 from the Mossen Fm. are synonymous to the species newly defined from Bornholm. Whether or not this species also occurs in Sweden (and if so where) needs additional study and confirmation.

PLATE 3

Illustrations of chitinozoans from Vasagård. Dimensions are in micrometer, Vesicle length × maximal diameter.

- | | |
|--|---|
| <p>a Chain of 4 specimens of <i>Desmochitina juglandiformis</i>, sample unB 30-40 UT, specimen 055, 416 (total length of chain) × 121 (maximal width of largest specimen);</p> <p>b <i>Belonechitina robusta</i>, sample unE 0-10 UT, specimen Vasagård_055, 262×128;</p> <p>c <i>Belonechitina robusta</i>, sample unC110-120 UT, specimen 036, 286×133;</p> <p>d <i>Belonechitina robusta</i>, sample unE 0-10 UT, specimen Vasagård_288, 226×109;</p> <p>e <i>Belonechitina robusta</i>, sample unC 170-180 UT, specimen Vasagård_1006, 276×146;</p> <p>f <i>Euconochitina</i> sp., sample unC 0-10 UT, specimen Vasagård_1104, 101×81;</p> <p>g <i>Desmochitina</i> sp. 1, sample unB 50-60 UT, specimen 146, 98×85;</p> <p>h <i>Desmochitina</i> sp. 1, sample unB 50-60 UT, specimen 147, 93×87;</p> <p>i <i>Belonechitina</i> sp. A, sample unE 0-10 UT, specimen Vasagård_063, 372×109;</p> <p>j <i>Belonechitina</i> sp. A, sample unB 60-70 UT, specimen Vasagård_871, 274×108;</p> <p>k <i>Cyathochitina kuckersiana</i>, sample unE 0-10 UT, specimen Vasagård_110, 178×104;</p> | <p>l <i>Cyathochitina campanulaeformis</i>, sample unE 20-30 OB, specimen Vasagård_2004, 360×200;</p> <p>m <i>Cyathochitina campanulaeformis</i>, sample unB 30-40 UT, specimen 028, 357×226;</p> <p>n <i>Cyathochitina campanulaeformis</i> – <i>kuckersiana</i> group, short, bell-shaped forms, sample unE 20-30 OB, specimen Vasagård_1988, 152×135;</p> <p>o <i>Cyathochitina campanulaeformis</i> – <i>kuckersiana</i> group, short, bell-shaped forms, sample unE 20-30 OB, specimen Vasagård_2030, 146×128;</p> <p>p <i>Cyathochitina campanulaeformis</i> – <i>kuckersiana</i> group, short, bell-shaped forms, sample unE 20-30 OB, specimen Vasagård_2067, 145×158;</p> <p>q <i>Lagenochitina baltica</i>, sample unF 20-30 UT, specimen Vasagård_1635, 283×151;</p> <p>r <i>Lagenochitina baltica</i>, sample unF 20-30 UT, specimen Vasagård_1740, 280×175;</p> <p>s <i>Lagenochitina baltica</i>, sample unF 20-30 UT, specimen Vasagård_1831, 344×177;</p> <p>t <i>Lagenochitina prussica</i>, sample unI 25-30 UT, specimen 02, 250×180;</p> <p>u <i>Pogonochitina</i> sp. 1, sample unB 50-60 UT, specimen 323, 127×62</p> |
|--|---|



Ancyrochitina cf. *bornholmensis*

Description: Transition forms between typical specimens of *Anc. bornholmensis* n. sp. and *Sp. multiradiata* (which has a more conical chamber, longer neck and overall more elongate silhouette than *Anc. bornholmensis*). The transition forms have a less well-developed flexure than true *A. bornholmensis* n. sp., and are less compact, but do not have the true cylindro-conical shape that is typical of the genus *Spinachitina*.

Order OPERCULATIFERA Eisenack 1931

Family DESMOCHITINIDAE Eisenack 1931, emend. Paris 1981

Subfamily DESMOCHITININAE Paris 1981

Genus DESMOCHITINA Eisenack 1931

Desmochitina sp. 1

Description: Desmochitina with a granular surface ornamentation, its maximal width within the aperturewards half of the chamber and a notably wide aperture without collarette.

Subfamily PTERMOCHITININAE Paris 1981

Genus ARMORICOCBITINA Paris 1981

Armoricochitina cf. *reticulifera*

Description: The species is in open nomenclature as there is not a single specimen recovered that displays the overall silhouette of *A. reticulifera* (i.e. has a base that is narrow enough at basal margin) in combination with the characteristic ridges and surface ornamentation of this species. Separately, these characteristics were observed in several specimens, but it is their combination in single specimens that is required for a positive identification.

Discussion: *Armoricochitina* cf. *reticulifera* is different from specimens placed in *Armoricochitina* spp. only by the presence of longitudinal ridges and a reticular network on the chamber. In the case of true *A. reticulifera*, they would be stratigraphically slightly out of place. If some of the *Armoricochitina* spp. also would be *A. reticulifera*, the species would be drastically longer ranging than elsewhere.

CHITINOZOAN BIOZONES

The chitinozoan assemblages from the Vasagård section on Bornholm conform to the biostratigraphic and biozonal framework defined for the Scanian Lithofacies Belt (Grahn and Nölvak 2010). They also conform to the scheme erected for Estonian confacies belts (Nölvak and Grahn 1993; Nölvak 1999).

The *Spinachitina cervicornis* Biozone is recognised based on its index species in open nomenclature, accompanied by *Spinachitina* ?*multiradiata* and *Desmochitina juglandiformis*. The latter has its FAD in the *S. cervicornis* Biozone and ranges upwards into the *Fungochitina spinifera* Biozone (Nölvak 2005, Vandenbroucke 2008b).

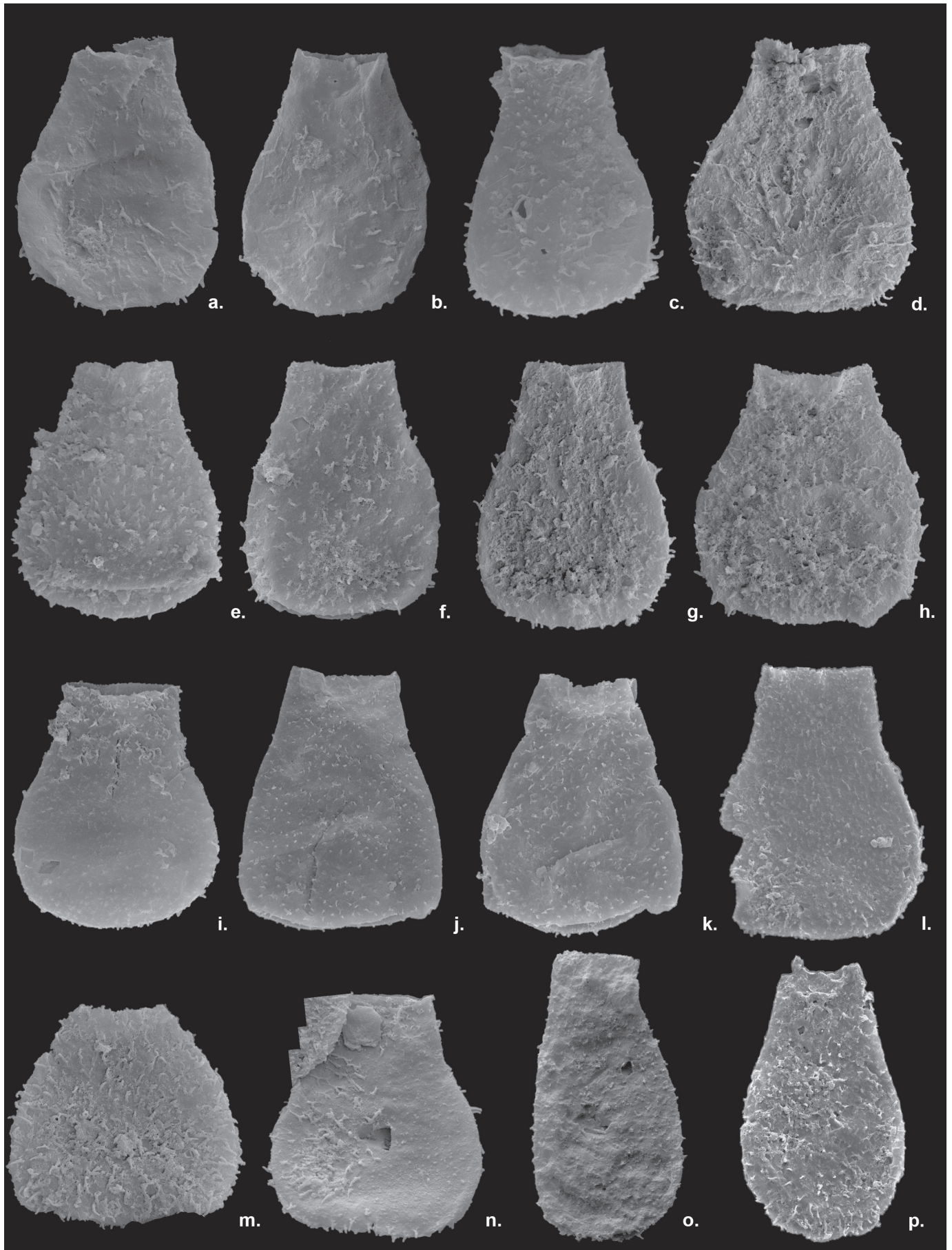
The '*Fungochitina fungiformis*' Biozone was originally defined by Nölvak and Grahn (1993), using the total range of the index fossil. Two subspecies were present, the smooth *Fungochitina fungiformis fungiformis* and the spiny *Fungochitina fungiformis spinifera*. These were revised to, respectively, *Saharochitina fungiformis* and *Fungochitina spinifera* by Paris et al. (1999). Nölvak (2005) and Nölvak, Hints and Männik (2006) subsequently realised that their ranges were not identical and changed the name of the biozone to the '*Fungochitina spinifera* Biozone'. *S. fungiformis* has a slightly earlier FAD than *F. spinifera* in Estonia (Nölvak 2005). In the Vasagård section, these species have not been recovered. Instead, the *F. spinifera* Biozone has been identified based on the FADs of *Lagenochitina baltica* and *Lagenochitina prussica*, which usually appear slightly above the base of the biozone.

The base of the *Tanuchitina bergstroemi* Biozone has been identified using the FAD of the index fossil. Occurrences of *Tanuchitina*-like species such as *Conochitina incerta* starting below the base of the *T. bergstroemi* Biozone herald its appearance. This has been observed earlier, e.g., in the Lelle section in Estonia where such specimens are identified as *T. sp. aff. bergstroemi* (see Hints et al. 2007, fig. 2), and in the UK (Vandenbroucke, Rickards and Verniers 2005; Vandenbroucke 2008a).

PLATE 4

Illustrations of chitinozoans from Vasagård. Dimensions are in micrometer, Vesicle length ×maximal diameter.

- | | |
|---|--|
| a-n: <i>Belonechitina hirsuta</i> complex | i Sample unE 70-80 UT, specimen Vasagård_1461, 129×108; |
| a Sample unE 0-10 UT, specimen Vasagård_102, 118×86; | j Sample unE 0-10 UT, specimen Vasagård_038, 118×94; |
| b Sample unE 0-10 UT, specimen Vasagård_407, 123×87; | k Sample unE 0-10 UT, specimen Vasagård_001, 120×93; |
| c Sample unE 0-10 UT, specimen Vasagård_521, 132×91; | l Sample unE 70-80 UT, specimen Vasagård_6420, 130×100; |
| d Sample unB 30-40 UT, specimen 101, 129×110; | m Sample unE 70-80 UT, specimen Vasagård_1475, 104×111; |
| e Sample unE 70-80 UT, specimen Vasagård_1463, 138×107; | n Sample unE 70-80 UT, specimen Vasagård_1498, 129×114; |
| f Sample unE 70-80 UT, specimen Vasagård_1471, 125×92; | o <i>Belonechitina cactacea</i> , sample unC 110-120 UT, specimen 088, 159×84; |
| g Sample unE 70-80 UT, specimen Vasagård_1540, 127×91; | p <i>Belonechitina cactacea</i> Sample unC 80-90 UT, specimen Vasagård_6175, 160×100 |
| h Sample unE 70-80 UT, specimen Vasagård_1553, 120×107; | |



Taking our suggested synonymy at face value, *Ancyrochitina bornholmensis* n. sp. has been included in the Estonian biozonation (as *Ancyrochitina* n. sp. 1), as the index species of a subzone high in the *S. cervicornis* Zone (Nölvak 1999).

In Sweden, *Ancyrochitina* sp. 1 and/or *Ancyrochitina* sp. have a range within the *F. spinifera* Biozone, and consequently, the “*Ancyrochitina* sp. 1 Subzone” has also been shown as a subzone of the *S. fungiformis* Zone in Grahn and Nölvak (2007, their fig. 9) or as a subzone of the *F. spinifera* Zone in Grahn and Nölvak (2010, their figure 27). Nevertheless, as we have explained in the systematics section of this paper, it remains unresolved whether these taxa may be synonymous with *Ancyrochitina bornholmensis* n. sp.

The published ranges of the open nomenclature species fit well with the observations from the Vasagård section, where *A. bornholmensis* n. sp. ranges in the (top of?) the *cervicornis* Biozone (base not observed) and slightly into the *F. spinifera* Biozone. Alternatively, and in absence of the index species *F. spinifera*, one could argue that the range of *A. bornholmensis* n. sp. can be used to elevate the base of the *spinifera* Zone above the LAD of the *Ancyrochitina* species, to fit the well-established Estonian scheme of Nölvak (1999), i.e., restricting the *A. bornholmensis* n. sp. Subzone within the *S. cervicornis* Zone. However, the succession with the FAD of *F. spinifera* before the FADs of *L. baltica* and *L. prussica* is well-established in many sections, so the authors prefer the option where *A. bornholmensis* n. sp. ranges into the basalmost *F. spinifera* Zone

Correlations

In the Baltoscandian realm, the limestone facies typically is well-developed and has been the dominant source for chitinozoans in the area. Good, continuous graptolite biostratigraphical control in such sections is unusual. This is different in the Scanian

Lithofacies Belt, where shaly, siliciclastic facies are much better developed and graptolites are found more frequently. As such, the Vasagård section represents one of the few sites where *clingani* and *linearis* graptolites co-occur with Baltoscandian-type chitinozoans. Our high-resolution sampling thus provide a useful calibration between both groups, but does not add fundamentally new insights vis-à-vis published understanding: *P. linearis* Biozone graptolites (including the index fossil) are known to co-occur with *T. bergstroemi* Biozone chitinozoans in several places in the Fjäckå Shale Formation (e.g., Laufeld 1967), and the loose constraints on the base of the *F. spinifera* Biozone (in absence of the index fossil) do not allow us to refine the existing calibrations. Interesting detailed information, however, is that the index fossil *T. bergstroemi* has its FAD above the base of the *linearis* Biozone in this section, though well-below the FAD of *P. linearis* itself.

It is interesting to compare our results with those of England and Wales, where Upper Ordovician sections have yielded chitinozoans with a predominantly ‘Baltoscandian’ signature (Vandenbroucke 2008b). In the *clingani/linearis* interval, two of the key study areas were the historical type regions of the Caradoc (Onny Valley, Welsh Borderlands; Vandenbroucke et al. 2009) and of the Ashgill (the type Rawtheyan and Cautleyan areas, in the Yorkshire Dales of N England; Vandenbroucke, Rickards and Verniers 2005). Much like we have done here, in near-absence of the index fossil, the FADs of *Lagenochitina baltica* and *Lagenochitina prussica* were used as a proxy for the base of the *F. spinifera* Biozone. Interestingly, the data showed that in the Avalonian part of the UK, the *F. spinifera* Biozone straddles the base of the Ashgill, and largely occupies the same stratigraphical position as the top *clingani*, *linearis* and (basal) *complanatus* graptolite biozones in the Purgillian and Onnian (following Fortey et al. 2000 and Zalasiewicz et al. 2009). Microfossils (questionably) attributed to *T. bergstroemi* only occur higher up in the stratigraphy, in the Cautleyan

PLATE 5

Illustrations of chitinozoans from Vasagård. Dimensions are in micrometer, Vesicle length × maximal diameter.

- | | |
|--|---|
| a <i>Conochitina incerta</i> , sample unF 10-20 UT, specimen stII-11, 350×100; | h <i>Armoricochitina</i> sp., sample unE 20-30 OB, specimen Vasagård_2050, 258×165; |
| b <i>Conochitina incerta</i> , sample unF 10-20 UT, specimen stII-15, 460×120; | i <i>Armoricochitina</i> sp., sample unE 0-10 UT, specimen Vasagård_449, 194×116; |
| c <i>Conochitina incerta</i> , sample unF 10-20 UT, specimen stII-19, 370×100; | j <i>Angochitina</i> sp A, sample unI 235-245 UT, specimen 267, 175×84; |
| d <i>Conochitina incerta</i> , sample unF 10-20 UT, specimen stII-24, 350×100; | k <i>Armoricochitina</i> cf. <i>reticulifera</i> , sample unI 235-245 UT, specimen, 242, 235×172; |
| e <i>Belonechitina wesenbergensis elongata</i> , sample unI 70-75 UT, specimen 03, 300×110; | l <i>Armoricochitina</i> cf. <i>reticulifera</i> , sample unI 235-245 UT, specimen, 238, 295×232; |
| f <i>Belonechitina wesenbergensis elongata</i> , sample unI 70-75 UT, specimen 24, 300×100; | m <i>Tanuchitina bergstroemi</i> , sample unI 235-245 UT, specimen 045, 850×83; |
| g <i>Belonechitina wesenbergensis elongata</i> , sample unI 235-245 UT, specimen 044, 229×111; | n <i>Tanuchitina bergstroemi</i> , sample unI 235-245 UT, specimen 68, 674×98 |



strata attributed to the *anceps* graptolite biozone. The British chitinozoan fossils, compared to Baltoscandia and using the 'classic' UK stratigraphy, thus are slightly 'too old' (text-fig. 6). In contrast, when using the revised age of the *linearis* Biozone by Rickards (2002; 2004), the British chitinozoans would be 'too young', as the Rawtheyan strata in the type Ashgill area contain post-*bergstroemi* index chitinozoans such as *Conochitina rugata*.

Another consideration to be made, is that Vandenbroucke, Rickards and Verniers (2005) note that *Tanuchitina bergstroemi* from the type Ashgill area invariably is poorly preserved, and that only fragments have been recovered, inconveniencing careful identifications. Additional fragments of *Tanuchitina* were found lower in the stratigraphy, and a lowering of the base of the *bergstroemi* Biozone could not be excluded. In addition, the index fossil of the *P. linearis* Zone is still to be found from these sections, and is hitherto not known from other sections in Wales and England (Vandenbroucke et al. 2008). A section in Fronoch, in the Cardigan area in South Wales, yielded fragments of *T. ?bergstroemi* (Vandenbroucke et al. 2008) alongside the graptolite *Climacograptus tubuliferus*, taken to be indicative of the *P. linearis* Zone (Williams et al. 2003).

In summary, comparison between an integrated chitinozoan-graptolite biostratigraphy on both sides of the Tornquist Ocean is not straightforward and requires further study, notably in the UK. Taken at face value, and using chitinozoans to correlate between the Scanian Lithofacies Belt and the Anglo-Welsh Basin, the *P. linearis* Biozone would plot 'in between' its original position around the Caradoc/Ashgill (C/A) boundary, and its revised position by Rickards (2002), with a slight preference for the original position based on the consistent position of the base of the *P. linearis* Zone within the *F. spinifera* Zone in both areas in this scenario, and on the liberty to lower the base of the *bergstroemi* Zone in England. We refrain from final conclusions, awaiting information from additional sections, and, crucially, a revision of some of the key faunas (graptolites and chitinozoans) in the UK. Ongoing work on the chitinozoan biostratigraphy of the classic Girvan succession, one of the places where the position of the *P. linearis* Zone around the C/A limit was first established, might prove useful in this context – a reconnaissance study (Vandenbroucke, Verniers and Clarkson 2003) already demonstrated the presence of certain stratigraphically useful chitinozoans that also occur in Baltoscandia, such as, *Lagenochitina baltica* and *Lagenochitina prussica*.

CONCLUSION

High-resolution sampling for chitinozoans in the classic section at Vasagård (Bornholm, Denmark) yielded abundant, well-known chitinozoans.

High-resolution calibration between graptolite and chitinozoan biostratigraphy at Vasagård largely confirms the previously understood relations between both groups, notably the linkage between at least part of the *P. linearis* and *T. bergstroemi* biozones.

Correlations with similar chitinozoans in the UK seem to confirm the base of the *P. linearis* to be of latest Caradoc age, but the extent of this graptolite zone into the Ashgill Series can not yet be constrained well, based on our data.

High-resolution data as presented here will be instrumental to help solve stratigraphical issues around the C/A interval, though

only if equally detailed information becomes available from the other key sections and groups.

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APPENDIX 1

SAMPLE LOCATIONS AT LÆSÅ STREAMLET, VASAGÅRD, BORNHOLM

Dicellograptus Shale Formation sample localities

All Dicellograptus Shale Fm. samples are from the main Vasagård section at loc O4 on the map (text-fig. 2). The shale wall is up to 6m high, c. 200m long. The strata tilt c. 10 degrees south so the oldest strata are upstream and the youngest strata downstream along the section.

Hadding's (1915) unit b:

unB 60-70 UT: 60-70cm below top of the unit
 unB 50-60 UT: 50-60cm below top of the unit
 unB 30-40 UT: 30-40cm below top of the unit
 unB 0-10 UT: 0-10cm below top of the unit

(Observation: Unit b is a little thicker than realized by Hadding 1915)

Hadding's (1915) unit c:

unC 170-180 UT: 170-180cm below top of the unit
 unC 140-150 UT: 140-150cm below top of the unit
 unC 110-120 UT: 110-120cm below top of the unit
 unC 80-90 UT: 80-90cm below top of the unit
 unC 40-50 UT: 40-50cm below top of the unit
 unC 0-10 UT: 0-10cm below top of the unit

Hadding's (1915) unit e:

unE 20-30 OB: 20-30cm above base of the unit
 unE 50-60 OB: 50-60cm above base of the unit
 unE 70-80 UT: 70-80cm below top of the unit
 unE 40-50 UT: 40-50cm below top of the unit
 unE 0-10 UT: 0-10cm below top of the unit

Hadding's (1915) unit f:

unF 60-70 UT: 60-70cm below top of the unit
 unF 20-30 UT: 20-30cm below top of the unit
 unF 10-20 UT: 10-20cm below top of the unit

Hadding's (1915) unit g:

unG 60-70 UT: 60-70cm below top of the unit
 unG 30-40 UT: 30-40cm below top of the unit
 unG 10-20 UT: 10-20cm below top of the unit

Hadding's (1915) unit i:

unI 20-10 OB: 10-20cm above base of the unit
 unI 235-245 UT: 235-245cm below top of the unit
 unI 205-215 UT: 205-215cm below top of the unit
 unI 145-155 UT: 145-155cm below top of the unit
 unI 115-125 UT: 115-125cm below top of the unit
 unI 70-75 UT: 70-75cm below top of the unit
 unI 25-30 UT: 25-30cm below top of the unit

LINDEGÅRD MUDSTONE FORMATION SAMPLE LOCALITIES

Vasagård I (= main section corresponding to loc. O4 in Text-fig. 2).

The strata at Loc. O4 are assumed to represent the *D. complanatus* Zone, but the graptolitic level is at another no longer existing locality slightly further downstream (Loc. O5A), corresponding to a horizon approx. 3.5m above the base of the Lindegård Mudstone. The trilobites from the Lindegård Mudstone are mainly found through time at locs O7 to O9

VI_45-53: Sample 45-53cm above the base of the Lindegård Mudstone

VI_82-94: Sample 82-94cm above the base of the Lindegård Mudstone

VI_163-170: Sample (limestone bed) 163-170cm above the base of the Lindegård Mudstone

VI_235-240: Sample 235-240cm above the base of the Lindegård Mudstone

Vasagård II

(= Loc. O7 on the map of text-fig. 2, level above the *D. complanatus* horizon)

VII_0.30: Sample 0.3m above base of the exposed section

VII_0.85-0.90: Sample 0.85-0.9m above the other sample = 1.15 -1.2 m above the base of that section

