Precise chitinozoan dating of Ordovician impact events in Baltoscandia

YNGVE GRAHN¹, JAAK NÕLVÅK² & FLORENTIN PARIS³
1 Swedish Museum of Natural History, Department of Palaeozoology, Box 50007, S-10405 Stockholm, Sweden
2 Estonian Academy of Sciences, Institute of Geology, 7 Estonia Avenue, EE-0105 Tallinn, Estonia
3 Université de Rennes, Laboratoire de Paléontologie et Stratigraphie, URA 1364 du CNRS, Avenue du Général Leclerc, F-35042 Rennes Cedex, France

ABSTRACT - The chitinozoan biostratigraphy of four Ordovician impact craters has been investigated. Three of these (Tvären, Kårdla and Lockne) contain complete sequences of early Caradoc age, while the Granby crater contains rocks of late Arenig age yielding two benthonic 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 inurenenensis and Tanachitina 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 during the early Arenig. The Lumparen event might be of an impact crater that was already deeply eroded during the early Arenig. The Lumparen event might be of 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.

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 Descriptions; Figs 3, 4; Pl. 1, figs 10, 11) and Tanachitina 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 benthonic horizons found in the Fylla 9 core (Fig. 3) are probably of the same age, as evidenced from the presence in these levels by Clauchitina pounomi (Pl. 1, figs 6, 7), a species reported from Upper Arenig strata in Australia (Combaz & Peniguel, 1982).
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 (Nölvak & 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.

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 X300. 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 X75. 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 X500. Fig. 4. Tanuchitina granbyensis sp. nov. Fylla 9 borehole, core sample at 270.20 m. Specimen in lateral view, SEM X75. 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 X500. Fig. 6. Clavachitina pournoti (Combaz & Peniguel 1972). Fylla 9 borehole, core sample at 199.35 m. Specimen in lateral view, SEM X150. IGR 58607 (O. 34/2). Fig. 7. Clavachitina pournoti (Combaz & Peniguel, 1972). Fylla 9 borehole, core sample at 199.35 m. Specimen in lateral view, SEM X100. IGR 58607 (R. 36). Fig. 8. Conochitina decipiens Taugourdeau & Jekhowsky, 1960. Fylla 9 borehole, core sample at 254.30 m. Specimen in lateral view, SEM X300. 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 X200. 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 X300. IGR 58604 (O. 37/1). Fig. 11. Cyathochitina hunderumensis sp. nov. Fylla 9 borehole, core sample at 265.30 m. Specimen in lateral view, SEM X300. IGR 58604 (P. 37/3).
An important taxon *L*. sp. 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 tsarenensis* 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. 3. Faunal log of the Fylla 9 borehole, Granby crater, with sedimentary legend.](image1)

![Fig. 4. Faunal log of the Fylla 3 borehole, Granby crater.](image2)

![Fig. 5. Map showing the site of the Tvären 1 and 2 boreholes in the Tvären crater, Södermanland, Sweden.](image3)
**Käräla crater**

The Käräla crater is situated in the subsurface, just east of the Käräla city, and on the north coast of the Island of Hiiumaa. It has been discussed by Puura & Suuroja (1992) and Grahn & Nölvak (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 Tatrus Formation (Pölama 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 & Nölvak, 1993). In both the Paluküla 383 and Männamaa boreholes Lagenochitina sp. A aff. capax and Spinachitina multis radiata 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. multis radiata 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 & Nölvak, 1993; Nölvak & Grahn 1993; Fig. 14).
Plate 2
**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 Granh & Nölvak (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 Ynntjarnsbacken, about 400 m east of Lake Ynntjarn (Fig. 12), and the third section is a railway-cut, described by Simon (1987; Fig. 23), situated about 400 m west of Lake Ynntjarn (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 (Granh & Nölvak, 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 Kärdda 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 campanuliformis* 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 Kukrase 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 (Granh, 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.)

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**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. IGR 58646 (Q. 36). **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 wauerenensis** sp. nov. Holotype. Tvären 2 borehole, core sample at 82.15 m. Detail of the base showing the processes. Note the mucron, SEM ×600. IGR 58643. **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 wauerenensis** 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 wauerenensis** 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. Fylka 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, Käräla 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 77 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 varennessis 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 Volkov Stage (chitinozoan Zone of Conochitina cucumis Nölvak & Grahn, 1993) to the top of Kunda Stage (upper Arenig–lower Llanvirn). The species is known from Oland (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 assigned to Cyathochitina campanulaeformis first occur in the Asker 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.

Spinachitina tuaerenensis 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, tuaerenensis, from Tvaren, 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. Tvaren 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.

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

Explanation of Plate 3
Selected chitinozoans from the Granhy (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 x500. 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 x500. IGR 58637 (P. 35/3). Fig. 3. Lagenochitina dalbyensis (Laufeld, 1967). Ynntjärnsbacken, basal 7 cm of the upper Dalby Limestone. Specimen in lateral view, SEM x300. 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 x200. IGR 58646 (R. 38/1). Fig. 5. Conochitina sp. 1. Fylla 3 borehole, core sample at 258.00 m. Specimen in lateral view, SEM x350. IGR 58610 (Q. 38). Fig. 6. Spinachitina tuaerenensis sp. nov. Tvären 2 borehole, core sample at 82.15 m. Detail of the basal part showing the processes, SEM x350. 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 x150. 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 x100. IGR 58610 (O. 38). Fig. 9. Lagenochitina esthoniaca Eisenack, 1955. Fylla 3 borehole, core sample at 254.30 m. Specimen in lateral view, SEM x80. 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 x300. IGR 58622 (M. 36). Fig. 11. Spinachitina tuaerenensis? sp. nov. Tvären 2 borehole, core sample at 82.15 m. Specimen in lateral view, SEM x300. IGR 58646 (O. 37/3).
Fig. 12. Faunal log of the Ynntjärnsbäcken outcrop section, 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. Spinachiita 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 Nölvak & 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.

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

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
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Fig. 14. Correlation table for the impact craters in the Ordovician of Baltoscandia.
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, Kärdda 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 deunfi* Paris 1974. The stratigraphic range is identical (*L. capax* is slightly younger than *L. deunfi* 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 deunfi*, but the neck of *L. deunfi* 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 Mannil, 1986). Its occurrence in the Tvären 2 borehole is the first safely established in Sweden.
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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 Tvaren 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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REFERENCES
Achab, A. 1986. Assemblages de chitinozoaires dans l’Ordovicien inférieur de l’est du Canada. Canadian Journal of Earth Sciences, 23: 682–695.
Bockelie, T. G. 1980. Early Ordovician Chitinozoa from Spitsbergen. Palynology, 4: 1–14.
Bruun, Å. & Dahlman, B. 1982. Granbystrukturen. In Wickman, H., Bruun, Ä., Dahlman, B. & Vidal, G. (Eds), Descriptions to the map of solid rocks Hjo NO. Serie A, 120: 102–109, Sveriges Geologiska Undersöknings Uppsala.
Combaz, A. & Peniguel, G. 1972. Étude palynostratigraphique de l’Ordovicien dans quelques sondages du Bassin de Canning (Australie Occidentale). Bulletin du Centre de Recherche de Paris, SNPA 6: 121–167.
Eisenack, A. 1931. Neue Mikrofossilien des baltischen Silurs I. Palaeontologische Zeitschrift, 13: 74–118.
Eisenack, A. 1937. Neue Mikrofossilien des baltischen Silurs IV. Palaeontologische Zeitschrift, 19: 218–243.
Eisenack, A. 1962. Neotypen baltischer Silur Chitinozoen und neue Arten. Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen 114: 291–316.
Eisenack, A. 1976. Mikrofossilien aus dem Vaginatenkalk von Hälludden, Öland. Palaeontographica A 154: 181–203.
Flodén, T., Tunander, P. & Wickman, F. E. 1986. The Tvären Bay structure, an astrobleme in southeastern Sweden. Geologiska Föreningen i Stockholm Förhandlingar, 108: 225–234.
Grahn, Y. 1980. Early Ordovician Chitinozoa from Öland. Sveriges Geologiska Undersöknings C, 775: 1–41.
Grahn, Y. 1981. Ordovician Chitinozoa from the Stora Åsbodarp boring in Västergötland, south-central Sweden. Sveriges Geologiska Undersöknings C, 787: 1–40.
Grahn, Y. 1984. Ordovician Chitinozoa from Tallinn, northern Estonia. Review of Palaeobotany and Palynology, 43: 5–31.
Grahn, Y. & Nõlvak, J. 1993. Chitinozoan dating of Ordovician impact events in Sweden and Estonia. A preliminary note. Geologiska Föreningen i Stockholm Förhandlingar, 115: 263–264.
Henkel, H. & Pesonen, L. J. 1992. Impact craters and crateriform structures in Fennoscandia. Tectonophysics, 216: 31–40.
Jaanusson, V. 1982. Introduction to the Ordovician of Sweden. In Bruton, D. L. & Williams, S. H. (Eds), IV International Symposium on the Ordovician System. Field Excursion Guide, 1–90, Palaeontological Contributions from the University of Oslo, 279.
Jenkins, W. A. M. 1967. Ordovician Chitinozoa from Shropshire. Palaeontological Society, 10: 436–488.
Lindström, M. 1971. Vom Anfang, Hochstand und Ende eines epikontinentalmeeres. Geologische Rundschau, 60: 419–438.
Lindström, M. & Sturkell, F. F. 1992. Geology of the Early Palaeozoic Locke impact structure, Central Sweden. Tectonophysics, 216: 169–186.
Lindström, M., Flodén, T., Grahn, Y., & Kathol, B. 1994. Post-impact deposits in Tvären, a marine Middle Ordovician crater south of Stockholm, Sweden. Geological Magazine, 131: 91–103.
Männil, R. 1986. Stratigraphy of kuckersite-bearing deposits C1b–C3. In Puura, V. (Ed.), Geology of the Kuckersite-bearing beds of the Baltic oil shale basin, 12–24, Institute of Geology. Estonian Academy of Science, Tallinn. [In Russian.]
Merrill, G. K. 1980. Ordovician conodonts from the Åland Islands, Finland. Geologiska Föreningen i Stockholm Förhandlingar, 101: 329–341, Stockholm.
Nilsson, R. 1983. The Didymograptus hirundo and Akiograptus ascensus Zones of the Lovisefred core, NW Scania, south Sweden. Geologiska Föreningen i Stockholm Förhandlingar, 105: 261–267.
Nõlvak, J. & Grahn, Y. 1993. Ordovician chitinoman zones from Baltoscandia. Review of Palaeobotany and Palynology, 79: 245–269.
Paris, F. 1981. Les Chitinozoaires dans le Paléozoique du Sud-Ouest de l’Europe. Mémoires de la Société géologique et minéralogique de Bretagne, 26: Rennes.
Pöima, L., Sarv, L. & Hints, L. 1988. Lithology and fauna of the type sections of the Caradoc Series in North Estonia. 1–101, Institute of Geology. Estonian Academy of Sciences, Tallinn.
Puura, V. & Suuroja, K. 1992. Ordovician impact crater at Kardla, Hiiumaa Island, Estonia. Tectonophysics, 216: 143–156.
Simon, H. 1987. Stratigraphie, Petrographie et Entstehungsbedingungen von Grobklastika in der autochthonen, ordovizischen Schichtenfolge Jämlands (Schweden). Sveriges Geologiska Undersökning, C 815: 1–156.
Thorslund, P. 1940. On the Chasmops series of Jämland and Södermanland (Tvären). Sveriges Geologiska Undersökning, C 436: 1–191.
Winterhalter, B. 1982. The bedrock geology of Lumparen Bay, Åland. Geological Survey of Finland. Bulletin, 317: 116–129.