

Upper Wenlock to Lower Pridoli (Silurian) conodont biostratigraphy of Saaremaa, Estonia, and a correlation with Britain

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ABSTRACT – The closely related conodonts *Ozarkodina bohémica*, *O. snajdri* and *O. crispa* form a clade that provides useful biostratigraphical indices through the upper Silurian. Collections from boreholes and surface outcrops on Saaremaa and from a borehole at Kolka, Latvia, contain new morphotypes of *O. bohémica* and *O. crispa*. A new subspecies, *O. snajdri parasnajdri*, is also distinguished, occurring above *O. crispa* in the Kuressaare and lowermost Kaugatuma stages. Evidence from conodonts and other fossils, primarily chitinozoans, ostracods and ichthyoliths, can be used to correlate the upper Silurian succession of Saaremaa with those of the Welsh Borderland and Gotland, although some problems remain to be solved. The microfossil distribution suggests that there may be a major break at the base of the Ludlow Bone Bed Member at Ludlow, equivalent to the Kuressaare Formation on Saaremaa. *J. Micropalaeontol.* 17(1): 33–50, April 1998.

INTRODUCTION

The study of the Silurian rocks of Estonia dates back to the last century, with the establishment of a Lower Palaeozoic stratigraphical scheme by Schmidt (1858). Details were added in the earlier part of this century, and more recently scientific investigations have been considerably advanced by a group of researchers at the Institute of Geology, Estonian Academy of Sciences, working under the leadership of D. Kaljo. Modern research has been greatly facilitated by the availability of numerous boreholes drilled by the Estonian Geological Survey, and a large number of papers and monographs has been published on Lower Palaeozoic palaeontology, stratigraphy and facies distribution. General summaries of the main results of this work may be found in volumes edited by Kaljo (1970, 1977), Kaljo & Klaamann (1982*a,b*) and Kaljo & H. Nestor (1990).

The current understanding of the Silurian stratigraphy of Estonia has been summarised by H. Nestor (1993) and the Wenlock–Pridoli correlation chart is shown in Fig. 1. The main stratigraphical units are regional chronostratigraphical stages, within which separate local lithostratigraphical units are distinguished in different parts of the Baltic basin (Bassett *et al.*, 1989). The local units reflect facies differences: Central Estonia and most of Saaremaa (Fig. 2) are dominated by shallow-water facies, whereas in South Estonia and on the Sõrve Peninsula of southern Saaremaa deeper water shelf and outer shelf sediments prevail (H. Nestor & Einasto, 1977; Bassett *et al.*, 1989). Gradual shifts of the facies belts occurred during the evolution of the basin.

The present paper deals with the succession representing the late Wenlock to early Pridoli interval, embracing the Rootsiküla, Paadla, Kuressaare and Kaugatuma stages. In the absence of graptolites, the correlation of these stages and their representative formations with other areas is currently only approximate. The Rootsiküla Formation is considered to correspond to the late Wenlock Klinte Secundo Episode of Jeppsson *et al.* (1995), when very variable shallow-water sediments were deposited with characteristic cyclic alternation of limestones and primary dolomites. The total thickness is 25–32 m, and the sediments

display frequent discontinuity surfaces, mud cracks, ripple marks and trace fossils. Abundant stromatolites and oncolites occur, but the fauna is restricted to eurypterids, thelodonts and conodonts. The Paadla Formation is 26–32 m thick and consists of detrital biomorphous and biohermal stromatoporoid-coral limestones, dolomites and marls. A hiatus beneath the base, established from chitinozoan data, has been reported to eliminate almost all local equivalents of the lower Ludlow Gorstian Stage in parts of the region (Nestor, V., 1982, 1990). The Kuressaare Formation comprises a broadly similar range of lithologies to those found in the Paadla, but there is a rich fauna that includes ostracods and thelodonts, both of which have proved useful in local correlations. Published conodont data are currently limited, with more precision required on the ranges of key taxa (Kaljo, 1990). Indirect correlation suggests that the Kuressaare Stage is at the level of the *formosus/balticus* standard graptolite biozone (Kaljo, 1990).

In this contribution, we present details of the distribution of key conodont species in exposed sections and borehole cores on the island of Saaremaa, Estonia, and in a borehole from Kolka, Latvia (Fig. 2). The evolving species complex comprising taxa referred to *Ozarkodina bohémica* (Walliser), *O. snajdri* (Walliser) and *O. crispa* (Walliser) is of particular importance, and this group is given especial attention. The conodont data are used in conjunction with information from other fossils to assess the correlations between the Estonian succession and those of Britain and other areas.

BACKGROUND TO CONODONTS

The *Ozarkodina bohémica* lineage

The oldest reported member of this lineage is *O. bohémica* subsp. nov. of Aldridge (1985, pl. 3.3, figs 13 a, b), from the lowermost Wenlock of Whitfield, Gloucestershire, England. Above this, there is a gap in records until well into the Homerian Stage (upper Wenlock), where *O. bohémica bohémica* is widely distributed. Ludlow representatives of the same lineage include *O. snajdri*, which appears in the upper part of the Gorstian Stage, and *O. crispa*, of latest Ludlow age; these two were

Series	Baltic Regional Stages	Central & West Estonia	West – Estonian Islands	South Estonia, North Latvia, Sorve Peninsula
PŘIDOLÍ	OHESAARE			Kaavi Mb. Ohesaare Fm. U. Lõo Beds
	KAUGATUMA K _{3b}		Kaugatuma Fm. U. Äigu Beds L. Äigu Beds	Kaugatuma Fm. L. Lõo Beds U. Äigu Beds L. Äigu Beds
LUDLOW	KURESSAARE K _{3a}		Kuressaare Fm. Kudjape Beds Tahula Beds	Kuressaare Fm. Kudjape Beds Tahula Beds
	PAADLA K ₂		Kinnu Fm. Paadla Fm. Uduvere Beds Himmiste Beds Sauvere Beds	Torgu Fm.
WENLOCK	ROOTSIKÜLA K ₁		Sakla Fm. Rootsiküla Fm. Soeginina Beds Vesiku Beds Kuusnõmme Beds Viita Beds	Rootsiküla Fm. Soeginina Beds Vesiku Beds Kuusnõmme Beds Viita Beds
	JAAGARAHU J ₂		Tagavere Fm. Maasi Fm. Kesselaid Fm. Paramaja Mb. Mustjala Mb.	Sörve Fm. Jamaja Fm.
	JAANI J ₁	Anelema Fm. Jaani Fm.	Muhu Fm. Jaagarahu Fm. Pangamägi Fm. Viisandi Fm. Ninase Mb. Riksu Fm.	Riga Fm. Tõlla Beds

Fig. 1. Current correlation chart of Wenlock–Přidolí stratigraphical units in Estonia and Latvia (from Nestor, 1993).

considered to be important fossils by Walliser (1964) in his conodont biozonation of the Silurian.

Early views of the relationships of these species varied. Walliser (1964) included *O. bohémica* as a subspecies of *O. sagitta* (Walliser) and commented that *O. snajdri* may be a descendant of *O. excavata* (Branson & Mehl). Pollock & Rexroad (1973) suggested that *O. snajdri* was ancestral to *O. remscheidensis eosteinhornensis* (Walliser), or that they shared common ancestry, and Mehrstens & Barnett (1976) also considered *O. snajdri* to be the ancestor of *O. eosteinhornensis*. Helfrich (1975) used morphological characteristics of Pa elements and multielement patterns to identify a '*Spathognathodus sagitta bohemicus* Lineage' which incorporated taxa that would now be referred to as *O. bohémica bohémica*, *O. bicornuta* (Helfrich), *O. snajdri*, *O. tillmani* (Helfrich), *O. crispa* and, tentatively, his N. gen. et n. sp. (Helfrich, 1975, pl. 16, figs 1–3, 6). The latter has subsequently been described as *Homeognathodus peniculus* (Denkler & Harris, 1988). Helfrich (1975) recorded that all Pa elements of this lineage possess a basal cavity of similar form which closes before the posterior tip of the blade in stratigraphically older forms but extends further posteriorly relative to the posterior blade in successively younger species. A further characteristic of all the Pa elements, except that of *O. bicornuta*, is a tendency towards fusion of denticles above the basal cavity.

Aldridge & Schönlaub (1989) stated that *O. crispa* was a direct descendant of *O. snajdri*, and that the two occurred in

stratigraphical succession. Miller (1995) agreed that *O. crispa* originated in *O. snajdri*, but showed that intermediate forms occurred in the Welsh Borderland at stratigraphically higher levels than the first occurrence of *O. crispa*, so the relationship was not one of simple phyletic transition.

The succession of these conodonts on Saaremaa is comparable with that identified by Helfrich (1975). *Ozarkodina bohémica bohémica*, *O. aff. bicornuta*, *O. snajdri snajdri* and *O. crispa* are all recognized, and some specimens of *O. crispa* are transitional to *O. tillmani*. The youngest representatives, above the last occurrence of *O. crispa*, are clearly of *snajdri* affinities and are here referred to as *O. snajdri parasnajdri* subsp. nov.

Previous records of *O. snajdri* and *O. crispa*

The holotype of *O. snajdri* is from Muslovka Quarry, Bohemia, a few metres below the base of the *ultimus* graptolite biozone, while that of *O. crispa* is from Santa Creu, Spain (Walliser, 1964). In his conodont biozonation, Walliser (1964) included a '*crispus* zone' in the uppermost Ludlow, and a '*snajdri*-Horizon' within the upper part of the middle/upper Ludlow *siluricus* zone; *O. crispa* was represented in samples from his reference section at Cellon in the Carnic Alps, whereas *O. snajdri* was not.

Subsequent records produced some uncertainties about the ranges of *O. snajdri*, *O. crispa* and the index taxon of the zone succeeding the '*crispus* zone', *O. r. eosteinhornensis*. Fähræus (1969) reported the Pa element of *O. crispa* on Gotland in strata above *O. r. eosteinhornensis*, leading Walliser (1971) to question

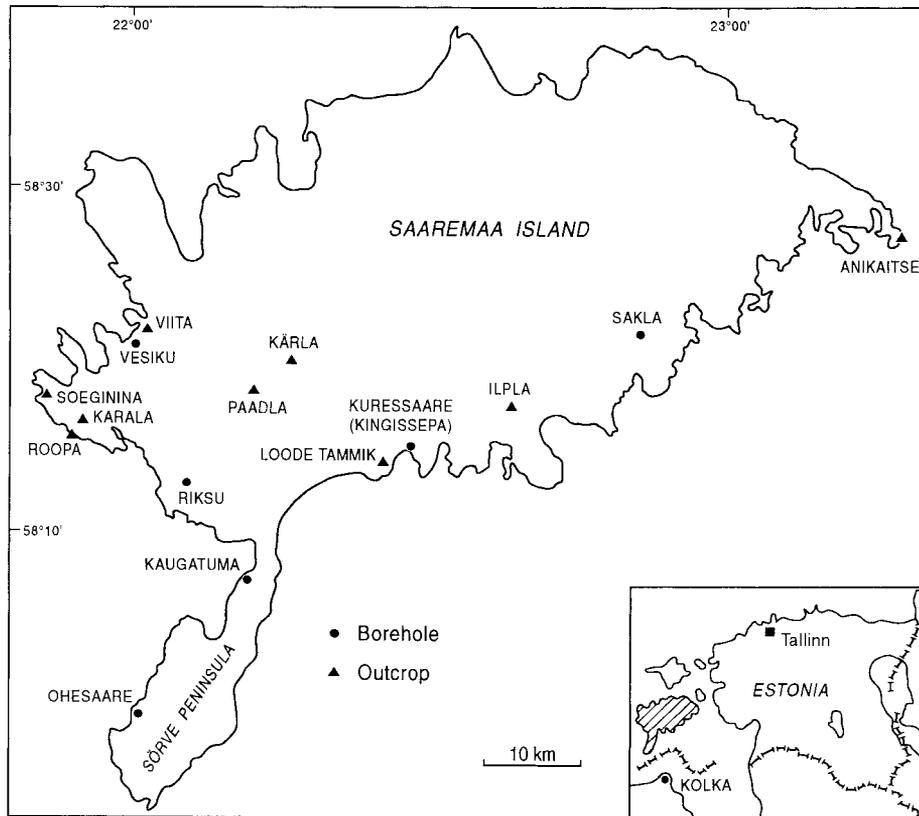


Fig. 2. Location map of outcrops (triangles) and boreholes (circles) on Saaremaa and northernmost Latvia.

whether the 'crispus zone' lay within the 'eosteinhornensis zone' or whether the two overlapped. In fact, the specimen illustrated by Fähræus (1969, pl. 2, figs 13, 14) may belong to *O. snajdri*, although subsequent work has resulted in records of *O. crispus* and representatives of the *steinhornensis* group in association on Gotland (Jeppsson, 1983; Jeppsson *et al.*, 1994) An association of *O. snajdri* with specimens referred to as primitive *O. r. eosteinhornensis* was reported by Rexroad & Craig (1971) in the Bainbridge Formation of Lithium, Missouri, and the two taxa were also recorded together in the Kokomo Limestone Member of the Salina Formation in north-central Indiana by Pollock & Rexroad (1973). The specimens illustrated by Pollock & Rexroad (1973, pl. 1, figs 30–34), however, show several characteristics of the Pa element of *O. crispus* and the specific assignment is equivocal. An overlap of the ranges of *O. crispus* and specimens referred to *O. r. eosteinhornensis* in North America was also found by Helfrich (1975) in the Central Appalachians, while Denkler & Harris (1988) reported that the range of *O. snajdri* in the same region began below that of *O. crispus* and terminated above it.

In Australia, De Deckker (1976) found some overlap of the ranges of *O. snajdri* and *O. crispus* in the Kildrummie Formation of New South Wales, and was the first to suggest that the range of *O. snajdri* might be longer than previously thought. He also considered a second possibility that the intraspecific variation of Pa elements of *O. crispus* may include specimens of similar

morphology to *O. snajdri*. However, his specimens are rather atypical, and resemble those described by Link & Druce (1972, pl. 9, figs 22–28) from the Yass Basin, New South Wales as *Spathognathodus* cf. *S. ranuliformis* Walliser, a species that is now assigned to the genus *Kockelella*.

In Europe, there are records of overlap between *O. snajdri* and *O. r. eosteinhornensis* s. l. in sections near Graz, Austria (Ebner, 1976) and in the uppermost Kopanina Formation of Pozarech Quarry, Bohemia (Mehrtens & Barnett, 1976). Feist & Schönlaub (1974) found *O. crispus*, *O. r. eosteinhornensis* s. l. and *Pedavis latialatus* (Walliser) together in the Montagne Noire, southern France, and Chlupác *et al.* (1980) demonstrated the overlap of *O. crispus* and *O. r. eosteinhornensis* s. l. in the Muslovka Quarry, Bohemia, leading to a proposal to incorporate a *crispus* subzone within the lower part of an extended *eosteinhornensis* zone. Chlupác *et al.* (1980) also showed an overlap in the ranges of *O. snajdri* and *O. crispus* in Kolednik Quarry, Bohemia. In Britain, uppermost Ludlow conodont faunas include *O. snajdri*, *O. cf. snajdri*, *O. crispus*, *O. cf. crispus*, *O. r. eosteinhornensis* s. l. and *O. remscheidensis baccata* Miller & Aldridge (Miller, 1995; Miller & Aldridge, 1997). In two sections, at Woolhope and at Tite's Point, Miller (1995) found *O. snajdri* above *O. crispus*.

In summary, all possibilities of co-occurrence of *O. snajdri*, *O. crispus* and specimens referred to *O. r. eosteinhornensis* are known; all three may occur together or any pairing. Only in

Bohemia are they represented in clearly succeeding order, in the Muslovka and Kolednik quarries, and even here there is some overlap of the ranges.

SYSTEMATIC DESCRIPTIONS

Systematics are given here for members of the *O. bohémica* lineage, based on material from Saaremaa. As noted by Miller & Aldridge (1997), there is some inconsistency regarding the usage of subspecies and morphotype designations in conodont taxonomy. We have followed the principle of retaining subspecies designations for populations that are separated in space and/or time; for morphological variants that occur together in some samples we have used morphotypes. The exceptions are where we subdivide subspecies or existing morphotypes: even if different forms seem to be chronologically or geographically separated, we have designated them as morphotypes.

Order **Ozarkodinida** Dzik, 1976

Family **Spathognathodontidae** Hass, 1959

Genus *Ozarkodina* Branson & Mehl, 1933

Ozarkodina bohémica bohémica (Walliser, 1964)

- 1964 *Spathognathodus sagitta bohémicus* Walliser: 83, pl. 7, fig. 4, pl. 18, figs 23, 24.
- 1964 *Ozarkodina edithae* Walliser: 55, pl. 26, figs 12–18.
- 1967 *Spathognathodus sagitta bohémicus* Walliser; Austin & Bassett: 278, pl. 14, fig. 19.
- 1967 *Spathognathodus* cf. *sagitta bohémicus* Walliser; Austin & Bassett: 279, pl. 14, fig. 20.
- ?1967 *Spathognathodus sagitta bohémicus* Walliser; Flajs: pl. 4, fig. 7.
- 1969 *Spathognathodus sagitta bohémicus* Walliser; Fähræus: pl. 2, figs 15, 16.
- 1975 *Spathognathodus sagitta bohémicus* Walliser; Helfrich: pl. 1, figs 2–4, 8, 12, 17, 20.
- 1975a *Ozarkodina sagitta bohémica* (Walliser); Aldridge: 327, pl. 47, fig. 21.
- 1975b *Ozarkodina sagitta bohémica* (Walliser); Aldridge: pl. 2, figs 18, 19.
- 1976 *Ozarkodina sagitta bohémica* (Walliser); Barrick & Klapper: 81, pl. 4, figs 1–7, 10, 12.
- 1981 *Ozarkodina sagitta bohémica* (Walliser); Aldridge, Dorning & Siveter: pl. 2.3, figs 1, 3.
- 1982a *Spathognathodus sagitta bohémica* Walliser; Viira: text-fig. 5.4, figs 31, 34.
- 1984 *Ozarkodina sagitta bohémica* (Walliser); Kozur: pl. 2, figs 4, 5.
- 1985 *Ozarkodina sagitta bohémica* (Walliser); Balogh & Kozur: pl. 2, fig. 5.
- 1985 *Ozarkodina bohémica bohémica* (Walliser); Aldridge: pl. 3.4, fig. 3.
- 1985 *Spathognathodus sagitta bohémicus* Walliser; Qiu: 32, pl. 2, figs 1–4.
- 1985 *Spathognathodus sagitta bohémicus* Walliser; Yu: 26, pl. 2, figs 1, 2, pl. 3, figs 1–3, 6, 11.
- 1987 *Ozarkodina sagitta bohémica* (Walliser); An: 200, pl. 32, figs 21, 22.
- 1990 *Ozarkodina bohémica* (Walliser); Kleffner: fig. 3, no. 20.
- 1990 *Ozarkodina tillmani* (Helfrich); Kleffner: fig. 3, nos 21, 22.
- 1993 *Ozarkodina bohémica* (Walliser), Morphotype 1; Schönlaub (In Kríz *et al.*): 829, pl. 1, figs 1, 3, 4.
- ?1993 *Ozarkodina bohémica* (Walliser), Morphotype 2; Schönlaub (In Kríz *et al.*): 829, pl. 1, fig. 9.
- 1993 *Ozarkodina bohémica* (Walliser), Morphotype 3; Schönlaub (In Kríz *et al.*): 829, pl. 1, figs 10–14.
- Diagnosis.** See Aldridge (1985, p. 88).
- Remarks.** Three morphotypes of *O. b. bohémica* were distinguished by Schönlaub (In Kríz *et al.*, 1993) and numbered 1–3; morphotype 1 has low posterior denticles, similar to *O. sagitta*, whereas morphotype 3 has an abrupt posterior termination and a widely flaring basal cavity. Morphotype 2 is very distinct, with an ornament of ridges of fused denticles on the basal cup. Schönlaub did not mention the specimens originally described by Walliser (1964), with a widely flaring basal cavity extending to the posterior tip, but they appear to be closest to morphotype 3. Because we cannot relate Walliser's specimens or ours to the Bohemian morphotypes we apply a different notation here. The type specimen and associates represent the α morph. Those from Saaremaa have a less flared cavity which does not extend right to the posterior tip and belong to the β morph.

Ozarkodina bohémica bohémica β morph
(Pl. 1, figs 1–15)

Description. Pa element: blade long, with 14–20 denticles that are largest posteriorly. Anterior edge gently convex, posterior edge upright. Basal cavity situated beneath posterior part of blade, terminating short of posterior tip. Small specimens shorter and relatively higher than large specimens. Large specimens usually with fused denticles above basal cavity and a longitudinal ledge in the lower third of the blade. All specimens with white matter, deep above basal cavity and narrowing anteriorly and posteriorly so that extreme denticles may be hyaline.

Occurrence on Saaremaa. Rootsiküla Stage: Vesiku borehole

Explanation of Plate 1

Figured specimens on all plates are Pa elements; they are deposited in the Institute of Geology, Estonian Academy of Sciences, Tallinn. **figs 1–15.** *Ozarkodina bohémica bohémica* (Walliser 1964) β morph. Rootsiküla Formation, figs 1, 9, 11, 15; lateral views, Cn 1454–Cn 1457, $\times 120$, $\times 50$, $\times 80$, $\times 65$, Viita Beds, Ohesaare borehole, 145.55 m. figs 2, 3; lateral and aboral views, Cn 1458, $\times 50$, Viita Beds, Ohesaare borehole, 142.25 m. figs 4–6, 10; lateral, lower lateral, aboral and oral views, Cn 1459, $\times 50$, $\times 50$, $\times 135$, Cn 1460, $\times 50$, Viita Beds, Kaugatuma borehole, 100.25 m. figs 7, 8; lateral and aboral views, Cn 1461, $\times 50$, $\times 85$, Viita Beds, Ohesaare borehole, 144.05 m. fig. 12; lateral view, Cn 1462, $\times 55$, Viita Beds, Vesiku borehole, 4.95 m. fig. 13; lateral view, Cn 1463, $\times 55$, Viita Beds, Viita outcrop. fig. 14; lateral view, Cn 1464, $\times 70$, Vesiku Beds, Kaugatuma borehole, 81.4 m. **figs 16–19.** *Ozarkodina* aff. *bicornuta* (Helfrich 1975). figs 16, 17; lateral views, Cn 1465, Cn 1466, $\times 65$, $\times 75$, Soeginina Beds, Soeginina cliff, sample 3-87. fig. 18; lateral view, Cn 1467, $\times 85$, lowermost Paadla Formation, Anikaitse outcrop, sample 4-76. fig. 19; lateral view, Cn 1468, $\times 80$, Soeginina Beds, Soeginina cliff, sample 2-87. **figs 20, 21.** *Ozarkodina snajdri* cf. *snajdri* (Walliser 1964). fig. 20; lateral view, Cn 1469, $\times 80$, Torgu Formation, Ohesaare borehole, 113.35 m. fig. 21, lateral view, Cn 1470, $\times 75$, Kuressaare Formation, Kolka borehole, 284.2 m.

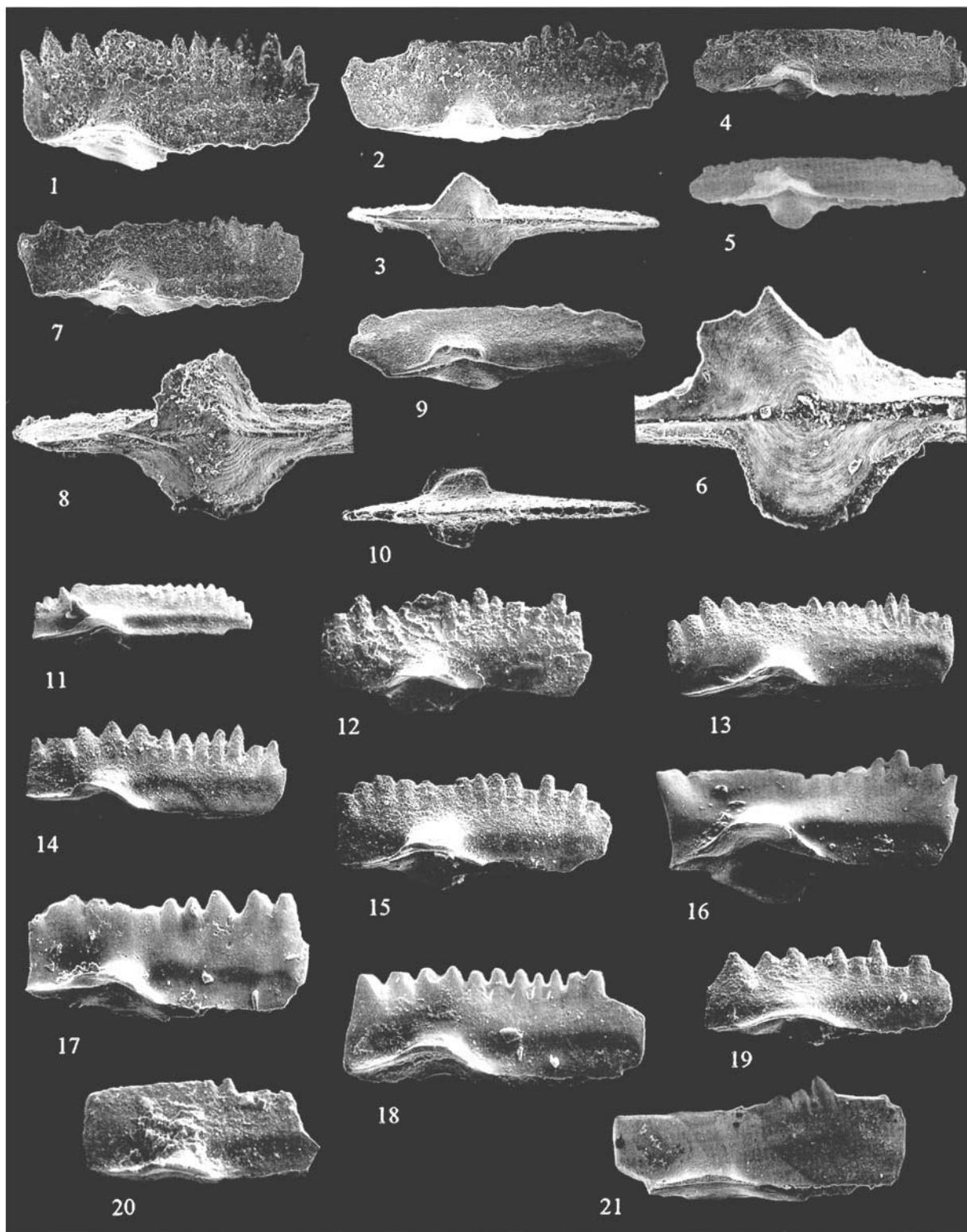
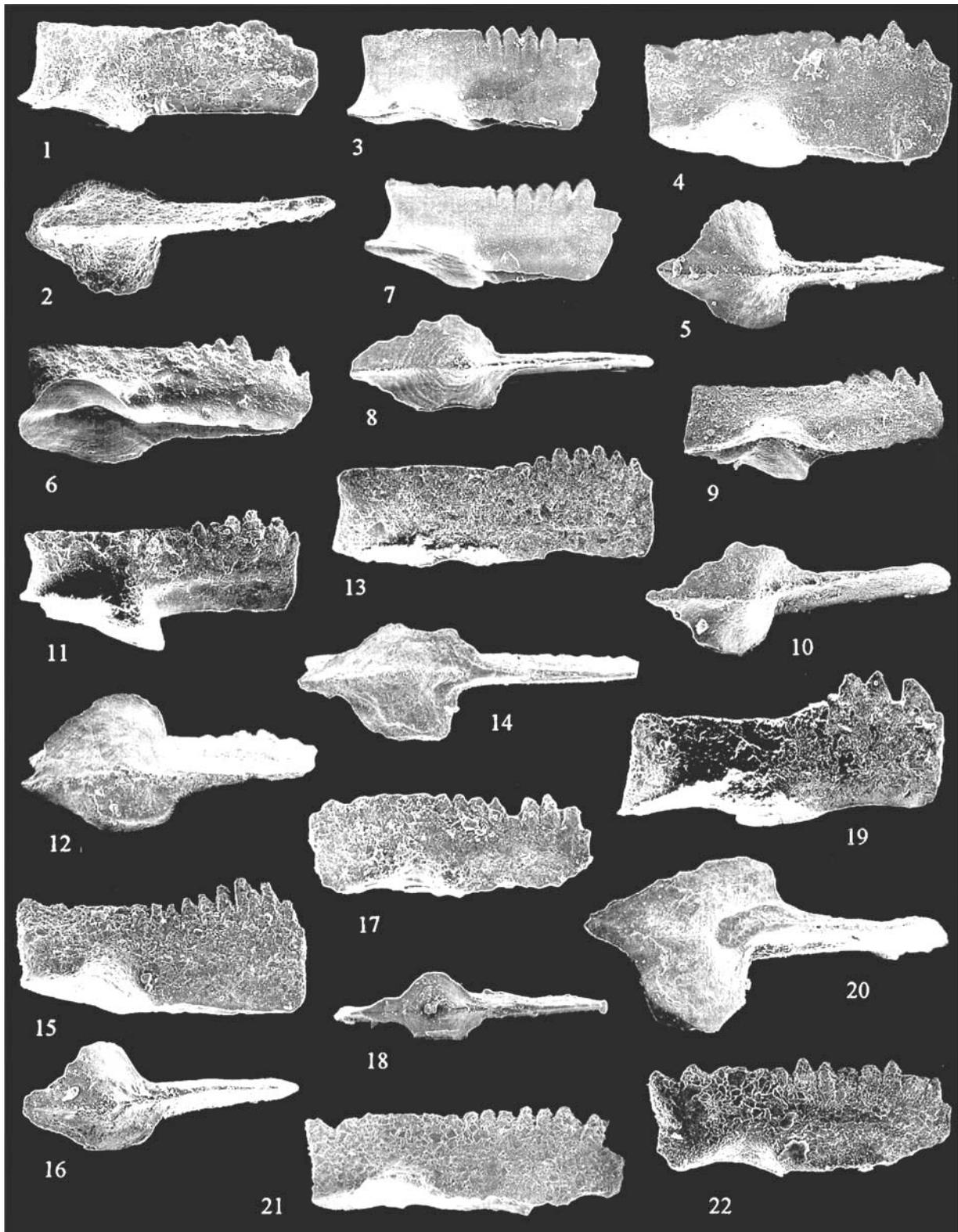


Plate 1



Explanation of Plate 2

Figs 1–16, 19, 20. *Ozarkodina crispa* (Walliser 1964) α_2 morph. figs 1, 2; lateral and oral views, Cn 1471, $\times 70$, Sauvere Beds, Kaugatuma borehole, 61.6 m. figs 3, 7, 8; lateral and aboral views, Cn 1472, Cn 1473, $\times 70$, $\times 85$, Kudjape Beds, Kolka borehole, 270.8 m. figs 4, 5; lateral and aboral views, Cn 1474, $\times 85$, Sauvere Beds, Riksu borehole, 33.5 m. Fig. 6; lower lateral view, Cn 1475, $\times 75$, Himmiste Beds, Kaugatuma borehole, 58.5 m. figs 9, 10; lateral and aboral views, Cn 1476, $\times 70$, $\times 85$, Sauvere Beds, Riksu borehole, 35.0 m. figs 11–16, 19, 20; lateral and aboral views, Cn 1477 – Cn 1480, $\times 65$, $\times 85$, $\times 70$, $\times 90$, Himmiste Beds, Karala outcrop. **figs 17, 18, 21, 22.** *Ozarkodina crispa* (Walliser 1964) α_3 morph; lateral and aboral views, Cn 1481 – Cn 1483, $\times 85$, $\times 70$, $\times 85$, Himmiste Beds, Karala outcrop.

4.95 m, Sakla borehole 51.86–54.45 m, Kaugatuma borehole 81.4–100.25 m, Ohesaare borehole 142.25–157.2 m, Kolka borehole 362.3 m, Viita outcrop.

Material. Pa element: 44 specimens.

Ozarkodina aff. *bicornuta* (Helfrich, 1975)

(Pl. 1, figs 16–19)

aff. 1975 *Spathognathodus bicornutus* Helfrich: pl. 1, figs 5–7, 11, 13–16, 18, pl. 2, figs 1, 4, 6, 16.

Description. Pa element: specimens small; blade rather high, denticles wide, usually 10–11 when not fused. Basal cavity beneath posterior part of blade, circular, not extending to posterior tip. Morphologically close to the smallest specimen illustrated by Helfrich (1975, pl. 1, fig. 5).

Remarks. The specimens illustrated by Helfrich (1975) are very variable, but most have a single high denticle at both ends of the blade; between these are 5–10 denticles which show no fusion on any of the figured specimens. The Estonian specimens have an enlarged posteriormost denticle, but the anterior denticle is not markedly different in size from its neighbours; the denticles above the cavity may be fused.

Occurrence. Uppermost Rootsiküla Stage: Soeginina samples 1–3, Anikaitse samples 4, 8.

Material. Pa element: 9 specimens.

Ozarkodina crispera (Walliser, 1964)

1964 *Spathognathodus crispus* Walliser: 74, pl. 9, fig. 3, pl. 21, figs 7–13.

?1969 *Spathognathodus crispus* Walliser; Fåhraeus: pl. 2, figs 13, 14.

1971 *Spathognathodus crispus* Walliser; Bultynck & Pelhate: pl. 1, figs 19, 20.

1971 *Spathognathodus crispus* Walliser; Drygant: 782, figs 1–3.

1974 *Spathognathodus crispus* Walliser; Feist & Schönlaub: pl. 7, figs 8, 9, 11, 12, 14, 15.

1974 *Ozarkodina crispera* (Walliser); Klapper & Murphy: 33, pl. 8, fig. 10.

1975 *Spathognathodus crispus* Walliser; Helfrich: pl. 14, figs 1–4, 9, 14, 19, 21, 24, 27.

1977 *Ozarkodina crispera* (Walliser); Cooper: 188, pl. 16, figs 16, 17.

1980 *Ozarkodina crispera* (Walliser); Chlupáč *et al.*: pl. 25, figs 12–15.

1980 *Spathognathodus crispus* Walliser; Wang: 374, pl. 1, figs 1–3, 14–16, 19–21, 24, 25, text-fig. 4.

1984 *Ozarkodina crispera* (Walliser); Kozur: pl. 4, fig. 4.

1984 *Spathognathodus crispus* Walliser; Drygant: 126, pl. 10, figs 12, 13.

1985 *Ozarkodina crispera* (Walliser); Balogh & Kozur: pl. 3, fig. 3.

1986 *Spathognathodus crispus* Walliser; Jiang *et al.*: pl. 4–4, fig. 9.

1987 *Spathognathodus crispus* Walliser; An: 202, pl. 34, figs 20, 21.

1988 *Ozarkodina snajdri crispera* (Walliser); Denkler & Harris: pl. 1, figs J, K.

1989 *Ozarkodina crispera* (Walliser); Walliser & Wang: 114, text-fig. 1, pl. 1, figs 1–16.

1990 *Ozarkodina* aff. *snajdri* (Walliser); Männik & Viira: pl. 18, fig. 10.

1990 *Ozarkodina crispera* (Walliser) β morphotype; van den

Boogaard: 11, pl. 6, figs 2–7.

1994 *Ozarkodina* aff. *snajdri crispera* (Walliser); Viira: pl. 1, fig. 8.

1994 *Ozarkodina snajdri* (Walliser); Jeppsson *et al.*: fig. 4d.

1995 *Ozarkodina crispera* (Walliser); Miller: pl. 3, figs 1–2, 4–5.

1995 *Ozarkodina* cf. *crispera* (Walliser); Miller: pl. 3, figs 3, 6–12

Remarks. Pa elements that have been assigned to *O. crispera* show considerable variation, and four morphotypes, designated α , β , χ , δ , were differentiated by Walliser & Wang (1989). The β , χ and δ morphs are all characterized by a furrow on the oral margin of the blade; the α morph lacks the furrow. The holotype selected by Walliser (1964, pl. 21, fig. 12) lacks a furrow and thus belongs to the α morph, as do all the specimens from the northern East Baltic. However, there is major variation within this group, and we distinguish α_1 , α_2 and α_3 morphs, with the holotype belonging to α_1 .

Ozarkodina crispera α_2 morph

(Pl. 2, figs 1–16, 19, 20, Pl. 3, figs 5, 6, 9–11)

Description. Pa element: specimens small; blade high, short with fused denticles towards posterior end. Denticle height decreases posteriorly from anterior end to fused portion. Posterior termination of blade concave to vertical. Basal cavity with wide subcircular lips, underlying posterior half of blade and extending to posterior tip. White matter fills denticles, extending down to tip of cavity beneath fused portion of blade.

Remarks. These specimens differ from the α_1 morph in the subcircular, rather than asymmetrical, shape of the basal cavity.

Occurrence on Saaremaa. Paadla Stage and lowermost Kur-essaare Stage: Sakla borehole 18.0–33.13 m, Riksu borehole 35.0 m, Kaugatuma borehole 49.7–69.3 m, Ohesaare borehole 99.75–100.8 m, Kolka borehole 270.8–284.2 m; Kärla, Roopa, Paadla and Karala outcrops.

Material. Pa element: more than 100 specimens.

Ozarkodina crispera α_3 morph

(Pl. 2, figs 17, 18, 21, 22, Pl. 3, figs 1–4, 7, 8)

Description. Pa element: similar to α_2 morph but with posterior denticles unfused or only partly fused. Basal cavity variable in position, normally extending to posterior tip. White matter occupies one-third to one-half of blade.

Remarks. Specimens in which the basal cavity does not extend beyond the posterior end of the blade are similar to *O. s. snajdri*, but differ in the smaller size of the cavity and the shorter blade. The specimens illustrated by Helfrich (1975) encompass the range of variation shown by α_2 and α_3 morphs.

Occurrence on Saaremaa. Paadla Stage and lowermost Kur-essaare Stage: Sakla borehole 30.15 m, Riksu borehole 33.5–35.0 m, Kuressaare (Kingissepa) borehole 39.14 m, Ohesaare borehole 100.8 m, Kolka borehole 276.15–284.2 m; Roopa and Karala outcrops.

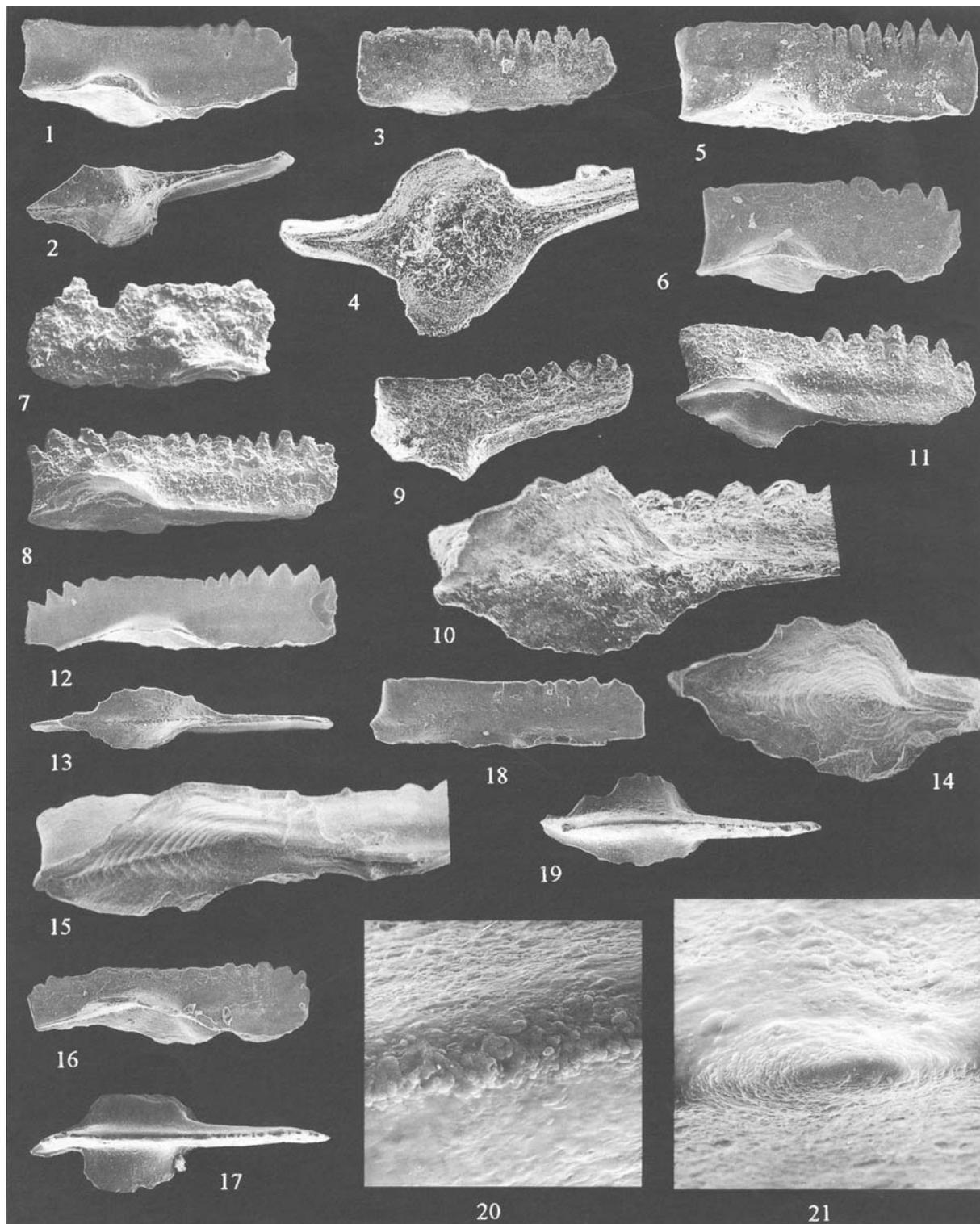
Material. Pa element: 31 specimens.

Ozarkodina snajdri (Walliser 1964)

1964 *Spathognathodus snajdri* Walliser: 84, pl. 9, fig. 2, pl. 21, figs 14–15, pl. 22, figs 1–4.

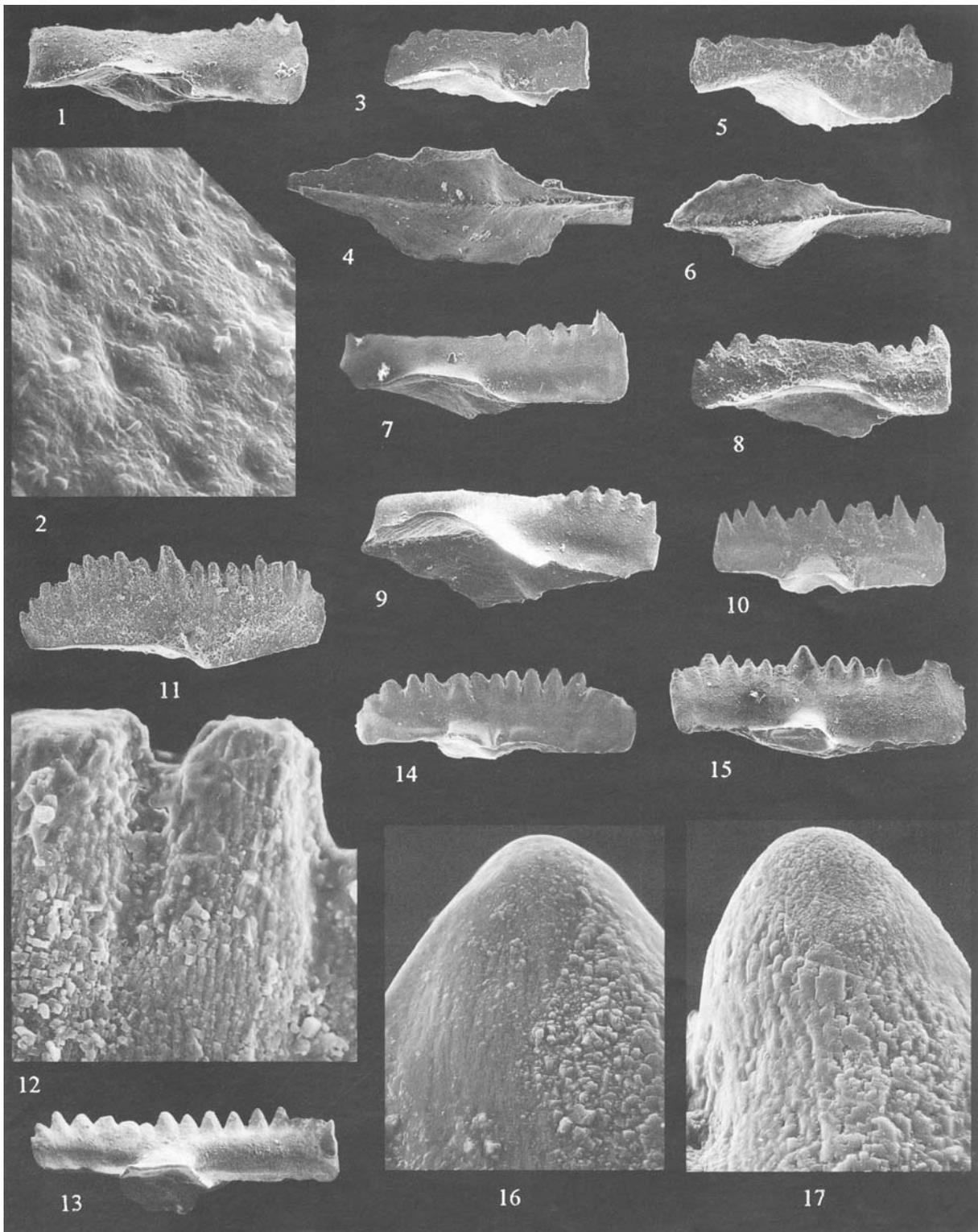
?1969 *Spathognathodus crispus* Walliser; Fåhraeus: pl. 2, figs 13, 14.

?1969 *Spathognathodus* cf. *snajdri* Walliser; Schönlaub: pl. 1, fig. 29.



Explanation of Plate 3

Figs 1–4, 7, 8. *Ozarkodina crisa* (Walliser 1964) α_3 morph. figs 1–4; lateral and aboral views, Cn 1484, Cn 1485, $\times 70$, $\times 85$, $\times 150$, Sauvere Beds, Sakla borehole, 30.15 m. fig. 7; lateral view, Cn 1486, $\times 80$, Sauvere Beds, Kërla outcrop. fig. 8; lateral view, Cn 1487, $\times 85$, Himmiste Beds, Roopa cliff. **figs 5, 6, 9–11.** *Ozarkodina crisa* (Walliser 1964) α_2 morph. fig. 5; lateral view, Cn 1488, $\times 85$, Sauvere Beds, Sakla borehole, 30.15 m. fig. 6; lateral view, Cn 1489, $\times 85$, Uduvere Beds, Sakla borehole, 18.0 m. figs 9–11; lateral and aboral views, Cn 1490, Cn 1491, $\times 70$, $\times 150$, $\times 95$, Himmiste Beds, Paadla outcrop, sample 3-73. **figs 12–21.** *Ozarkodina snajdri parasnajdri* subsp. nov. figs 12, 13; lateral and aboral views, Cn 1492, $\times 50$, Äigu Beds, Ohesaare borehole, 67.4 m. Figs 14, 16; aboral and lateral views, Cn 1493, Cn 1494, $\times 120$, $\times 50$, Äigu Beds, Ohesaare borehole, 64.65 m. figs 15, 17; lower lateral and oral views, Cn 1495, Cn 1496, $\times 120$, $\times 45$, Äigu Beds, Ohesaare borehole, 61.2 m. figs 18–21; lateral and oral views, oral views of fused denticles and a discrete denticle, Cn 1497, $\times 50$, $\times 850$, Äigu Beds, Ohesaare borehole, 67.4 m.



Explanation of Plate 4

Figs 1–9. *Ozarkodina snajdri parasnajdri* subsp. nov. figs 1, 2; lateral view, Cn 1498, $\times 50$, detail $\times 2600$, Äigu Beds, Kolka borehole, 263.4 m. figs 3, 4; lateral and aboral views, Cn 1499, Äigu Beds, Kolka borehole, 263.4 m. Figs 5, 6, 8; lateral and aboral views, Cn 1500, Cn 1501, $\times 85$, $\times 95$, $\times 50$, Kuressaare Formation, Ilpla outcrop. fig 7; lateral view, Cn 1502, $\times 50$, Äigu Beds, Kolka borehole, 264.4 m. fig. 9; lower lateral view, Cn 1503, $\times 45$, Tahula Beds, Kaugatuma borehole, 45.5 m. **figs 10, 13–17.** *Ozarkodina remscheidensis eosteinhornensis* (Walliser 1964) *sensu lato*. fig. 10; lateral view, Cn 1505, $\times 40$, Kaugatuma Formation, Ohesaare borehole, 58.7 m. fig. 13; lateral view, Cn 1506, $\times 40$, Kuressaare Formation, Vaivere outcrop. fig. 14; lateral view, $\times 50$, Kaugatuma Formation, Ohesaare borehole, 64.65 m. figs 15–17, lateral view, Cn 1508, $\times 40$, details of lateral surfaces of denticles $\times 600$, Kaugatuma Formation, Ohesaare borehole, 67.4 m. **figs 11, 12.** *Ozarkodina confluens densidentata* (Viira 1983). Lateral view, Cn 1504, $\times 50$, lateral surfaces of two anterior denticles $\times 650$, Viita Beds, Ohesaare borehole, 144.05 m.

- 1971 *Spathognathodus snajdri* Walliser; Rexroad & Nicoll: pl. 2, figs 4, 5.
 1971 *Spathognathodus snajdri* Walliser; Rexroad & Craig: 700, pl. 82, figs 16, 17.
 ?1973 *Spathognathodus snajdri* Walliser; Pollock & Rexroad: 83, pl. 1, figs 30–34.
 1975 *Spathognathodus snajdri* Walliser; Helfrich: pl. 2, figs 3,7, 10–15, 17.
 1976 *Spathognathodus snajdri* Walliser; Ebner: 20 (292), pl. 4, figs 1, 2.
 1976 *Ozarkodina remscheidensis snajdri* Mehtens & Barnett (sic); Mehtens & Barnett: 497, pl. 1, figs 19, 22.
 1980 *Ozarkodina snajdri* (Walliser); Chlupac *et al.*: pl. 25, figs 1, 4–11.
 1985 *Ozarkodina snajdri* (Walliser); Aldridge: pl. 3.4, fig. 18.
 1994 *Ozarkodina snajdri* (Walliser); Jeppsson *et al.*: fig. 4e
 1995 *Ozarkodina snajdri* (Walliser); Miller: pl. 3, figs 14–15, 17–18.
 1995 *Ozarkodina cf. snajdri* Walliser; Miller: pl. 3, figs 13, 16.
Remarks. A new subspecies, *O. s. parasnajdri*, is described here. The holotype and all previously described material belong to the nominate subspecies *O. s. snajdri* (Walliser).

Ozarkodina snajdri parasnajdri subsp. nov.
 (Pl. 3, figs 12–21, Pl. 4, figs 1–9)

Holotype. Specimen Cn 1498, Kolka Borehole 263.4 m; pl. 4, fig. 1,2.

Type stratum. Kaugatuma Formation, Äigu Beds.

Diagnosis. Pa element with large subquadrangular basal cavity extending to posterior end of blade; denticles above cavity fused. Other elements unknown.

Description. Blade commonly long and low, with small denticles, fused above cavity; anterior end higher, posterior portion arched. Posterior termination of blade vertical or oblique concave. Basal cavity with tip a little posterior of centre of blade; lips commonly quadrangular and extending to posterior tip of blade; cavity extends as a narrow groove to anterior tip. White matter deepest above cavity, rising anteriorly and posteriorly; anterior denticles may lack white matter.

Remarks. There is variation in the length of the fused part of the blade and in the position of the basal cavity tip. However, this subspecies differs from *O. s. snajdri* in always possessing fused denticles and in the more central position of the cavity tip. The cavity lips always extend to the posterior tip of the blade.

Occurrence. Kuressaare Stage and lowermost Kaugatuma Stage: Kaugatuma borehole 28.9–45.4 m, Ohesaare borehole 61.2–93.4 m, Kolka borehole 253.6–263.4 m; Ilpla and Loode Tammik outcrops.

Material. Pa element: 84 specimens.

Ozarkodina snajdri cf. snajdri (Walliser 1964)
 (Pl. 1, figs 20,21)

Remarks. Seven specimens in the Ohesaare and Kolka boreholes are close to *O. s. snajdri*. All have fused denticles above the basal cavity, but on unbroken specimens the cavity can be seen to terminate just short of the posterior end of the blade.

CONODONT BIOSTRATIGRAPHY OF SAAREMAA

Samples have been processed for conodont recovery from seven boreholes and nine outcrops (Fig. 2). Spacing of samples in the

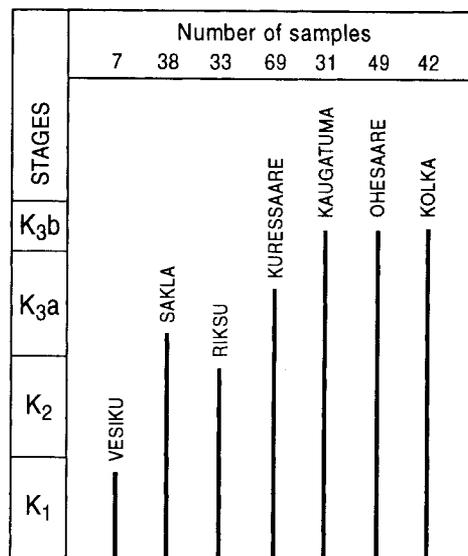


Fig. 3. Stratigraphical spans and numbers of samples for the studied boreholes.

boreholes was 1–3 m (Fig. 3), with a standard sample weight of 1–1.5 kg, except in the Kuressaare (Kingissepa) borehole where weights were c. 0.5 kg. All samples yielded conodont elements. The distribution of members of the *O. b. bohémica* lineage is shown in Fig. 4. In addition, samples from the Rootsiküla Stage contain *O. confluens densidentata* (Viira) and *Ctenognathodus munchisoni* (Pander), generally in small numbers. Samples from the Paadla Stage contain *O. confluens coridentata* (Viira), *O. excavata* (Branson and Mehl), *O. roopaensis* Viira, *Oulodus siluricus* (Branson and Mehl), *Panderodus* spp. and, in the upper part, *Coryssognathus dubius* (Rhodes), while those from the Kuressaare Stage have *O. r. eosteinhornensis* s. l., *O. confluens ambigua* (Viira) and *Oulodus elegans* (Walliser) (Viira, 1982 *a,b*, 1994).

The *O. bohémica* lineage is most completely represented in the Ohesaare borehole (Figs 5 and 6). In the lower part of the Viita Beds *O. b. bohémica* β morph appears at a depth of 157.2 m and is found in seven samples through to 142.25 m. The lineage is not represented in the succeeding 29 m, but rare broken specimens of *O. s. cf. snajdri* are identified at 113.35 m and 106.25 m, in the Torgu Formation of the Paadla Stage. At 100.8 m two specimens of *O. crispa* α_3 morph occur, and a specimen of *O. crispa* α_2 morph is found at 99.75 m. In the interval 93.4–61.2 m, seven samples contain *O. snajdri parasnajdri*. The lowest specimens are small and not well preserved, but have the widely open basal cavity characteristic of this subspecies. The largest specimens occur in the uppermost sample. The lower boundary of the Kuressaare Stage is identified by the occurrence of the thelodont *Theolodus sculptilis* Gross at 95.15 m, just below the first occurrence of *O. r. eosteinhornensis* at 93.40 m.

The next borehole to the north of Ohesaare is at Kaugatuma, where *Ozarkodina b. bohémica* β morph is represented in two samples at depths of 100.25 m (Viita Beds) and 81.4 m (Vesiku Beds). Four samples from the Paadla Stage at 49.7–69.3 m contain *O. crispa* α_2 morph, with good typical specimens present

	VESIKU		SAKLA		RIKSU	KUESSAARE			KAUGATUMA				OHESAARE				KOLKA													
	8.65 4.95	54.45 51.86	33.13 31.06	30.15 18.0	35.0 33.5	39.14 4.80	100.25 81.4	89.3 61.6	58.5 49.7	45.4 50.62	48.5 37.45	33.75 32.2	28.9	157.21 151.7	149.8 149.5	145.55 144.05	142.25 113.35	106.25 100.8	99.75 95.95	93.4 90.75	84.95 76.7	73.5 69.9	67.4 64.65	61.20	367.5 362.3	346.6 344.6	289.5 287.4	284.2 276.15	270.8 263.4	239.6
	K ₁	K ₁	K ₂	K ₂	K ₂ K _{3a}	K ₁	K ₂	K _{3a}	K ₁	K ₂	K _{3a}	K _{3a}	K ₁	K ₂	K _{3a}	K _{3a}	K ₁	K ₂	K _{3a}	K _{3b}										
<i>O. b. bohemia</i> β morph	1 1	6 1				4 2			1 1	2 3	1 1 1 3						2 ? ?													
<i>O. aff. bicornuta</i>																														
<i>O. cf. s. snajdri</i>														1 1												1 1 3				
<i>O. crisper</i> α ₂ morph			2 1 1 4 2		2		1 4 1 1								1												3 15			
<i>O. crisper</i> α ₃ morph			3		1 3 1 1										2 ?												1 3			
<i>O. s. parasnajdri</i>						?			2 2 1 4 2 1 4								2 1 1 1 4 4 14 12 3													28 5

	OUTCROPS								TOTAL		
	VIITA	SOEGININA		ANIKAITSE		KÄRLA	ROOPA	PAADLA		KARALA	ILPLA
	1	2	3	4	8						
<i>O. b. bohemia</i> β morph	3	2									44
<i>O. aff. bicornuta</i>		3	4	1	1						9
<i>O. cf. s. snajdri</i>											7
<i>O. crisper</i> α ₂ morph					2	1	4	>50			>103
<i>O. crisper</i> α ₃ morph						1					22
<i>O. s. parasnajdri</i>									1	2	94

Fig. 4. Distribution of taxa in the *Ozarkodina bohemia* lineage on Saaremaa and northern Latvia.

in the uppermost Sauvere Beds and the Himmiste Beds. *Ozarkodina s. parasnajdri* occurs in the interval 28.9–45.4 m of the Kuressaare Stage; as noted in the Ohesaare borehole, small specimens are found in the lowest samples and the biggest specimens are from the upper samples.

In the Riksu borehole further to the north, the highest strata are assigned to the Uduvere Beds. The *O. bohemia* lineage is represented only by *O. crisper* α₂ and α₃ morphs at 33.5–36.0 m in the Sauvere Beds. The most northerly borehole sampled from West Saaremaa is at Vesiku, where *O. b. bohemia* β morph has been recovered from two samples in the Viita and Kuusnõmme Beds.

The Sakla borehole is situated in East Saaremaa, where the strata are generally dolomitized. Nevertheless, *O. b. bohemia* β morph has been recovered from the Viita Beds and *O. crisper* α₂ and α₃ morphs occur in the Sauvere Beds and in a single sample from the Uduvere Beds (Fig. 7).

In all the boreholes, including the Kolka borehole in northernmost Latvia, *O. b. bohemia* β morph usually occurs in the Viita Beds and occasionally also in the Kuusnõmme and Vesiku Beds of the Rootsiküla Stage. All records of *O. crisper* on Saaremaa are in the Paadla Stage: in the Sauvere Beds of Riksu, the Sauvere and Himmiste beds of Kaugatuma, and the Torgu

Formation of Ohesaare. In the Kolka borehole, *O. crisper* occurs with *O. r. eosteinhornensis* s. 1 in the Kuressaare Stage, with the most typical specimens at a depth of 270.8 m. In general, there is a pattern of increasingly high occurrence of *O. crisper* in the lithostratigraphical sequence from north to south, i.e. towards deeper water facies.

The exposure of Himmiste Beds or uppermost Sauvere Beds at Karala has yielded more than 50 specimens of the Pa element of *O. crisper*, with α₂ morphs dominant, but with some α₃ morphs and transitional forms (Fig. 8). A few specimens of the α₂ morph have also been recovered from Kärla (Sauvere Beds) and Paadla (Himmiste Beds). One specimen from Roopa Cliff (Himmiste Beds) is identified as an α₃ morph.

Small specimens with short blades and large posterior and anterior denticles have been recovered from the Soeginina cliff section (uppermost Rootsiküla Stage) of West Saaremaa and from the outcrop at Anikaitse in East Saaremaa. They are identified as *O. aff. bicornuta*. *O. bicornuta* was placed in the *bohemia* lineage between *O. b. bohemia* and *O. snajdri* by Helfrich (1975).

The relative completeness of the *O. bohemia* lineage in the Ohesaare borehole is complemented by evidence that *Coryssognathus dubius* has its longest range in this section. A more

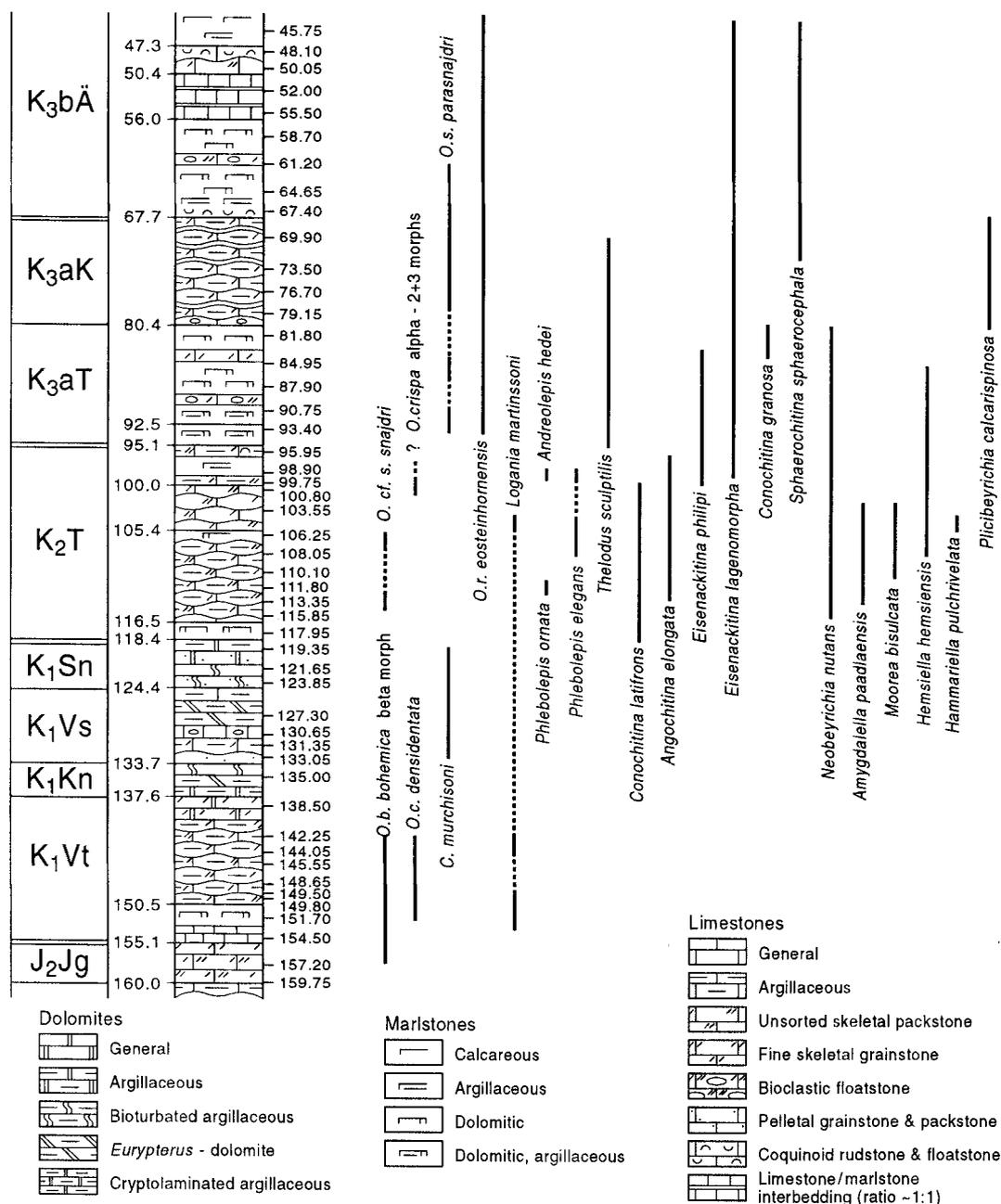


Fig. 5. Distribution of conodonts, ichthyoliths (Märss, 1986), chitinozoans (Nestor, 1982) and ostracods (Sarv, 1971) in the Ohesaare borehole. J₂Jg – Jaagarahu Formation, K₁Vt – Viita Beds, K₁Kn – Kuusnõmme Beds, K₁Vs – Vesiku Beds, K₁Sn – Soeginina Beds, K₂T – Torgu Formation, K_{3a}T – Tahula Beds, K_{3a}K – Kudjape Beds, K_{3b}Ä – Äigu Beds. Lithological column and stratigraphical divisions after Kaljo & Nestor (1990).

complete section in this borehole than in others is also confirmed by occurrences of ichthyoliths and ostracods (Märss, 1986, 1990; Sarv, 1971).

The distribution of conodonts in the Paadla Formation, in particular, suggests the presence of gaps in the Saaremaa succession. V. Nestor (1982) has previously suggested on the basis of chitinozoan data that there is a gap between the Rootsiküla and Paadla stages, and an increase in the scale of this gap northwards has been recognized (Nestor, V., 1990; Nestor,

H., 1993). Conodont correlations with Gotland confirm a hiatus at this level (Jeppsson *et al.*, 1994), and the absence of *O. s. snajdri* in all studied sections except Ohesaare provides consistent evidence. A break between the Paadla and Kuressaare stages was also postulated by Einasto (1991) and Märss (1992), and is corroborated by the fact that overlap between *O. crispa* and *O. r. eosteinhornensis* s. l. is apparent in the Kolka section, but has not been found anywhere on Saaremaa. Alternatively, the restricted nearshore facies represented by the Uduvere Beds

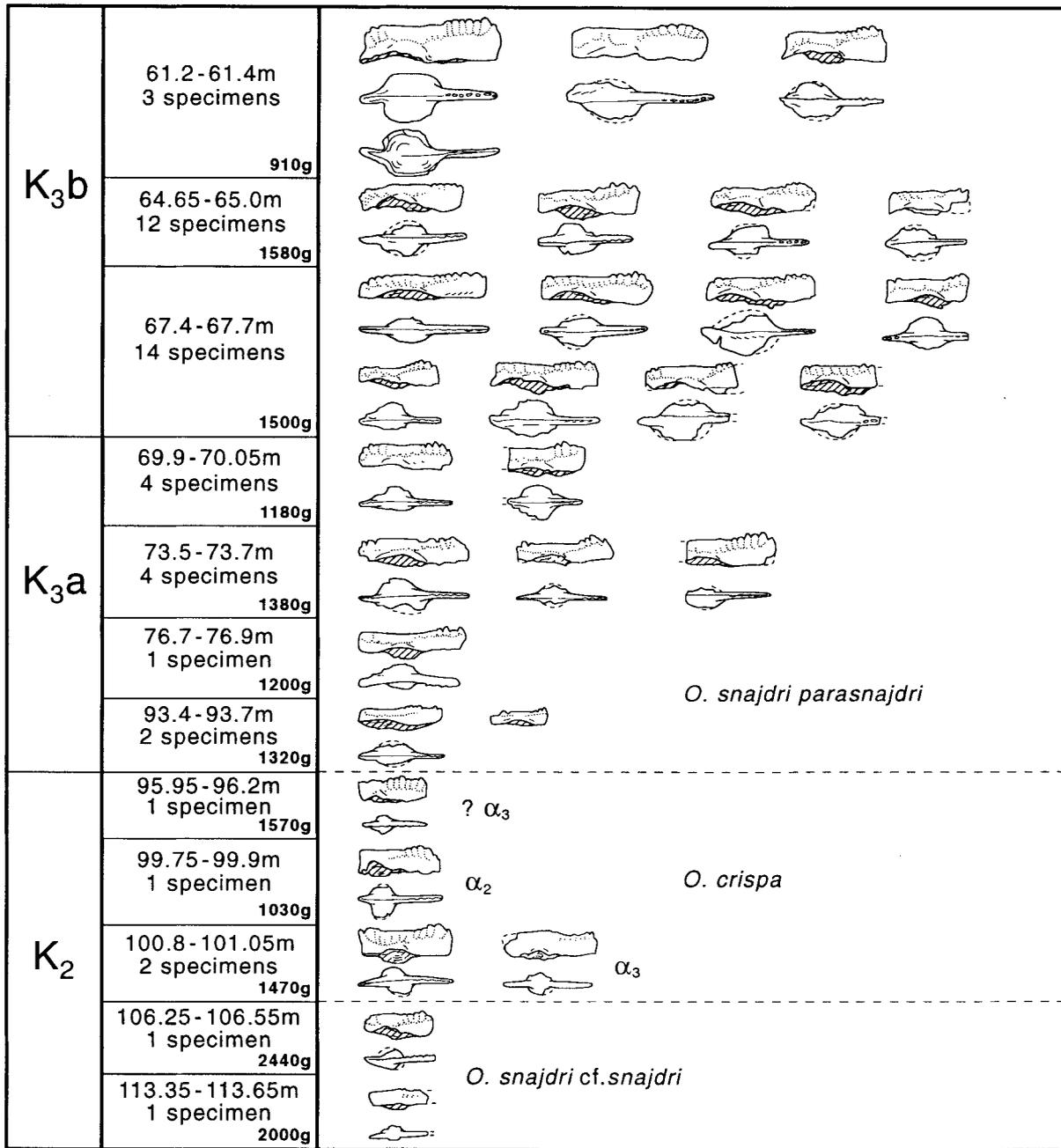


Fig. 6. Specimens of *Ozarkodina snajdri* cf. *snajdri* *O. crista* α₂ and α₃ morphs and *O. s. parasnajdri* in the Ohesaare borehole.

may be a factor in producing the differences in the observed stratigraphical distributions of the conodonts.

OTHER FOSSIL DATA

Chitinozoans

Chitinozoans are very poorly represented in the Rootsiküla Stage, but a biozonal scheme has been developed for the Paadla and Kuressaare stages (Nestor, V., 1982, 1990). All biozonal species occur in the Ohesaare borehole (Fig. 5). *Conochitina*

latifrons Eisenack and *Angochitina elongata* Eisenack appear in the lowermost Paadla Formation, and by correlation with the Ventspils borehole, Latvia, Nestor, V. (1982) deduced that strata representing the *nilssoni* and *scanicus* graptolite biozones are absent. In the Ohesaare borehole, *Eisenackitina lagenomorpha* (Eisenack) and *E. philipi* Laufeld range from the uppermost Paadla Stage into the Kuressaare Stage, with *E. lagenomorpha* extending much further upwards. The succeeding biozones of the Kuressaare Stage have as index species *Conochitina granosa*

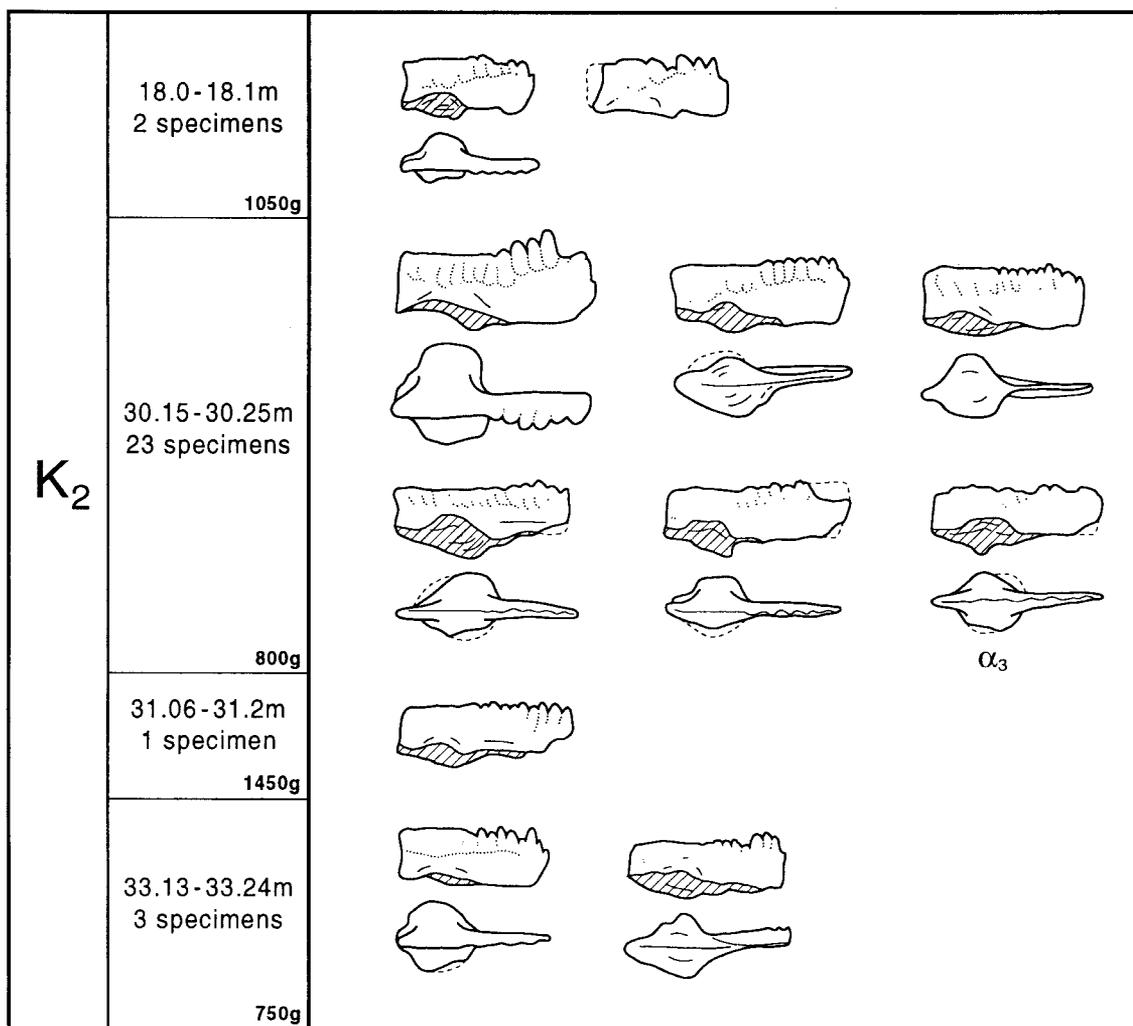


Fig. 7. Specimens of *Ozarkodina crispera* α_2 and α_3 morphs in the Sakla borehole; all except for the specimen labelled are α_2 morphs.

Laufeld and *Sphaerochitina sphaerocephala* Eisenack.

In the Ludlow type area, Britain, *C. latifrons* is restricted to the Gorstian, with the highest record at the top of the Lower Bringewood Formation, while *A. elongata* occurs throughout the Gorstian from the uppermost Middle Elton Formation and extends into the Lower Leintwardine Formation (Sutherland, 1994). Sutherland (1994) also showed no overlap between the ranges of *E. lagenomorpha* and *E. philipi*, with the former spanning the Lower Bringewood Formation to Lower Leintwardine Formation and the latter ranging from the Upper Leintwardine Formation to the Upper Whitcliffe Formation. On Gotland, *C. latifrons* and *A. elongata* appear in the topmost Klinteberg Beds, and *E. lagenomorpha* and *E. philipi* appear together in the upper part of the Hemse Beds coincident with the highest occurrence of *C. latifrons* (Laufeld, 1974).

Ostracods

The distribution of ostracods in the Ohesaare borehole has been documented by Sarv (1971), and the ranges of key species are

shown in Fig. 5. Ostracods are rare in the Rootsiküla Stage and absent from the lowermost Paadla Stage, but in the Paadla Stage above a depth of 115 m, rich assemblages occur. Sarv (1971) reported that five species, including *Neobeyrichia nutans* Martinsson, had not been found in the northern East Baltic other than in the Ohesaare borehole, but included a *N. nutans* biozone in the upper Paadla Stage of Saaremaa (Sarv, 1982). In Britain, *N. nutans* occurs in the Lower Leintwardine Formation (Siveter, 1989), but other species recorded in the Ohesaare borehole are not represented.

Ichthyoliths

A microvertebrate biozonation for the Silurian of the northern East Baltic has been established by Märss (1982, 1990), and all the zonal species for the Rootsiküla, Paadla and Kuressaare stages are represented in the Ohesaare borehole (Märss, 1986; see Fig. 5). *Logania martinssoni* (Gross) occurs in the Rootsiküla and lowermost Paadla stages, and has also been found in the Halla, Mulde, Klinteberg and Hemse beds of Gotland (Fred-

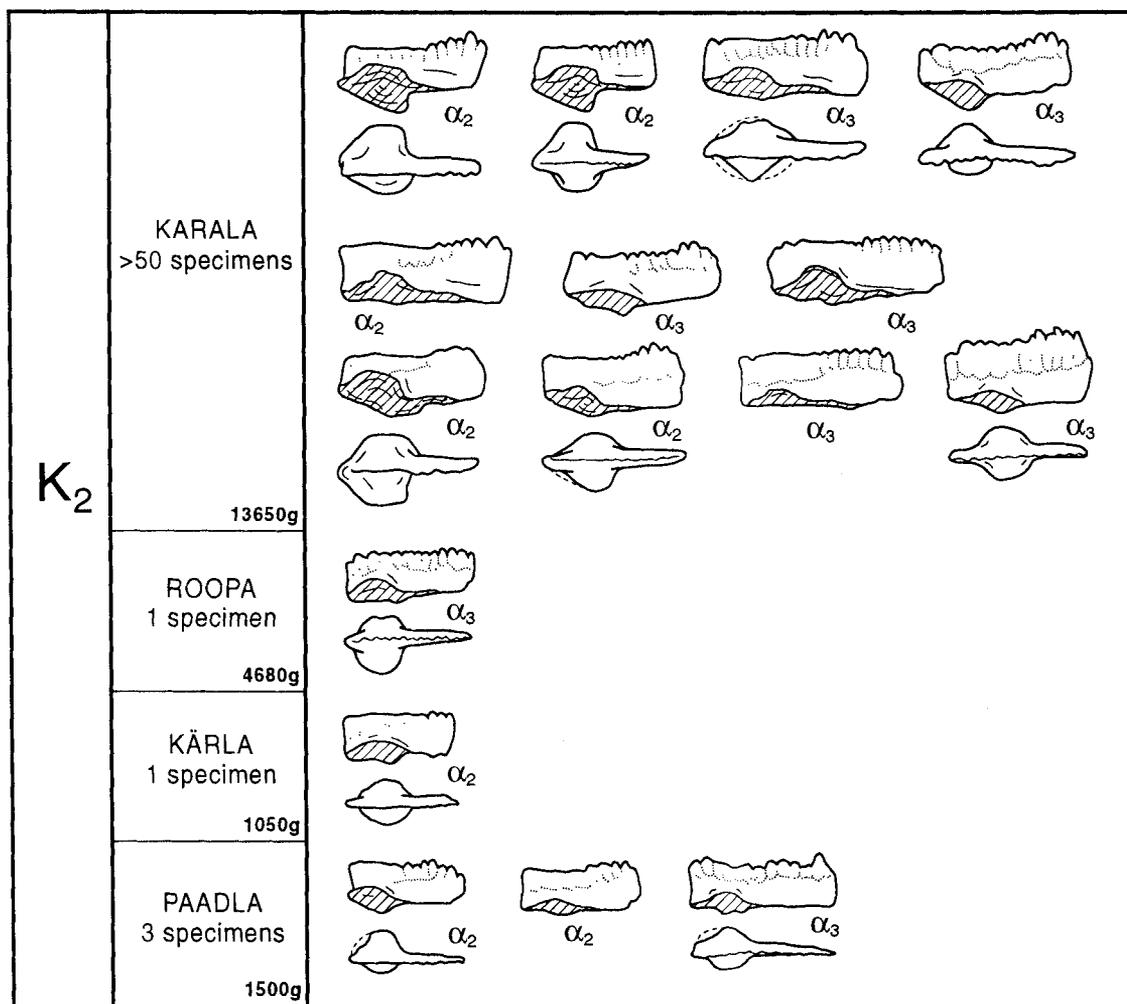


Fig. 8. Specimens of *Ozarkodina crisa* α_2 and α_3 morphs in the Karala, Roopa, Kärla and Paadla outcrops.

holm, 1990). *Phlebolepis ornata* Märss characterizes strata assigned to the upper Sauvere Beds by Märss (1986); this species has not been found in the other boreholes, but occurs in the lower Hemse Beds on Gotland (Fredholm, 1988). *Phlebolepis elegans* Pander ranges from the upper Sauvere Beds to the lowermost Uduvere Beds, and has been recorded widely in Estonia and Latvia. *Andreolepis hedei* Gross is restricted to the Uduvere Beds, and is also known from the upper Hemse Beds on Gotland (Fredholm, 1988, 1989) and the Long Quarry Beds (lowermost Pridoli) of South Wales (Märss, 1982).

CORRELATION

The evidence given by conodonts, chitinozoans and ichthyoliths for correlations is not always consistent. An attempt to provide the most parsimonious correlation between the succession on Saaremaa and those of the Ludlow type area and of Gotland is shown in Fig. 9. The correlation with Gotland is based on the recent conodont work by Jeppsson *et al.* (1994), who confirmed the presence of gaps in the exposed Saaremaa sequence. One of these gaps is between the Jaagarahu and Rootsiküla stages,

embracing strata referred to the upper Slite Beds, Mulde Beds and Halla Beds on Gotland. This results in only part of the *O. b. bohémica* Biozone being recognized on Saaremaa, here characterized by the β morph.

The gap between the Rootsiküla and Paadla stages on Saaremaa corresponds to the uppermost Klinteberg Beds and lower Hemse Beds of Gotland (Jeppsson *et al.*, 1994). Chitinozoan evidence, particularly the presence of *C. latifrons* in the Ohesaare borehole, indicates that at least the upper part of the Gorstian Stage is represented on Saaremaa; the occurrence of *Phlebolepis ornata* is consistent with this. The hiatus is probably of greater significance in shallower facies away from Ohesaare, where *P. ornata* has not been found, and Kaljo (1990, p. 26) has suggested that the entire Gorstian may be lacking in the shoreward region. The conodont *O. s. cf. snajdri* and the ostracod *N. nutans* have also been found only in the Ohesaare borehole.

Jeppsson *et al.* (1994) also determined the presence of a gap between the Paadla and Kuressaare stages, equivalent to the upper Hemse and Eke beds of Gotland. Part of the evidence for

SERIES & STAGES		WENLOCK & LUDLOW AREA	SAAREMAA (SOUTHERN)	GOTLAND
PŘÍDOLÍ (part)		Downton Castle Sandstone Fm.	Kaugatuma Formation	
LUDLOW	LUDFORDIAN	?	Kuressaare Formation	Sundre Beds
		Upper Whitcliffe Formation	?	Hamra Beds
		Lower Whitcliffe Formation		Burgsvik Beds
		U. Leintwardine Fm.	Torgu Formation	Eke Beds
		L. Leintwardine Fm.		
	GORSTIAN	U. Bringewood Fm.		Hemse Beds
		L. Bringewood Fm.		
		U. Elton Fm.		
		M. Elton Fm.		
		L. Elton Fm.		
WENLOCK (part)	HOMERIAN (part)	Much Wenlock Limestone Fm.	Rootsiküla Formation	Klinteberg Beds
		Coalbrookdale Fm. (upper part)		Mulde & Halla Beds

Fig. 9. Correlation of the upper Wenlock to lower Přídolí sequences of Britain (Wenlock Edge and Ludlow area), Estonia (southern Saaremaa) and Gotland.

this is the absence of *Polygnathoides siluricus* Walliser on Saaremaa, although this species is rare in most facies and its distribution may have been environmentally controlled. However, there is a marked change in conodonts at the Paadla/Kuressaare boundary on Saaremaa, with *C. dubius*, *O. excavata* and *O. crista* disappearing, and a fauna characterized by *O. r. eosteinhornensis*, s. l., *O. confluentis*, *Oulodus elegans* (Walliser) and *O. snajdri parasnajdri* appearing.

Uppermost Ludlow and lowermost Downton conodont faunas from the Welsh Borderland have recently been documented in detail by Miller (1995). He noted that the top of the Upper Whitcliffe Formation in the Ludlow area is characterized by *C. dubius* and *O. s. snajdri*, with less common *O. r. eosteinhornensis* and *O. cf. crista*. At Ludlow itself, *O. cf.*

crista ranges 30–15 cm below the top of the formation; the specimens compare with the α_3 morph described in this paper and found in the upper Paadla Stage on Saaremaa. Miller (1995), however, also recovered *O. crista* from the lower part of the Whitcliffe Formation at Tite's Point, Gloucestershire, and from the lower part of the Upper Perton Beds at Woolhope; these specimens have a narrow furrow on the upper surface and are similar to the β morph of Walliser & Wang (1989).

There is a problem in using the appearance of *O. crista* in correlating the Saaremaa succession with that of the type Ludlow, as the species is found throughout the upper Sauvere Beds, the Himmiste Beds and the Uduvere Beds. This part of the sequence is usually correlated with the middle part of the Ludlow Series. A revision of this correlation would contradict the evidence from the thelodont *P. elegans*, which has been found by RJA in the Upper Bringewood Formation of the Welsh Borderland, but co-occurs with *O. crista* in the Sakla Borehole. An explanation may be that the fluctuating nearshore environment of Saaremaa was suited to the earlier evolution of populations of *O. crista*, which spread into the Welsh Borderland with the onset of appropriate conditions. Further stratigraphical evidence, perhaps from acritarchs or from chemostratigraphy, is required to clarify this question.

The base of the Přídolí Series is commonly identified by the appearance of the ostracod *Frostiella groenvalliana* Martinsson (Hansch & Siveter, 1994), which occurs in the basal Downton Castle Sandstone Formation of Ludlow (Bassett *et al.*, 1982; Miller, 1995) and in the lower part of the Kaugatuma Stage on Saaremaa (Sarv, 1982). However, the conodont fauna of the Kuressaare Stage suggests a Přídolí age, or at least an age post-dating the highest Upper Whitcliffe Formation at Ludlow. One explanation that fits all the fossil data would be the existence of a gap in the succession at Ludlow at the top of the Upper Whitcliffe Formation, as intimated by Jeppsson (1983, p. 137), equivalent to the Kuressaare Stage of Estonia and encompassing the highest part of the Ludlow Series. Bassett *et al.* (1982, p. 6), however, while noting that the basal contact of the Downton Castle Sandstone Formation is sharp and scoured, considered there to be no indication of a major break in sedimentation at this level.

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APPENDIX: Locality information

Ohesaare borehole – situated in the southern part of the Ohesaare cliff, on the west coast of the Sõrve Peninsula.
 Kaugatuma borehole – situated near Kaugatuma cliff on the west coast of the Sõrve Peninsula.
 Riksu borehole – Situated near Riksu lake, Riksu village, southwest Saaremaa.
 Vesiku borehole – situated near the mouth of Vesiku brook, westernmost Saaremaa.
 Kuressaare (Kingissepa) borehole – situated in the centre of Kuressaare (in the yard of the restaurant 'Tuulik').
 Sakla borehole – situated on the south side of Sakla village,

southeast Saaremaa.

Kolka borehole – situated south of Kola village, on the east coast of the Kola cape, northernmost Kuseme Peninsula, Latvia. Anikaitse – small cliff (2.7 m) on the coast of the Kübassaare Peninsula, Anikaitse cape, easternmost Saaremaa.

Ilpla – outcrop on the shore terrace, western part of Ilpla village, south Saaremaa.

Karala – small old quarry at the west end of Karala village, westernmost Saaremaa.

Kärla – outcrop in Kärla brook, central Kärla village, westernmost Saaremaa.

Loode Tammik – small old quarry (1.2 m) in Loode Oak Wood (Tammik), 2 km west of Kuressaare, south Saaremaa.

Paadla – old quarry (1.8 m) in Paadla village, 50 m south of the Kuressaare–Kihelkonna road, central Saaremaa.

Roopa – small cliff (1.5 m) on the southernmost cape of the Atla Peninsula, western coast of Saaremaa.

Soeginina – cliff (4.2 m) on the south-west shore of the Atla Peninsula, westernmost Saaremaa.

Viita – old trench on the shore at Rootsiküla village, 2 km southwest of Kihelkonna, western Saaremaa.

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