Conodont dating of some Telychian (Silurian) sections in Estonia

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Abstract. Several Telychian–Sheinwoodian strata exposed in Estonia are precisely dated using conodont biostratigraphy. The beds in the Valgu-1 section correspond to the uppermost *Distomodus staurognathoides* and *Pterospathodus eopennatus* ssp. n. 1 zones. In the Valgu-2 and Valgu-3 sections only the *P. eopennatus* ssp. n. 1 Zone is exposed. The strata in the Velise-Kõrgekalda section correspond to the Lower subzone of the *P. amorphognathoides angulatus* Zone. Marlstones in the Jädivere section are assigned to the *P. a. lennarti* Zone. In the Avaste section part of the *P. a. lithuanicus* Zone is exposed. On the Saastna Peninsula two stratigraphical intervals, the lower corresponding to the Upper subzone of the *P. a. amorphognathoides* Zone and the upper to the Upper *Kockelella ranuliformis* Zone, crop out along the shoreline. In Saastna the exposed strata are separated by a covered interval corresponding to five conodont zones, from the Lower *Pseudooneotodus bicornis* Zone to the Lower *K. ranuliformis* Zone.

Key words: conodonts, stratigraphy, Telychian, Sheinwoodian, Silurian, Estonia.

INTRODUCTION

Different intervals of Telychian (Adavere Stage) and/or lower Sheinwoodian (Jaani Stage) strata are exposed in the sections discussed below. The intervals are dominated by various marlstones which, according to Nestor & Einasto (1997), formed during a transgressive (deepening) phase of the late Llandovery–middle Wenlock macrocycle of basin development. Three units, the Rumba and Velise formations in the Adavere Stage, and the Mustjala Member of the Jaani Formation in the lower part of the Jaani Stage, span this interval in the outcrop area. In terms of sequence stratigraphy, the strata of the Adavere Stage correspond to Sequence 4 (S4) and those of the Mustjala Member to the lower part of Sequence 5 (S5) (Harris et al. 2005). A major flooding event marks the base of S4. This sequence is separated from the underlying sequence S3, which corresponds to the upper half of the Raikküla Stage, by an extensive gap in the region. At this level a gap has been recognized globally, e.g. in Australia, where it is known as the Panuara Hiatus (Bischoff 1986). The boundary between S4 and S5 is marked by submarine erosion (or slumping) on the buried palaeoslope and local (along the western coast of modern Estonia) deposits of redeposited ooids. To the east of the belt with ooids a distinct gap occurs at the sequence boundary, increasing in duration to the northeast.

The Rumba Formation is represented by a cyclic succession of marlstones to argillaceous limestones and relatively pure limestones (Einasto et al. 1972). A very rich association of shallow-water benthic fossils occurs in these strata, sometimes as scattered valves, sometimes as clusters of complete shells in living position, and sometimes as tempestitic accumulations of *Pentamerus oblongus* Sowerby (Kaljo 1970). The overlying Velise Formation and the succeeding Mustjala Member of the Jaani Formation are lithologically very similar. These units consist of different marlstones and mudstones (plastic clays in the lower part of the succession) and are difficult to separate in continuous sections where lithological changes are gradual (e.g. in the Viki core of western Saaremaa; Nestor 1990). However, it has been argued that in the mainland part of Estonia the strata of the Mustjala Member are much more dolomitized than marlstones of the Velise Formation (Aaloe 1970; Nestor 1997) and these two units can be separated on the basis of this feature. As the boundary between the Velise and Jaani formations has traditionally been considered to correspond to the boundary between the Adavere and Jaani stages (e.g. Nestor 1997), dolomitic marlstones in some sections (e.g. in Avaste; Aaloe 1970) have been dated as of Jaani (early Wenlock) age. However, it is evident now (see below) that this dating is not correct and that the strata exposed in the Avaste section are older.

Recent detailed studies of conodonts from Telychian and Sheinwoodian strata have enabled considerable improvement of conodont biostratigraphy for this interval (Jeppsson 1997; Männik 2007a). On the basis of these data, it has become possible to date precisely the Telychian–lowermost Sheinwoodian strata exposed in many sections in western Central Estonia (Fig. 1). Below, several of these sections are characterized briefly and the conodont faunas are discussed.

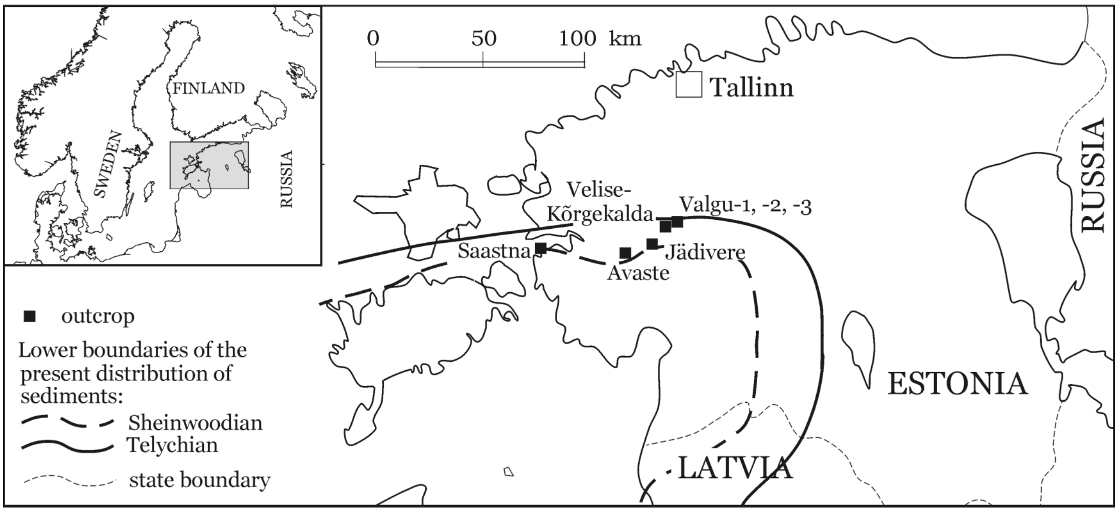


Fig. 1. Location of the studied sections.

All figured specimens of conodonts are deposited in collection GIT 555 in the Institute of Geology at Tallinn University of Technology, Estonia.

STUDIED SECTIONS

Seven sections (Valgu-1, Valgu-2, Valgu-3, Velise-Kõrgekalda, Jädivere, Avaste, and Saastna), located in west-central and western continental Estonia, were sampled for conodonts (Fig. 1). The average size of samples was 2–4 kg, but some samples from the Valgu-1 section (M-882, M-872, M-873, M-874, M-876), weighing more than 10 kg, were processed. All samples except for the lowermost one (M-1963) in the Valgu-1 section yield rich conodont faunas, allowing reliable location of the studied strata in the conodont zonal succession.

Sections in the Valgu region

Three sections, one at the drainage canal (Valgu-1) and two on the left bank of the Velise River (Valgu-2 and Valgu-3) were studied. All sections are located close to one another, about 0.8 km east-northeast of the main crossroad in Valgu village (Figs 1, 2).

The Valgu-1 section

In this section the upper part of the Rumba Formation and the lowermost Velise Formation are exposed (Fig. 2). Lithologically the Rumba Formation (exposed mainly just north of the Valgu–Rapla road; Fig. 2B) is dominated by light-grey variously dolomitized argillaceous to bioclastic limestones with abundant shells of *Pentamerus oblongus* in many beds. Discontinuity surfaces are common. As a rule, the surfaces are smooth, with abundant up to 2 cm deep holes, and variously pyritized. Often the discontinuity surfaces cut the shells of *Pentamerus oblongus*. Occasional tabulate corals, stromatoporoids, and trilobites have been found (Klaamann 1984b).

Two samples were studied from the uppermost Rumba Formation (Fig. 2), both of which yielded conodonts. In the lower sample (M-1963; 0.05–0.15 m below the upper boundary of the Rumba Formation; weight 4.15 kg) only two conodont specimens, one identified as *Panderodus* cf. *unicostatus* (Branson & Mehl) and the other as *Distomodus* cf. *staurognathoides* (Walliser), were found. The next sample (M-1962; weight 5.31 kg) comes from a bed between two discontinuity surfaces, the upper of which is considered to correspond to the boundary between the Rumba and Velise formations. This sample contains rich conodont fauna, similar to that of the overlying Velise Formation (see below). The contact between the Rumba and Velise formations is exposed close to the road (on both sides). The base of the Velise Formation is represented by a bed (2–3 cm in thickness) of bioturbated argillaceous bioclastic limestone.

The Velise Formation is dominated by grey, bluish-grey, and greenish-grey argillaceous to calcareous, often bioturbated, marlstones, with rare thin interbeds of argillaceous limestone, sometimes rich in bioclastic material. Nodules of similar limestone are common in some intervals. Three bentonites have been found in the section. The lowermost one is up to 10–13 cm thick, of light yellowish colour and hard. The uppermost part of this bentonite is strongly bioturbated. The burrows are filled with greenish-grey calcareous marlstone. A thin

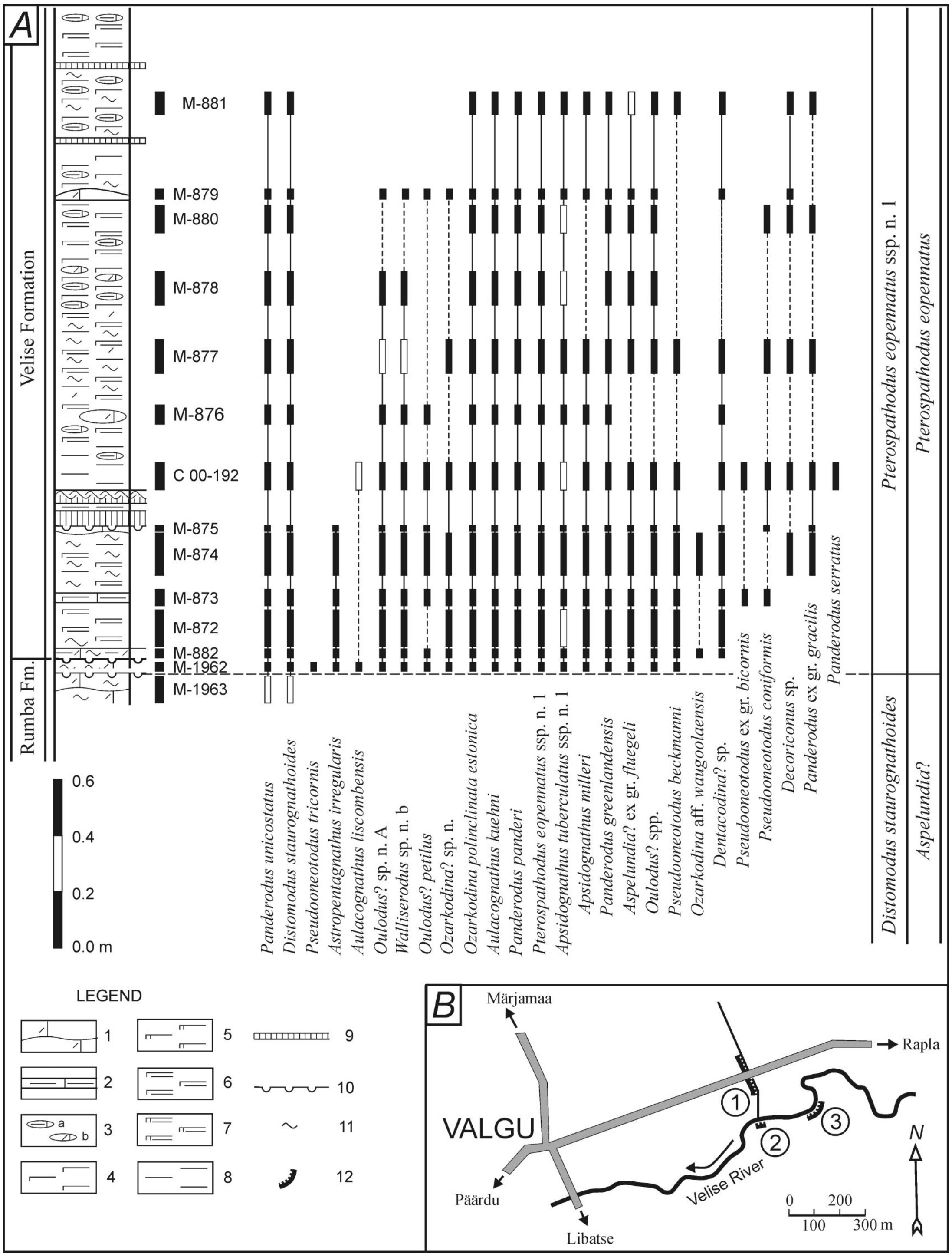


Fig. 2. (A) Distribution of conodonts in the Valgu drainage canal (Valgu-1) section. From left to right: formation, lithological log of the section, sample, sample number in the section, distribution of taxa (solid line – continuous occurrence of a taxon; dotted line – sporadic occurrence of a taxon; filled box – precise identification of a taxon; empty box – problematic identification of a taxon), zone, superzone. Legend: 1, limestone with small bioclasts; 2, interbed of argillaceous limestone; 3, nodules of argillaceous limestone (a) and limestone with bioclasts (b); 4, calcareous marlstone; 5, dolomitized calcareous marlstone; 6, argillaceous marlstone; 7, dolomitized argillaceous marlstone; 8, plastic clay and/or claystone; 9, bentonite; 10, discontinuity surface; 11, bioturbation; 12, studied section. (B) Detailed map indicating location of the studied sections: 1, Valgu drainage canal (Valgu-1) section; 2, Valgu-2 section; 3, Valgu-3 section. Grey thick lines indicate main roads.

(2–3 cm) interbed of calcareous clay divides the bentonite into two parts of almost equal thickness. Two additional bentonites, located higher in the section, are thin (1–3 cm), light-coloured (yellowish), and also hard. All three bentonites are also recognized in the Valgu-2 section and the upper two in the Valgu-3 section (see below; Fig. 3).

The samples from the Velise Formation contain rich and variable conodont faunas (Fig. 2) characterized mainly by *Pterospathodus eopennatus* ssp. n. 1 Männik, *Aulacognathus kuehni* Mostler, *Apsidognathus milleri* (Over & Chatterton), and, only in the lower part of the section, *Astropentagnathus irregularis* Mostler. Platform-

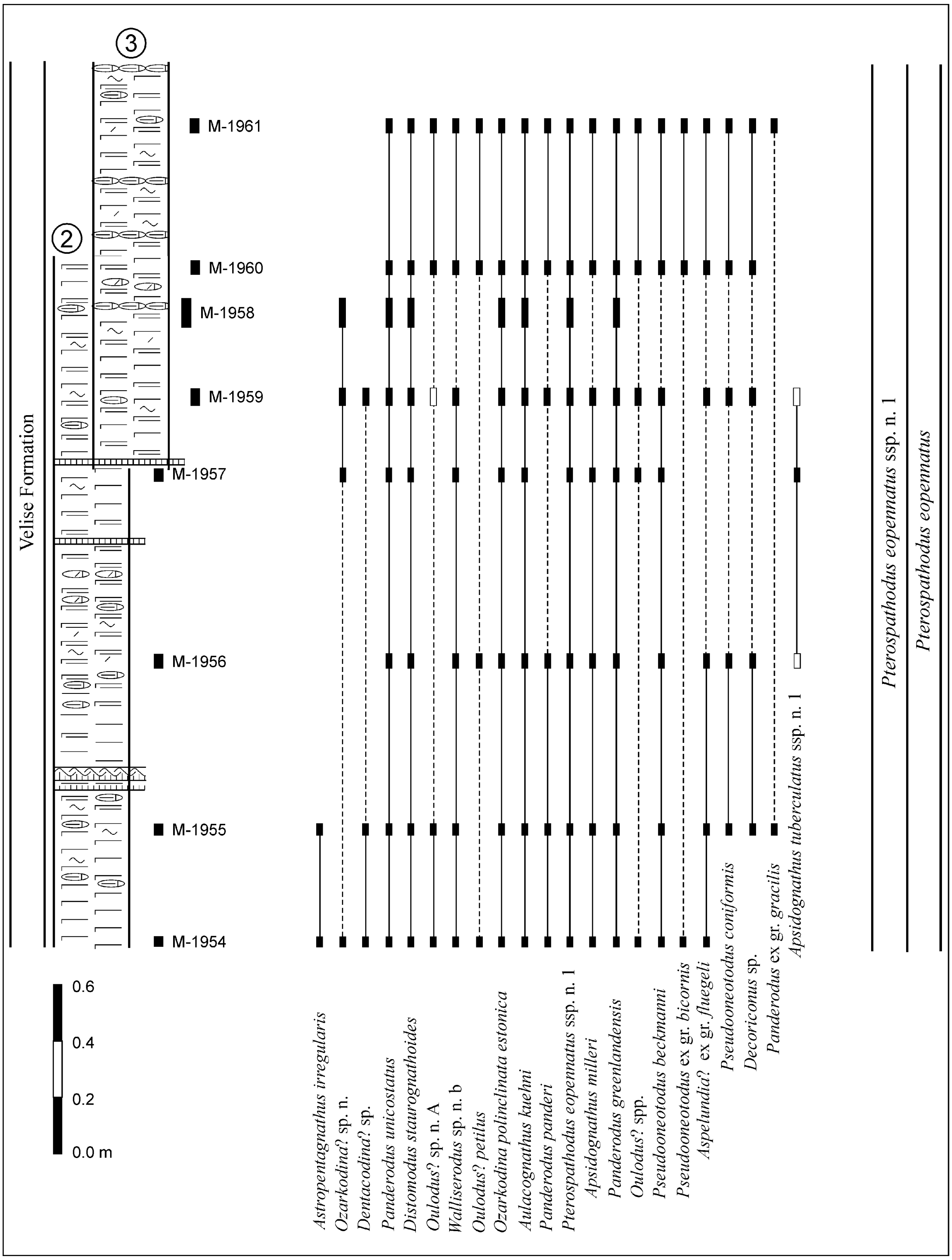


Fig. 3. Distribution of conodonts in the Valgu-2 and Valgu-3 sections. For location of the sections see Figs 1 and 2B; for legend and explanations refer to Fig. 2. Sample M-1958 comes from the Valgu-2 section.

bearing genera (*Apsidognathus*, *Astropentagnathus*, *Aulacognathus*, *Distomodus*) are important, with *Apsidognathus* being represented at least by two different species.

The Valgu-2 and Valgu-3 sections

Outcrops along the Velise River in Valgu village have been known for a long time (e.g. Rosenstein 1939; Jürgenson 1964, 1966). Now the cliffs, once well exposed along the river, are mostly covered and just a few parts of them are accessible for study. The two sections sampled for conodonts and to be discussed here are located on the left bank of the Velise River, about 1.0 and 1.2 km upstream from the bridge across the river on the Valgu–Libatse road (Fig. 2). In these sections the same strata (excluding the Rumba Formation) as in the Valgu-1 section are exposed. In the upper part of the Valgu-3 section strata younger than the uppermost beds studied in Valgu-1 are exposed. Lithologically, the succession of strata in these two sections is similar to that in the Valgu-1 section (Figs 2 and 3), although in Valgu-2 and Valgu-3 the rock is slightly dolomitized. Conodont faunas are similar in all three sections. In the Valgu-3 section only the strata above the uppermost bentonite were sampled for conodonts (Fig. 3).

The Velise-Kõrgekalda section

The section is located on the left bank of the Velise River, about 2.3 km from the bridge at Velise towards Päärdu village, 0.2 km north of the road (Figs 1, 4). The outcrop, mostly covered by debris and vegetation, is a natural cliff up to 4–5 m high, and can be followed for more than 100 m along the river. The strata are better exposed at the downstream end of the cliff. Here, the section shown in this paper was described and sampled.

The lowermost strata accessible in the section consist of argillaceous bioclastic limestones with abundant pyrite aggregates of various sizes. This bed forms the floor of the river channel. An interbed of similar limestone, a few decimetres thick, occurs about a metre higher in the section. The section is dominated by argillaceous marlstones which contain abundant nodules of calcareous marlstone, and burrows up to 2.5–3 cm in diameter, filled with calcareous material rich in bioclasts. This interval, as a rule, is covered by debris and vegetation. The uppermost 1 m of the section is more calcareous and forms an almost vertical cliff. The upper contact of the Telychian strata is erosional and is followed by Quaternary glacial and limnoglacial deposits with a thickness of up to 2 m.

Most significant in the rich conodont faunas in the Velise-Kõrgekalda section is the occurrence of *Pterospathodus amorphognathoides angulatus* (Walliser) and *Apsidognathus tuberculatus* ssp. n. 3 (Fig. 4). The oldest known specimen of *Nudibelodina sensitiva* Jeppsson has been found in sample Vl-2 from the base of this section.

The Jädivere section

The section is located on the left bank of the Enge River, west of the bridge (about 200 m downstream of it) on the Tallinn–Pärnu road (Figs 1, 5). The section is up to 2.5 m high and nowadays almost completely covered by debris. However, as the layer of debris is thin, the bedrock is easy to clean out. Lithologically the section consists of monotonous light bluish-grey marlstones, more calcareous in the lower and argillaceous in the upper parts of the section. Benthic macrofossils appear to be entirely absent, although rare tiny fragments of unidentified organisms(?) occur sporadically. The age of the strata exposed in the Jädivere outcrop has been problematic. Originally, they were assigned to the Jaani Stage (Aaloe 1970). Later, *P. amorphognathoides* Walliser was indentified in the section, which dated the marlstones outcropping here to the corresponding zone at the Llandovery–Wenlock transition (Klaamann 1984a). Recent studies have revealed that *P. amorphognathoides* in this section is represented by *P. a. lennarti* Männik, known only from strata of Telychian age (Männik 1998, 2007a). The relatively rich conodont faunas include also *Aulacognathus* sp. n. (Fig. 5).

The Avaste section

The section is located about 8 km west of the Kivi-Vigala settlement in western Estonia (Figs 1, 6). The strata sampled for conodonts are exposed in shallow gullies just opposite Järsu farmhouse. The gullies are cut in the upper part of a steep, up to 10 m high terrace which is an ancient coastal cliff of the Litorina Sea, now completely buried and covered by vegetation (Kessel & Raukas 1967). No continuous section is available, but small intervals are exposed in the upper half of the slope. An attempt to clean a section at the base of the slope was unsuccessful, and only two samples from the upper half and the top of the slope were studied (Fig. 6).

The strata sampled are represented by grey, more or less argillaceous dolomitized marlstones. No macrofauna has been found. The beds exposed in the Avaste section have previously been considered to correspond to the Paramaja Member of the Jaani Stage and, accordingly, to be of early Wenlock (Sheinwoodian) age (Aaloe 1961, 1970). The samples processed from this section yielded a conodont fauna, most significantly including *P. a. lithuanicus* Brazauskas and *Aspelundia*? ex gr. *fluegeli* (Walliser), and lacking *Ozarkodina polinclinata* (Pollock, Rexroad & Nicoll) (Fig. 6).

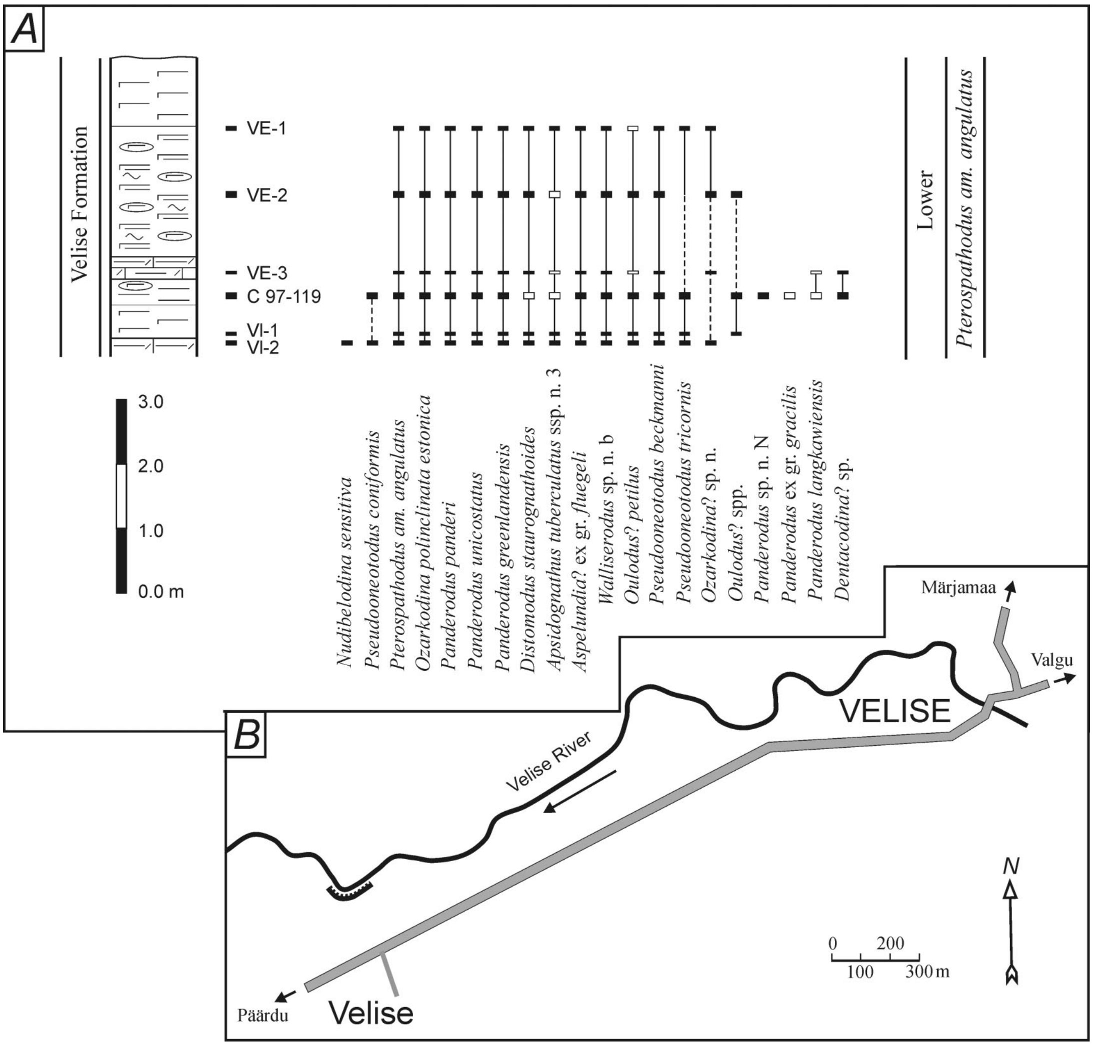


Fig. 4. (A) Distribution of conodonts in the Velise-Kõrgekalda section. For legend and explanations refer to Fig. 2. (B) Detailed map with location of the section.

Sections on the western end of the Saastna Peninsula

The Saastna Peninsula is located in western Estonia, between Matsalu Bay in the north and Topu Bay in the south (Figs 1, 7). Several small outcrops, mainly exposed surfaces of bedrock, occur on the coastline around the western end of the peninsula. In some of them, a few decimetres thick sections can be compiled. Several spot-samples have been processed from these outcrops (in Fig. 7 the samples are arranged in their probable stratigraphic order).

Along the northwestern coast of the Saastna Peninsula the uppermost Velise Formation, represented by calcareous marlstones and argillaceous limestones, is exposed. The strata are rich in fine bioclastic material, light-coloured ooids, and pyrite. In some beds below sea level, large (up to 2–3 cm) euhedral crystals of pyrite occur. The strata are bioturbated and partly dolomitized. In these outcrops the coral *Palaeocyclus porpita* Lamark has been found. The rich conodont faunas of these strata are characterized by the occurrences of *P. a. amorphognathoides*, *Apsidognathus walmsleyi* Aldridge, *Aps. ruginosus*, *O. polinclinata polinclinata* (Pollock, Rexroad & Nicoll), and *N. sensitiva* (Fig. 7; samples M-853, M-852, M-1811).

Two main types of rock occur in the exposures along the southern coast of the peninsula (samples M-1809 and M-1810; Fig. 7). The lower part of the succession (sample M-1810) is composed of intercalations of grey argillaceous thin-bedded limestone and argillaceous to calcareous marlstone. The rock is bioturbated and contains fine bioclastic material, pyrite aggregates of various sizes, and rare fragments of halysitid corals and

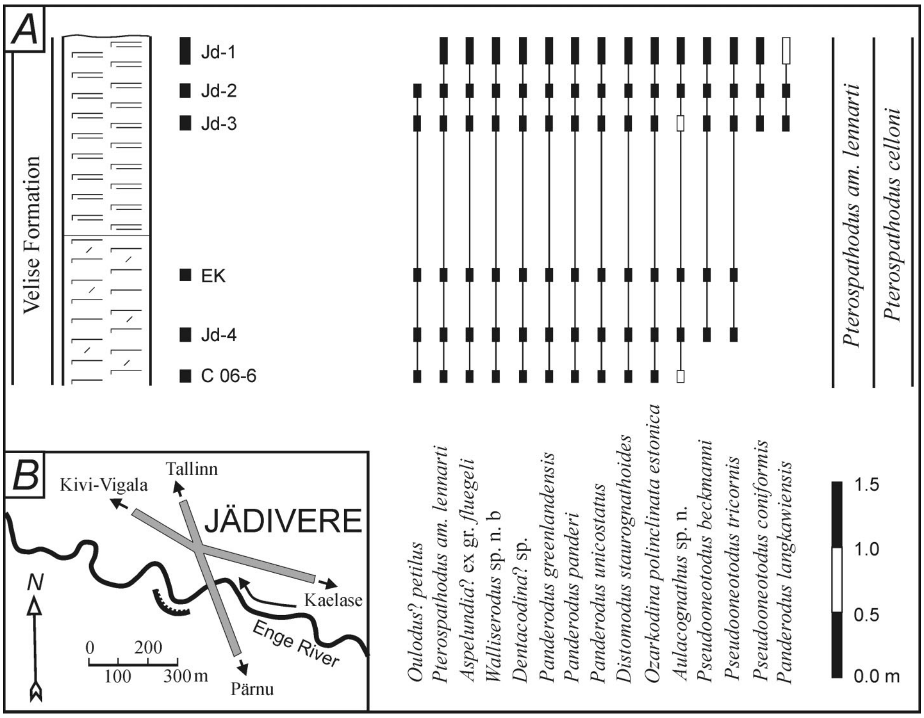


Fig. 5. (A) Distribution of conodonts in the Jädivere section. For legend and explanations refer to Fig. 2. (B) Detailed map with location of the section.

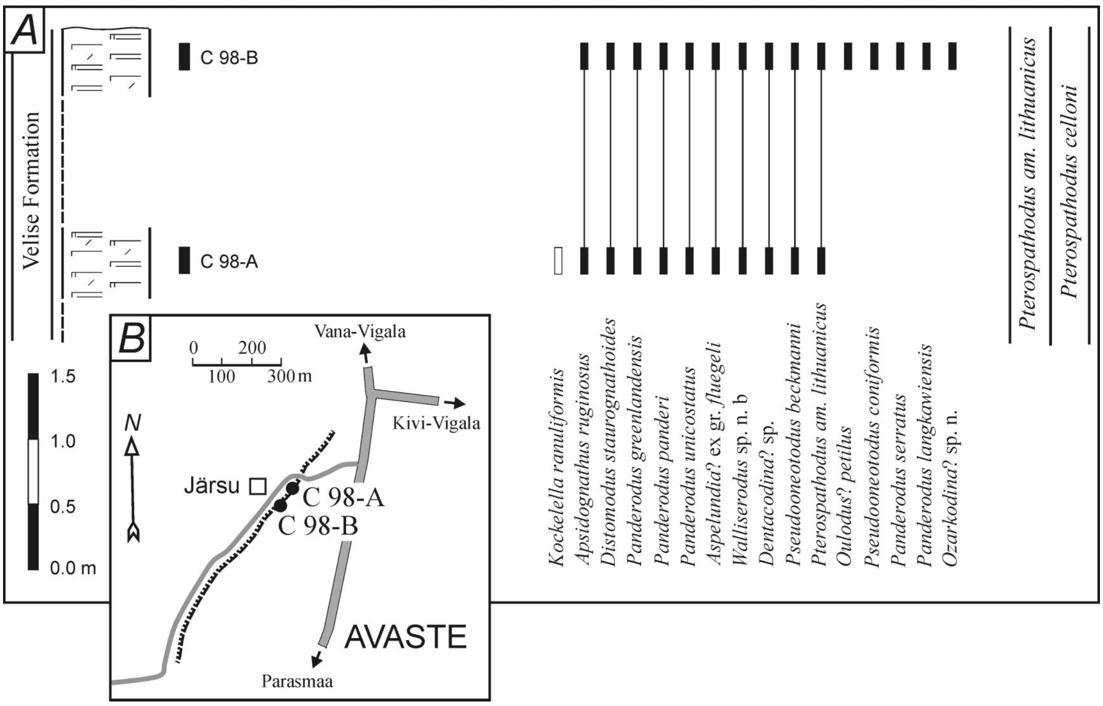


Fig. 6. (A) Distribution of conodonts in the Avaste section. For legend and explanations refer to Fig. 2. (B) Detailed map with location of the section.

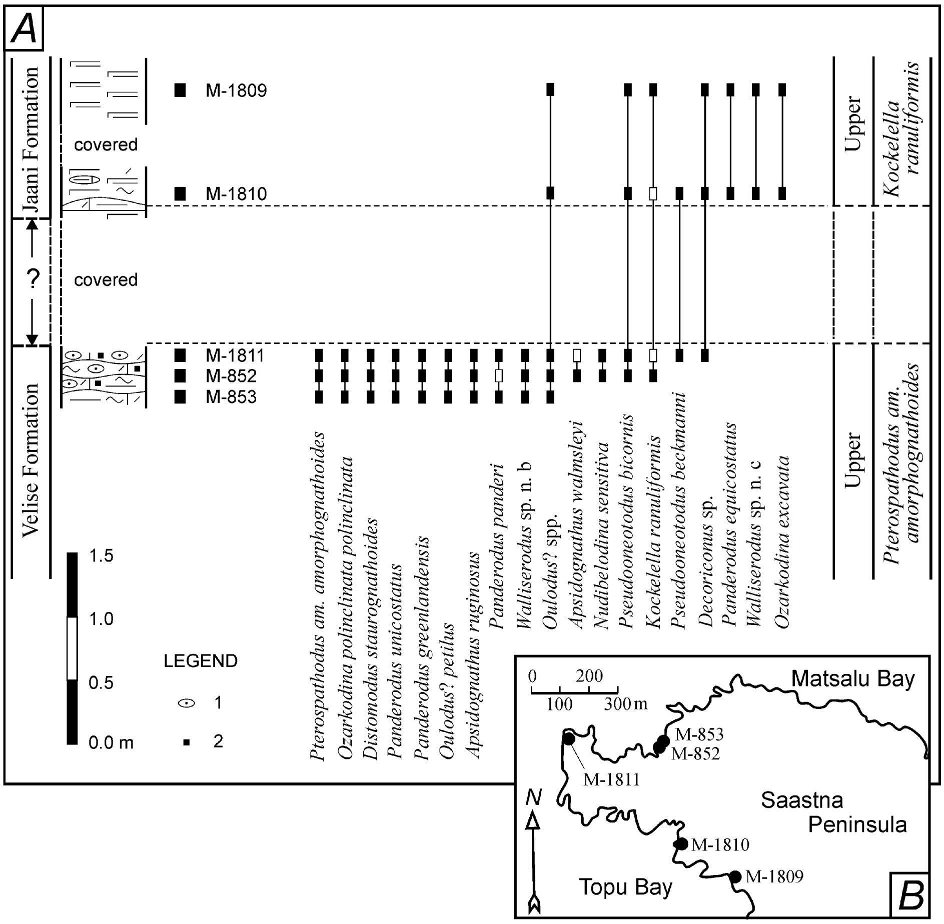


Fig. 7. (A) Distribution of conodonts in several spot-samples from the outcrops on the Saastna Peninsula. Legend: 1, ooids; 2, crystals of pyrite. For other explanations refer to Fig. 2. (B) Map indicating location of the studied samples (outcrops).

of cephalopods. Ooids have not been found in these strata. The calcareous interval is followed by monotonous grey argillaceous marlstone (sample M-1809). The conodont fauna in these strata differs completely from that in outcrops along the northern coast of the peninsula (Fig. 7) and is dominated by *Panderodus equicostatus* (Rhodes). *Walliserodus* sp. n. b, characteristic of Telychian strata (Männik 2007a), is replaced here by *Walliserodus* sp. n. c. *Ozarkodina excavata* (Branson & Mehl) is common. Most of the taxa identified in older strata are missing.

DISCUSSION

All studied sections yielded rich conodont faunas of specific composition, allowing precise dating of the exposed strata. The three outcrops just east of the Valgu settlement are characterized by the occurrence of *P. eopennatus* ssp. n. 1 (Figs 2, 3, 8A–C) and, accordingly, correspond to the *P. eopennatus* ssp. n. 1 Zone *sensu* Männik (2007a) (Fig. 9). In the Valgu-1 section (Valgu drainage canal) the lower boundary of the zone is exposed in the uppermost Rumba Formation. The boundary is marked by a pyritized discontinuity surface suggesting a gap below this level, which may also account for the abrupt appearance of the rich *P. eopennatus* ssp. n. 1 Zone conodont fauna in the section. The single sample just below the discontinuity surface contains only two poorly preserved conodont specimens, one of which was identified as *Panderodus* cf. *unicostatus* and the other as *Distomodus* cf. *staurognathoides*. These strata probably correspond to the *D. staurognathoides* Zone (Figs 2, 9).

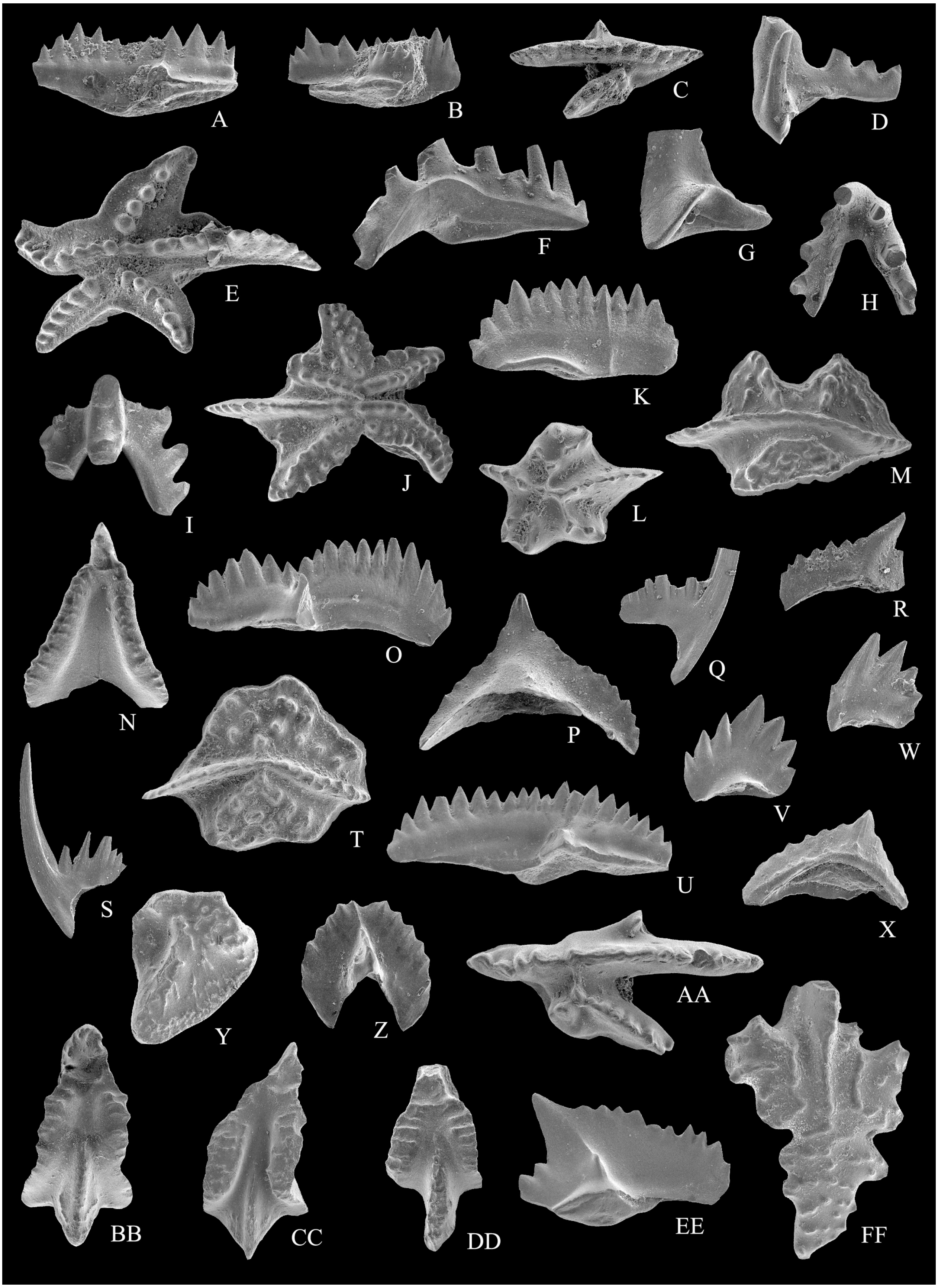
At the boundary between the *D. staurognathoides* and *P. eopennatus* ssp. n. 1 zones the abundance of conodont specimens increases abruptly, reaching many hundreds to more than a thousand per 1 kg of rock. Also, many taxa appear, including *P. eopennatus* ssp. n. 1 (Fig. 8A–C), *Astropentagnathus irregularis* (Fig. 8E), *Oulodus*? sp. n. A Over & Chatterton (Fig. 8D, F–I), *Aulacognathus kuehni* (Fig. 8J), *Ozarkodina polinclinata estonica* Männik (Fig. 8K), *Apsidognathus tuberculatus*

Walliser (represented in this interval by *Aps. tuberculatus* ssp. n. 1; Fig. 8M, N, P), and *Aps. milleri* (Over & Chatterton) (Fig. 8L, R). *Astropentagnathus irregularis* disappears, as in Valgu-1 and Valgu-2, just below the lowermost, thick double(?) bentonite (Figs 2, 3). The level of disappearance (extinction) of *Astr. irregularis* marks Datum 1 of the Valgu Event *sensu* Männik (2007b). The strata above this level correspond to the uppermost *P. eopennatus* ssp. n. 1 Zone, as indicated by the occurrence here of morph 5 of the Pa element of *P. eopennatus* ssp. n. 1 of Männik (1998) (Fig. 8A–C). The upper boundary of the *P. eopennatus* ssp. n. 1 Zone is not exposed in the Valgu sections.

The abrupt appearance of many new conodont taxa and rapid increase in the number of conodont specimens at the lower boundary of the *P. eopennatus* ssp. n. 1 Zone evidently indicates a next (after that marking the lower boundary of the sequence) major flooding event in Sequence 4 (S4) *sensu* Harris et al. (2005). However, the most distinct lithological change occurs a little higher in the section, at the boundary between the Rumba and Velise formations (between samples M-1962 and M-882 in the Valgu-1 section; Fig. 2). The succession of events in this interval (i.e. abrupt appearance of rich *P. eopennatus* ssp. n. 1 Zone fauna, followed by lithological change at the formational boundary) can be observed in all studied sections in Estonia (e.g. Männik 2003, 2007a; Rubel et al. 2007). It seems possible that, in terms of sequence stratigraphy, the strata of the Rumba Formation formed during the initial stage of the transgression above the S3/S4 boundary, i.e. they correspond to the Lowstand Systems Tract of sequence S4. If so, then one of the levels discussed above (the boundary between the Rumba and Velise formations?) most probably correlates with the Transgressive Surface in the sequence.

Faunas from the Velise-Kõrgekalda section are characterized by *P. a. angulatus* (Fig. 8O, Q, S, U, V, W; Fig. 4), the total range of which corresponds to the *P. a. angulatus* Zone (Männik 2007a). *Apsidognathus tuberculatus* ssp. n. 3 (Fig. 8T, X–Z, BB–DD) indicates that these strata correspond to the lower subzone of the zone (Fig. 9). Judging from the morphologies of the elements of *P. a. angulatus* [typical Sc_2 and Pb_2 elements of the taxon (Fig. 8Q, V) are accompanied by morphologies characteristic of *P. eopennatus* (Fig. 8S, W)] and *Aps. tuberculatus* ssp. n. 3 [typical lyriform elements of this taxon (Fig. 8DD) occur together with specimens bearing features characteristic of the older subspecies *Aps. tuberculatus* ssp. n. 2 (Fig. 8BB, CC)], it is most probable that the lower boundary of the *P. a. angulatus* Zone lies not far (just?) below the lowermost sample in the section.

Fig. 8. Selected conodonts from the sections studied. **A–C**, *Pterospathodus eopennatus* ssp. n. 1 Männik. A, GIT 555-1, inner lateral view of dextral Pa element, Valgu-1 section, sample M-877, ×70; B, GIT 555-2, inner lateral view of sinistral Pa element, Valgu-1 section, sample M-877, ×50; C, GIT 555-3, upper view of dextral Pa element, Valgu-1 section, sample M-877, ×50. **D**, **F–I**, *Oulodus*? sp. n. A Over & Chatterton. D, GIT 555-4, inner lateral view of dextral Sc element, Valgu-1 section, sample M-882, ×40; F, GIT 555-5, inner lateral view of sinistral Pa? element, Valgu-1 section, sample M-882, ×40; G, GIT 555-6, inner lateral view of dextral M element, Valgu-1 section, sample M-882, ×40; H, GIT 555-7, posterior view of sinistral Sb element, Valgu-1 section, sample M-882, ×50; I, GIT 555-8, posterior view of Sa element, Valgu-1 section, sample M-882, ×50. **E**, *Astropentagnathus irregularis* Mostler, GIT 555-9, upper view of sinistral Pa_1 element, Valgu-1 section, sample M-882, ×40. **J**, *Aulacognathus kuehni* Mostler, GIT 555-10, upper view of sinistral Pa element, Valgu-2 section, sample M-1956, ×20. **K**, *Ozarkodina polinclinata estonica* Männik, GIT 555-11, outer lateral view of dextral Pa element, Valgu-1 section, sample M-882, ×50. **L**, **R**, *Apsidognathus milleri* (Over & Chatterton). L, GIT 555-12, upper view of sinistral Pa element, Valgu-2 section, sample M-1956, ×50; R, GIT 555-13, outer lateral view of sinistral Pb element, Valgu-1 section, sample M-881, ×50. **M**, **N**, **P**, *Apsidognathus tuberculatus* ssp. n. 1. M, GIT 555-14, upper view of sinistral Pa element, Valgu-1 section, sample M-882, ×50; N, GIT 555-15, upper view of lyriform element, Valgu-1 section, sample M-882, ×50; P, GIT 555-16, inner lateral view of sinistral Pb element, Valgu-1 section, sample M-882, ×40. **O**, **Q**, **S**, **U**, **V**, **W**, *Pterospathodus amorphognathoides angulatus* (Walliser). O, GIT 555-17, inner lateral view of sinistral Pa element, Velise-Kõrgekalda section, sample Vl-2, ×50; Q, GIT 555-18, inner lateral view of sinistral Sc_2 element, Velise-Kõrgekalda section, sample Vl-2, ×70; S, GIT 555-19, inner lateral view of dextral Sc_2 element, Velise-Kõrgekalda section, sample Vl-2, ×70; U, GIT 555-20, inner lateral view of dextral Pa element, Velise-Kõrgekalda section, sample Vl-2, ×50; V, GIT 555-21, inner lateral view of dextral Pb_2 element, Velise-Kõrgekalda section, sample Vl-2, ×70; W, GIT 555-22, outer lateral view of sinistral Pb_2 element, Velise-Kõrgekalda section, sample Vl-2, ×70. **T**, **X–Z**, **BB–DD**, *Apsidognathus tuberculatus* ssp. n. 3. T, GIT 555-23, upper view of sinistral Pa element, Velise-Kõrgekalda section, sample Vl-2, ×40; X, GIT 555-24, outer lateral view of sinistral Pb element, Velise-Kõrgekalda section, sample Vl-2, ×50; Y, GIT 555-25, upper view of lenticulariform element, Velise-Kõrgekalda section, sample Vl-2, ×50; Z, GIT 555-26, lateral view of astrognathiform element, Velise-Kõrgekalda section, sample Vl-2, ×50; BB, GIT 555-27, upper view of lyriform element, Velise-Kõrgekalda section, sample Vl-2, ×40; CC, GIT 555-28, upper view of lyriform element, Velise-Kõrgekalda section, sample Vl-2, ×40; DD, GIT 555-29, upper view of lyriform element, Velise-Kõrgekalda section, sample Vl-2, ×40. **AA**, *Pterospathodus amorphognathoides lennarti* Männik, GIT 555-30, upper view of sinistral Pa element, Jädivere section, sample Jd-4, ×40. **EE**, **FF**, *Aulacognathus* sp. n. EE, GIT 555-31, inner lateral view of sinistral Pb element, Jädivere section, sample Jd-2, ×40; FF, GIT 555-32, upper view of sinistral Pa element, Jädivere section, sample Jd-2, ×40.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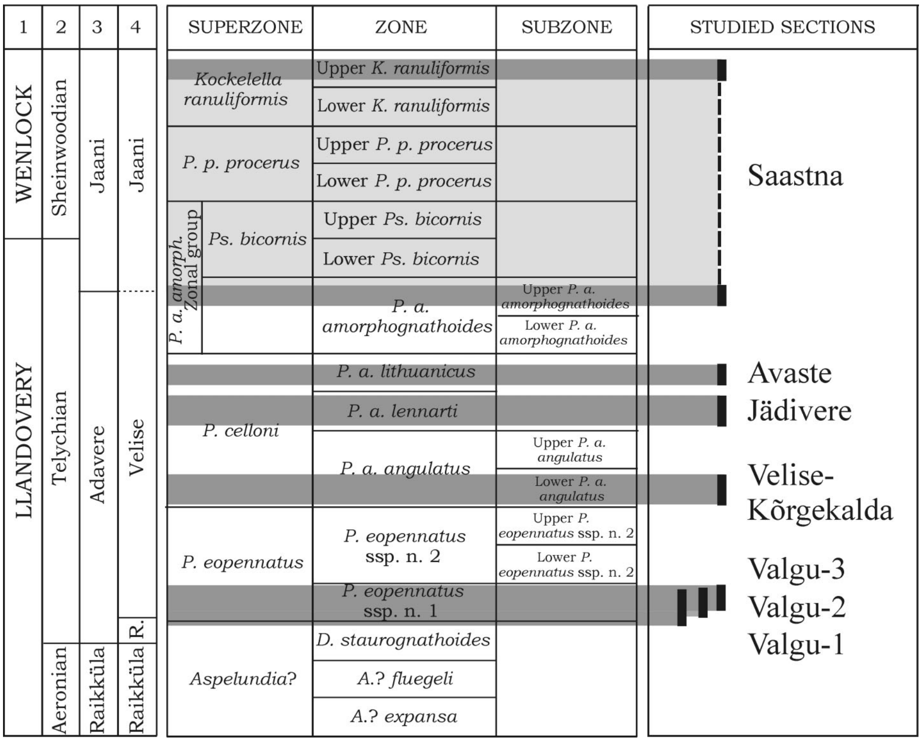
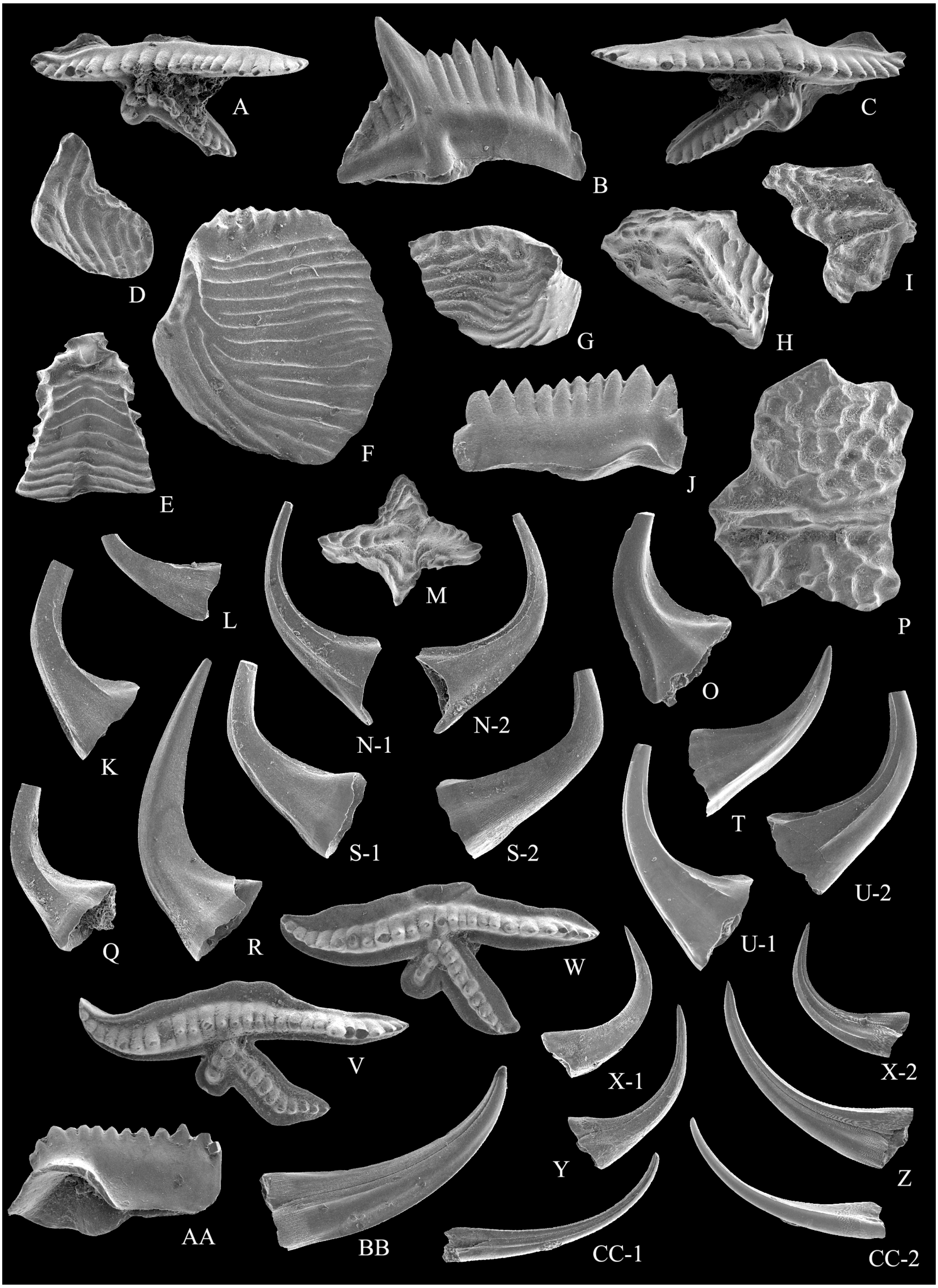


Fig. 9. Dating of the sections studied in terms of the conodont zonation. Conodont zonation according to Männik (2007a). 1, series; 2, stage; 3, regional stage; 4, formation. Grey intervals indicate intervals in the conodont zonation to which the studied sections correspond. The dotted line and interval in lighter grey in the Saastna section correspond to unsampled (unexposed) strata. Abbreviations: *P.*, *Pterospathodus*; *P. a. amorph.*, *Pterospathodus amorphognathoides amorphognathoides*; *Ps.*, *Pseudooneotodus*; *P. p.*, *Pterospathodus pennatus*; *A.*, *Aspelundia*; *D.*, *Distomodus*; *K.*, *Kockelella*; R., Rumba.

Fig. 10. Selected conodonts from the sections studied. **A–C**, *Pterospathodus amorphognathoides lithuanicus* Brazauskas. A, GIT 555-33, upper view of sinistral Pa element, Avaste section, sample C98-B2, ×50; B, GIT 555-34, outer lateral view of dextral Pb_1 element, Avaste section, sample C98-B2, ×50; C, GIT 555-35, upper view of dextral Pa element, Avaste section, sample C98-B2, ×50. **D–I**, **M**, *Apsidognathus ruginosus* Mabillard & Aldridge. D, GIT 555-36, upper view of lenticulariform element, Avaste section, sample C98-B2, ×50; E, GIT 555-37, upper view of lyriform element, Saastna section, sample M-853, ×50; F, GIT 555-38, upper view of lenticulariform element, Avaste section, sample C98-B1, ×50; G, GIT 555-39, upper view of lenticulariform element (fragment), Saastna section, sample M-853, ×50; H, GIT 555-40, upper view of sinistral Pb element, Saastna section, sample M-853, ×50; I, GIT 555-41, upper view of Pa element (fragment), Saastna section, sample M-853, ×50; M, GIT 555-42, upper view of astrognathiform element, Saastna section, sample M-852, ×50. **J**, *Ozarkodina polinclinata polinclinata* (Nicoll & Rexroad), GIT 555-43, inner lateral view of dextral Pa element, Saastna section, sample M-852, ×50. **K**, **L**, **N**, **Q–S**, *Walliserodus* sp. n. b. K, GIT 555-44, lateral view of symmetrical dyscritiform element, Velise-Kõrgekalda section, sample VE-1, ×70; L, GIT 555-45, outer lateral view of sinistral multicostatiform element, Velise-Kõrgekalda section, sample VE-1, ×70; N, GIT 555-46, inner lateral (N-1) and outer lateral (N-2) views of dextral multicostatiform element, Velise-Kõrgekalda section, sample VE-1, ×70; Q, GIT 555-47, inner lateral view of dextral curvatiform element, Velise-Kõrgekalda section, sample VE-1, ×70; R, GIT 555-48, outer lateral view of sinistral unicostatiform element, Velise-Kõrgekalda section, sample VE-1, ×50; S, GIT 555-49, inner lateral (S-1) and outer lateral (S-2) views of dextral high-base deboltiform element, Velise-Kõrgekalda section, sample VE-1, ×70. **P**, *Apsidognathus walmsleyi* Aldridge, GIT 555-50, upper view of Pa element (broken), Saastna section, sample M-852, ×50. **O**, **T**, **U**, *Walliserodus* sp. n. c. O, GIT 555-51, inner lateral view of dextral curvatiform element, Saastna section, sample M-1809, ×70; T, GIT 555-52, outer lateral view of dextral unicostatiform element, Saastna section, sample M-1809, ×50; U, GIT 555-53, inner lateral (U-1) and outer lateral (U-2) views of dextral low-base deboltiform element, Saastna section, sample M-1809, ×70. **V**, **W**, *Pterospathodus amorphognathoides amorphognathoides* Walliser. V, GIT 555-54, upper view of sinistral Pa element, Saastna section, sample M-852, ×40; W, GIT 555-55, upper view of sinistral Pa element, Saastna section, sample M-852, ×40. **X–Z**, **BB**, **CC**, *Panderodus equicostatus* (Rhodes). X, GIT 555-56, unfurrowed (X-1) and furrowed (X-2) faces of dextral truncatiform element, Saastna section, sample M-1809, ×50; Y, GIT 555-57, lateral view of aequaliform element, Saastna section, sample M-1809, ×50; Z, GIT 555-58, furrowed face of sinistral tortiform element, Saastna section, sample M-1809, ×40; BB, GIT 555-59, furrowed face of dextral falciform element, Saastna section, sample M-1809, ×40; CC, GIT 555-60, furrowed (CC-1) and unfurrowed (CC-2) faces of dextral asymmetrical graciliform element, Saastna section, sample M-1809, ×50. **AA**, *Kockelella ranuliformis* (Walliser), GIT 555-61, lateral view of sinistral Pa element, Saastna section, sample M-1809, ×50.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The age of the strata exposed in the Jädivere section has been problematic for a long time. Aaloe (1961) assigned these strata, as well as those in the Avaste section (see below), to the Paramaja Member of the Jaani Stage (Sheinwoodian in age). Later, based on the identification of *P. amorphognathoides* in the Jädivere section, Klaamann (1984a) dated the marlstones here as of latest Llandovery–earliest Wenlock age. Restudy of the section and collections of conodonts revealed that these strata correspond to the *P. a. lennarti* Zone (to an interval in the upper part of the Adavere Stage, Telychian; Figs 5, 9). The most characteristic conodonts in this section are *P. a. lennarti* Männik (Fig. 8AA) and *Aulacognathus* sp. N. (Fig. 8EE, FF). So far, the latter taxon has not been found below the *P. a. lennarti* Zone in Estonia, and there are no data about its occurrence in other parts of the world. *Aulacognathus* sp. n. disappears close to the upper boundary of the zone, probably in the basal part of the overlying *P. a. lithuanicus* Zone.

As indicated above, previously the strata in the Avaste section have also been assigned speculatively, based only on their lithological composition, to the Jaani Stage (Sheinwoodian). However, conodont data indicate that these strata are considerably older and correspond to the *P. a. lithuanicus* Zone (upper part of the Adavere Stage, i.e. to the upper Telychian; Figs 6, 9). The faunas in two samples from the middle and uppermost parts of the section are typical of the zone, being characterized by the occurrence of the nominal taxon, *P. a. lithuanicus* (Fig. 10A–C) and a total lack of *O. polinclinata* (which is also very characteristic of the zone). The occurrence here of *Aps. ruginosus* (Fig. 10D, F) probably indicates that the uppermost part of the *P. a. lithuanicus* Zone is exposed in the section. *Apsidognathus ruginosus*, as known to date, appears just below the boundary between the *P. a. lithuanicus* and *P. a. amorphognathoides* zones.

Two sets of samples were studied from the outcrops at the western end of the Saastna Peninsula (Fig. 7). The three samples from the northern coast (M-852, M-853, and M-1811; Fig. 7) all yielded rich *P. a. amorphognathoides* Zone faunas, characterized by the occurrence of *P. a. amorphognathoides* (Fig. 10V, W), *O. polinclinata polinclinata* (Fig. 10J), *Aps. ruginosus* Fig. 10E, G–I, M), *Aps. walmsleyi* (Fig. 10P), and *Walliserodus* sp. n. b (Fig. 10K, L, N, Q–S). Among the specimens of Pa elements of *P. a. amorphognathoides* there are morphologies characteristic of Population 4 *sensu* Männik (1998) of the taxon (Fig. 10V), indicating that these strata correlate with the Upper subzone of the *P. a. amorphognathoides* Zone. This agrees with the occurrence of *Nudibelodina sensitiva* in these samples, which dates this level older than the Ireviken Event (Fig. 9).

The two samples (M-1809 and M-1810) from the southern coast of the Saastna Peninsula yielded low-diversity faunas of the Upper *Kockelella ranuliformis* Zone (Figs 7, 9). Most characteristic of these faunas is the occurrence of *K. ranuliformis* (Walliser) (Fig. 10AA), *Ozarkodina excavata* (Branson & Mehl), *Panderodus equicostatus* (Rhodes) (Fig. 10X–Z, BB, CC), and *Walliserodus* sp. n. c (Fig. 10O, T, U).

As revealed by the data above, at present no information is available from an interval corresponding to five conodont zones, from the Lower *Pseudooneotodus bicornis* Zone below up to the Lower *K. ranuliformis* Zone (Fig. 9). Considering that the average southward dip of strata is about 2.5–3.5 m per 1 km in Estonia, it can be assumed that the unexposed interval between outcrops on the northern and southern coasts of the Saastna Peninsula is about 1 m thick. Such a small thickness of the strata corresponding to the Ireviken Event on the Saastna Peninsula agrees with data from core sections from western mainland Estonia and the islands in the Muhu Strait (e.g. Hints et al. 2006; Rubel et al. 2007), indicating that the Llandovery–Wenlock boundary interval is highly condensed in this region. Some gaps cannot be excluded.

The boundary between sequences S4 and S5 lies in this unexposed interval. The strata exposed along the northern coast of the peninsula, being represented by dolomitized calcareous marlstones–argillaceous limestones with ooids, evidently correspond to the topmost S4 (top of the Highstand Systems Tract) in the region. On the southern coast of the peninsula, the lowermost part of S5 is exposed. It is not yet possible to tell the precise level of the sequence boundary in terms of conodont biostratigraphy – below or within the Ireviken Event.

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Telychiani (Silur) paljandite vanusest Eestis konodontide leviku põhjal

Peep Männik

Konodontide leviku detailsed uuringud on võimaldanud usaldusväärselt dateerida Eestis mitmetes Ülem-Llandovery ja Alam-Wenlocki läbilõigetes paljanduvaid kihte. Läbilõige Valgu-1 korreleerub *Distomodus staurognathoides*'e tsooni kõige ülemise osaga ja *Pterospathodus eopennatus* ssp. n. 1 tsooniga, läbilõigetes Valgu-2 ning Valgu-3 paljanduvad ainult *P. eopennatus* ssp. n. 1 tsoonile vastavad kihid, Velise-Kõrgekaldal *P. amorphognathoides angulatus*'e tsooni alumisele alamtsoonile vastavad kihid ja Avaste läbilõikes intervall *P. a. lithuanicus*'e tsoonist. Saastna poolsaare põhjarannal avanevad kihid vastavad *P. a. amorphognathoides*'e tsooni ülemisele alamtsoonile ja lõunarannal paljanduvad kihid ülemisele *Kockelella ranuliformis*'e tsoonile. Nimetatud stratigraafiliste tasemete vahele jääv ja viiele konodonditsoonile vastav läbilõike osa Saastna poolsaarel ei paljandu.