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

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ABSTRACT – The closely related conodonts *Ozarkodina bohemica*, *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. bohemica* 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–Přídolí 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 Sörve 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 Přídolí 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 bohemica* (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 bohemica* lineage

The oldest reported member of this lineage is *O. bohemica* 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. bohemica bohemica* 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

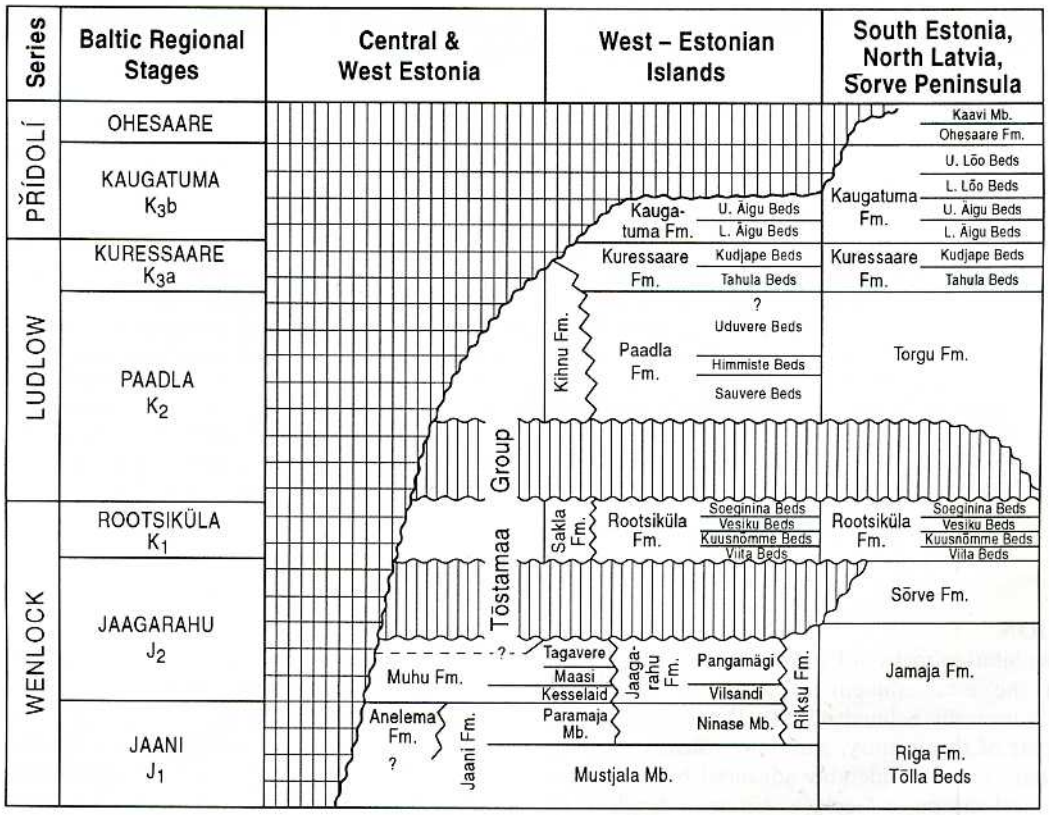

Fig. 1. Current correlation chart of Wenlock–Přídolí stratigraphical units in Estonia and Latvia (from Nestor, 1993).

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. bohemica* 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 Mehrtens & 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. bohemica bohemica*, *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 posess 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 bohemica bohemica*, *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*. Fåhraeus (1969) reported the Pa element of *O. crispa* on Gotland in strata above *O. r. eosteinhornensis*, leading Walliser (1971) to question

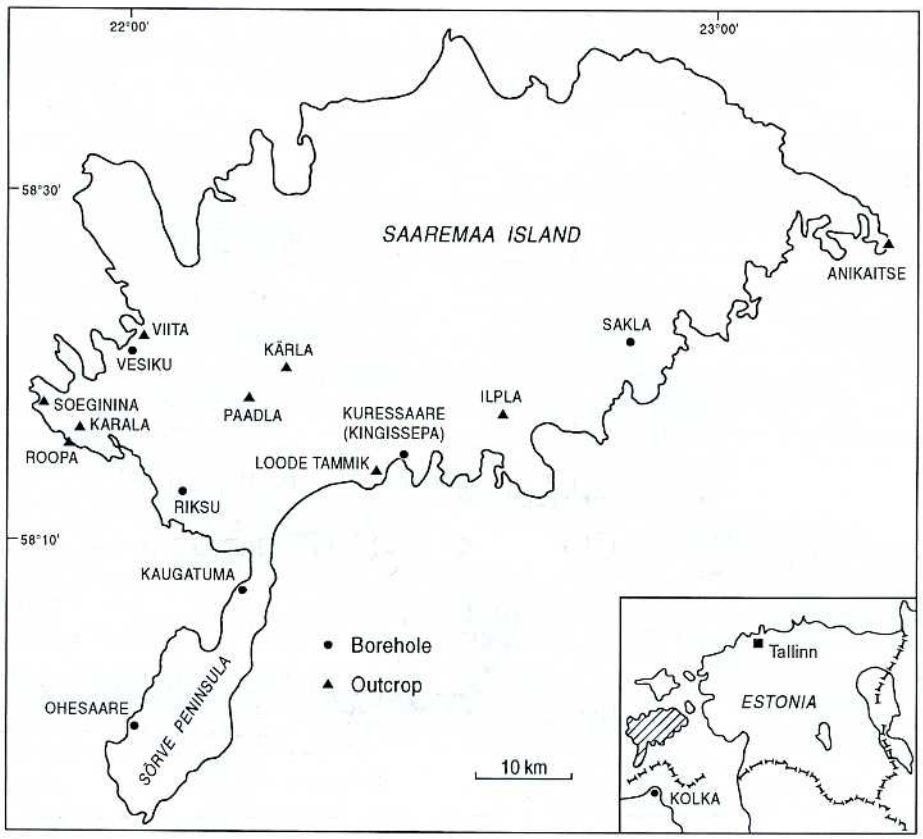

Fig. 2. Location map of outcrops (triangles) and boreholes (circles) on Saaremaa and northernmost Latvia.

whether the '*crispus* zone' lay within the '*eosteinhornensis* zone' or whether the two overlapped. In fact, the specimen illustrated by Fåhraeus (1969, pl. 2, figs 13, 14) may belong to *O. snajdri*, although subsequent work has resulted in records of *O. crispa* 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. crispa* and the specific assignment is equivocal. An overlap of the ranges of *O. crispa* 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. crispa* and terminated above it.

In Australia, De Deckker (1976) found some overlap of the ranges of *O. snajdri* and *O. crispa* 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. crispa* 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. crispa*, *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. crispa* and *O. r. eosteinhornensis* s. l. in the Muslovka Quarry, Bohemia, leading to a proposal to incorporate a *crispa* 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. crispa* in Kolednik Quarry, Bohemia. In Britain, uppermost Ludlow conodont faunas include *O. snajdri*, *O.* cf. *snajdri*, *O. crispa*, *O.* cf. *crispa*, *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. crispa*.

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