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Precise chitinozoan dating of Ordovician impact events in Baltoscandia

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ABSTRACT - The chitinozoan biostratigraphy of four Ordovician impact craters has been investigated. Three of these (Tvären, Kärdla and Lockne) contain complete sequences of early Caradoc age, while the Granby crater contains rocks of late Arenig age yielding two bentonitic horizons at their top. Chitinozoans, together with graptolites and other planktic organisms, were the first to invade the craters after the impact event. It has therefore been possible to date the impact events with a precision of less than one million years. An immigration of graptolites from Australia during the late Arenig corresponds to an immigration of chitinozoans from Gondwana at this time. Two stratigraphically important taxa, not previously described or discussed, *Lagenochitina* sp. A aff. *capax* and *Laufeldochitina* sp. A aff. *striata* are commented upon. Three species, *Cyathochitina hunderumensis*, *Spinachitina tvaerenensis* and *Tanuchitina granbyensis*, are described as new. *J. Micropalaeontol.* **15**(1): 21–35, April 1996.

INTRODUCTION

Five impact events of supposed Ordovician age have been reported from Baltoscandia (see Henkel & Pesonen, 1992). Four of these were recently dated by Grahn & Nõlvak (1993). A crater below the bottom of the Lumparen Bay in the Åland archipelago, between Sweden and the mainland of Finland, was for a long time considered to be of tectonic origin (see Winterhalter 1982), but Merrill (1980) regarded it to be an Ordovician or younger impact structure. More recent investigations show that the Lumparen Bay structure probably is an impact crater that was already deeply eroded when Ordovician sedimentation commenced in the area during the early Arenig. The Lumparen event might be of early Cambrian age since sandstones of this age, reminiscent of resurge deposits, are distributed in the area (Hagenfeldt, pers. comm. 1993). The oldest Ordovician crater, of late Arenig age, is situated at Granby in south Sweden (Fig. 1). The three other craters, of early Caradoc age, occur at Tvären and Lockne in central Sweden, and at Kärdla on the Island of Hiiumaa in northwest Estonia (Fig. 1).

The maximum thickness of the Ordovician sequences outside the craters is less than 200 m in Sweden and Estonia, and stratigraphical gaps occur frequently through the sequence. In contrast to the sequences surrounding the craters, those within the craters are virtually complete. The crater sequences are therefore excellent models for ecological studies of restricted environments and for high-resolution biostratigraphy. The present paper is a detailed study of the chitinozoan biostratigraphy in the four Ordovician craters investigated. The illustrated specimens are deposited in the collections of the Institute of Geology, Rennes (IGR) under the numbers 58601–58646. The coordinates are those of the England Finder grid.

CHITINOZOAN BIOSTRATIGRAPHY

Nõlvak & Grahn (1993) recently published a chitinozoan biozonation comprising 23 zones and subzones for the Ordovician of Baltoscandia. All eight crater sections investigated from or close to the four craters yielded the index species and/or characteristic species for three of these zones, which allowed a very precise dating. The biostratigraphy from the sections related to the four craters will be described below.

Granby crater

The Granby crater is situated in the subsurface about 4 km southeast of Vadstena, a little town on the east shore of Lake Vättern. It has been discussed by Bruun & Dahlman (1982) and Grahn & Nõlvak (1993). Two cores from the crater were investigated, viz. from the Fylla 9 borehole about 1 km east of the west crater rim, and the Fylla 3 borehole, about 800 m further to the east (Fig. 2). The latter borehole was made near the centre of the crater above the central uplift (Bruun & Dahlman, 1982). The impact sediments in the crater are overlain by calcareous and glauconitic mudstone interbedded by grey limestone. The impact event is placed in the lower part of the *Cyathochitina regnelli* chitinozoan Zone, since a characteristic chitinozoan assemblage from the *Conochitina cucumis* chitinozoan Zone is missing (Nõlvak & Grahn 1993). The index fossil has not been found (Grahn & Nõlvak, 1993), but the presence of for instance *Conochitina decipiens* (Pl. 1, figs 8, 9) together with *Cyathochitina hunderumensis* sp. nov. (see Systematic Desciptions; Figs 3, 4; Pl. 1, figs 1, 10, 11) and *Tanuchitina granbyensis* sp. nov. (see Systematic Descriptions; Figs 3, 4; Pl. 1, figs 2–5) suggests a late Arenig age. In the crater sequence occur also, among others, *Rhabdochitina gracilis* (Pl. 3, fig. 8), *Conochitina* sp. 1 (Pl. 3, fig. 5) and *Lagenochitina esthonica* (Pl. 3, fig. 9). Two bentonitic horizons found in the Fylla 9 core (Fig. 3) are probably of the same age, as evidenced from the presence in these levels by *Clavachitina poumoti* (Pl. 1, figs 6, 7), a species reported from Upper Arenig strata in Australia (Combaz & Peniguel,

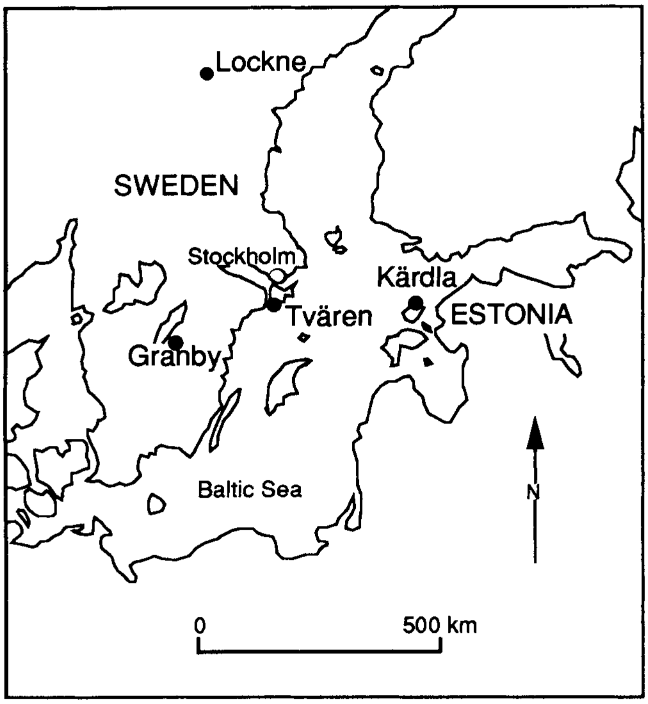

Fig. 1. Map showing the sites of the investigated Ordovician impact craters in Baltoscandia.

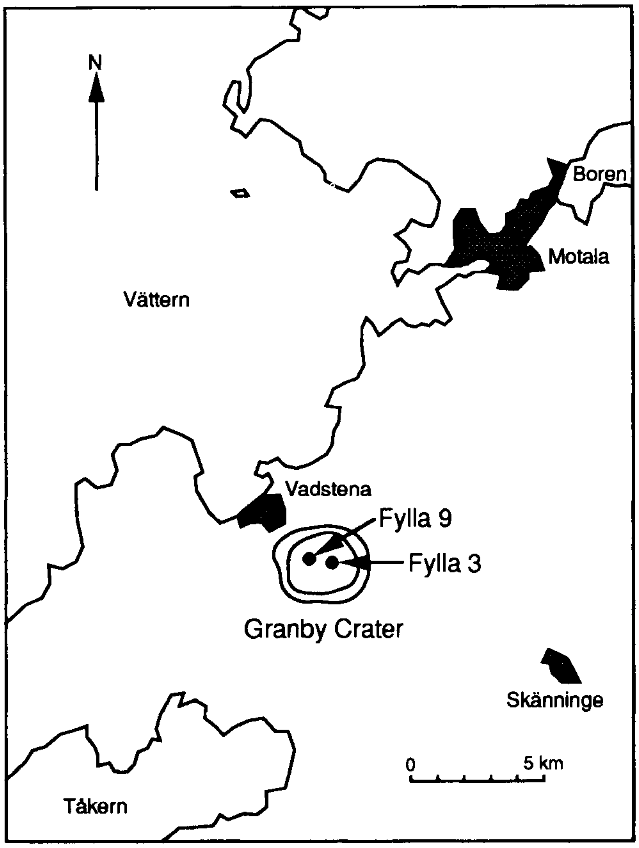

Fig. 2. Map showing the sites of the investigated boreholes in the Granby crater, Östergötland, Sweden.

1972), Svalbard (Bockelie 1980) and eastern Canada (Achab, 1986). It should be noted that in the graptolite Zone of *Didymograptus hirundo* (late Arenig) there is also evidence of an immigration of graptolites from Australia into Baltoscandia (Nilsson, 1983).

Tvären crater

The Tvären crater is situated below the bottom of the Tvären Bay, about 72 km south–southwest of Stockholm. It has been discussed by Flodén *et al.* (1986) and Lindström *et al.* (1994). Two boreholes, Tvären 1 and 2, were drilled in the structure (Fig. 5). The former borehole was placed in the crater rim, while the latter (Fig. 6) penetrated the whole sedimentary sequence ending in the basement breccia. In the first post-impact sediments, consisting of dark grey calcareous mudstone with interbedded limestone, the index species *Laufeldochitina stentor* (Pl. 2, fig. 6) occur together with *Lagenochitina* sp. A aff. *capax* (Pl. 3, figs. 1, 2) and *Laufeldochitina* sp. A aff. *striata* (Pl. 2, figs 9, 10). The presence of *L.* sp. A aff. *striata* is characteristic for a short interval in the upper part of the *L. stentor* Zone, where the index species is rare or absent (Nõlvak & Grahn, 1993). *Laufeldochitina* sp. A aff. *striata* was also found in a coarse breccia formed by the resurge turbidite immediately after the impact. This places the base of the Tvären post-impact sequence, and the impact event, within beds corresponding to the lower Peetri Member of the Viivikonna Formation

Explanation of Plate 1

Selected chitinozoans from the Granby crater. Late Arenig. **Fig. 1.** *Cyathochitina hunderumensis* sp. nov. Holotype. Fylla 3 borehole, core sample at 254.30 m. Specimen in lateral view, SEM ×300. IGR 58614 (L. 39/4). **Fig. 2.** *Tanuchitina granbyensis* sp. nov. Holotype. Fylla 9 borehole, core sample at 272.20 m. Specimen in lateral view, SEM ×75. IGR 58601 (O. 43). **Fig. 3.** *Tanuchitina granbyensis* sp. nov. Holotype. Fylla 9 borehole, core sample at 272.20 m. Detail of the base showing the carina, SEM ×500. **Fig. 4.** *Tanuchitina granbyensis* sp. nov. Fylla 9 borehole, core sample at 270.20 m. Specimen in lateral view, SEM ×75. IGR 58601 (O. 40/1). **Fig. 5.** *Tanuchitina granbyensis* sp. nov. Same species as in fig. 4. Detail of the base showing the broken carina, SEM ×500. **Fig. 6.** *Clavachitina poumoti* (Combaz & Peniguel 1972). Fylla 9 borehole, core sample at 199.35 m. Specimen in lateral view, SEM ×150. IGR 58607 (O. 34/2). **Fig. 7.** *Clavachitina poumoti* (Combaz & Peniguel, 1972). Fylla 9 borehole, core sample at 199.35 m. Specimen in lateral view, SEM ×100. IGR 58607 (R. 36). **Fig. 8.** *Conochitina decipiens* Taugourdeau & Jekhowsky, 1960. Fylla 3 borehole, core sample at 254.30 m. Specimen in lateral view, SEM ×300. IGR 58614 (N. 36). **Fig. 9.** *Conochitina decipiens* Taugourdeau & Jekhowsky, 1960. Fylla 9 borehole, core sample at 228.10 m. Specimen in lateral view, SEM ×200. IGR 58604 (Q. 41/2). **Fig. 10.** *Cyathochitina hunderumensis* sp. nov. Fylla 9 borehole, core sample at 265.30 m. Specimen in lateral view, SEM ×300. IGR 58604 (Q. 37/1). **Fig. 11.** *Cyathochitina hunderumensis* sp. nov. Fylla 9 borehole, core sample at 265.30 m. Specimen in lateral view, SEM ×300. IGR 58604 (P. 37/3).

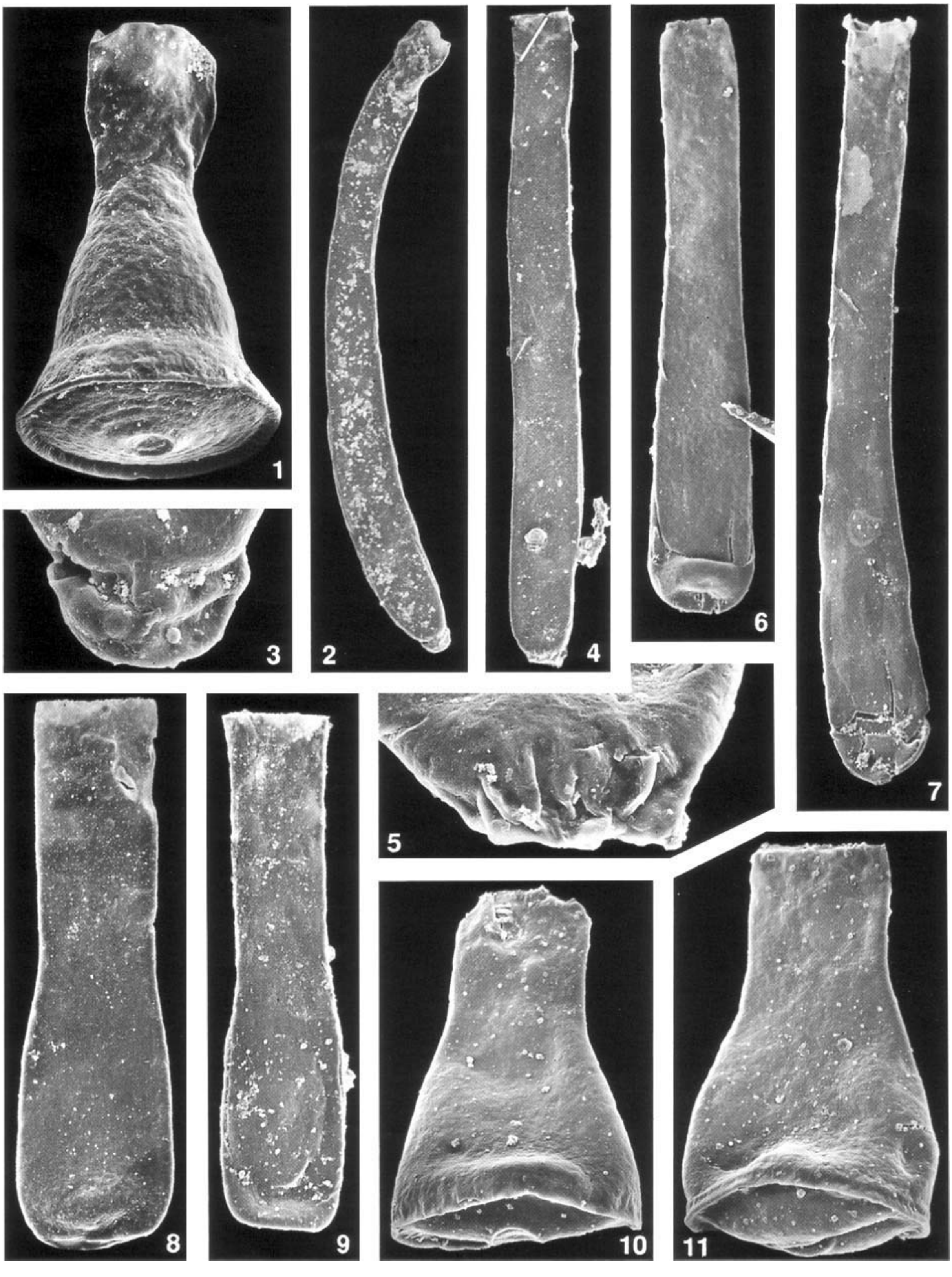

Plate 1

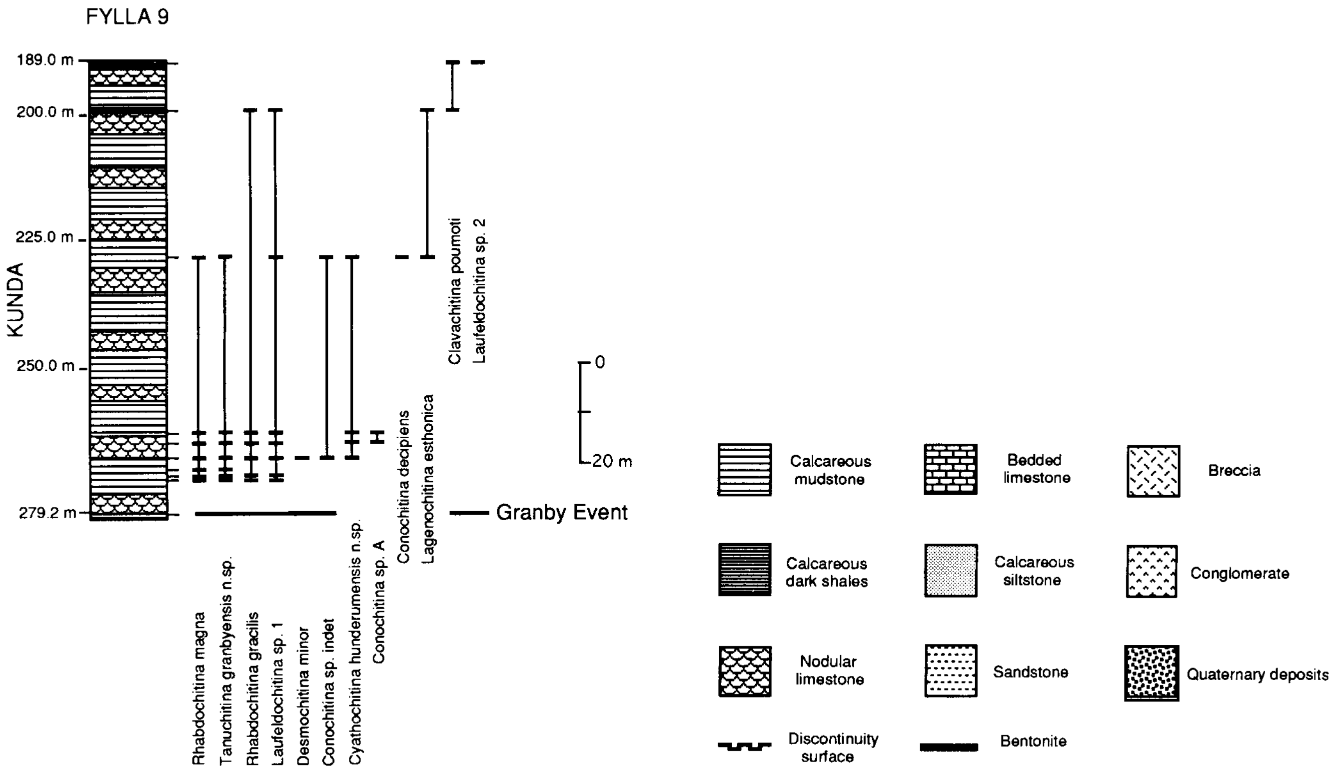

Fig. 3. Faunal log of the Fylla 9 borehole, Granby crater, with sedimentary legend.

(Kukruse Stage) in North Estonia (Figs 6, 14). An important taxon *L.* sp. A aff. *capax* (ranging from upper Kukruse to lower Idavere; Nõlvak, unpublished data), is also confirming an early Caradoc age (Fig. 14). Other common species are *Conochitina minnesotensis* (Pl. 3, fig. 7), *Calpichitina complanata*, *Calpichitina lecaniella* (Pl. 2, figs 3, 5), *Cyathochitina kuckersiana* and *Desmochitina ovulum*. In the topmost layer of the pre-Quaternary rocks in the Tvären 2 borehole *Conochitina tigrina* (Pl. 2, figs 1, 2, Pl. 3, fig. 4) occurs with *Spinachitina tvaerenensis* sp. nov. (see Systematic Descriptions; Fig. 6; Pl. 2, figs 4, 7, 8, Pl. 3, fig. 6, 11). These species appear in a short interval at the top of the Kukruse Stage in Baltoscandia.

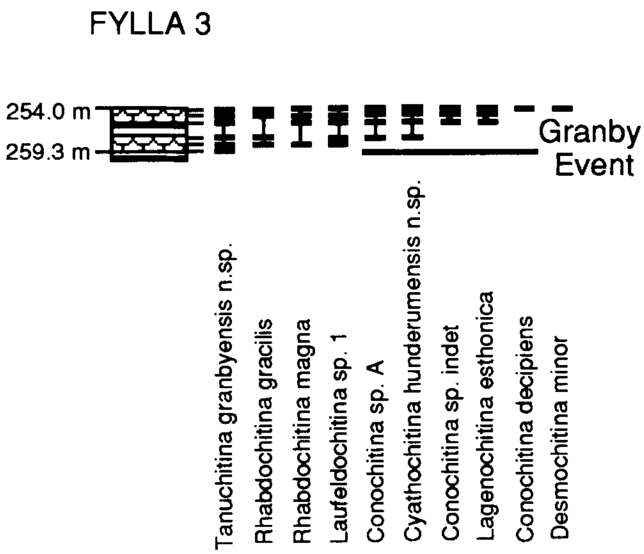

Fig. 4. Faunal log of the Fylla 3 borehole, Granby crater.

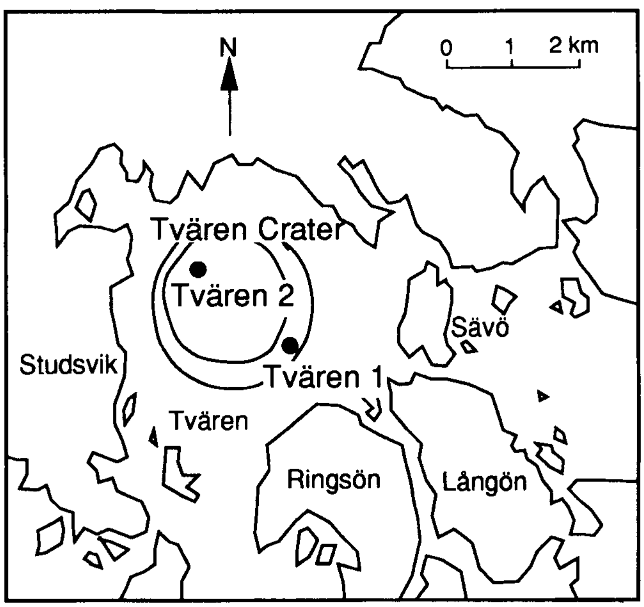

Fig. 5. Map showing the site of the Tvären 1 and 2 boreholes in the Tvären crater, Södermanland, Sweden.

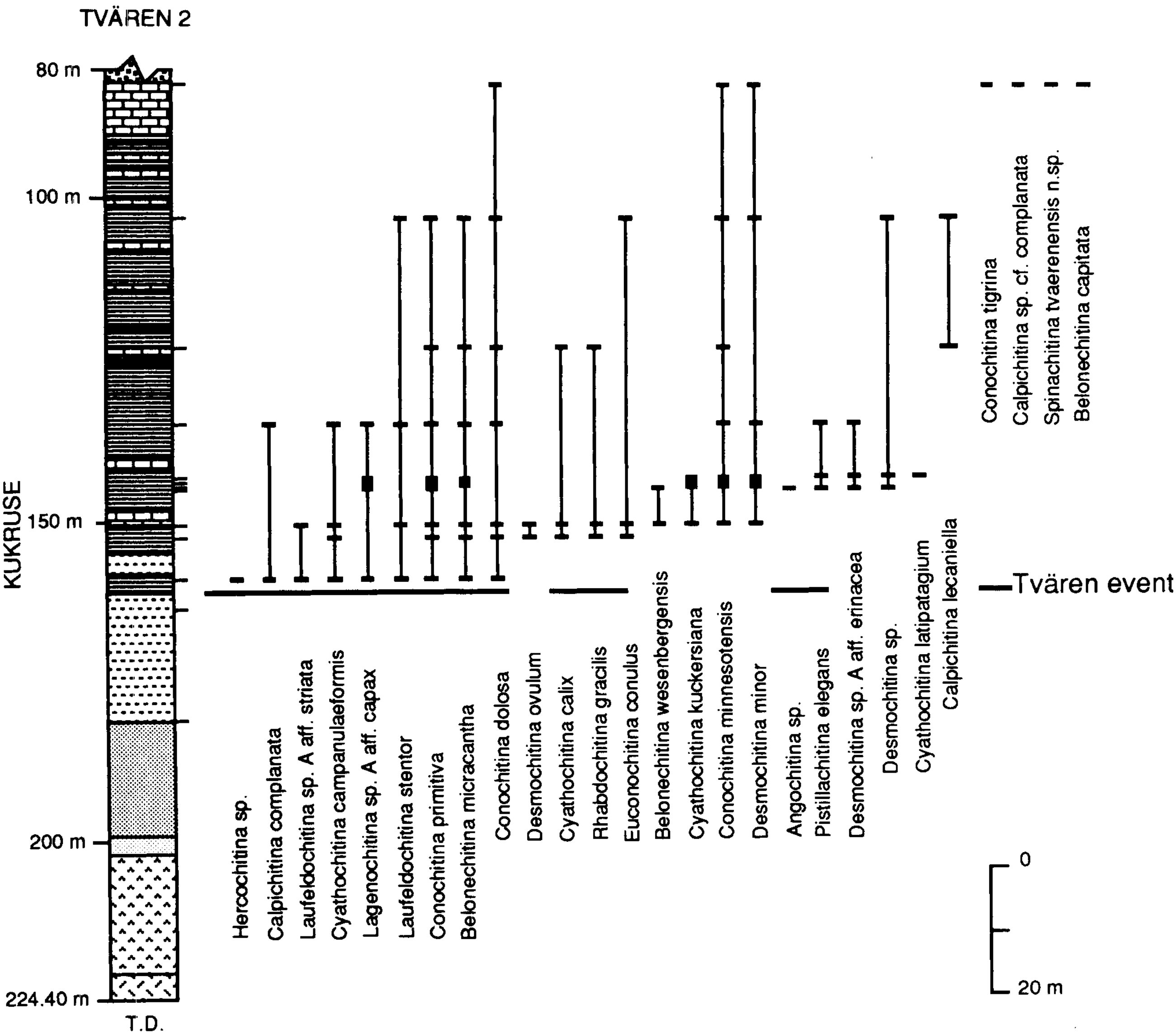

Fig. 6. Faunal log of the Tvären 2 borehole, Tvären crater.

Kärdla crater

The Kärdla crater is situated in the subsurface, just east of the Kärdla city, and on the north coast of the Island of Hiiumaa. It has been discussed by Puura & Suuroja (1992) and Grahn & Nõlvak (1993). The chitinozoan biostratigraphy in two boreholes drilled in the structure has been investigated. Paluküla 383 (Fig. 8) is situated within the crater near the northeastern rim, and Männamaa (Fig. 9) about 20 km southwest of the crater (Fig. 7). The Paluküla 383 borehole terminated just above the first post-impact sediments, which consist of calcareous mudstone with rare limestone intercalations. However, ejecta from the impact are spread over large areas in northwest Estonia. They consist of a quartz-rich limestone, known as the Kisuvere Member of the lower Tatruse Formation (Põlma *et al.* 1988). This layer is present at 164.82–164.93 m and has been dated in the Männamaa borehole. It gives a precise dating of the first post-impact sedimentation in the crater, as well as the impact event (Grahn & Nõlvak, 1993). In both the Paluküla 383 and Männamaa boreholes *Lagenochitina* sp. A aff. *capax* and *Spinachitina multiradiata* appear above the first occurrence of the index species *Lagenochitina dalbyensis*. This suggests that the impact event cannot be much younger than the middle part of the *L. dalbyensis* Zone, since *S. multiradiata* has its first occurrence in the middle part of this zone. In the Männamaa borehole the Kisuvere Member is situated above the last occurrence of *Angochitina curvata*, and before the first occurrence of *L. dalbyensis*, which means that the impact event, and the first post-impact sedimentation, took place in the early Caradoc and corresponds to the transition between the chitinozoan Zones of *A. curvata* and *L. dalbyensis* (Grahn & Nõlvak, 1993; Nõlvak & Grahn 1993; Fig. 14).

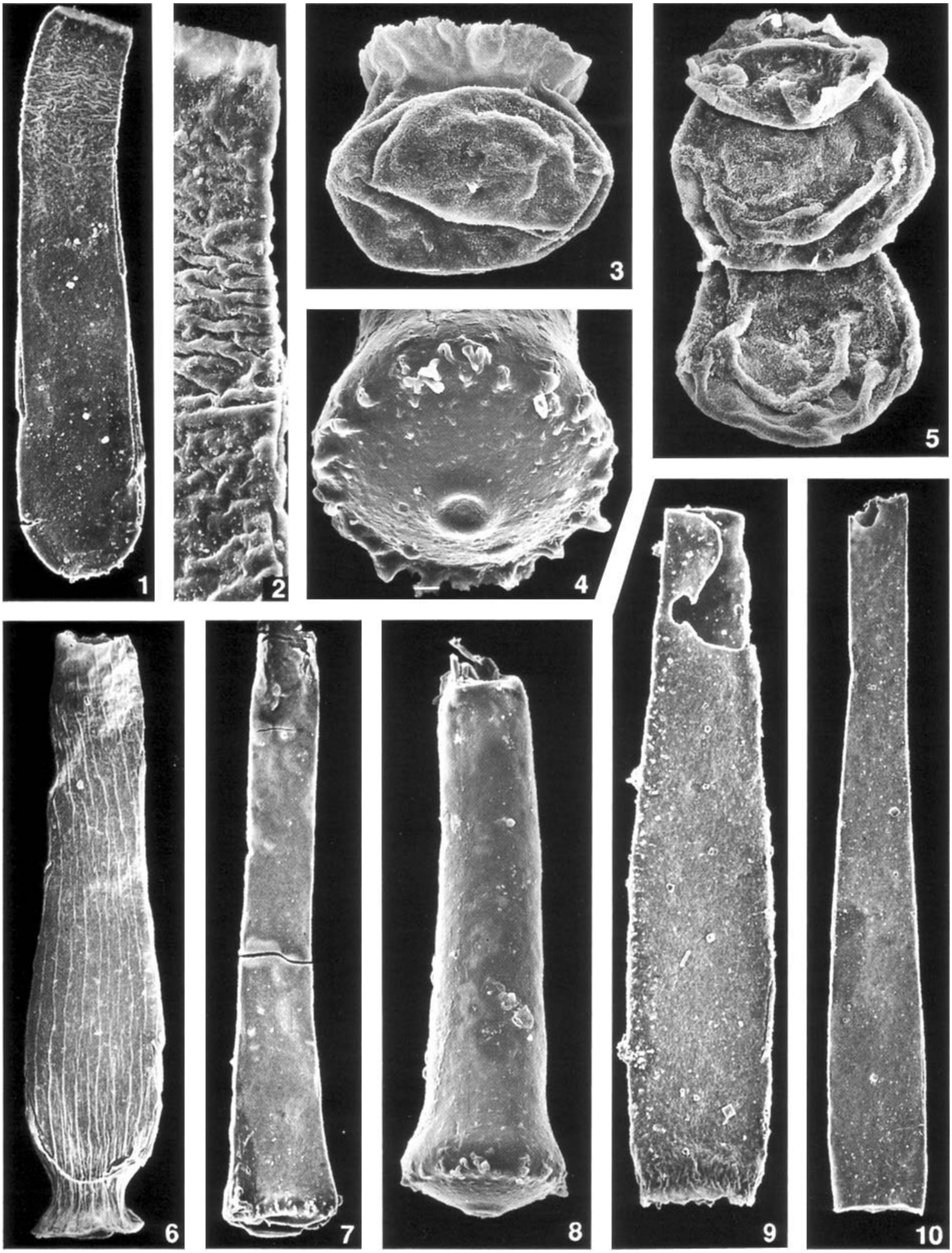

Plate 2

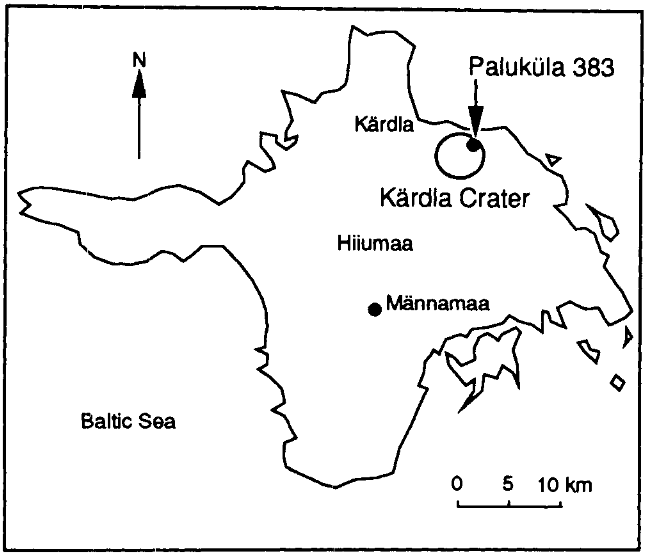

Fig. 7. Map showing the sites of the investigated boreholes in connection with the Kärdla crater, Hiiumaa, Estonia.

Lockne crater

The Lockne crater is situated at Lake Lockne, about 20 km southeast of the town of Östersund in the province of Jämtland. The crater has been described by Simon (1987), Lindström & Sturkell (1992) and Grahn & Nõlvak (1993). Three sections outside the west rim of the crater were investigated southwest of the village of Tandsbyn (Fig. 10). The first section, described by Thorslund (1940, fig. 21), is a railway-cut at Lappgrubban about 1.1 km southwest of the Tandsbyn church (Fig. 11). The second section is along the stream Ynntjärnsbäcken, about 400 m east of Lake Ynntjärn (Fig. 12), and the third section is a railway-cut, described by Simon (1987; Fig. 23), situated about 400 m west of Lake Ynntjärn (Fig. 13). All three localities exhibit the sandy resurge deposit locally known as 'Loftarstone', which is followed upwards by the first post-impact sediments, a limestone with interbedded calcareous shales. Locally the limestone contains patch reefs that grew on the crater rim. Characteristic of the chitinozoan fauna is the presence of the index species *Lagenochitina dalbyensis* (Pl. 3, fig. 3) together with *Lagenochitina* sp. A aff. *capax* in two of the localities (Lappgrubban and Ynntjärnsbäcken). This means that the Lockne event (Grahn & Nõlvak, 1993), and the first post-impact sedimentation in the crater, took place in the early Caradoc, and correspond to the lower part of the *L. dalbyensis* chitinozoan Zone. The Lockne event may be coeval with the Kärdla event, but most probably is slightly younger. The occurrence of *Belonechitina hirsuta* in the section at Ynntjärnsbäcken (Fig. 12) suggests that beds younger than those corresponding to the *L. dalbyensis* Zone are also present at this locality. Other chitinozoan species present are, for instance *Cyathochitina campanulaeformis* characteristic of the earliest Caradoc, *Calpichitina lecaniella, Desmochitina ovulum*, and *Belonechitina capitata* (Pl. 3, fig. 10). It should be noted that one boulder from the impact-related coarse breccia at Ynntjärnsbäcken yielded a chitinozoan assemblage from the upper? part of the Kukruse Stage (Zone of *Laufeldochitina stentor*, i.e. *Laufeldochitina stentor, Conochitina primitiva, C.* cf. *minnesotensis, Belonechitina capitata, Desmochitina erinacea*, and *D. minor*). Previously beds of this age had not been reported from the autochthon in Jämtland (Jaanusson & Karis 1982, fig. 1).

CONCLUSION

The immediate appearance of chitinozoans in the craters after the impact events, and their rapid evolution, have made it possible to achieve a high-resolution biostratigraphy of virtually complete sequences related to the impact craters. The planktic nature of the chitinozoophorans (Grahn, 1981) may also make it possible to date other types of natural hazards in marine environments (e.g. volcanic eruptions, earthquakes, etc.), from Ordovician through Devonian, sometimes with a precision of less than one million years. Chitinozoans occur in most lithologies, except for coarse sandstones, reef limestones, carbonate mounds and also marine redbeds and dolomites.

The environments within the craters were restricted. The first Ordovician reefs known from Baltoscandia started to grow on the rim of the Lockne crater during early Caradoc (lower Idavere Stage) times (Fig. 14). The climate was obviously warm enough for the formation of reefs, and the absence of other contemporary reefs in Baltoscandia indicates that the seas were probably deeper (Lindström 1971) than generally believed earlier. (For a summary see Jaanusson, 1982.)

Explanation of Plate 2

Selected chitinozoans from the Tvären crater. Early Caradoc. **Fig. 1.** *Conochitina tigrina* Laufeld, 1967. Tvären 2 borehole, core sample at 82.15 m. Specimen in lateral view, SEM ×150. IGR 58646 (Q. 36). **Fig. 2.** *Conochitina tigrina* Laufeld, 1967. Same specimen as in fig. 1. Detail showing the corrugations on the neck, SEM ×750. **Fig. 3.** *Calpichitina lecaniella* (Eisenack, 1965). Tvären 2 borehole, core sample at 123.02–123.05 m. Specimen in lateral view, SEM ×500. IGR 58643 (M. 36/1). **Fig. 4.** *Spinachitina tvaerenensis* sp. nov. Holotype. Tvären 2 borehole, core sample at 82.15 m. Detail of the base showing the processes. Note the mucron, SEM ×600. **Fig. 5.** *Calpichitina lecaniella* (Eisenack, 1965). Tvären 2 borehole, core sample at 123.02–123.05 m. Chain with two specimens in lateral view, SEM ×500. IGR 58643 (L. 39/4). **Fig. 6.** *Laufeldochitina stentor* (Eisenack, 1937). Tvären 2 borehole, core sample at 102.97 m. Specimen in lateral view, SEM ×100. IGR 58644 (Q. 40). **Fig. 7.** *Spinachitina tvaerenensis* sp. nov. Tvären 2 borehole, core sample at 82.15 m. Specimen in lateral view, SEM ×200. IGR 58645 (R. 38/3). **Fig. 8.** *Spinachitina tvaerenensis* sp. nov. Holotype. Tvären 2 borehole, core sample at 82.15 m. Specimen in lateral view, SEM ×350. IGR 58645 (R. 40). **Fig. 9.** *Laufeldochitina* sp. A aff. *striata*. Tvären 2 borehole, core sample at 158.77–158.80 m. Specimen in lateral view, SEM ×200. IGR 58634 (R. 37/2). **Fig. 10.** *Laufeldochitina* sp. A aff. *striata*. Tvären 2 borehole, core sample at 150.78–150.81 m. Specimen in lateral view, SEM ×100. IGR 58636 (S. 41/1).

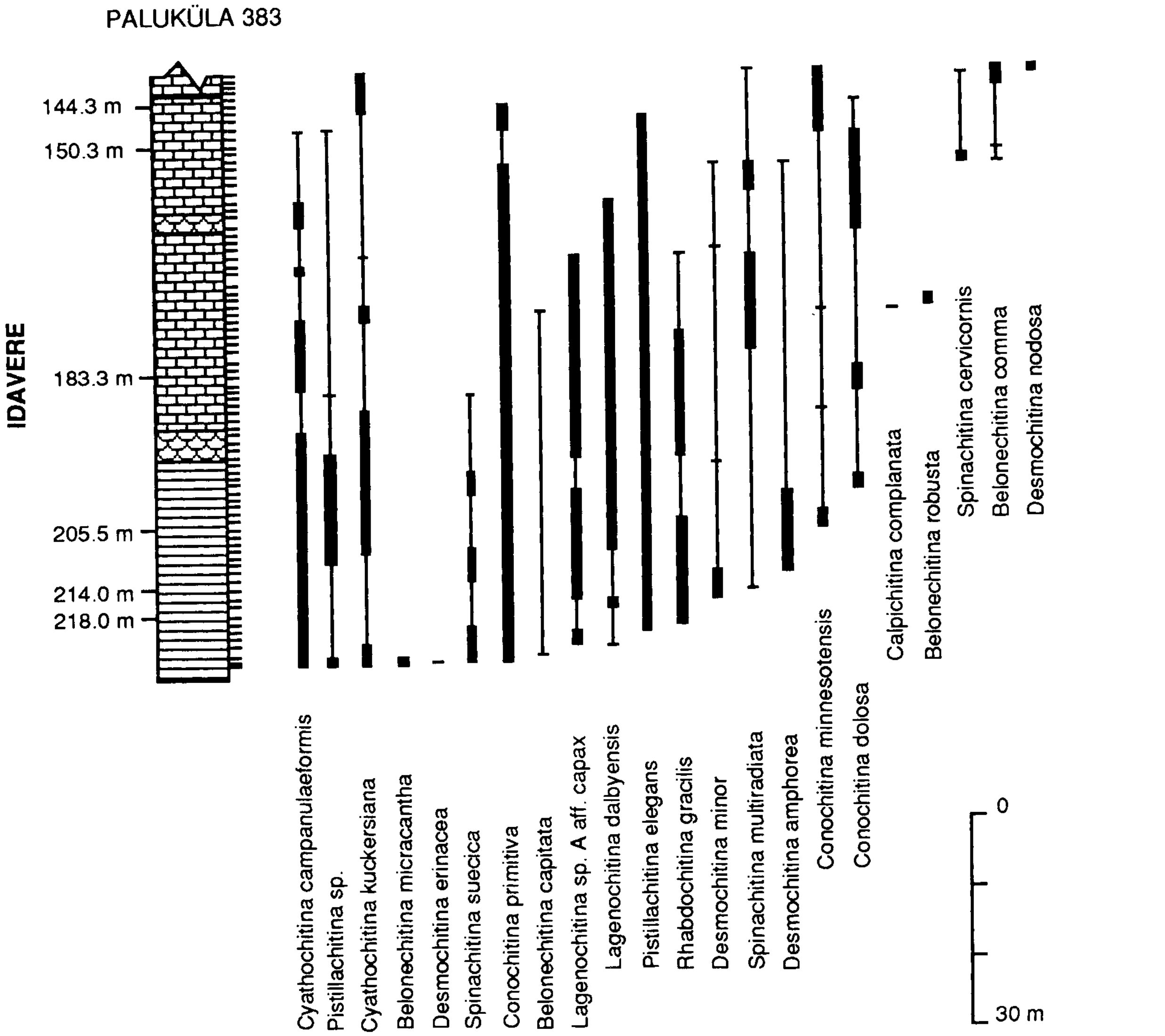

Fig. 8. Faunal log of the Paluküla 383 borehole, Kärdla crater. The depths on the left side of the column indicate the levels of discontinuity surfaces.

SYSTEMATIC DESCRIPTIONS

Cyathochitina hunderumensis sp. nov.

(Pl. 1, figs 1, 10, 11)

?1967 *Cyathochitina campanulaeformis* Eisenack; Jenkins: 456–458, pl. 71, figs 8–11.

1976 *Cyathochitina campanulaeformis* Eisenack: 187, pl. 2, fig. 4

1980 *Cyathochitina* cf. *campanulaeformis* Eisenack; Grahn: 25–27, pl. 15, figs A–D.

1984 *Cyathochitina campanulaeformis* Eisenack; Grahn: 16–17.

Derivation of name. Latin, *hunderumensis*, from the late Arenig substage of Hunderum where the species is common.

Diagnosis. Small *Cyathochitina* with a short thickened carina and a basal scar on the apex of the vesicle.

Holotype. Pl. 1, fig.1. IGR 58614 (L. 39/4).

Type locality. Fylla 3 borehole, core sample at 254.30 m, Granby crater, Östergötland, south Sweden.

Description. A small species of *Cyathochitina*. Vesicle smooth with a characteristic bell-like to conical shape. The maximum width is at the margin. The margin is provided with a short thickened carina. A basal scar is present. The neck is cylindrical, and shorter than half the total length. Aperture straight.

Dimensions. The dimensions given by Grahn (1980, p. 27) are characteristic also for the specimens from the Granby crater. He noted that also the main parts of the populations fall within the length:width ratio 1.25–2:1. From the type level 30 flattened specimens were measured. A coefficient of 0.7 was used to restore the diameter of chamber and neck. The total length is 156–280 μm (holotype 233 μm, mean value 199 μm),

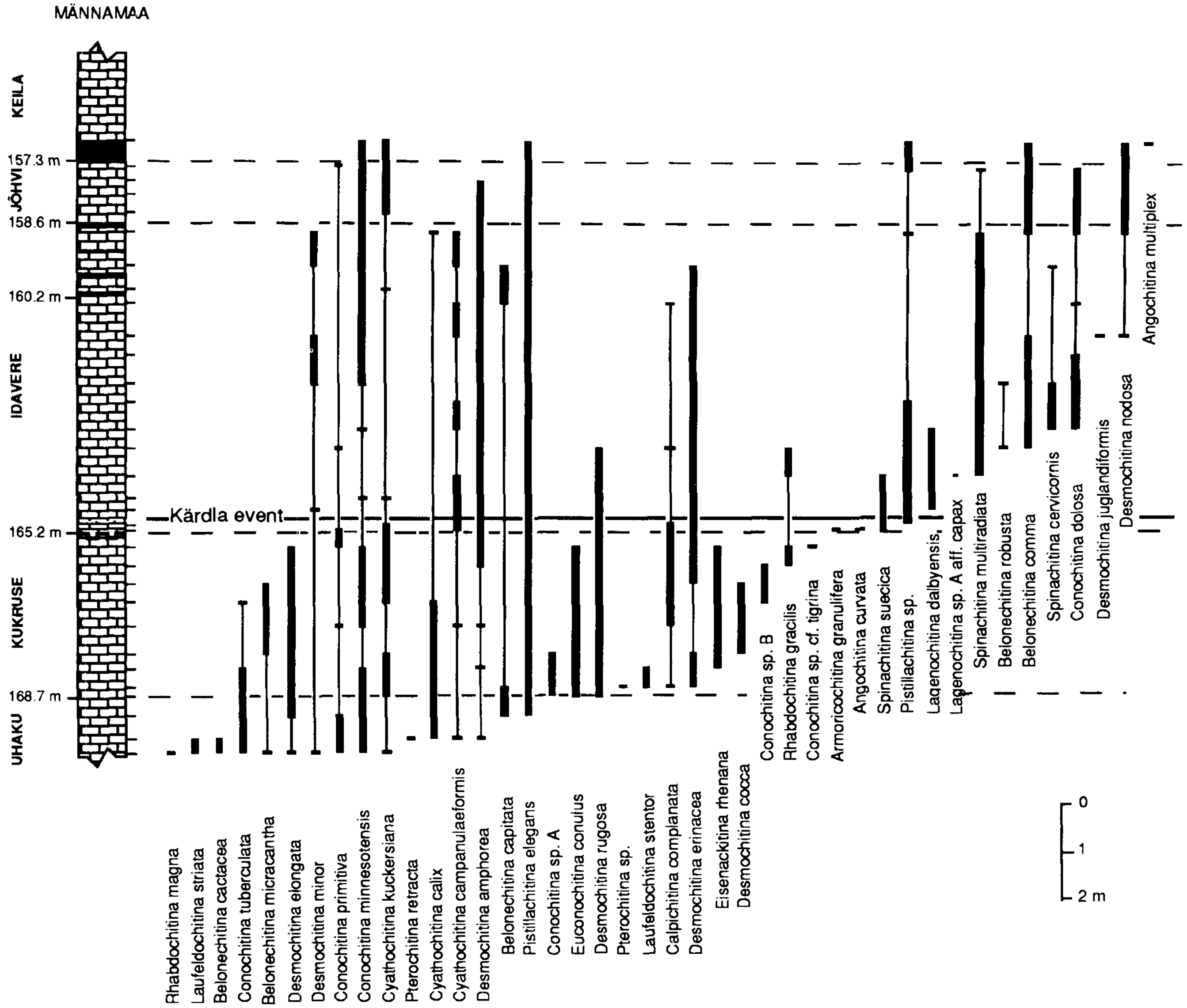

Fig. 9. Faunal log of the Männamaa borehole, Kärdla crater. The depths on the left side of the column indicate the levels of discontinuity surfaces.

maximum width 73–124 μm (holotype 123 μm, mean value 94 μm), width of neck 42–53 μm (holotype 48 μm, mean value 47 μm) and the length of the neck 50–94 μm, (holotype 90 μm, mean value 70 μm). The ratio of vesicle length/chamber diameter for specimens from the type level is shown in Fig. 15, and the ratio of chamber diameter/neck diameter in Fig. 16.

Discussion. The small *C. hunderumensis* sp. nov. are easily distinguished from typical specimens of *Cyathochitina campanulaeformis* as defined by Eisenack (1931, 1962) through its small size, and because of the short and thickened carina. *Cyathochitina varennensis* Paris 1981, from the early Llanvirnian of western France, has a similar size. However, the ratio of length of the neck/length of the vesicle is significantly different.

Occurrence. *Cyathochitina hunderumensis* sp. nov. ranges from the upper Volkhov Stage (chitinozoan Zone of *Conochitina cucumis* Nõlvak & Grahn, 1993) to the top of Kunda Stage (upper Arenig–lower Llanvirn). The species is known from Öland (Eisenack, 1976; Grahn, 1980) and Närke (Grahn, unpublished data), Sweden and from the Granby crater (this paper). It occurs also in North Estonia (reported but not illustrated from the Suhkrumägi section in Tallinn by Grahn 1984 as *Cyathochitina campanulaeformis*). It should be noted that specimens assignated to *Cyathochitina campanulaeformis* first occur in the Aseri Stage, after the last occurrence of *C. hunderumensis* sp. nov. Specimens similar to *C. hunderumensis* sp. nov. have been reported from the lower Hope Shales (early Llanvirn) in Shropshire, England (Jenkins, 1967).

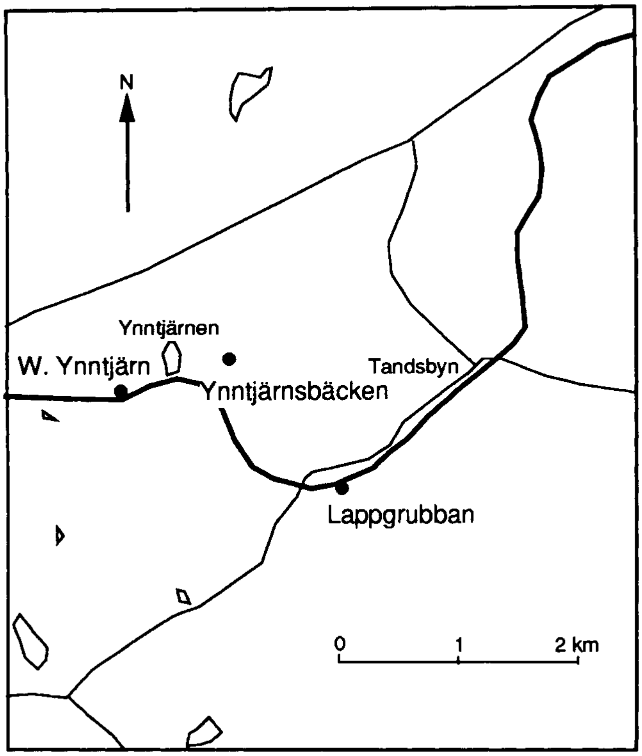

Fig. 10. Map showing the sites of the outcrop localities in connection with the Lockne crater, Jämtland, Sweden.

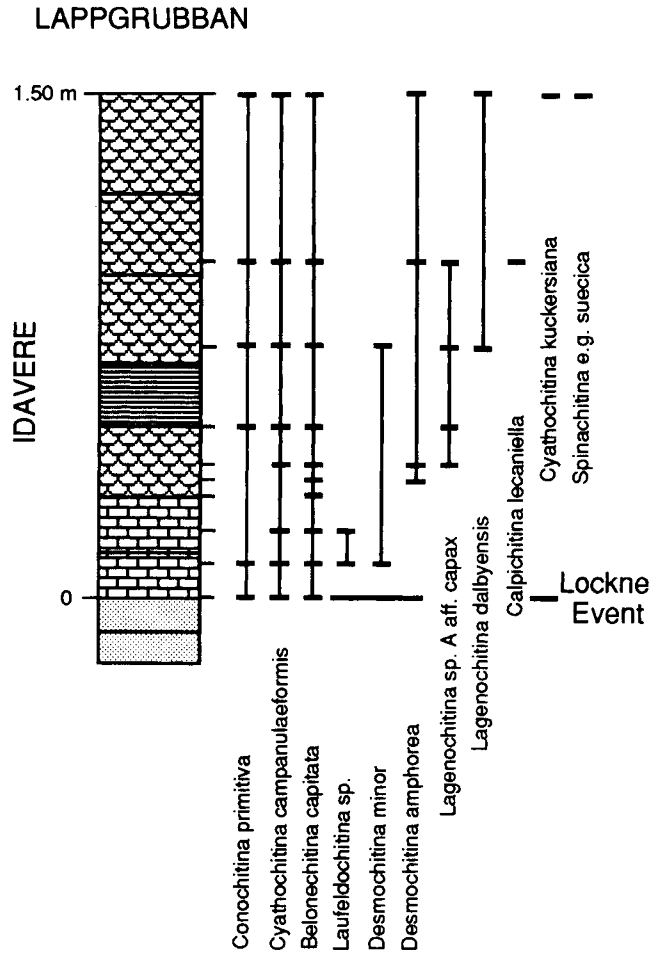

Fig. 11. Faunal log of the Lappgrubban outcrop section, Lockne crater.

Spinachitina tvaerenensis sp. nov.
(Pl. 2, figs 4, 7, 8; Pl. 3, fig. 6, 11)

? 1986 *Coronochitina* sp. Männil, fig. 2.1.1.

Derivation of name. Latin, *tvaerenensis*, from Tvären, the type locality for the species.

Diagnosis. Elongated conical species of *Spinachitina* with a convex base provided with mucron. Crown with about 20 thick processes at the margin.

Holotype. Pl. 2, figs 4, 8. IGR 58645 (R 40).

Type locality. Tvären 2 borehole, core sample at 82.15 m, Tvären crater, Södermanland, south Sweden.

Description. This elongated conical *Spinachitina* species is characterized by the conical expansion of the chamber close to the margin. The neck is cylindrical and indistinct with a straight aperture. Flexure and shoulder absent. The greatest width is at the margin, which is provided with about 20 robust short and simple conical processes, elongated parallel to the vesicle axis with their proximal end (insertion zone). A mucron is present. The vesicle wall is smooth aperturewards the margin.

Explanation of Plate 3

Selected chitinozoans from the Granby (Late Arenig), Tvären (Early Caradoc) and Lockne (Early Caradoc) craters. **Fig. 1.** *Lagenochitina* sp. A aff. *capax*. Tvären 2 borehole, core sample at 144.99–145.00 m. Specimen in lateral view, SEM ×500. IGR 58637 (L. 32/4). **Fig. 2.** *Lagenochitina* sp. A aff. *capax*. Tvären 2 borehole, core sample at 144.99–145.00 m. Specimen in lateral view, SEM ×500. IGR 58637 (P. 35/3). **Fig. 3.** *Lagenochitina dalbyensis* (Laufeld, 1967). Ynntjärnsbäcken, basal 7 cm of the upper Dalby Limestone. Specimen in lateral view, SEM ×300. IGR 58632 (L. 37/3). **Fig. 4.** *Conochitina tigrina* Laufeld, 1967. Tvären 2 borehole, core sample at 82.15 m. Specimen in lateral view, SEM ×200. IGR 58646 (R. 38/1). **Fig. 5.** *Conochitina* sp. 1. Fylla 3 borehole, core sample at 258.00 m. Specimen in lateral view, SEM ×350. IGR 58610 (Q. 38). **Fig. 6.** *Spinachitina tvaerenensis* sp. nov. Tvären 2 borehole, core sample at 82.15 m. Detail of the basal part showing the processes, SEM ×350. IGR 58646 (O. 34/3). **Fig. 7.** *Conochitina minnesotensis* (Stauffer, 1933). Tvären 2 borehole, core sample at 144.40 m. Specimen in lateral view, SEM ×150. IGR 58639 (N. 45/2). **Fig. 8.** *Rhabdochitina gracilis* Eisenack, 1962. Fylla 3 borehole, core sample at 258.00 m. Specimen in lateral view, SEM ×100. IGR 58610 (O. 38). **Fig. 9.** *Lagenochitina esthonica* Eisenack, 1955. Fylla 3 borehole, core sample at 254.30 m. Specimen in lateral view, SEM ×80. IGR 58614 (L. 40/3). **Fig. 10.** *Belonechitina capitata* (Eisenack, 1962). West Ynntjärn, basal 10 cm of the upper Dalby Limestone. Specimen in lateral view, SEM ×300. IGR 58622 (M. 36). **Fig. 11.** *Spinachitina tvaerenensis*? sp. nov. Tvären 2 borehole, core sample at 82.15 m. Specimen in lateral view, SEM ×300. IGR 58646 (O. 37/3).

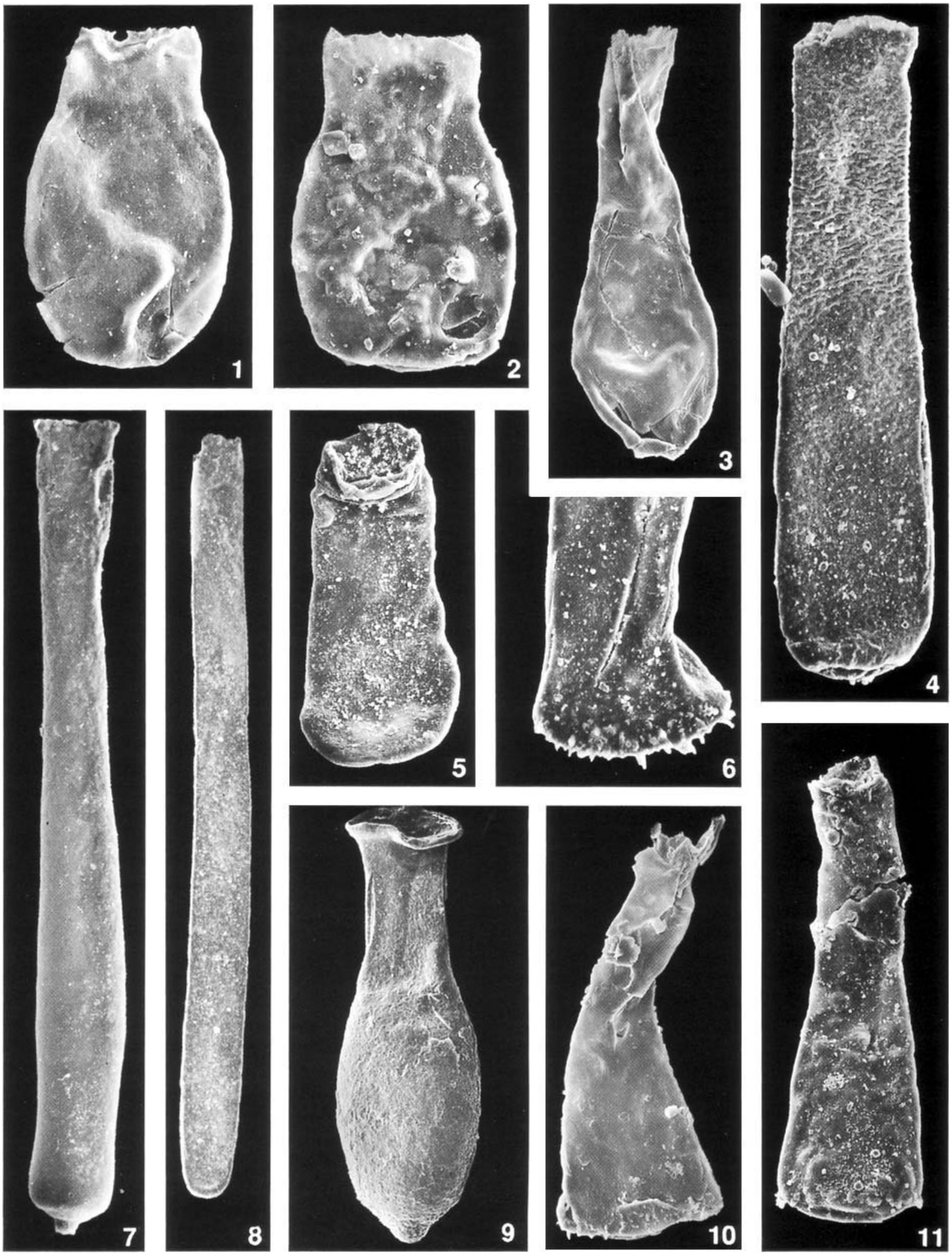

Plate 3

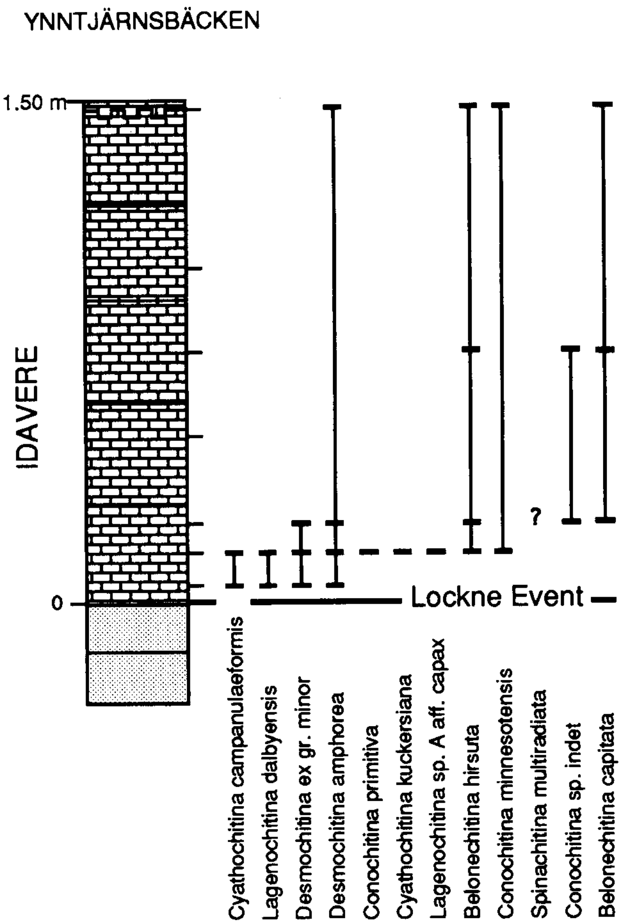

Fig. 12. Faunal log of the Ynntjärnsbäcken outcrop section, Lockne crater.

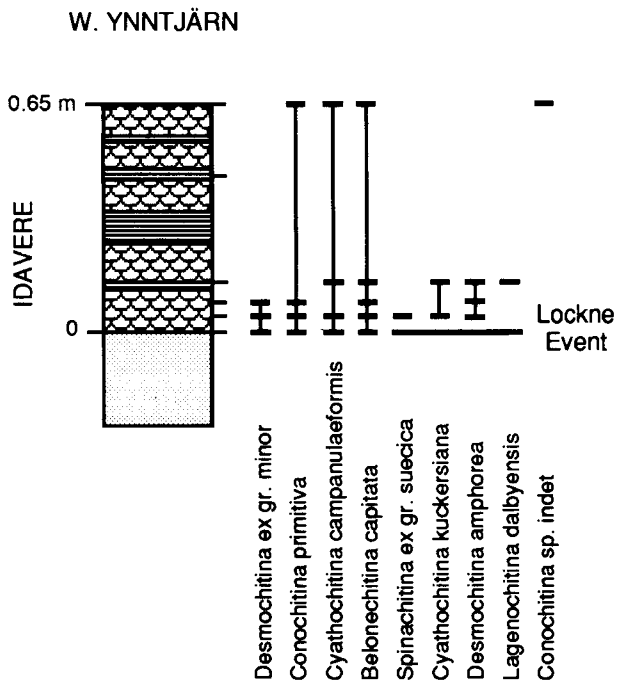

Fig. 13. Faunal log of the outcrop section west of Ynntjärn, Lockne crater.

Corrected dimensions. (7 specimens, flattening corrected by a coefficient of 0.7.) Total length 247–568 μm (holotype >257 μm, broken neck), max width 73–117 μm (holotype 76 μm), aperture 41–78 μm (holotype, width of neck 43 μm), spines about 7 μm (holotype 7 μm).
Occurrence. *Spinachitina tvaerenensis* sp. nov. has a restricted range in the uppermost Kukruse Stage. It probably corresponds to *Coronochitina* sp. by Männil (1986), who indicated a range from uppermost Kukruse to lowermost Idavere Stage, where it disappears before the first occurrence of the index species for the chitinozoan Zone of *Armoricochitina granulifera* Nõlvak & Grahn 1993 (*Cyathochitina* cf. *reticulifera* by Männil, 1986) in the lowermost Idavere Stage.

Tanuchitina granbyensis sp. nov.
(Pl. 1, figs. 2–5)

V. ? 1981 *Tanuchitina* sp. aff. *achabae* Paris: 216–217, pl. 40, figs 14, 15.
Derivation of name. Latin, *granbyensis*, from Granby, the type locality for the species.
Diagnosis. A long subcylindrical species of *Tanuchitina* with its carina erected on an ovoid base.
Holotype. Pl. 1, figs 2, 3. IGR 58601 (D 43).
Type locality. Fylla 9 borehole, core sample at 272.20 m, Granby crater, Östergötland, south Sweden.
Description. A very long slender, almost cylindrical *Tanuchitina* with a smooth vesicle. Aperture straight. Greatest width about one quarter aperturewards from the ovoid base. Fairly long membranaceous carina surrounding the apex.
Corrected dimensions. (27 specimens, flattening corrected by a coefficient of 0.7.) Total length >672–1533 μm (holotype 1466 μm, mean value 1262 μm), max. width 82–138 μm (holotype 117 μm, mean value 97 μm), aperture 60–118 μm (holotype 85 μm, mean value 71 μm), and carina 16–34 μm (holotype 30 μm). The ratio vesicle length/chamber diameter for specimens from the type level is shown in Fig. 17.
Discussion. The length of this species makes it easily distinguishable from any other early Ordovician *Tanuchitina* species described to date. *Tanuchitina achabae* from the middle Arenig of western France (Paris, 1981) is half the size in terms of vesicle length. *Tanuchitina* sp. aff. *achabae* from the late Arenig of western France is probably a synonym to *T. granbyensis* sp. nov. They are of a similar length and the vesicle is frequently curved along its longitudinal axis. *T. granbyensis* sp. nov. may be confused with *Rhabdochitina gracilis* Eisenack when the carina is strongly eroded. The latter is also commonly curved along the long axis of the vesicle.
Occurrence. *Tanuchitina granbyensis* sp. nov. has so far only been found in late Arenig strata in the Granby crater, Östergötland, south Sweden. It is probably present

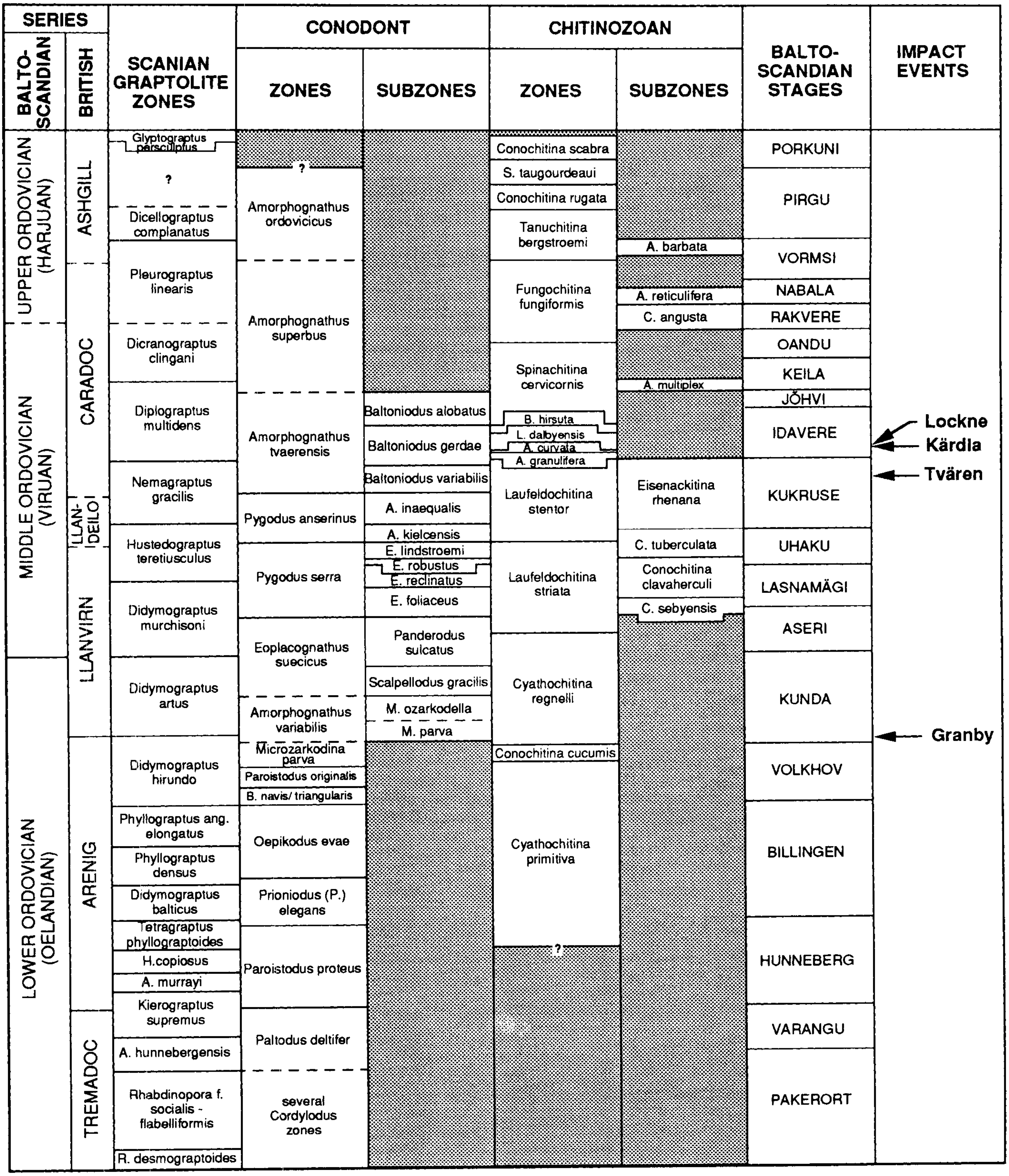

Fig. 14. Correlation table for the impact craters in the Ordovician of Baltoscandia.

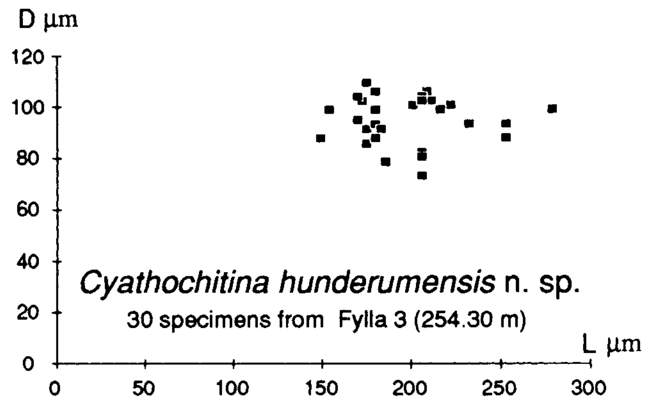

Fig. 15. Diagram showing the vesicle length (L) with regard to the diameter of the chamber (D) for *Cyathochitina hunderumensis* sp. nov. (30 flattened specimens measured from the type level, flattening restored with a coefficient of 0.7.)

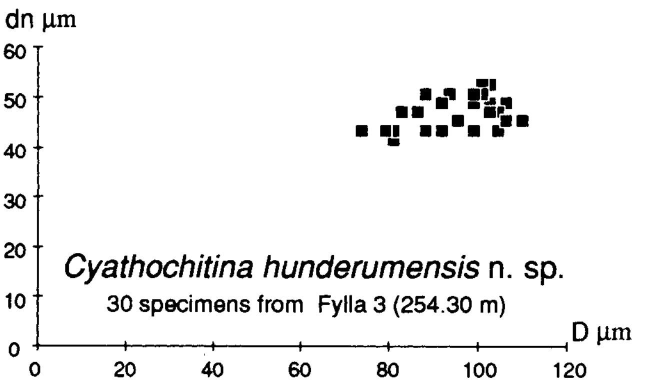

Fig. 16. Diagram showing the chamber diameter (D) with regard to the diameter of the neck (dn) for *Cyathochitina hunderumensis* sp. nov. (30 flattened specimens measured from the type level, flattening restored with a coefficient of 0.7.)

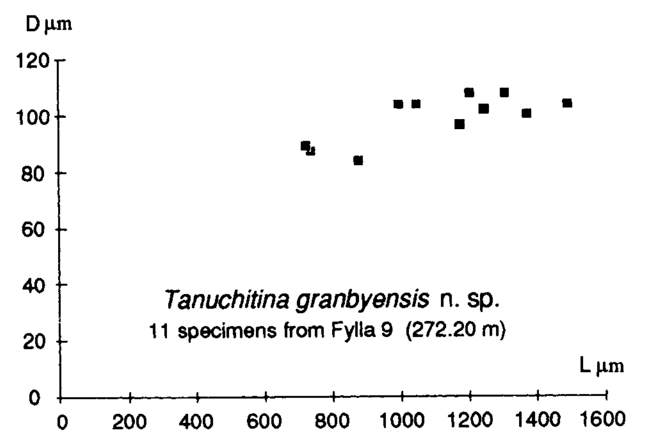

Fig. 17. Diagram showing the vesicle length (L) with regard to the diameter of the chamber (D) for *Tanuchitina granbyensis* sp. nov. (11 flattened specimens measured from the type level, flattening restored with a coefficient of 0.7.)

in the late Arenig in the lowermost Pissot Formation in western France.

Lagenochitina sp. A aff. *capax*

(Pl. 3, figs 1, 2)

Occurrence. *Lagenochitina* sp. A aff. *capax* ranges from the upper Kukruse to the lower Idavere Stage. It is a common species in the sequences related to the Tvären, Kärdla and Lockne craters. Its stratigraphical range is concluded from observations in Estonia, as *L.* sp. A aff. *capax* is not previously recorded from Sweden.

Remarks. *Lagenochitina* sp. A aff. *capax* has great similarities with the holotype of *Lagenochitina capax* Jenkins 1967 (pl. 73, fig. 3) and with *Lagenochitina deunffi* Paris 1974. The stratigraphic range is identical (*L. capax* is slightly younger than *L. deunffi* but they may overlap; Paris 1981), and it cannot be excluded that *L.* sp. A aff. *capax* is conspecific with one of these species. The size falls completely within the range of *Lagenochitina deunffi*, but the neck of *L. deunffi* is more narrow than that of *L.* sp. A aff. *capax*. For a population of 40 flattened specimens (flattening corrected by a coefficient of 0.7) from 144.40 and 144.99–145.00 m the total length is 88–122 μm (mean value 103 μm), maximum width 38–51 μm (mean value 44 μm), width of aperture 23–33 μm (mean value 30 μm), and length of the neck 13–22 μm (mean value 16 μm). The ratio vesicle length/chamber diameter for specimens from level 144.40 and 144.99–145.00 m is shown in Fig. 18, and the ratio vesicle length/neck length in Fig. 19.

Laufeldochitina sp. A aff. *striata*

(Pl. 2, figs 9, 10)

Occurrence. *Laufeldochitina* sp. A aff. *striata* has a short range in the upper Kukruse Stage (corresponding to the middle part of the lower Peetri Member of the Viivikonna Formation) in North Estonia (*Laufeldochitina* cf. *striata* by Männil, 1986). Its occurrence in the Tvären 2 borehole is the first safely established in Sweden.

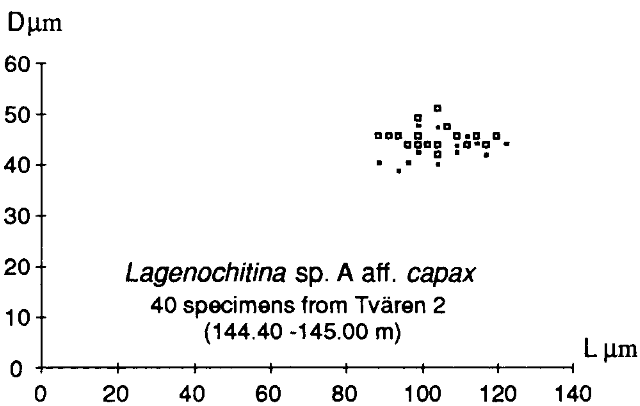

Fig. 18. Diagram showing the vesicle length (L) with regard to the diameter of the chamber (D) for *Lagenochitina* sp. A aff. *capax*. (40 flattened specimens measured from levels 144.40 m (black dot) and 144.99–145.00 m (squares) in the Tvären 2 borehole, flattening restored with a coefficient of 0.7.)

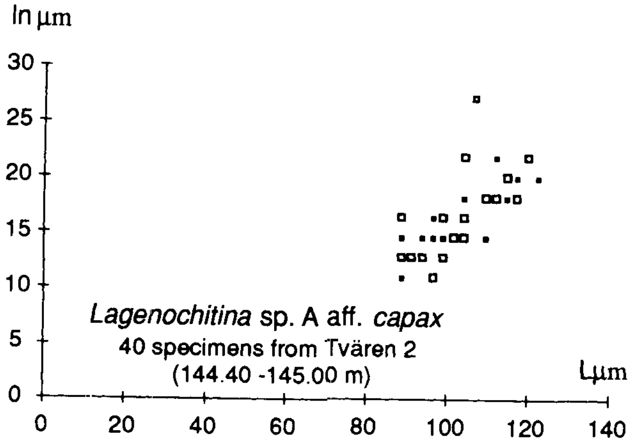

Fig. 19. Diagram showing the vesicle length (L) with regard to the length of the neck (ln) for *Lagenochitina* sp. A aff. *capax*. (40 flattened specimens measured from levels 144.40 m (black dot) and 144.99–145.00 m (squares) in the Tvären 2 borehole, flattening restored with a coefficient of 0.7.)

Remarks. Characteristic *Laufeldochitina* sp. A aff. *striata* differ from *Laufeldochitina striata* (Eisenack, 1937) in possessing a predominantly smooth wall. A striate ornamentation restricted to the basalmost part may occur on some specimens (Pl. 2, fig. 9). The dimensions fall within the range of *Laufeldochitina striata*.

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