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# On the lower boundary of the Floian Stage in Estonia

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**Abstract.** The lower boundary of the Second Stage of the Lower Ordovician Series, the Floian Stage, is defined by the first appearance of the graptolite *Tetragraptus approximatus*. In the stratotype section of Diabasbrottet at Hunneberg, southern Sweden, the boundary falls within the *Megistaspis planilimbata* trilobite Zone and within the *Oelandodus elongatus–Acodus deltatus deltatus* conodont Subzone of the *Paroistodus proteus* Zone, and within the Hunneberg Regional Stage. Graptolites, including the index species *T. approximatus*, are missing in the terrigenous sediment of Estonia. The earliest trilobites are poorly preserved in this terrigenous succession. They represent an interval older than the *Megalaspides dalecarlicus* Zone but probably younger than the *M. planilimbata* Zone, and are correlative to the *Prioniodus elegans* conodont Zone. Thus the lower boundary of the Second Stage can be detected using mainly conodonts. In accordance with conodont occurrence, the base of the Floian (i.e. somewhat higher than the base of the *O. elongatus–A. d. deltatus* Subzone) falls within the Joa Member of the Leetse Formation. Probable levels have been suggested in some localities. Thus the lower part of the Leetse Formation belongs to the Tremadoc Stage, and to the Hunneberg Regional Stage.

**Key words:** Hunneberg, Billingen, Floian, graptolites, conodonts, trilobites, Baltoscandia.

## INTRODUCTION

The lower boundary of the Floian Stage in Estonia has been set at different levels. Viira (2011) correlated it with the base of the *Oelandodus elongatus–Acodus deltatus* conodont Subzone. In a recent overview of conodont diversity in the northern Baltic, Männik & Viira (2012, fig. 2) drew that boundary at the lower boundary of the *Prioniodus elegans* Zone. This position, however, is incorrect or too approximate, considering the graptolite, trilobite and conodont distribution and the correlation data in the stratotype section in Sweden. In some other recent reports on the Ordovician stratigraphy of Estonia, the resolution is lower and a particular level is not bonded with lithostratigraphical units (e.g. Nõlvak et al. 2006, 2007). The aim of our paper is to specify the position of the lower boundary of the Floian Stage in Estonia.

The GSSP of the Second Stage of the Lower Ordovician Series, the Floian Stage, has been set in the Diabasbrottet section at Hunneberg in Västergötland, southern Sweden, and is defined by the first appearance of the graptolite *Tetragraptus approximatus* Nicholson (Bergström et al. 2004, 2009). In this stratotype section *T. approximatus* first appears at the same level with *T. phyllograptoides* Strandmark – just above the limestone bed with the trilobite *Megistaspis planilimbata* (Angelin) and conodonts of the *Oelandodus elongatus–Acodus deltatus deltatus* Subzone of the *Paroistodus proteus* Zone (Löfgren 1993, 1996; Maletz et al. 1996; Löfgren & Bergström 2002). *Tetragraptus approximatus* is an index of the nominal zone of the Pacific Province and is relatively rare in comparison with *T. phyllograptoides*, which has been the index for the graptolite biozone in Baltoscandia since Törnquist's times (Törnquist 1901). Unlike the latter species, *T. approximatus* is globally distributed, providing a valuable correlation datum (Cooper & Lindholm 1990). Regionally, these two taxa appear at different levels. For instance, they come in on the same level in the Mossebo section nearby the GSSP (Maletz et al. 1996), but in Scania *T. phyllograptoides* appears lower than *T. approximatus* (see, e.g., Maletz & Ahlberg 2011, fig. 2). Only a few graptolites, including *T. phyllograptoides*, have been recorded in the Leetse Formation in the St Petersburg Region neighbouring Estonia (Tolmacheva et al. 2001; Suyarkova & Koren′ 2009). *Tetragraptus phyllograptoides* appears there in the middle of the range of *O. elongatus* (Lindström) where the sediment becomes more clayey. It co-occurs with *Didymograptus rigoletto* (Maletz, Rushton & Lindholm) (see Tolmacheva et al. 2001, figs 2, 3), which is found somewhat higher in the Diabasbrottet section of Västergötland (Maletz et al. 1996, fig. 4) or together with *T. approximatus* in the Lerhamn drill core of

Scania (Maletz & Ahlberg 2011, fig. 2). Consequently, in the St Petersburg Region, the base of the Floian Stage is marked by the appearance of these graptolites. Graptolites are lacking or very rare in most of the Ordovician succession of Estonia, thus here the base of the Floian cannot be spotted using graptolites. However, the type section as well as other sections nearby exposes both the faunas of the graptolitic facies and of the shelly facies, allowing correlations between regions where only one of those can be found. The correlation of limestone sections can be made via distribution of conodonts and trilobites.

## TRILOBITES

The trilobites in Diabasbrottet, Hunneberg and elsewhere in Sweden were studied in detail by Tjernvik (1956). Jaanusson (1982) used his zonation to define the Baltoscandian regional stages. From base to top, the *Megistaspis armata* and *M. planilimbata* zones correspond to the Hunneberg Regional Stage and the succeeding *M.* aff. *estonica*, *Megalaspides dalecarlicus* and *Megistaspis estonica* zones to the Billingen Regional Stage (Fig. 1). *Megistaspis planilimbata* occurs in the thin limestone beds preceding and following the shales with *T. approximatus* and *T. phyllograptoides* at the GSSP. Higher, *T. approximatus* continues alone, but the graptolite zone is still called the *T. phyllograptoides* Zone despite lack of the index species (see comments in Lindholm 1991; Maletz et al. 1996, p. 139). Based on the correlation of graptolites with trilobites, consequently the lower boundary of the Floian Stage is somewhere above the lower boundary of the *M. planilimbata* Zone, in the middle of the Hunneberg Regional Stage (Fig. 1). Trilobites have not been investigated in the beds with *P. gracilis* Lindström in the stratotype section, but from Mossebo we can learn that *M. planilimbata* appears in the *P. gracilis* Zone (Maletz et al. 1996, figs 4, 5). The lower boundary of the *Oelandodus elongatus–Acodus deltatus deltatus* conodont Subzone falls somewhere in the middle of the *M. planilimbata* Zone in the Diabasbrottet section, Västergötland. The same situation is observed in more calcareous outcrops at Sjurberg, Dalarna (compare sections in Tjernvik 1956, p. 166, fig. 23; Löfgren 1994, p. 1352, fig. 3). This fact shows that evidently the base of the Floian is above the lower boundary of the *M. planilimbata* Zone over the entire basin.

Revision of finds of *Megistaspis planilimbata* from Estonia (Schmidt 1906) has shown that they actually are *M. estonica* (Tjernvik) (Tjernvik 1956; Tjernvik & Johansson 1980; Pärnaste 2006a). *Megistaspis estonica*, which is characteristic of the Päite Member, defines the

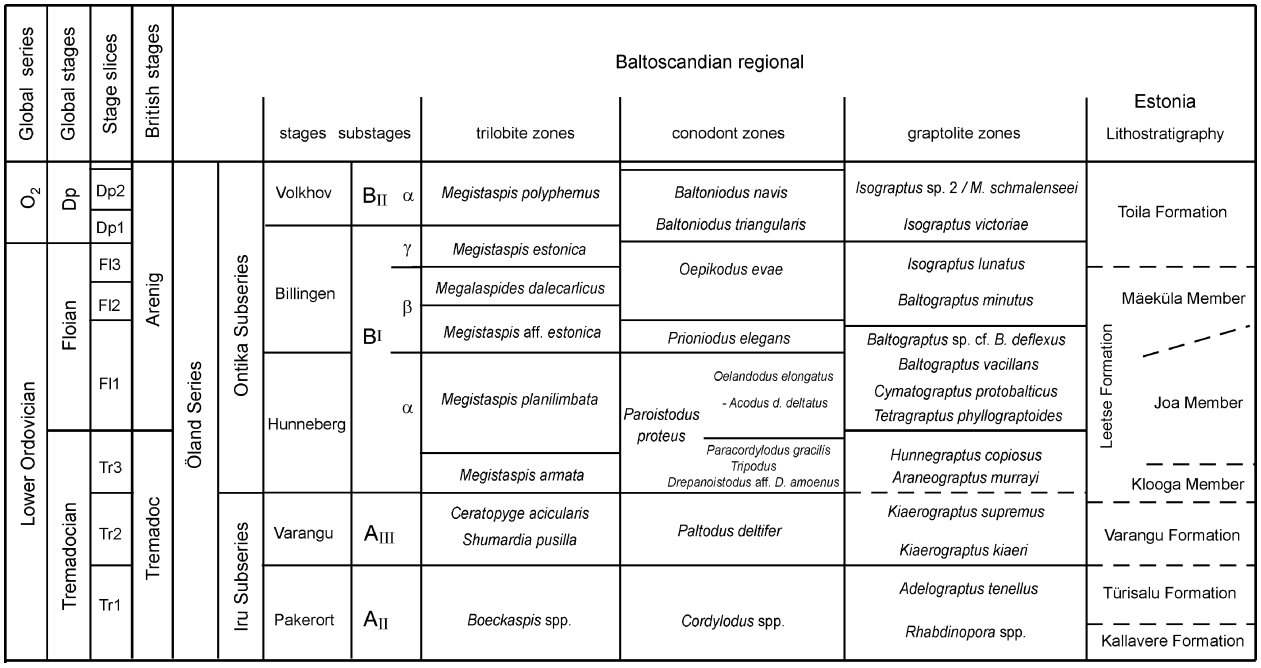


**Fig. 1.** Stratigraphic classification with biostratigraphical subdivision of the Lower Ordovician in Baltoscandia, modified from Pärnaste (2006a; see discussion and references there) and Pärnaste et al. (2012), with refreshed graptolite data by Maletz & Ahlberg (2011), conodont data by Viira (2011), and following the revised global standard (Bergström et al. 2009).

uppermost trilobite zone of the Billingen Regional Stage. In Estonia the first trilobites appear at a level where sandy terrigenous rocks are replaced by calcareous ones, i.e. at the boundary between the Joa and Mäeküla members of the Leetse Formation. This level is evidently geographically diachronous, pending in the *Prioniodus elegans* and *Oepikodus evae* zones (Pärnaste 2003, 2006a; Viira et al. 2006). In the Uuga section, northwestern Estonia, the boundary between the Joa and Mäeküla members reaches down into the *P. proteus* Zone (Löfgren et al. 2005, figs 2, 4). The calcareous beds of the Mäeküla Member (upper Leetse Formation) contain very rare, poorly preserved trilobites, which were recently restudied (Pärnaste 2003, 2006a, 2006b; Pärnaste et al. 2009). The taxonomic association of trilobites in Estonia differs from that in Sweden (Pärnaste 2006a; Pärnaste et al. 2012; Bergström et al. 2013) and complicates the correlation between these regions. Mainly, the research (of H. P.) was stuck at the unpublished new species mentioned by Tjernvik as being characteristic of the *M.* aff. *estonica* Zone in Sweden (Tjernvik & Johansson 1980). These taxa need to be studied and compared with specimens from Estonia and the St Petersburg Region to improve the correlation based on trilobites. It has been established that in the East Baltic the *Megalaspides dalecarlicus* Zone (based on the occurrence of its index species) occurs in the Vassilkovo beds in the uppermost Leetse Formation above the Mäeküla beds in NW Russia. The lower Mäeküla beds possibly represent the preceding *Megistaspis* aff. *estonica* Zone (Pärnaste 2006a). Note that the *M.* aff. *estonica* Zone of Tjernvik & Johansson (1980) corresponds to the topmost part of the *M. planilimbata* Zone in sense of Tjernvik (1956). This transitional bed was separated from the *M. planilimbata* Zone of the Hunneberg Stage and included into the Billingen Stage because of the new arrival of the trilobite fauna known from Billingen (Tjernvik & Johansson 1980). However, so far the real *M. planilimbata* (and that zone) is not known from Estonia and the lower boundary of the Floian cannot be assessed using the trilobite occurrences.

## CONODONTS

The conodonts of the type and neighbouring sections at Hunneberg were studied by Löfgren (1993). The conodont zonation of the Hunneberg and Billingen succession, previously united into the Latorp Stage (Tjernvik 1956; Jaanusson 1960), is based on her work not only in the type area, but also in Jämtland, Siljan District, Finngrundet drill core and elsewhere, and is formally defined by its boundaries (Löfgren 1994). Four successive subzones are distinguished within the *Paroistodus proteus* Zone as follows (from base to top): the *Drepanoistodus* aff. *D. amoenus* Subzone, the *Tripodus* Subzone, the *Paracordylodus gracilis* Subzone and the *Oelandodus elongatus–Acodus deltatus deltatus* Subzone. In the Diabasbrottet section the base of the Floian, i.e. appearance of *T. approximatus*, is above the lower boundary of the *O. elongatus–A. deltatus deltatus* Subzone, in the lower part of the *M. planilimbata* trilobite Zone (Bergström et al. 2004, fig. 10).

In Estonia, the *Paroistodus proteus* Zone is recognized in glauconitic sandstones of the Leetse Formation. It extends from the basal Klooga Member to the middle or upper part of the Joa Member and is followed by the *Prioniodus elegans* Zone (Viira et al. 2001, fig. 2, 2006, fig. 3). The species content and the combination of the occurrences of the subzones and their extent vary between localities and differ slightly from those in Sweden, where limestones and shales constitute this interval and four subzones were originally established (Löfgren 1993, 1994). The lowermost, *Drepanoistodus* aff. *D. amoneus* Subzone is missing or the sediment containing fauna characteristic of this subzone was reworked and mixed with that of the following subzone(s) in northern Estonian sections. The second, *Tripodus* Subzone is recognized in the Cape Pakri, Keila-Joa, Mäekalda, Saka, Ontika and probably some other sections (Löfgren et al. 2005; Viira et al. 2006 and references therein). Findings of the index species are rare, but those of *Paltodus subaequalis* Pander, another characteristic taxon of this zone, are more common. The third, *Paracordylodus gracilis* Subzone has been established on the basis of a single specimen in the Saka section only, in a bed with calcareous nodules in the lower third of the Leetse Formation (Viira et al. 2006, fig. 2). That species may reach up to the *Oepikodus evae* Zone in Sweden (Löfgren 1994). The *O. elongatus–A. d. deltatus* Subzone is defined by the first appearance of *O. elongatus* (Lindström) within the range of *A. d. deltatus* Lindström, although the lowest record of the latter conodont comes already from the *Tripodus* Subzone (e.g. in the Siljan district, Sweden: Löfgren 1994). *Oelandodus elongatus* appears in the lower part of the Leetse Formation, below the clayey bed with *T. phyllograptoides* in the St Petersburg Region (Tolmacheva et al. 2001). In Estonia, *O. elongatus* is very rare and may appear locally as high in the section as in the *P. elegans* Zone (e.g. Saka section: Viira et al. 2006). In the Mäekalda section (Viira et al. 2001, fig. 4), *O. elongatus* occurs in sample Mä95-4, marking the lowest possible level for the base of the Floian Stage. In the Saka section, the level above the calcareous nodules (sample A, Viira et al. 2006, fig. 2), carrying the *P. gracilis* elements and below the FAD of *P. elegans* at about the lowest quarter of the Leetse Formation, may

correspond to the *O. elongatus–A. d. deltatus* Subzone. Possibly, the approximate level for the lower boundary of the Floian lies somewhere there. In the Uuga section (Löfgren et al. 2005, fig. 4), the conodonts defining the uppermost two subzones have not been found so far. The records of *Acodus deltatus* upwards from sample Pa-96-7 in the lower third of the Leetse Formation gives us only an approximate lowest limit where the base of the Floian could be; it can be anywhere between that sample and sample Pa-96-20, where *P. elegans* appears.

## CONCLUSION

The lower boundary of the Floian Stage in Estonia cannot be detected either by graptolites or by trilobites due to the sedimentation conditions unfavourable for preservation of these fossils. However, conodont distribution gives us an alternative option to define an approximate position of this boundary through the entire Baltoscandia to Estonia. The lower boundary of the Floian lies somewhere close to the lower boundary of the *Oelandodus elongatus–Acodus deltatus deltatus* Subzone within the Leetse Formation. Thus the lower portion of the Leetse Formation belongs to the Tremadoc Stage, and to the Hunneberg Regional Stage.

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## REFERENCES

Bergström, J., Pärnaste, H. & Zhou, Z.-Y. 2013. Trilobites and biofacies in the Ordovician Öland Series (Tremadocian–mid Darriwilian) of Baltica and a brief comparison with the Yangtze Plate. *Estonian Journal of Earth Sciences*, **62** [accepted].

Bergström, S. M., Löfgren, A. & Maletz, J. 2004. The GSSP of the Second (Upper) Stage of the Lower Ordovician Series: Diabasbrottet at Hunneberg, Province of Västergötland, southwestern Sweden. *Episodes*, **27**, 265–272.

Bergström, S. M., Chen, X., Gutiérrez-Marco, J. C. & Dronov, A. 2009. The new chronostratigraphic classification of the Ordovician System and its relations to major regional series and stages and to $\delta^{13}C$ chemostratigraphy. *Lethaia*, **42**, 97–107.

Cooper, R. A. & Lindholm, K. 1990. A precise worldwide correlation of Early Ordovician graptolite sequences. *Geological Magazine*, **127**, 497–525.

Jaanusson, V. 1960. Graptoloids from the Ontikan and Viruan (Ordov.) limestones of Estonia and Sweden. *Bulletin of the Geological Institutions of the University of Uppsala*, **38**, 289–366.

Jaanusson, V. 1982. Introduction to the Ordovician of Sweden. In *Field Excursion Guide. IV International Symposium on the Ordovician System* (Bruton, D. L. & Williams, S. H., eds), *Paleontological Contributions from the University of Oslo*, **279**, 1–9.

Lindholm, K. 1991. Ordovician graptolites from the early Hunneberg of southern Scandinavia. *Palaeontology*, **34**, 283–327.

Löfgren, A. 1993. Conodonts from the lower Ordovician at Hunneberg, south-central Sweden. *Geological Magazine*, **130**, 215–232.

Löfgren, A. 1994. Arenig (Lower Ordovician) conodonts and biozonation in the eastern Siljan District, Central Sweden. *Journal of Paleontology*, **68**, 1350–1368.

Löfgren, A. 1996. Lower Ordovician conodonts, reworking, and biostratigraphy of the Orrenholmen quarry, Västergötland, south-central Sweden. *GFF*, **118**, 169–183.

Löfgren, A. & Bergström, S. 2002. A stratigraphically significant conodont fauna from the base of the *Tetragraptus approximatus* Zone at Holsbrotten, Mt. Hunneberg, SW Sweden. *GFF*, **124**, 131–134.

Löfgren, A., Viira, V. & Mens, K. 2005. Conodont biostratigraphy and sedimentary history in the upper Tremadoc at Uuga, Pakri Cape, NW Estonia. *GFF*, **127**, 283–293.

Maletz, J. & Ahlberg, P. 2011. The Lerhamn drill core and its bearing for the graptolite biostratigraphy of the Ordovician Tøyen Shale in Scania, southern Sweden. *Lethaia*, **44**, 350–368.

Maletz, J., Löfgren, A. & Bergström, S. M. 1996. The base of the *Tetragraptus approximatus* Zone at Mt. Hunneberg, SW Sweden: a proposed global stratotype for the base of the second series of the Ordovician System. *Newsletters on Stratigraphy*, **52**, 129–159.

Männik, P. & Viira, V. 2012. Ordovician conodont diversity in the northern Baltic. *Estonian Journal of Earth Sciences*, **61**, 1–14.

Nõlvak, J., Hints, O. & Männik, P. 2006. Ordovician timescale in Estonia: recent developments. *Proceedings of the Estonian Academy of Sciences, Geology*, **55**, 95–108.

Nõlvak, J., Hints, O., Männik, P. & Pärnaste, H. 2007. Ordovician time scale in Estonia. *Acta Palaeontologica Sinica*, **46** (Suppl.), 351–356.

Pärnaste, H. 2003. The Lower Ordovician trilobite *Krattaspis*: the earliest cyrtometopinid (Cheiruridae) from the Arenig of the east Baltic. *Special Papers in Palaeontology*, **70**, 241–257.

Pärnaste, H. 2006a. The Early Ordovician trilobite distribution and zonation of the East Baltic. *Proceedings of the Estonian Academy of Sciences, Geology*, **55**, 109–127.

Pärnaste, H. 2006b. The earliest encrinurid trilobites from the East Baltic and their taxonomic interest. *Palaeontology*, **49**, 1–16.

Pärnaste, H., Popp, A. & Owens, R. M. 2009. Distribution of the order Proetida (Trilobita) in Baltoscandian Ordovician strata. *Estonian Journal of Earth Sciences*, **58**, 10–23.

Pärnaste, H., Bergström, J. & Zhou, Z.-Y. 2012. High-resolution trilobite stratigraphy of the Lower–Middle Ordovician Öland Series of Baltoscandia. *Geological Magazine* [accepted].

Schmidt, F. 1906. Revision der ostbaltischen Trilobiten. Abtheilung V: Asaphiden. Leif 4. *Mémoires de l'Académie Impériale des Sciences de St-Pétersbourg VIII*, **19**(10), 1–63, pls 1–8.

Suyarkova, A. A. & Koren′, T. N. 2009. Advances in the Ordovician graptolite biostratigraphy of the St Petersburg area, Russia. *Estonian Journal of Earth Sciences*, **58**, 3–9.

Tjernvik, T. E. 1956. On the Early Ordovician of Sweden. *Bulletin of the Geological Institutions of the University of Uppsala*, **36**, 107–284.

Tjernvik, T. E. & Johansson, J. V. 1980. Description of the upper portion of the drill-core from Finngrundet in the South Bothnian Bay. *Bulletin of the Geological Institutions of the University of Uppsala, n.s.*, **8** (for 1979), 173–204.

Tolmacheva, T., Koren′, T. N., Holmer, L. E., Popov, L. E. & Raevskaya, E. 2001. The Hunneberg Stage (Ordovician) in the area east of St. Petersburg, north-western Russia. *Paläontologische Zeitschrift*, **74**, 543–561.

Törnquist, S. L. 1901. Researches into the graptolites of the lower zones of the Scanian and Vestrogothian Phyllo-Tetragraptus beds, Part 1. *Lunds Universitets Årsskrift*, **37**, 1–26, 3 pls.

Viira, V. 2011. Lower and Middle Ordovician conodonts from the subsurface of SE Estonia and adjacent Russia. *Estonian Journal of Earth Sciences*, **60**, 1–21.

Viira, V., Löfgren, A., Mägi, S. & Wickström, J. 2001. An Early to Middle Ordovician succession of the conodont faunas at Mäekalda, northern Estonia. *Geological Magazine*, **138**, 699–718.

Viira, V., Mens, K. & Nemliher, J. 2006. Lower Ordovician Leetse Formation in the North Estonian Klint area. *Proceedings of the Estonian Academy of Sciences, Geology*, **55**, 156–174.

## Flo lademe alumine piir Eestis

Helje Pärnaste ja Viive Viira

On diskuteeritud Alam-Ordoviitsiumi Flo lademe alumise piiri üle Baltoskandias, näidates erinevate faunagruppide levikut ja tsonaalsust. Kuna erinevate faunagruppide uurijate poolt on seda piiri Eesti geoloogilises läbilõikes näidatud erineval tasemel, siis on siin ära toodud korrelatsioon Rootsis asuva tüüpläbilõikega ja täpsustatud piiri asukoht Eesti läbilõigetes. Lähtuvalt konodontide levikust eelviidatud Rootsi läbilõikes langeb Flo lademe alumine piir Eestis Leetse kihistu Joa kihistikku. Seega on Leetse kihistu alumine osa Tremadoci-ealine, kuuludes samas Hunnebergi regionaalsesse lademesse.