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Devonian stratigraphy in Estonia: current state and problems

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Abstract. An updated version of the Devonian stratigraphical chart of Estonia with comments is presented. Estonian regional stratigraphical units are correlated with the standard conodont zonation and miospore zonation, used in the western part of the East European Platform. The fossil fish zonations, largely accepted in the Main Devonian Field, are discussed. Differences in the position of series and stage boundaries and age determination of regional units in the Baltic area, Belarus and NW Russia are dealt with. Two key markers for the correlation of the Middle Devonian of the Baltic area and Scotland, based mainly on placoderms, are described. Special attention is paid to occurrences of inarticulate brachiopods and finds of rare articulate brachiopods in siliciclastic rocks of the Baltic area, indicating their marine origin.

Key words: Devonian, biozones, regional stratigraphy, correlations, Estonia.

INTRODUCTION

Devonian deposits on the territory of Estonia form a comparatively minor part of the extensive Devonian strata on the East European (Russian) Platform. They are found in the northwestern area of the Platform close to the Baltic Shield. The Lower and Upper Devonian (Frasnian) are incomplete: the former is known from some drill cores in South Estonia and the latter occurs only in a limited area of SE Estonia. In contrast, the Middle Devonian (Eifelian, Givetian) is well developed. It is exposed across a broad outcrop area in the whole of South Estonia, stretching from the Baltic Sea in the west to Lake Peipsi in the east, and in a small area in NE Estonia (Fig. 1). The large number of natural exposures and some quarries together with numerous drill cores

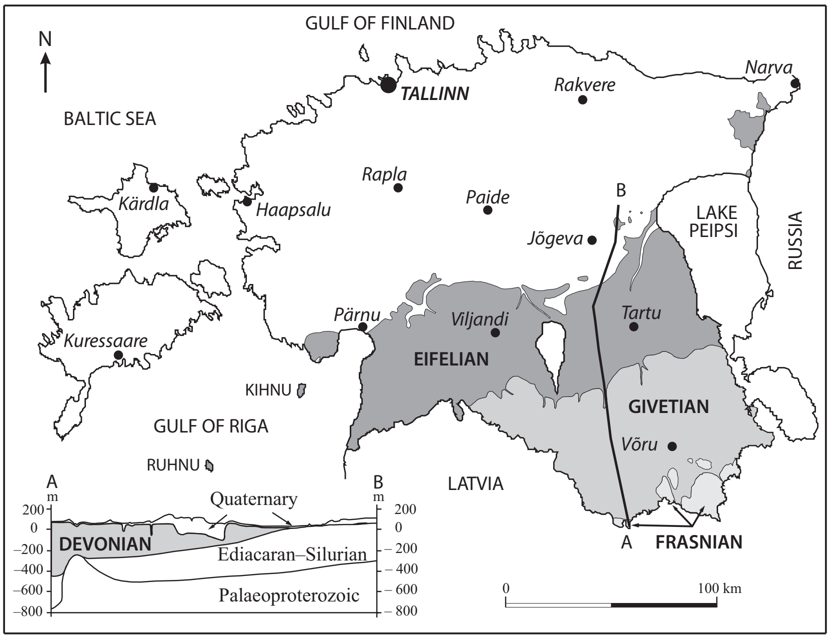

Fig. 1. The distribution of the Devonian (Eifelian, Givetian, Frasnian) in Estonia, and the simplified cross section (A–B) of the Palaeoproterozoic, Ediacaran, Cambrian, Ordovician, Silurian and Devonian (Lochkovian, Emsian, Eifelian, Givetian, Frasnian) rocks, and Quaternary sediments (modified from Suuroja 1997).

have enabled a detailed subdivision of the Devonian sequence into regional stages (RS), substages, formations (Fm) and members (Mb) (Fig. 2).

Siliciclastic rocks predominate in the Devonian sequence, except in the lower Middle Devonian (Narva RS) and Upper Devonian (interval from the Pļaviņas RS to the Daugava RS), which consist largely of carbonate and carbonate-terrigenous rocks. As invertebrate fossils are comparatively scarce in clastic and carbonate rocks, a biozonation based on different groups of fossil fishes is applied. Standard conodont zones are in rare cases recognized in areas close to Estonia (Lithuania, NW Russia) and Belarus. On the basis of these zones the age of at least some Middle and lower Upper Devonian levels can be dated in our sequence. Additional information can also be obtained from miospore zones, which have been established in the western part of the East European Platform and have, in other areas, been correlated with conodont zones.

The Devonian stratigraphy in Estonia, as currently accepted, was published more than ten years ago by Kleesment & Mark-Kurik (1997) and Kajak (1997) in the book *Geology and Mineral Resources of Estonia* (Raukas & Teedumäe 1997). This essential publication is now sold out, however, an electronic version, which contains the original unaltered text, together with illustrations and tables, is available on-line (http://sarv.gi.ee/geology).

An updated version of the stratigraphical chart, showing the extent of the Devonian strata on Estonian territory (SE, SW and NE belts) and a correlation of biozones with chronostratigraphical and lithostratigraphical units, was compiled by A. Põldvere and E. Mark-Kurik in 2006 and has been used as a working draft for the Estonian Commission on Stratigraphy. The chart shown in Fig. 2 illustrates the current understanding of the Devonian stratigraphy in Estonia.

ABSOLUTE TIME SCALES

Two absolute time scales are shown in Fig. 2. The first scale (A) comes from the International Stratigraphic Chart, accepted by the International Commission of Stratigraphy in 2010 (see the ICS home page http://www.stratigraphy.org/column.php?id=Chart/Time%20Scale). A recent alternative version (B) by Kaufmann (2006) is a revised Devonian chronology, based on isotopic (U–Pb) ages, and derived from volcanic ashes and bentonites, intercalated in marine sedimentary successions. The ages of stage boundaries vary between these time scales within 1.1–5.6 Ma, whereas the largest differences occur in the dating of the Emsian/Eifelian and Eifelian/Givetian boundaries (5.6 and 3.7 Ma). The Emsian Stage appears to be much longer than earlier considered, and the Eifelian and Givetian are significantly shorter (Kaufmann 2006, fig. 1). The Emsian age dates (Kaufmann et al. 2005) are of special interest as they come from the Rhenish Massif, one of the Devonian stratotype areas. As the reconstruction of the Rheic Ocean and the extent of its shallow marine margins show (Scotese 2002; Marshall et al. 2007, fig. 10), our area is palaeogeographically connected with the above region.

BIOSTRATIGRAPHICAL OVERVIEW

Five biozonations are significant for the regional stratigraphy (Fig. 2), depending on the specific lithological character of Devonian strata and the occurrence and preservation conditions of fossils in the NW of the East European (Russian) Platform or the Main Devonian Field. The standard conodont zonation is presented here as it has been used for the Platform by Rzhonsnitskaya (1998) and some others (e.g. Valiukevičius 1995, 2000). Although there are other modified ‘standards’, the classical biozonations should not be abandoned (Bultynck 2007). As an exception, the *kockelianus*, *eiflius* and *ensensis* zones are recognized in the late Eifelian (Marshall et al. 2010). The miospore zonation, used in the western part of the East European Platform (Avkhimovitch et al. 1993; Obukhovskaya 1999), and three fish zones, established in the NW of the Platform, are also used. As the Upper Devonian in Estonia is incomplete, the later Frasnian and Famennian biozones are not shown in the stratigraphical chart.

Conodonts

Although Devonian conodonts have not been found in Estonia, their zones are significant from the aspect of interregional correlation. The zones, established comparatively close to Estonia, in Lithuania and Belarus, are of particular value. The accurate correlation with the Devonian sections of the Baltic area and Belarus is based on the character of the sedimentary rocks gradually changing in the southern and southeastern directions, largely due to the deepening of the basin and correlation with the use of the rather similar fish assemblages. It was well exemplified by the integrated study of lithology, and the distribution of fish fossils, invertebrates and miospores of the Narva RS from the outcrop area in NE Estonia to the drill core sections in N and NE Belarus (Valiukevičius et al. 1986). As the local stratigraphical units are not equivalents of the standard conodont zones, we can only correlate certain intervals of local units with probable intervals of conodont zones, e.g. the Pärnu–Narva units with the *partitus–ensensis* interval.

In Lithuania Devonian conodonts have been found from the lower part of the Tilžė RS at the base of the Lochkovian, and very rarely in the Pragian–?early Emsian Saunoriai Regional Substage (Valiukevičius 1998). No names of taxa are indicated for these occurrences. Conodonts are fairly common in the upper part of the Narva RS, the Eifelian Kernavė Fm (Narbutas et al. 1993; Valiukevičius & Ovnatanova 1993; Valiukevičius 1995, 2000). They have been discovered in cores from more than 10 boreholes. According to Valiukevičius & Ovnatanova (1993), the conodont assemblage consists of *Icriodus struvei* Weddige, *Polygnathus linguiformis linguiformis* Hinde, *P. linguiformis alveolus* Weddige, *P.* cf. *costatus oblongus* Weddige, *P. parawebbi* Chatterton, *P.* cf. *xylus ensensis* Ziegler & Klapper, *Coelocerodontus klapperi* Chatterton and *Coelocerodontus* sp. These authors correlated this conodont assemblage with the uppermost *costatus–kockelianus* and lower *ensensis* zones of the Eifelian standard zones. An additional conodont occurrence was determined in the lower part of the Ledai Fm in the Zibalai-187 core, E Lithuania. This level corresponds to the Vadja Regional Substage in Estonia.

An occurrence of chitinozoans together with acritarchs and scolecodonts in the Kernavė Fm (Svedasai-252 drill core, Lithuania) is of note. ?*Desmochitina minor* and *Angochitina devonica* (both by Plicher 1971) were identified in a sample of this core (Marshall et al. 2007).

In Belarus the Osveya RS, coeval with the Vadja Regional Substage, has yielded conodonts together with scolecodonts in the Eividovichi-328 drill core (Valiukevičius et al. 1995). Conodonts are more common in the Kostyukovitchi RS, which is coeval with the Kernavė Fm (Valiukevičius et al. 1995; Valiukevičius 1998; Kruchek et al. 2001; Marshall et al. 2007). These are *Polygnathus linguiformis linguiformis*, *P. parawebbi*, *Icriodus nodosus* (Huddle), *I. symmetricus* Branson & Mehl, etc. (Kruchek et al. 2001). An earlier identification includes *Polygnathus linguiformis alveolus*, *Icriodus struvei* and *I.* ex gr. *arkonensis* Staufer (Valiukevičius et al. 1995). This conodont assemblage is very close to the Kernavė assemblage. A recent study of the Kostyukovichi conodonts from drill cores of the Pripyat Graben has contributed to the correlation of the Middle Devonian of Belarus and SE Poland (Narkiewicz & Kruchek 2008).

In the Lower Frasnian conodonts of the *falsiovalis* Zone (e.g. *Polygnathus pennatus* Hinde) have been identified in the Baltic area at the base of the Pļaviņas RS (Valiukevičius 1995, 2000, p. 276). The range of the *P. pennatus* assemblage corresponds to the entire Pļaviņas RS (Valiukevičius 2000, fig. 2). In the eastern part of the Main Devonian Field a long-ranging conodont, *Polygnathus lanei* Kuzmin, is reported from the Podsnetogorskie Beds, i.e. the upper part of the Amata RS. The overlying Snetnaya Gora Fm has yielded seven conodont species. These are mainly of the genus *Polygnathus* and range through the Lower and Middle Frasnian. Five local conodont zones have been recognized for the Amata–Daugava interval, corresponding roughly to the *transitans–hassi* standard zones (Ivanov et al. 2005).

Miospores

In Estonia Devonian miospores have been discovered on four levels, mainly in the Lower Devonian to the lower Middle Devonian, i.e. in the Rēzekne–lower Narva (Vadja) interval (Valiukevičius et al. 1986; Kõrts & Mark-Kurik 1997). The Rēzekne miospores from the Mehikoorma (421) drill core (243–244.6 m) represent two rather different assemblages (Kõrts & Mark-Kurik 1997, table 30; Mark-Kurik & Valiukevičius 2005, appendix 22). Earlier a number of these miospores were listed by G. Vaitiekūnienė, who paid attention to their difference from the spores of the Pärnu RS (Kleesment et al. 1975). According to Obukhovskaya (1999), the Rēzekne Fm and the coeval Vitebsk RS from eastern Belarus correspond to the *Diaphanospora inassueta* (DI) Zone. She compared the DI Zone miospores with those of the *Grandispora douglastownensis–Ancyrospora eurypterota* Zone in the upper part of the Emsian and lowermost part of the Eifelian (Richardson & McGregor 1986). Miospores were reported from the Tori Mb of the Pärnu Fm (Kedo & Obukhovskaya 1981, p. 422) for which a corrected list was later given by T. G. Obukhovskaya (Kõrts & Mark-Kurik 1997, table 30). *Periplecotriletes tortus* Egorova, a key species of the *P. tortus* (PT) Zone, and *Calyptosporites velatus* (Eisenack) Richardson are characteristic of the Pärnu Fm. The miospore assemblage higher up in the Vadja Regional Substage of the Narva RS has almost 20 forms, of which two thirds differ from those in the Tori Mb.

Red or even slightly reddish sandstones, siltstones and claystones, dominating further up in the sequence, do not contain miospores, except for the grey claystone in the upper part of the Gauja Fm, specifically the Lode Mb. A sample from Küllatova refractory clay quarry (SE Estonia) yielded a miospore assemblage, which most probably comes from the *Ancyrospora incisa–Geminospora micromanifesta* (IM) Subzone of late Givetian age. The IM Subzone is known from Belarus and also from the Moscow Basin (Mark-Kurik et al. 1999).

Fishes

The fossil fishes that have so far been used for distinguishing zones are agnathans, placoderms and acanthodians (e.g. Valiukevičius 1995, 2006; Blieck et al.

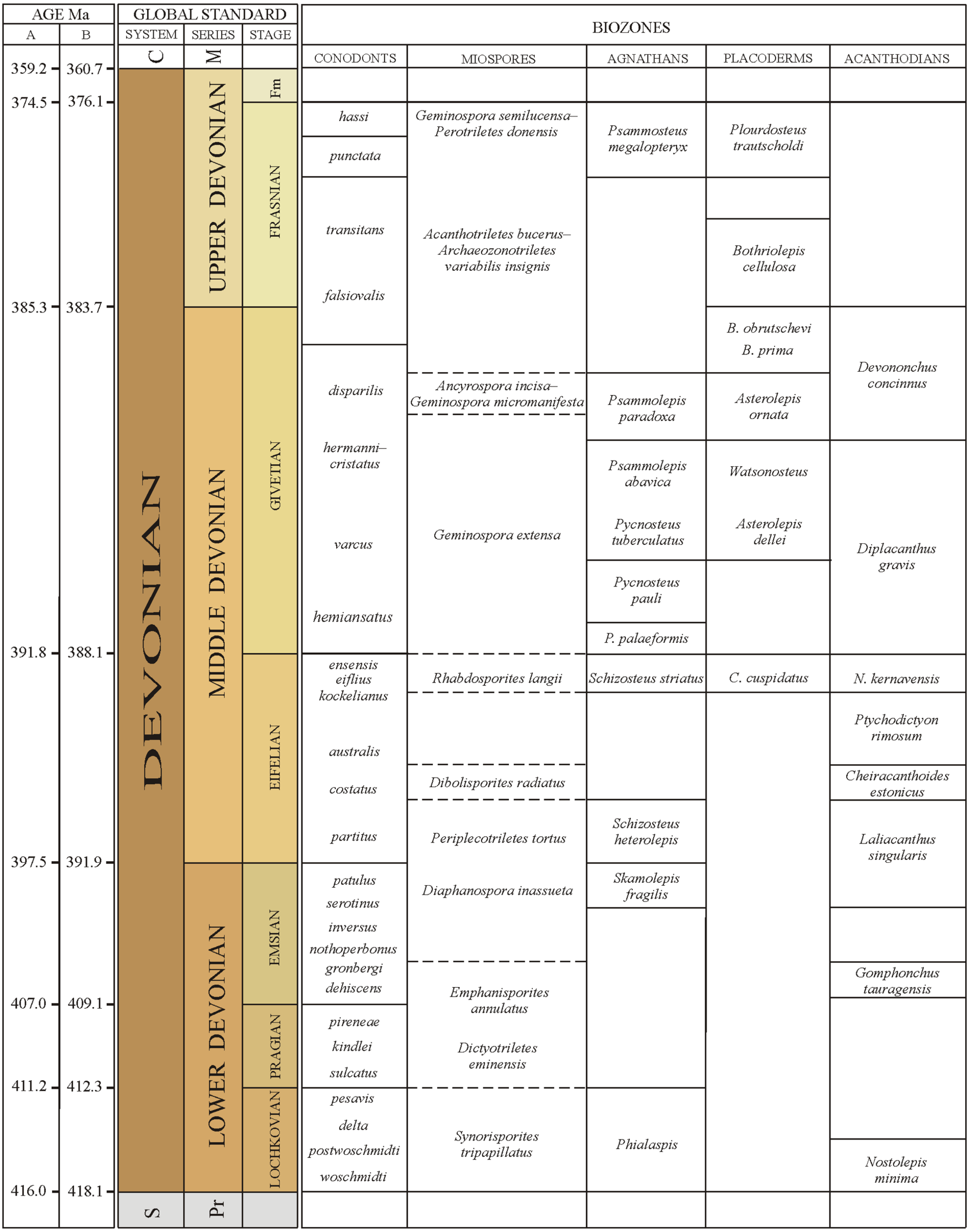

Fig. 2. The Devonian stratigraphical chart of Estonia. *B.*, *Bothriolepis*; C, Carboniferous; *C.*, *Coccosteus*; Fm, Famennian; M, Mississipian; Mb, Member; *N.*, *Nostolepis*; Pr, Pridoli; RS, Regional Stage; S, Silurian.

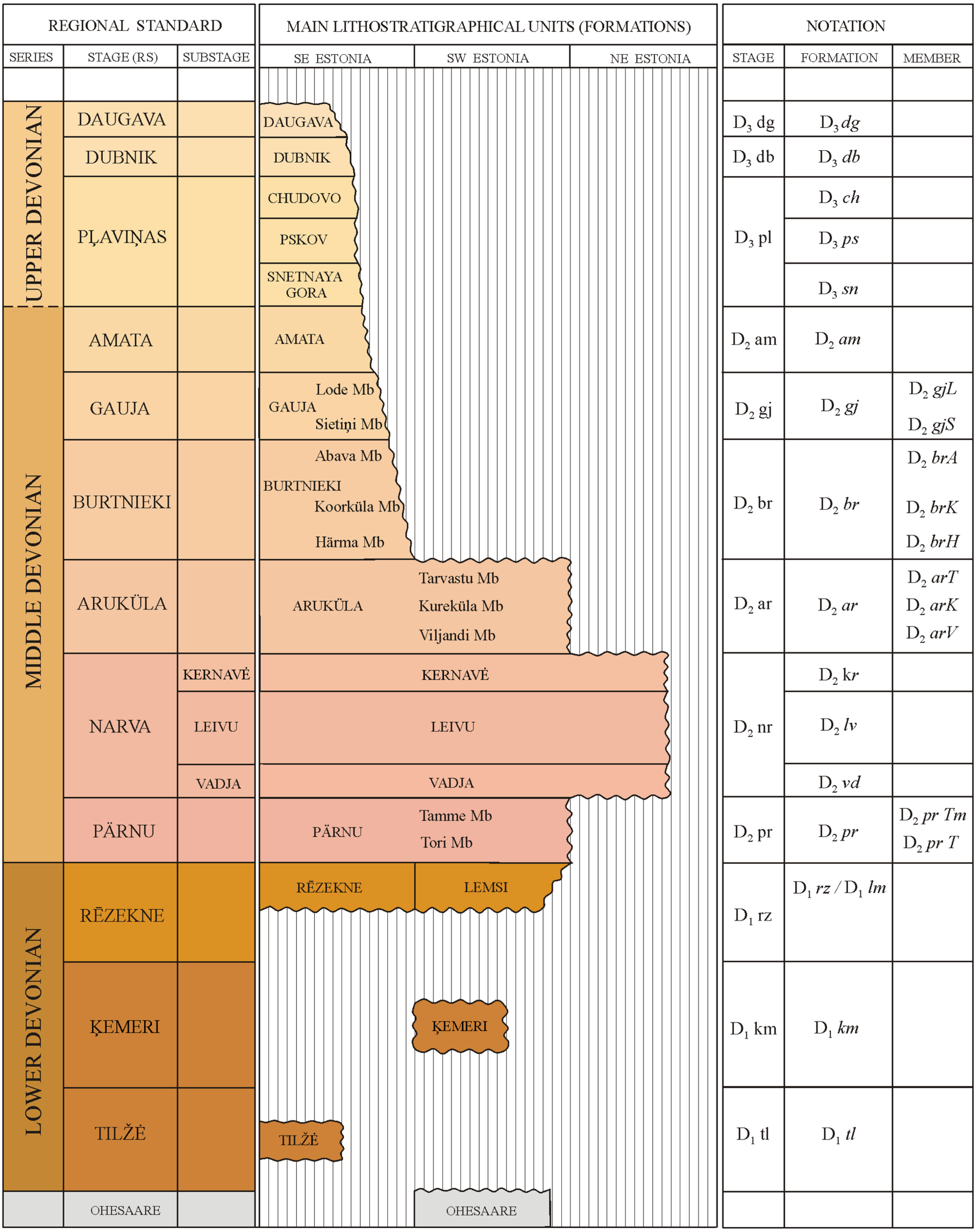

Fig. 2. *Continued.*

2000; Mark-Kurik 2000; Lukševičs 2001; Ivanov et al. 2005). Their representatives have different stratigraphical values, depending on the kind of preserved skeletal elements and the frequency of their occurrences. Tiny scales of acanthodians often dominate fish micro-remains, particularly in drill core samples, and are much more common than macroremains of jawless fishes heterostracans (psammosteids) and/or placoderms. However, the development rate of the representatives of the above fish groups is different.

On the basis of **acanthodian** scales the *Nostolepis minima*, *Lietuvacanthus fossulatus*, *Gomphonchus tauragensis* and *Laliacanthus singularis* zones have been established in the Lower Devonian (Valiukevičius 2006). In Estonia a gap corresponds to the *Lietuvacanthus fossulatus* Zone in the Lochkovian. The *Laliacanthus singularis* Zone corresponds to the Rēzekne and Pärnu RSs, i.e. to the upper Emsian–lower Eifelian. Acanthodians are valuable for the identification of the subdivisions of the Narva RS in the Eifelian, including the *Cheiracanthoides estonicus*, *Ptychodictyon rimosum* and *Nostolepis kernavensis* zones. The longer-ranging *Diplacanthus gravis* and *Devononchus concinnus* zones are identified in the Givetian (Fig. 2). The former corresponds to four and the latter to two psammosteid zones of this age.

Agnathan zones include mainly these of the psammosteid heterostracans. In the incomplete Lower Devonian sequence the *Phialaspis* (previous *Traquairaspis*) heterostracan Zone and the *Skamolepis fragilis* thelodont Zone have been recognized. In Estonia the Lochkovian *Phialaspis* Zone is established based on the occurrence of the thelodont *Turinia pagei* (Powrie), a characteristic species of this zone (Kleesment & Mark-Kurik 1997). The thelodont *Skamolepis fragilis* Karatajūtė-Talimaa appears in the Emsian but is rare in drill core sections. Still, twelve scales of this thelodont are reported from 437.2–438.2 m in the Baltinava drill core, E Latvia (Karatajūtė-Talimaa 1978). Psammosteid macroremains are valuable for zonation of the interval from the Pärnu RS to the Gauja RS. In the Eifelian psammosteids of the genus *Schizosteus* enabled the establishment of the *S. heterolepis* Zone corresponding to the Pärnu RS, and of the *S. striatus* Zone corresponding to the Kernavė Regional Substage. Species of the genus *Pycnosteus* – *P. palaeformis* Preobrazhensky, *P. pauli* Mark and *P. tuberculatus* (Rohon) – are of value for biozonation in the Aruküla RS and the lower part of the Burtnieki RS (Givetian). *Psammolepis abavica* Mark-Kurik is the zonal form in the upper part of the Burtnieki RS (Abava Mb), as is *Psammolepis paradoxa* Agassiz in the Gauja RS. The Upper Devonian, uppermost Lower and most of the Middle Frasnian (Dubnik–Daugava interval), has a key fossil *Psammosteus megalopteryx* (Trautschold). It has not been found in Estonia but is common in adjacent areas.

The usage of the psammosteid microremains, i.e. isolated tubercles in biostratigraphy is significant. These remains can barely be identified to the generic level because of the enormous variety in ornament, characteristic of this group of jawless fishes. Therefore, the establishment of species on the basis of single tubercles may cause misleading conclusions in both stratigraphy and the evolution of psammosteids. For example, in a paper by Niit et al. (2005) the psammosteid species *Tartuosteus maximus* and *Pycnosteus tuberculatus* characteristic of the Burtnieki RS were reported in all three parts of the underlying Aruküla RS. Yet, even the richest Aruküla fish localities have never yielded any skeletal elements or larger fragments of the above psammosteids, which could confirm the range of these species both in the Aruküla and Burtnieki RSs. The ornament of the psammosteids is first of all important for the identification of isolated skeletal elements of the same species (Obruchev & Mark-Kurik 1965, p. 50).

Placoderms are very common in the Middle–Upper Devonian units, particularly in the Givetian and Frasnian. These are represented by species of arthrodires *Coccosteus*, *Watsonosteus* and *Plourdosteus* and antiarchs *Asterolepis* and *Bothriolepis*. The psammosteid and placoderm fish fossils have been used as characteristic or zonal forms in the Baltic area (Gross 1933, 1942; Sorokin 1981) and on the whole of the East European Platform (Rzhonsnitskaya & Kulikova 1990) since the last century.

REGIONAL STANDARD

The Lower Devonian is fairly incomplete on the Estonian territory, except for its uppermost part, corresponding roughly to the upper Emsian. Large gaps separate the local units of Lochkovian, Pragian and Emsian age. The Frasnian is also incomplete, being represented by the lower substage and the major part of the middle substage, whereas the upper Frasnian and the Famennian Stage are lacking in Estonia. It is worth mentioning that the Frasnian substages can be informally used before they are ratified (Becker 2011, p. 11).

The regional standard includes regional stages and some substages (in the Narva RS). The distribution of formations is shown in Fig. 2. The Lower Devonian units, the Lochkovian Tilžė Fm and Pragian Ķemeri Fm, have a very limited distribution. The upper part of the Emsian Rēzekne Fm and the Pärnu Fm are known in SE and SW Estonia, whereas the former varies laterally. The Lemsi Fm is the western equivalent of the Rēzekne Fm in the east. Kleesment (2005) considered the Rēzekne Fm as the locally developed Mehikoorma Fm in SE Estonia.

We suggest that in the eastern part of Estonia the Rēzekne Fm does not differ so markedly from the coeval unit in East Latvia that a new formation is required. Earlier this formation was also named the Rēzekne Fm (e.g. Kleesment & Mark-Kurik 1997, table 10).

The Narva RS, consisting of the Vadja, Leivu and Kernavė substages, is the most widely distributed Devonian stratigraphical unit in Estonia. The overlying Middle Devonian Aruküla and Burtnieki RSs are less widespread, though covering a large part of the territory of South Estonia. The upper Middle Devonian Gauja and Amata RSs occupy SE Estonia, and the Upper Devonian is distributed in the most southeastern part of Estonia (Fig. 1).

SERIES AND STAGE BOUNDARIES

Lower/Middle Devonian (= Emsian/Eifelian) boundary

The position of the Lower/Middle Devonian (= Emsian/ Eifelian) boundary between the Rēzekne and Pärnu RSs has been discussed for a fairly long time. Lyarskaya (1974) preliminarily identified the Rēzekne RS as a separate unit underlying the Pärnu Fm in core sections in central and eastern Latvia. She considered these deposits older than the Pärnu–Narva strata, possibly of early Eifelian age. The fish fossils appeared to belong largely to the Middle Devonian, except *Diadsomaspis*, an Early Devonian placoderm from the Rhineland (Lyarskaya 1974, table I). Later Mark-Kurik (2002) reidentified it as *Diadsomaspis* cf. *elongata* (Gross), known from the Late Emsian. Valuable data on the Rēzekne Fm were provided by a series of integrated studies (Kleesment et al. 1975) on the Mehikoorma drill core (SE Estonia). In addition, data on fossils of the same unit were acquired from drill cores of Estonia (Valga) and adjacent areas: Latvia (Ludza), Pskov Region of Russia (Pechory) and Belarus (Vil′chitsy, Pochtary, Gashniki, Liozno). The Middle Devonian fishes (placoderms, acanthodians, sarcopterygians, actinopterygians) were identified to a generic or higher level. However, the occurrences of several new placoderm genera, different from those of the Middle Devonian, were also reported. Fish otoliths were discovered in the Devonian deposits, and thus in the Baltic area and Belarus, for the first time (Kleesment et al. 1975, pl. 4 fig. 7).

Data on miospores, identified by G. Vaitiekūnienė (Kleesment et al. 1975, p. 180), are of special interest. She mentioned that miospores from the Rēzekne Fm differed from these in the underlying Ķemeri Series and in the overlying Pärnu RS and were of Late Emsian–Early Eifelian age (*Archaeozonotriletes memorabilis* Umnova, *Retusotriletes* cf. *priscus* Umnova). Some of them (*Dibolisporites eifeliensis* (Lanninger) McGregor) were known from the Emsian of Canada and France. According to Steemans (1989), *D. eifeliensis* also occurs in the Emsian Wetteldorf Fm of the Rhineland. Vaitiekūnienė (1985) gave a species list of a miospore assemblage from the lower part of the Rēzekne RS, identified in several Lithuanian drill cores. In addition to *Dibolisporites eifeliensis*, it contained several other Lower Devonian forms: *D. echinaceus* (Eisenack) Richardson, *D. wetteldorfensis* Lanninger, *Retusotriletes dittonensis* Richardson & Lister and *Emphanisporites annulatus* McGregor. The same assemblage included also Middle Devonian miospores *Grandispora velata* (Eisenack) Playford, *Calyptosporites spinosus* Tiwari & Schaarschmidt, *Ancyrospora angulata* (Tiwari & Schaarschmidt) McGregor and *Hystricosporites elegans*. According to Vaitiekūnienė (1985), the characteristic spores of the lower part of the Rēzekne Fm were the zonal form *Calyptosporites*, and miospores *Ancyrospora* and *Hystricosporites* with anchor-like processes. She inferred that the Lower Devonian miospores, including *Emphanisporites annulatus*, continued to occur together with later forms. She also pointed out that an assemblage with the same content was established in the Heisdorf Beds of the uppermost Upper Emsian. It is of note that *Grandispora velata* first appears in the Eifel region near the base of the Eifelian Stage (Streel et al. 2000). Therefore, it is possible that the uppermost part of the Rēzekne RS may be of Eifelian age. Obukhovskaya (1999) assigned an Eifelian age also to the uppermost part the Vitebsk RS in eastern Belarus. Most of this unit in Belarus corresponds to the Late Emsian *Retusotriletes clandestinus* (RC) and *Diaphanospora inassueta* (DI) zones (Avkhimovitch et al. 1993).

In his numerous papers Valiukevičius (1993–2006) considered trends in the acanthodian evolution particularly important in biostratigraphy. He noted that the *Laliacanthus singularis* Zone, corresponding to both the Rēzekne and Pärnu RSs, marked the beginning of a new Middle Devonian level in the phylogenetic development of acanthodians, i.e. start of the domination of acanthodids and diplacanthids (Valiukevičius 1993). The genera *Diplacanthus*, *Cheiracanthus*, *Ptychodictyon* and *Rhadinacanthus* among others are characteristic of this level. In several papers (Valiukevičius 1998, 2000, 2006) the Late Emsian age of the Rēzekne RS was clearly questioned, but in others (Valiukevičius 1995) this unit was included in the Emsian. A gap of Emsian age between the Ķemeri and Rēzekne RSs was considered by Valiukevičius (1995) as corresponding to more than three conodont zones, i.e. from the uppermost *gronbergi* to lowermost *patulus* zones. According to Vaitiekūnienė

(1985), the gap could be shorter and correspond approximately to the *inversus–serotinus* zones. However, the concept that a significant change occurred in the evolution of the acanthodians close to the end of the Early Devonian in the Baltic area may have been largely influenced by this gap. The list of acanthodian species, established from isolated scales in the Rēzekne RS (Valiukevičius 1994, 2000), shows that at least four species, *Ectopacanthus flabellatus* Valiukevičius, *Markacanthus paralellus* Valiukevičius, *Ptychodictyon ancestralis* Valiukevičius and *Watsonacanthus*? sp. occur in this unit (or appear in the underlying Lower Devonian Saunoriai Fm). *Cheiracanthus krucheki* Valiukevičius, *Diplacanthus*? sp. nov. and *D. kleesmentae* Valiukevičius from the Vitebsk RS, Belarus (Valiukevičius 2000), can also be added to the above list. Lyarskaya (1978) described three species from the Rēzekne RS, based on fin spines: *Diplacanthus*? *berziensis*, *Acanthoides*? *latgalica* and *Haplacanthus ludziensis*. These data show that in the Rēzekne RS there occur a number of acanthodian species, different from those in the Middle Devonian Pärnu RS. However, the Rēzekne assemblage contains nine acanthodian species with longer ranges: five species, including *Laliacanthus singularis*, are common with the Pärnu RS and four species even range into the Frasnian (Valiukevičius 2006). If we apply the general Middle Devonian age of these longer-ranging species to the Rēzekne RS, we shall get a reverse age determination: the longer-ranging species determine the age of an earlier unit.

The Early Devonian age was proposed for the Rēzekne RS, using fish faunas in the interregional correlation, among others those from the Eifel Hills sequence (Mark-Kurik 1991, fig. 4). Several placoderms, particularly phlyctaeniids, e.g., *Diadsomaspis* cf. *elongata* from the Liepkalnis drill core (Lithuania), *Kartalaspis belarussica* Mark-Kurik nomen nudum from the Lepel′ and Obol′ beds, Vitebsk RS (Vil′chitsy drill core, Belarus) and Rēzekne RS (Raigla drill core, Estonia), and the earliest species of *Actinolepis*, *A. spinosa* Mark-Kurik (Ventspils drill core, Latvia) are characteristic of the Rēzekne RS (Mark-Kurik 2002). Phlyctaeniids are common in the Emsian of the Rhineland. The occurrence of a new ptyctodont genus from the Rēzekne RS in the East Latvian Ludza-15 drill core at a depth of 430.8 m is worthy of note. This ptyctodont with its very long spinal plates differs considerably from the Middle Devonian *Rhamphodopsis* and *Ptyctodopsis* having shorter spinals.

Recent studies of the ichthyofauna and other fossils (conodonts, miospores) in the Baltic area and Belarus show some controversy concerning the position of the Emsian/Eifelian boundary. In Belarus (Plaxa 2006; Plax 2008; Plax et al. 2008) the Vitebsk RS, which is largely coeval with the Rēzekne RS, is considered to be of Late Emsian age. The overlying Adrov RS, coeval with the Pärnu RS in the Baltic, corresponds to the Lower Eifelian *partitus* Zone (Narkiewicz & Kruchek 2008). According to Obukhovskaya (1999), the topmost part of the Vitebsk RS is already of Eifelian age. However, analysing the Middle and Late Devonian fish communities, Lukševičs et al. (2010) and Lebedev et al. (2010, table 9) concluded that the Rēzekne RS was of Early Eifelian age and also a gap existed between the Rēzekne and Pärnu RSs. It is hard to agree with the views of these authors, based solely on the identification of fish at the generic level. In the age determination of the Rēzekne RS and coeval units they omitted the species level of the fish, and the miospore age dates. Despite the above controversies it seems reasonable to treat the Rēzekne RS as a Lower Devonian unit.

Eifelian/Givetian boundary

Correlation of the Eifelian/Givetian boundary has not received much discussion. Its position was established when conodonts were discovered in the upper part of the Narva RS, in the Kernavė Regional Substage. From the time aspect, however, the position of this boundary has changed more than, for example, that of the Emsian/Eifelian boundary. The Middle Devonian subdivision into stages was not considered in the classical works by Gross (1933, 1942) and Obruchev (1951). Somewhat later, Obruchev (1958) placed the whole Pärnu–Tartu (= Aruküla + Burtnieki) interval from the Russian Platform into the Givetian. Still later, when comparing fish assemblages of the Baltic area with those in other regions of the Russian platform, as well as in Scotland and Spitsbergen, he suggested that only the Burtnieki Fm was of Givetian age (Obruchev 1972, 1973). Analysing the Middle Devonian fish faunas in Latvia, Lyarskaya (1972), reached the same conclusion. Further study of Devonian deposits in the Baltic area produced two positions for the Eifelian/Givetian boundary: either between the Narva and Aruküla RSs or the Aruküla and Burtnieki RSs (Sorokin 1981). The boundary between the Aruküla and Burtnieki RSs was accepted in the stratigraphical chart for the Russian Platform (Rzhonsnitskaya & Kulikova 1990) and with some doubt also in the Estonian chart (Kleesment and Mark-Kurik 1997). In Lithuania somewhat earlier (Narbutas et al. 1993) the uppermost part of the Narva RS and coeval *kockelianus* conodont Zone and *Polygnathus parawebbi* assemblage marked the probable upper boundary of the Eifelian. However, the age of the Aruküla RS was still under discussion. Valiukevičius (1994, 1995, 2000) considered the Kernavė Fm and Kastyukovichi RS in Belarus coeval with the *kockelianus* Zone, and the Aruküla + Burtnieki RSs and Polotsk RS (Belarus) as age equivalents with the interval of the *hemiansatus–varcus–hermanni–cristatus* zones. The *Rhabdosporites langii* (RL) miospore Zone, corresponding to the Kernavė and Kastyukovichi level, is also a marker of the upper boundary of the Eifelian (Avkhimovitch et al. 1993). According to Obukhovkaya (1999), on the basis of the absence of ex gr. *Geminospora lemurata* miospores in the Kastyukovichi RS, this unit can be included into the Eifelian. The Polotsk RS with the *Geminospora extensa* Zone is of Givetian age. It is noteworthy that in the Russian Devonian chart of Rzhonsnitskaya (1998) the Eifelian/Givetian boundary, i.e. the *kockelianus*/*hemiansatus* zones boundary is at a somewhat higher level, approximately in the middle of the Aruküla Fm and its eastern age equivalents – the Chernyi Yar and Koiva Fms.

Middle/Upper Devonian (= Givetian/Frasnian) boundary

Special attention should be paid to the Middle/Upper Devonian (= Givetian/Frasnian) boundary in Estonia, and also in the NW of the East European Platform, in general. Classically, according to Gross (1933, 1942), the lowermost unit of the Upper Devonian was the *Cellulosa*-Mergel or Snetogor-Stufe (= Snetogor Beds). At present it is called the Snetnaya Gora Beds and lies at the base of the Pļaviņas RS (Ivanov et al. 2005, fig. 3). Obruchev (1933) concluded that the Podsnetogor Beds could also be included into the Upper Devonian and the underlying Oredezh Beds into the Middle Devonian. In 1951, correlating geological units and fish faunas of the Middle and Upper Old Red Sandstone of Scotland with the Baltic, he suggested the occurrence of significant gaps at the boundary of these units in the Baltic area and particularly in the Leningrad and Pskov regions. The gap was supposed to be the largest in the area of the Luga and Plyussa rivers, corresponding to the Upper Tartu Beds (now Burtnieki RS) and to the whole of the Gauja Beds in the Baltic (Obruchev 1951, p. 983). So, since the 1950s the boundary has been placed between the Burtnieki and Gauja RSs or their coeval units, and a gap between these units has generally been recognized on the East European (Russian) Platform and in the adjacent areas (Sorokin 1981, fig. 1a, 1992, fig. 1; Rzhonsnitskaya & Kulikova 1990).

However, the magnitude of the gaps has evidently been overemphasized. Recent data show that two localities with the characteristic Burtnieki fish fauna occur in the basins of the Luga and Oredezh rivers, to the NE of the town of Luga. One of these, a sandstone quarry is situated near the Novinka railway station. It has yielded, e.g., *Tartuosteus* (cf. *T. maximus* Mark-Kurik), *Pycnosteus tuberculatus* (Rohon), *Ganosteus stellatus* Rohon, *Homostius* sp., *Heterostius* sp., *Coccosteus* (cf. *C. markae* O. Obrucheva) (Averianov 1990). The other locality is near Pehenets on the right bank of the Yashchera River, about 16 km upstream from the river mouth. In 1984 V. Kuršs found a similar fish assemblage in this locality, consisting of *Pycnosteus tuberculatus*, *Ganosteus stellatus*, *Homostius*, *Heterostius*, etc. (identified by E. Mark-Kurik). The Oredezh Beds have again been recognized in the eastern part the Main Devonian Field as an age equivalent of the Gauja RS of the Baltic area (Ivanov et al. 2005, fig. 3).

Obruchev (1951) also mentioned a shorter break between the Upper Tartu (i.e. Burtnieki RS) and Gauja beds in the Baltic area. However, a gradual change in fish faunas can be observed particularly during the late Burtnieki age. The uppermost part of the Burtnieki Fm, the Abava Mb, has yielded some elements of a fish fauna close to that in the Gauja RS, e.g., a large form of *Asterolepis* (*A. essica* Lyarskaya), *Laccognathus* sp., and the appearance of tristichopterids. Noteworthy is the absence of the characteristic Middle Devonian arthrodires *Homostius* and *Heterostius* (Mark-Kurik & Nemliher 2003).

Variation in boundaries

The position of the boundaries varies in the stratigraphical charts of the Baltic area, Belarus and NW Russia. Taking into account that the fish faunas of the Gauja and Amata RSs were closer than those of the Amata and Pļaviņas RSs, and the carbonate sedimentation started to predominate in Pļaviņas time, in **Estonian charts** the Middle/Upper Devonian boundary was provisionally kept at the base of the Pļaviņas RS. It was marked either with a question mark (Kleesment & Mark-Kurik 1997) or with a dashed line (Mark-Kurik 2000). However, on the basis of miospore data it was supposed that the boundary could be situated somewhat above the upper limit of the Gauja Fm – in the Amata Fm (Mark-Kurik et al. 1999).

In **Latvia** the Givetian/Frasnian boundary was defined between the Burtnieki and Gauja RSs (Stinkulis 2003). Somewhat earlier Forey et al. (2000) included the Gauja Fm into the Givetian. According to Lukševičs (2001), in the Main Devonian Field the boundary could be somewhere between the base of the Amata RS and that of the Pļaviņas RS.

In **Lithuania** the boundary of the Middle and Upper Devonian was placed between the equivalents of the Burtnieki and Gauja units – the Upninkai and Šventoji Fms (Narbutas et al. 1993; Paškevičius 1997; Sidaravičienė 1999). Probably in these cases the traditional Baltic boundary position (Sorokin 1981) was followed. Narbutas (1994, table 23), like Obruchev (1951), indicated a break between the Upninkai and Šventoji Fms. According to Valiukevičius (2000, p. 276), conodonts of the *falsiovalis* Zone were recovered just above the base of the Pļaviņas RS. However, he decided that the series boundary between the Šventoji and Pļaviņas RSs was probably too high and gave a possible lower variant of the boundary in the Main Devonian Field down in the Šventoji RS (Valiukevičius 2000, fig. 1; Valiukevičius 2006, fig. 6).

In **Belarus** the Givetian/Frasnian boundary earlier occupied the traditional place between the local Middle Devonian unit Polotsk RS and the Upper Devonian Lan RS (Kruchek et al. 2001; Obukhovskaya et al. 2007). However, recently it was considered to lie between the lower and upper parts of the previous Lan RS. The lower part, the Khotimsk (Ubort) RS, coeval with the Gauja RS, now belongs to the Givetian, and the upper part, the Zhelon RS, coeval with the Amata RS, to the Frasnian (Plax 2008; Plax et al. 2008).

In **Russia**, comprising the eastern part of the Main Devonian Field, the probable Givetian/Frasnian boundary was earlier considered to be in the lower part of the Amata Fm (Rzhonsnitskaya 1998, table) or above the Amata Fm (Esin et al. 2000, figs 2, 3). The same position is given by Lebedev et al. (2010, table 9), who also indicated a gap between the Gauja and Amata RSs, corresponding to a part of the early *falsiovalis* conodont Zone. Noteworthy is the detailed Devonian stratigraphy of the Leningrad Region by Ivanov et al. (2005). It was decided that the boundary should be above the Oredezh Beds, the age equivalent of the Gauja Fm. The Amata RS consists of the Staritsa and Podsnetogorskie beds. It is remarkable that the Podsnetogorskie Beds have yielded conodonts, which together with those of the Snetnaya Gora Beds form the local *Polygnathus lanei* Zone.

At present the level of the boundary between the Middle and Upper Devonian, or the Givetian and Frasnian, is not unambiguously defined in the Main Devonian Field. It is possible that this series/stage boundary lies somewhere in the Amata RS. This position has been suggested earlier in several instances as indicated in the text above. In Belarus it could be in the Zhelon RS.

CORRELATION OF THE MIDDLE DEVONIAN OF SCOTLAND AND THE BALTIC AREA

Recent correlation of the Middle Devonian of Scotland and the Baltic area, based on fossil fishes, is of special interest (Ahlberg et al. 1999; Mark-Kurik 2009; Fig. 3). Earlier authors (e.g. Obruchev 1951, 1973) have repeatedly

SCOTLAND			ESTONIA			
Regional stratigraphy		Fishes	Reg. Stage, Formation	Member	Fishes	Stage
	Whitemire Beds	*Pl. mironovi*?	**Pļaviņas**		*Pl. mironovi***	**Frasnian**
	Nairn Sandstones	*Psl. undulata*	**Amata**		*Psl. undulata*	?
			Gauja	**Sietiņi, Lode**	*E. kurshi***	
	John o'Groats Sandstones, **Eday** Flagstones	*Tristichopterus Watsonosteus Microbrachius*	**Burtnieki**	**Abava**	tristichopterid *Watsonosteus Microbrachius*	
Upper Caithness Flagstone Group	**Mey** Subgroup, **Rousay** Flagstone Formation	*Millerosteus*		**Koorküla** **Härma**		**Givetian**
	Latheron Subgroup, **Ham-Scarfskerry** Subgroup, **Upper Stromness** Flagstones		**Aruküla**	**Tarvastu** **Kureküla** **Viljandi**	*Millerosteus*	
Lower Caithness Flagstone Group	**Achanarras** Limestone Member, **Sandwick** Fish Bed	*Coccosteus Rhamphodopsis*	**Kernavė** **Narva**		*Coccosteus Rhamphodopsis**	
	Robbery Head Subgroup, **Lower Stromness** Flagstones	*Coccosteus*	**Leivu** **Vadja**			**Eifelian**
	Lybster Subgroup		**Pärnu**	**Tori, Tamme**		

Fig. 3. The correlation of the Middle Devonian and lowermost part of the Upper Devonian of Scotland and Estonia with two key markers or biohorizons (shaded). Modified from the poster by Mark-Kurik (2009) on the 69th Annual Meeting of the Society of Vertebrate Paleontology in Bristol. Compiled mainly after Ahlberg et al. (1999) and den Blaauwen et al. (2005, fig. 1); Scottish stratigraphic unit names after Trewin & Thirlwall (2002). Some fish fossils (to the right) come from the units coeval with Estonian units: * in Lithuania, ** in Latvia. *E.*, *Eusthenopteron kurshi* Zupiņš, 2008; *Pl.*, *Plourdosteus*; *Psl.*, *Psammolepis*.

used fish faunas of these distant regions for correlation, despite their basic difference in environmental aspect. Briefly, it is supposed that the Scottish Orcadian Basin was a large lake or series of inter-connected lakes with rare marine incursions (Marshall et al. 1996, 2007), whereas the Baltic area was a part of shallow shelf sea (Kuršs 1992). It is noteworthy that in the course of time the number of 'endemic' fish genera and species of both these regions has gradually diminished. For example, typical Scottish 'endemics' *Millerosteus*, *Watsonosteus* and *Microbrachius* have been found in Estonia, and *Actinolepis*, common in the Baltic area, is now known from Scotland (Newman & Trewin 2008).

There are two markers, which permit the correlation of the Middle Devonian units of these regions. The **first marker** is the upper Eifelian Kernavė Fm, containing placoderms *Coccosteus cuspidatus* Miller ex Agassiz and *Rhamphodopsis* cf. *threiplandi* Watson. Moreover, the Kernavė Fm in Lithuania and the coeval Kastyukovichi RS in Belarus have yielded conodonts valuable for age dating. According to Valiukevičius (1995) and Narkiewicz & Kruchek (2008), these units correspond to the *kockelianus–ensensis* zones. Marshall et al. (2010, p. 23) discussed the conodont assemblage of this marker and suggested that the Kernavė Fm and the Achanarras/Sandwick Fish Bed horizon occurred somewhere within the *eiflius* to *ensensis* interval. In Estonia the placoderm *Millerosteus* appeared probably earlier than in Scotland, i.e. in the Tarvastu Mb of the Aruküla Fm.

The Abava Mb in the Baltic area is the **second marker**, revealing the characteristic placoderms *Watsonosteus* and *Microbrachius*, both of which were known for a long time as Scottish endemics. However, Obruchev (1973) noted that *Watsonosteus* was found at the base of the Gauja Beds (now considered as the Abava Mb). Recently sarcopterygian remains belonging to a tristichopterid were identified in the Abava Mb in Estonia (I. Zupiņš pers. comm. 2010). In Scotland *Tristichopterus alatus* Egerton occurs together with *Watsonosteus fletti* (Watson) and *Microbrachius dicki* Traquair in the John o'Groats Sandstone Group (Trewin & Thirlwall 2002, p. 236). It is noteworthy that there seems to be no direct equivalent of the Gauja RS in Scotland. Correlation of the Amata RS with the Nairn Sandstone is based on the psammosteid species *Psammolepis undulata* Agassiz (Ahlberg et al. 1999).

In connection with depositional environment problems, we should mention valuable data on invertebrates, particularly brachiopods, occurring in the Middle Devonian of the Baltic area (Gravitis 1981). Although published more than 30 years ago, this information has not attracted much attention. Inarticulated lingulate brachiopods *Bicarinatina*, *Laima* and *Orbiculoidea* occur in the Rēzekne–Gauja interval, whereas *Bicarinatina* is most common (for comparison see Zabini et al. 2010). In Latvia clastic rocks of the Burtnieki Fm and, more often, of the Gauja Fm have yielded rare articulated brachiopods – rhynchonellids and spiriferids, preserved as moulds in poorly cemented sandstone. In one case, in the environs of Kraslava (SE Latvia), silicified shells of Cyrtospiriferidae and 'Camarotoechiidae' together with stromatoporoid and coral remains (*Hermatostroma* aff. *verhovense* Riabinin, *Syringostromella* aff. *pskovensis* (Riabinin), *Taeniodictyon* sp. indet.) were preserved (Sorokin 1981, pp. 149, 387). These rare finds evidence that siliciclastic rocks of the Main Devonian Field were not suitable for the preservation of marine shelly faunas and thus the invertebrates are poorly represented in the fossil record. The occurrences of the above invertebrates are valuable for the study of the Middle Devonian depositional environment in the Baltic area and indicate a marine origin of the Devonian clastic rocks of the Main Devonian Field.

SUMMARY AND CONCLUSIONS

Correlation and age determination of Devonian regional stratigraphical units (stages, formations) in the Baltic area, i.e. the NW part of the East European (Russian) Platform, has gradually improved since the 1950s. In the Lower and Middle Devonian these units are largely based on fish fossils. Differences in faunas and facies have complicated correlation with stratigraphical units in the stratotype areas of Western Europe. In the 1990s standard conodont and miospore zonations were applied. Unfortunately, miospore and particularly conodont occurrences are not numerous; these fossils are somewhat more common in Belarus and NW Russia.

The utility of the fish biozones varies and depends on the different development stages of fish groups: psammosteid heterostracans, placoderms and acanthodians. Acanthodians are a perfect tool for identification of the Eifelian units, psammosteids for the Givetian units, whereas placoderms are significant in the subdivision of the Givetian–lower Frasnian part of the sequence. Local stratigraphical units are evidently not direct equivalents of the standard conodont zones or miospore zones. This is exemplified, e.g. by the Rēzekne RS that corresponds approximately to the *Diaphanospora inassueta* miospore Zone, but its uppermost part can be included into the *Periplecotriletes tortus* Zone.

At present the problems concerning series and stage boundaries, particularly the Middle/Upper Devonian (= Givetian/Frasnian) boundary, are still unsolved. The position of the boundary varies in the stratigraphical charts of the Baltic area, Belarus and NW of Russia.

Gaps in the Scottish sequences and probable coeval ?larger gaps in the Main Devonian Field led in the 1950s to redefinition of the Middle and Upper Devonian boundary position over the East European Platform. It was agreed to define that boundary between the Burtnieki and Gauja RSs and their age equivalents. However, recent data show that the length of breaks was over-estimated, as evidenced by the discovery of the Burtnieki fish fauna in the SW of the Leningrad Region. Two key markers for the correlation of the Baltic and Scottish Middle Devonian are of note: the Kernavė/Achanarras and Abava/Eday-John o'Groats levels.

From the depositional environmental aspect, the occurrences of inarticulated brachiopods (lingulids) and moulds of articulated brachiopods (rhynchonellids, spiriferids) in the Middle Devonian siliciclastic rocks are of great significance. These indicate a marine origin of the rocks.

Correlation of the Baltic Devonian sequences via Belarus and Poland with those of the stratotype region in the Rhineland is still important and needs to be improved. More conodont and/or miospore data are required for the establishment of the series and stage boundaries.

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Eesti Devoni stratigraafia: hetkeseis ja probleemid

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On esitatud Eesti Devoni stratigraafilise skeemi täiendatud variant koos kommentaaridega. Devoni skeemi geokronoloogiline raamistik on seotud 2010. aasta rahvusvahelise stratigraafia skeemi (A) ja Bernd Kaufmanni U–Pb isotoopide (B) andmete absoluutse vanuse skaala dateeringutega, mille suurimad erinevused on Emsi ning Eifeli ja Eifeli ning Giveti piiril. Devoni rahvusvaheline liigestus on skeemis seotud biotsoonidega: rahvusvahelised konodontide tsoonid, Ida-Euroopa platvormi läänepoolsete piirkondade miospooride tsoonid ja platvormilise ala loodeosas, nn Peadevoniväljal laialdaselt kasutatavad erinevate fossiilsete kalade tsoonid. On esile toodud piirkondlike lademete ja kihistute ning mitmesuguste biotsoonide korreleerimisega kaasnevad vastuolud. Erilist tähelepanu on pööratud ladestute ja ladejärkude piiride asendile piirkondlike lademete suhtes Baltikumis ning Valgevenes. Nende piiride asendit pole seni ühemõtteliselt käsitletud. Šotimaa läbilõigetes leiduvad settelüngad ja oletatavad samaaegsed suured settelüngad Peadevoniväljal andsid omal ajal põhjuse muuta Kesk- ning Ülem-Devoni piiri asendit tervel Ida-Euroopa platvormil, paigutades selle varasemasse aega (Burtnieki ja Gauja lademe ning teiste sama vanusega üksuste vahele). Tänapäeval on selgunud, et nende lünkade suurust on ülehinnatud. Artiklis on kirjeldatud kaht eriti iseloomulikke rüükalu sisaldavat markeerivat taset, mida saab edukalt kasutada Baltikumi ja Šotimaa Kesk-Devoni korreleerimisel. Märkimisväärsed on lukuta käsijalgsete (Lingulida) ja lukuliste käsijalgsete leiud Baltikumi Devonis. Need leiud nõrgalt tsementeerunud purdkivimites osutavad mainitud setendite merelisele päritolule.