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# CHITINOZOAN BIOSTRATIGRAPHY OF THE MIDDLE ORDOVICIAN DALBY LIMESTONE IN THE FJÄCKA SECTION, SILJAN DISTRICT, SWEDEN

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**Abstract**. The main section at Fjäcka, Dalarna, is a classic Ordovician locality in Sweden. It is the type section of three North Atlantic conodont zones and subzones, three Baltoscandian chitinozoan zones, and of several topoformations. Detailed analysis of chitinozoan distribution in the Middle Ordovician Upper Dalby Limestone showed variable thickness of chitinozoan biozones caused by block movements, as well as clear variations in the content of acid-resistant organic-walled fossils in different blocks. Nevertheless, the boundary of the East Baltic Kukruse and Haljala stages was established in one part of the section, and a composite section was worked out in spite of some complications caused by tectonic dislocation of beds.

**Key words**: Middle Ordovician, Sweden, Dalby Limestone, biostratigraphy, chitinozoans.

## INTRODUCTION

The initial purpose of the present study was to ascertain whether any traces of the Lockne impact in Jämtland (Lindström & Sturkell, 1992; Lindström et al., 1996; Grahn et al., 1996; Grahn, 1997) existed in the contemporaneous sedimentary sequence of the Siljan district, some 200 km to the south. The

appropriate interval in the main section at Fjäcka (localities 7 and 8 in Jaanusson, 1947, fig. 1; 1963, fig. 11) was closely examined macrolithologically as well as with respect to the succession of acid-resistant organic-walled microfossils, mainly chitinozoans.

No indications of the Lockne impact were found, which were expected to occur in the lithology of beds at locality 8. Chitinozoans, however, yielded new biostratigraphic information, and thus the chitinozoan biostratigraphy is the main subject of the present contribution.

The main section at Fjäcka is a classic Ordovician locality of Sweden and one of the best studied sections of the Central Baltoscandian Confacies. It is situated along the Moldå Stream at Fjäcka in Dalby village, Siljan District, Dalarna. Törnquist (1867) first described the locality as a group of isolated exposures including a small, now abandoned quarry. During 1945–47 the section was excavated, and a continuous outcrop from the upper Furudal Limestone to the Jonstorp Formation was exposed (Jaanusson, 1982, p. 36). Fossils and lithology have been described in numerous papers (Jaanusson, 1947, 1962, 1963, 1976, 1982; Jaanusson & Martna, 1948; Martna, 1955; Laufeld, 1967; Bergström, 1971a, b; Holmer, 1989). In 1976 further excavations were carried out and the section was designated as a nature reserve. Bergström (1971a, b) defined the main section at Fjäcka as the type locality of three North Atlantic conodont zones: *Pygodus anserinus*, *Amorphognathus tvaerensis* (and its three subzones), and *A. superbus*. Nõlvak & Grahn (1993) used it as a reference section for three chitinozoan zones: *Lagenochitina dalbyensis*, *Belonechitina hirsuta*, and *Spinachitina cervicornis*. It is also the type locality of the Dalby, Moldå, and Fjäcka formations (Jaanusson, 1982).

## MATERIAL

The main series of samples from locality 8 is from the steep, some metres high bank. It was collected by E. F. F. Sturkell in 1995 along subsections 305 and 306 (Fig. 1). Five samples were provided by H. Bauert, collected during the WOGOGOB excursion in 1990, and additional samples were secured by J. Nõlvak in 1995. The sample intervals were kept particularly small in the levels where the chitinozoan zones are known to have a limited vertical range in other regions (see Nõlvak & Grahn, 1993). The size of the samples varied between 200 and 500 g. All material is deposited in the Institute of Geology, Tallinn.

In sampling the Dalby Limestone sequence at locality 8, the lowermost K-bentonite bed (about 9.5 m below the base of the complex of K-bentonite beds according to Jaanusson, 1963, fig. 9; or 11 m below the Kinnekulle bed after Bergström et al., 1995, fig. 2) was used as an index horizon (level B-1, Figs.1, 2).

Another locality (No. 7 in Jaanusson, 1947, fig. 1; and along subsections 13 and 14, see Figs. 1, 3 herein) was sampled by J. Nõlvak in 1992, just adjacent to

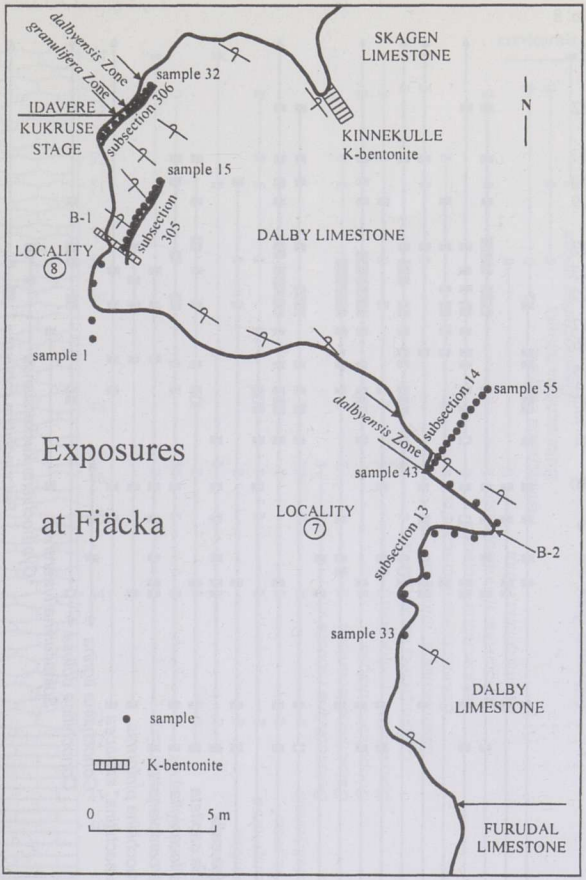


**Fig. 1.** Sketch-map of the southern part of the exposures at Fjäcka. Localities 7 and 8 according to Jaanusson (1947, fig. 1). The thick line outlines the area of small terraces or acclivities (locality 8) or the edge of the old quarry (locality 7).

the northeastern corner of the abandoned old quarry. In this area the bedrock probably became first exposed in 1976 (V. Jaanusson, pers. comm. 1997). The most argillaceous bed (level B-2, Figs. 1, 3) was used as an index horizon. The beds (subsection 14) with chitinozoans indicating the *L. dalbyensis* Zone rest on limestones (subsection 13, samples 33–42) barren of acid-resistant organic-walled macro- and microfossils, such as acritarchs, scolecodonts, graptoloids, dendroids, organic-walled foraminifera, hydroids, and chitinozoans. The lack of chitinozoans was already noticed by Laufeld (1967, p. 292). Nevertheless, the absence of chitinozoans and the other fossils has no regional significance, since at locality 8, only 15 m to the northwest, the lowermost beds contain all mentioned groups of fossils (see samples 1–4 and higher, Figs. 1, 2). Lithologically these

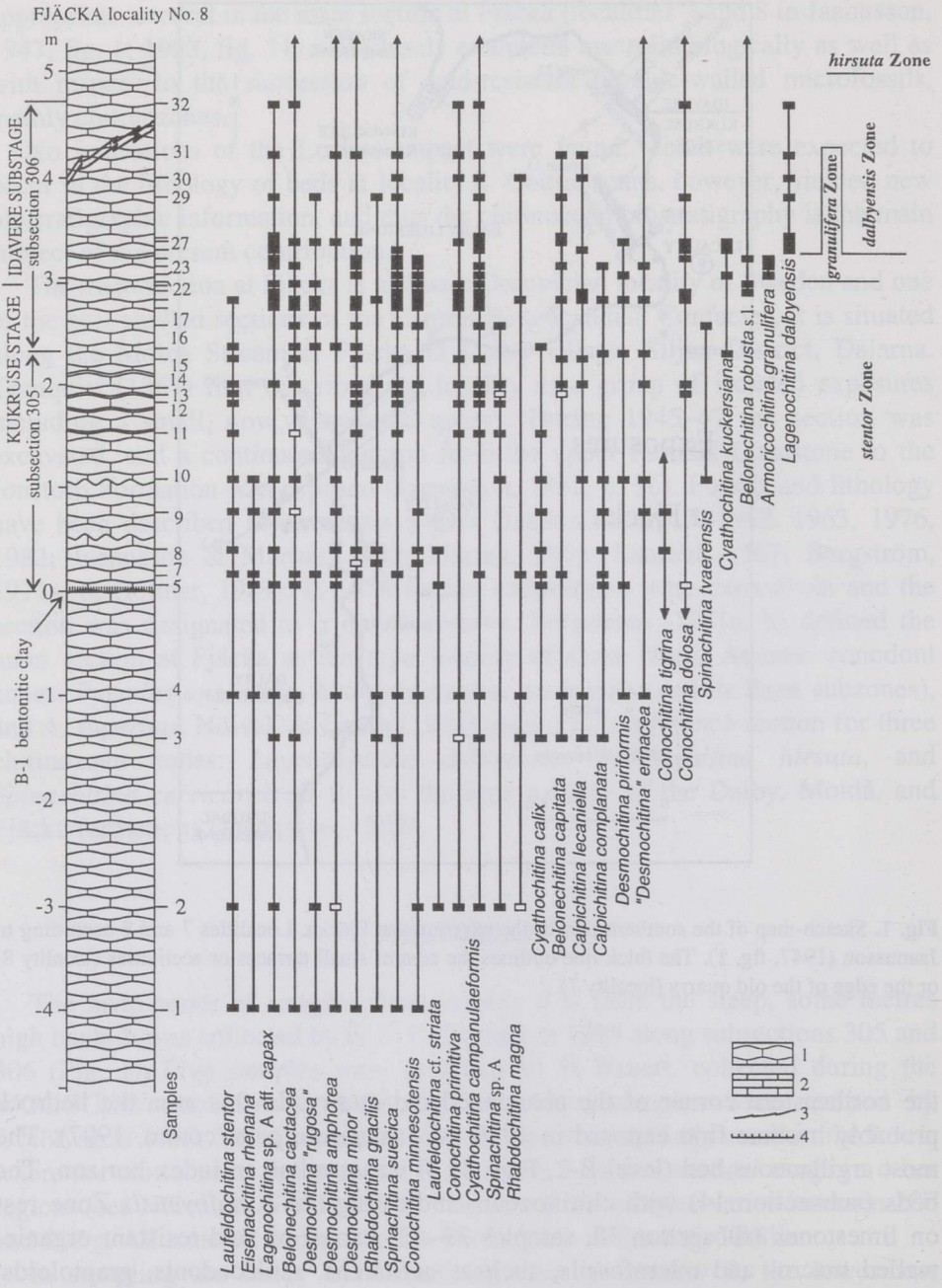


**Fig. 2.** Faunal log showing the range of chitinozoans in the upper part of the Dalby Limestone (Upper Member in Jaanusson, 1982, p. 38) at Fjäcka locality 8. 1, seminodular limestone (parallel lines mark clayey intercalations); 2, bedded limestone; 3, fault; 4, K-bentonite bed. Open squares represent forms referred to as cf. The lower boundary of the *hirsuta* Zone, about 5 m above the bentonitic clay layer, is shown according to the data from sample 60-166 in Laufeld (1967).

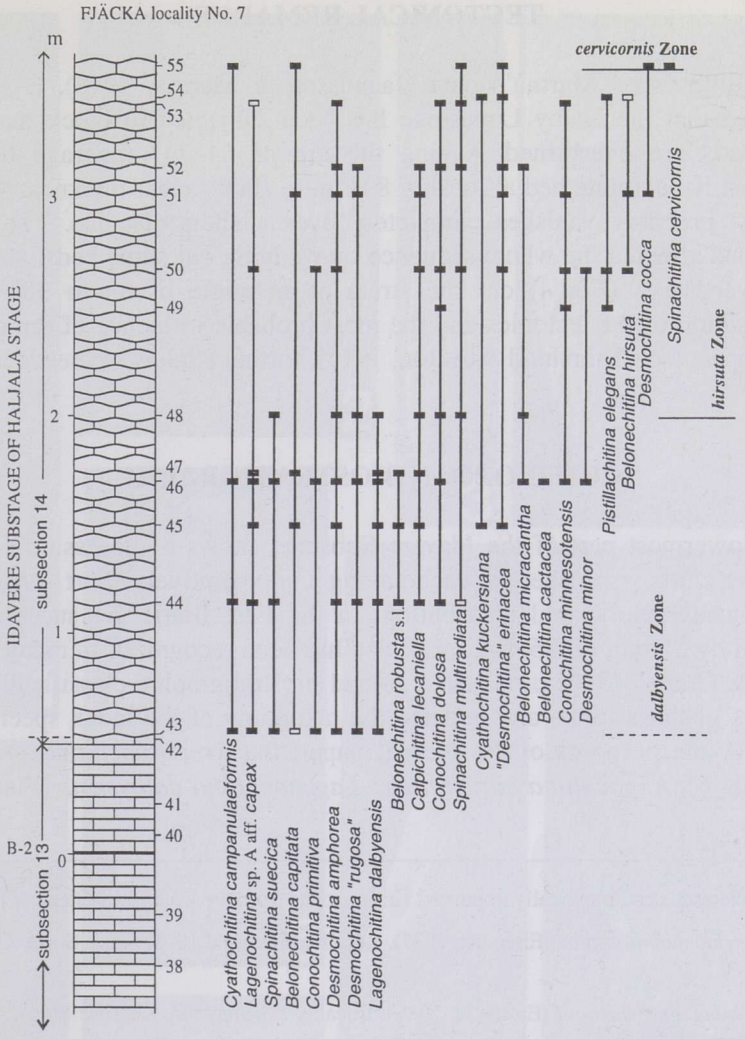


**Fig. 3.** Faunal log showing the range of chitinozoans in the middle part of the Dalby Limestone at Fjäcka locality 7. Barren samples 33–37 (see Fig. 1) are not shown. The dashed line marks the appearance level of chitinozoan fauna. For legend refer to Fig. 2.

fossiliferous rocks are grey, somewhat nodular limestones with irregular argillaceous intercalations. However, barren limestones in the limits of subsection 13 are clearly more greenish (more weathered?) and less nodular, although in general the same as described by Jaanusson (1982, p. 39).

Subsection 14 continues upwards into the *B. hirsuta* Zone (Plate, fig. 9) and the basal *S. cervicornis* Zone (Fig. 3). The position of these zones is abnormally low and indicates some tectonic dislocation.

## TECTONICAL REMARKS

In addition to J. Martna's data (Jaanusson & Martna, 1948), it should be mentioned that the Dalby Limestone has been subjected to block movements. These beds are overturned, having the dip of 64–74° (average 68°). The lowermost K-bentonite bed at locality 8 (Fig. 1) shows clear thickness variations and most probably vanishes completely over a short distance. The tectonic movements affected the whole sequence by wedging out some beds, and several small overthrusts (Fig. 4) cut the strata at an angle of up to 30°. For the reconstruction of the tectonics and the most probable influence of the Devonian Siljan impact (see Thorslund & Auton, 1975), further studies are needed.

## CHITINOZOAN BIOSTRATIGRAPHY

The lowermost part of the Idavere Substage shows a succession of several distinctive chitinozoan species, each having a comparatively short vertical range but a considerable spatial distribution. In the East Baltic the succession was described by Männil (1986, fig. 2.1.1) and has been recognized in many sections. Nõlvak & Grahn (1993) proposed a formal biostratigraphic classification based on ranges of these forms and updated the taxonomy of the index species of the zones. For the purposes of the present paper, the *Armoricochitina granulifera* (Plate, fig. 6), *Angochitina curvata*, and *Lagenochitina dalbyensis* (Plate, fig. 8)

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PLATE. Selected, stratigraphically important chitinozoans from the Dalby Limestone at Fjäcka.

Fig. 1. *Laufeldochitina stentor* (Eisenack, 1937). Locality 8, sample 10, Kukruse Stage. Ch 2075/10, SEM × 140.

Fig. 2. *Eisenackitina rhenana* (Eisenack, 1939). Locality 8, sample 9, Kukruse Stage. Ch 2242/9, SEM × 515.

Figs. 3, 4. *Conochitina tigrina* Laufeld, 1967. Locality 8, sample 8, Kukruse Stage. Ch 2210/8, SEM × 100, × 405.

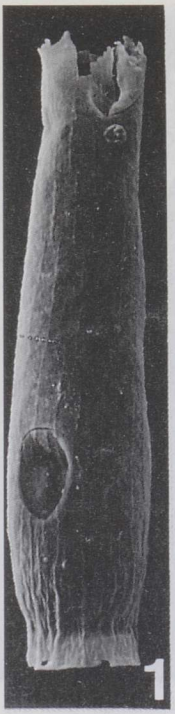
Figs. 5, 10. *Spinachitina tvaerensis* Grahn, Nõlvak & Paris, 1996. Locality 8, sample 10, Kukruse Stage. Ch 2083/10, SEM × 300, × 960.

Fig. 6. *Armoricochitina granulifera* Nõlvak & Grahn, 1993. Locality 8, sample 24, Idavere Substage. Ch 2257/24, SEM × 255.

Fig. 7. *Lagenochitina* sp. A aff. *capax*. Locality 7, sample 44, Idavere Substage. Ch 2229/44, SEM × 650.

Fig. 8. *Lagenochitina dalbyensis* (Laufeld, 1967). Locality 7, sample 43, Idavere Substage. Ch 2127/43, SEM × 400.

Fig. 9. *Belonechitina hirsuta* (Laufeld, 1967). Locality 7, sample 51, Idavere Substage. Ch 2113/51, SEM × 480.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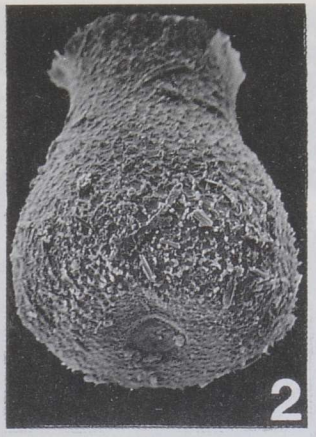
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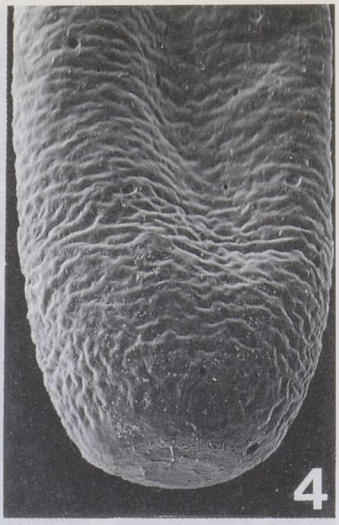
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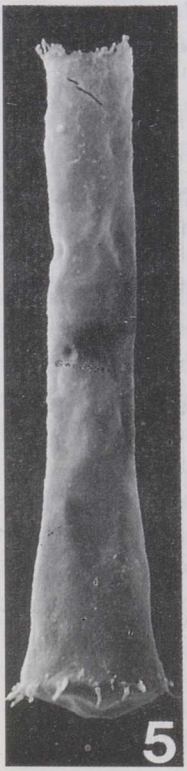
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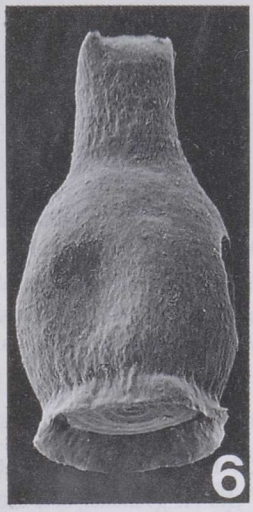
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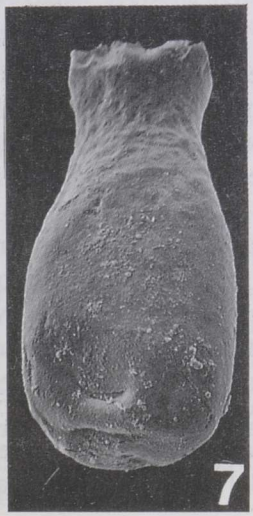
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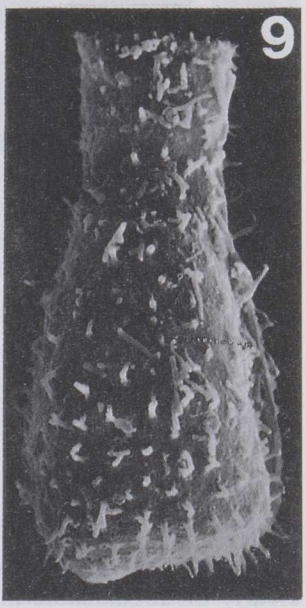
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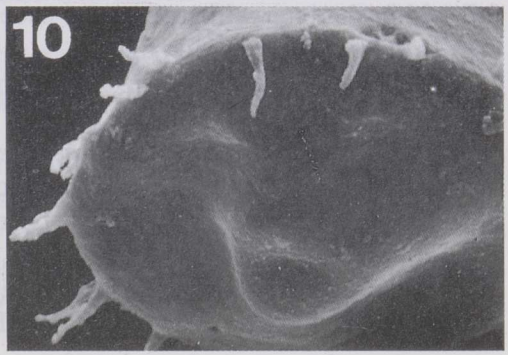
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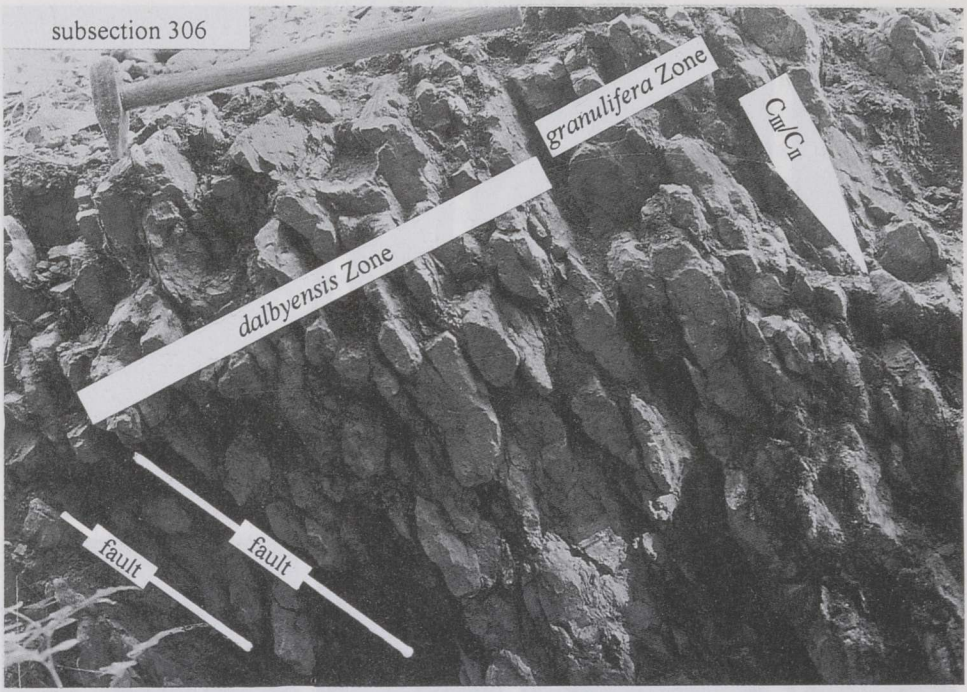


**Fig. 4.** Overthrusts and thickness of layers with chitinozoan biozones in the lowermost Idavere Substage in subsection 306 (see Fig. 1). $C_{II}$, Kukruse Stage; $C_{III}$, Idavere Substage of the Haljala Stage. Note the differences in the thickness of the *dalbyensis* Zone caused by faults.

zones are of particular interest. It should be noted that the base of the Idavere Substage was proposed to specify as that of the *A. granulifera* Zone (Hints et al., 1995).

Previous information on chitinozoans from the main section at Fjäcka is confined to Laufeld (1967), which can be regarded as a pioneer work on the biostratigraphy of Ordovician chitinozoans. There, the *L. dalbyensis* Zone is clearly distinguishable in the faunal log, but the beds containing *A. granulifera* fall within the interval between two successive samples analysed (60-170 and 60-174 in Laufeld, 1967, fig. 6).

Unfortunately, the sample size of 50 g has proved to be too small in the whole Baltoscandia to yield sufficient data on Ordovician chitinozoans. Our study revealed firm presence of the *A. granulifera* Zone (Figs. 2, 4) with a thickness not exceeding 15 cm. The recognition of this chitinozoan zone is of great importance for a precise correlation between the sequences of the North Estonian and Lithuanian Confacies and that of the Siljan district. In the main section at Fjäcka, the level of the base of the Haljala Stage (and Idavere Substage) is situated 2.9 m above the K-bentonite bed (B-1 in Fig. 2) in subsection 306.

*Angochitina curvata* Nõlvak & Grahn has not been encountered at Fjäcka. The thickness of the corresponding zone in North Estonian sections is often only a few centimetres, so the bed containing the zonal fossils may simply have been missed in the Fjäcka section.

An additional detail which may have biostratigraphic significance is the occurrence of abundant acritarchs *Leiosphaeridia* sp. in a thin bed just below the *A. granulifera* Zone (sample 22, Figs. 2, 4) and in higher levels at Fjäcka. Such a mass occurrence of acritarchs is widespread at the same level also in North Estonian sections, being a useful, and not only a local indication of the lower boundary of the Idavere Substage (Nõlvak, 1972, fig. 2).

The chitinozoan succession of the upper Dalby Limestone below the *A. granulifera* Zone agrees with that in many Estonian and Swedish sections (Grahn et al., 1996). The highest level of *Laufeldochitina stentor* (Eisenack) (Plate, fig. 1) is just below the base of the *A. granulifera* Zone. *Eisenackitina rhenana* (Eisenack) (Plate, fig. 2), which is, most probably, not separated from *Belonechitina cactacea* in samples 60-184, 60-182, 60-178, 60-174 by Laufeld (1967, fig. 6), disappears somewhat lower down. It is also interesting to note that two distinctive species, *Conochitina tigrina* Laufeld (Plate, figs. 3, 4) and *Spinachitina tvaerensis* Grahn, Nõlvak & Paris (Plate, figs. 5, 10; the latter species was described from the Tvären impact crater by Grahn et al., 1996, fig. 6), which are characteristic of the upper part of the *Laufeldochitina stentor* Zone, occur at Fjäcka roughly in the same interval. *Lagenochitina* sp. A aff. *capax* (Plate, fig. 7) has the same vertical range as in East Baltic sections (Grahn et al., 1996, p. 34).

The material from Fjäcka includes also several new chitinozoan species, but their description is postponed to a separate paper.

To sum up, we may note that the succession of comparatively short-range chitinozoans in the main section at Fjäcka is the same as in the earlier studied East Baltic Ordovician sections (Nõlvak & Grahn, 1993, fig. 6). Bed-by-bed sampling of lithologically variable rocks has revealed the presence of some very short-range chitinozoan zones.

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## REFERENCES


Bergström, S. M. 1971a. Conodont biostratigraphy of the Middle and Upper Ordovician of Europe and Eastern North America. In *Symposium on Conodont Biostratigraphy* (Sweet, W. C. & Bergström, S. M., eds.). *Geol. Soc. Am. Mem.*, **127**, 83–157.

Bergström, S. M. 1971b. Correlation of the North Atlantic Middle and Upper Ordovician conodont zonation with the graptolite succession. *Mem. Bur. rech. geol. minieres*, **73**, 177–187.

Bergström, S. M., Huff, W. D., Kolata, D. R. & Bauert, H. 1995. Nomenclature, stratigraphy, chemical fingerprinting, and areal distribution of some Middle Ordovician K-bentonites in Baltoscandia. *Geol. Fören. Stockh. Förh.*, **117**, 1–13.

Grahn, Y. 1997. Chitinozoan biostratigraphy of the early Caradocian Lockne impact structure, Jämtland, Sweden. *Meteoritics Planet. Sci.*, **32**, 745–751.

Grahn, Y., Nõlvak, J. & Paris, F. 1996. Precise chitinozoan dating of Ordovician impact events in Baltoscandia. *J. Micropalaeontol.*, **15**, 21–35.

Hints, L., Meidla, T. & Nõlvak, J. 1995. Ordovician sequences of the East European Platform. *Geologija (Vilnius)*, 1994, 17, 58–63.

Holmer, L. E. 1989. Middle Ordovician phosphatic inarticulate brachiopods from Västergötland and Dalarna, Sweden. *Fossils and Strata*, **26**.

Jaanusson, V. 1947. Zur Fauna und zur Korrelation der Kalksteine mit *Illaenus crassicauda* (sog. Flagkalk) im Siljan-Gebiet Dalarnas. *Geol. Fören. Stockh. Förh.*, **69**, 41–50.

Jaanusson, V. 1962. Two Plectambonitacean brachiopods from the Dalby Limestone (Ordov.) of Sweden. *Bull. Geol. Inst. Univ. Upps.*, **39**, 1–8.

Jaanusson, V. 1963. Lower and Middle Viruan (Middle Ordovician) of the Siljan district. *Bull. Geol. Inst. Univ. Upps.*, **42**, 1–40.

Jaanusson, V. 1976. Faunal dynamics in the Middle Ordovician (Viruan) of Balto-Scandia. In *The Ordovician System: Proceedings of a Palaeontological Association Symposium* (Bassett, M. G., ed.), pp. 301–326. University of Wales Press, Cardiff.

Jaanusson, V. 1982. The Siljan District. In *IV. International Symposium on the Ordovician System. Field Excursion Guide* (Bruton, D. L. & Williams, S. H., eds.). *Palaeontol. Contrib. Univ. Oslo*, **279**, 15–42.

Jaanusson, V. & Martna, J. 1948. A section from the Upper *Chasmops* Series to the Lower *Tretaspis* Series at Fjäcka rivulet in the Siljan area, Dalarna. *Bull. Geol. Inst. Univ. Upps.*, **32**, 183–193.

Laufeld, S. 1967. Caradocian Chitinozoa from Dalarna, Sweden. *Geol. Fören. Stockh. Förh.*, **89**, 275–349.

Lindström, M. & Sturkell, E. F. F. 1992. Geology of the Early Palaeozoic Lockne impact structure, Central Sweden. *Tectonophysics*, **216**, 169–185.

Lindström, M., Sturkell, E. F. F., Törnberg, R. & Ormö, J. 1996. The marine impact crater at Lockne, Central Sweden. *Geol. Fören. Stockh. Förh.*, **118**, 193–206.

Männil, R. 1986. Stratigraphy of kukersite-bearing deposits $C_1b$–$C_{III}$. In *Geology of the Kukersite-Bearing Beds of the Baltic Oil Shale Basin* (Puura, V., ed.), pp. 12–24. Valgus Publishers, Tallinn.

Martna, J. 1955. Studies on the Macrourus and Slandrom Formations I. *Geol. Fören. Stockh. Förh.*, **77**, 275–349.

Nõlvak, J. 1972. A characterization of the boundary beds of the Kukruse and Idavere stages in the Lipu boring. *Loodusuurijate Seltsi aastaraamat*, **61**, 39–59. Valgus Publishers, Tallinn.

Nõlvak, J. & Grahn, Y. 1993. Ordovician chitinozoan zones from Baltoscandia. *Rev. Palaeobot. Palynol.*, **79**, 245–269.

Thorslund, P. & Auton, C. 1975. Evidence of meteorite impact in the Siljan structure, Central Sweden. *Bull. Geol. Inst. Univ. Upps. N.S.*, **6**, 69–72.

Törnquist, S. L. 1867. Om lagerföljden i Dalarnas Undersiluriska bildningar. *Lunds Universitets Årsskrift*, **3**, 1–20.

## KITIINIKUTE BIOSTRATIGRAAFIA KESKORDOVIITSIUMI FJÄCKA LÄBILÕIKE DALBY LUBJAKIVIDES SILJANI PIIRKONNAS ROOTSIS

Jaak NÕLVAK, Yngve GRAHN ja Erik F. F. STURKELL

On esitatud andmed kitiinikute leviku kohta Rootsi Siljani piirkonna Fjäcka tüüpläbilõike keskordoviitsiumi kihtides. Uuritud läbilõikest on defineeritud mitmeid Põhja-Atlandi provintsi konodontide biotsoone ja Baltoskandia kitiinikute biotsoone, mis võimaldavad suhteliselt täpseid korrelatsioone ordoviitsiumibasseini osade vahel. Detailsete prooviseeriatega tehti kindlaks Idavere alamlademe varem vaid Baltikumi läbilõigetes määratud alumine piir, mis on põhjendatud 15 cm paksuse *Armoricochitina granulifera* biotsooni levikuga. Raskused ilmnesid Fjäcka läbilõikes levivate fossiilideta kihtide vanuselise järjestuse määramisel paljandi eri osades, sest kihtide lasumus on ilmselt mõjutatud devoniaegse Siljani impaktkraatri tekkeprotsessidest.

## БИОСТРАТИГРАФИЯ ХИТИНОЗОЙ В СРЕДНЕОРДОВИКСКИХ ИЗВЕСТНЯКАХ ДАЛБЮ В РАЗРЕЗЕ ФЯКА, РАЙОН СИЛЬЯН, ШВЕЦИЯ

Яак НЫЛВАК, Ингве ГРАН и Эрик Ф. Ф. СТУРКЕЛЛ

Приведены подробные данные о распределении хитинозой в стратотипических известняках Далбю в разрезе Фяка. В этом разрезе обнаружен ряд стратиграфически важных зон конодонтов для Северо-Атлантической провинции и хитинозой для Балтоскандии, по наличию которых можно сравнительно точно сопоставить между собой разрезы в разных регионах ордовикского Балтийского бассейна. По распространению в прибалтийских разрезах узкой (мощностью 15 см) биозоны *Armoricochitina granulifera* установлен уровень нижней границы идавереского подгоризонта. Выяснено, что затруднения при определении возрастных соотношений "немых" слоев в разных частях обнажения обусловлены нарушением их залегания в процессе образования девонского метеоритного кратера в районе Сильяна.