The crystalline basement of Estonia: rock complexes of the Palaeoproterozoic Orosirian and Statherian and Mesoproterozoic Calymmian periods, and regional correlations

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Abstract. New data on the Fennoscandian Shield and the Baltic area suggest a need for reinterpretation of the stratigraphy of Estonian Precambrian rock complexes. The rocks of the Tallinn Zone formed in the framework of the Fennian orogeny at the margin of the Bergslagen microcontinent 1.90–1.88 Ga ago. The precise age of the Alutaguse Zone is not known. It may have formed either during the 1.93–1.91 Ga Lapland–Savo orogeny or as a rifted eastern part of the Tallinn Zone in the Fennian orogeny. The granulites of western and southern Estonia belong to the volcanic arcs inside the 1.84–1.80 Ga Svecobaltic orogenic belt and show peak metamorphic conditions of 1.78 Ga. Small shoshonitic plutons formed 1.83–1.63 Ga, the small granitic plutons of the Wiborg Rapakivi Subprovince 1.67–1.62 Ga, and the Riga pluton 1.59–1.54 Ga ago.

Key words: geochronology, stratigraphy, Precambrian basement, Fennoscandia, Estonia.

INTRODUCTION

New achievements in the Precambrian geology in general and especially in the geology of the Fennoscandian–Baltic region enable development of a new insight into the history of the formation of the basement rocks. During the last decade, however, only a few new results have been obtained on the Estonian–Latvian territory, whereas a considerable amount of new geological-geochemical and geophysical material on the Precambrian basement structure and rocks in the surrounding areas in Fennoscandia and in the southern Baltic Sea region has been accumulated through various research programmes such as, for example, Europrobe-Eurobridge (Bogdanova et al. 2006, 2008; Korja et al. 2006; Lahtinen et al. 2008). These new data suggest that reinterpretation of local Precambrian geology needs to be discussed.

Firstly, the understanding of the development of the Svecofennian continental crust within the large domain between the Karelian and Ukrainian protocratons has essentially changed. The primary model of the historically uniform, 1.93–1.8 Ga Svecofennian Domain of the Fennoscandian Shield and NW Russian Platform basement (Gaal & Gorbatschev 1987; Gorbatschev & Bogdanova 1993) has been divided into a series of slightly temporally different orogenic belts. The belts are composed of volcanic island arc, back-arc sedimentary basin, and (granitoid-rich) microcontinent-type of terrains, amalgamated in the course of the active margin of Svecofennian ocean around 1.93–1.8 Ga (Nironen 1997; Korja et al. 2006). In this respect the traditional structural zones of the Estonian basement (Puura et al. 1983; Soesoo et al. 2004) may obtain distinct settings within the regional basement structures.

Secondly, for the geological survey and mapping purposes, the age of the basement suites is suitable to discuss according to the latest stratigraphic scheme issued by the IUGS (Gradstein et al. 2004).

Thirdly, new opportunities for the Precambrian studies have appeared due to the advances in laboratory techniques in Estonian universities. Hopefully these will create a basis for future research activities.

GEOLOGICAL OUTLINE OF THE PALAEO-PROTEROZOIC (OROSIRIAN) OROGENIC COMPLEXES IN THE FOLDED BASEMENT OF ESTONIA AND ADJACENT AREAS

Intensely folded, deeply metamorphosed and migmatized stratified sedimentary and volcanic suites predominate in the Precambrian crystalline basement of Estonia

(Puura et al. 1983). Since 1991 (Huhma et al.1991; Puura & Huhma 1993), the orogenic metamorphic and related igneous rock bodies of the Estonian basement have been described as Palaeoproterozoic structures inside the juvenile Svecofennian Domain of the Fennoscandian crustal megablock (Puura & Flodén 1999; Puura et al. 2004). The latter forms the northwestern section of the East European Craton (Gaal & Gorbatschev 1987; Gorbatschev & Bogdanova 1993; Bogdanova et al. 2008). The Fennoscandian megablock consists of three domains – the Archaean Karelian Protocraton in the northeast, the Palaeoproterozoic Svecofennian Domain in the central and southern parts, and the Palaeo- to Mesoproterozoic Southwest Scandinavian Domain in the southwest (Gorbatschev & Bogdanova 1993). The geochronological studies carried out in the 2000s have provided evidence that the interior of the Svecofennian Domain is more complex than previously supposed. Within the Svecofennian Orogen, a mosaic of orogenic belts and microcontinents of different age has been revealed (Skridlaite & Motuza 2001; Skridlaite et al. 2003; Krzeminska et al. 2005; Lahtinen et al. 2005; Bogdanova et al. 2006, 2008; Korja et al. 2006). The mosaic formed in the course of terrain accretionary processes, which created a series of Palaeoproterozoic orogenic belts towards the edges of Archaean protocratons: along the western and southwestern borders of Karelia and Volgo-Uralia and along the northwestern border of Sarmatia (Bogdanova et al. 2008). Inside the Svecofennian Domain it is expressed as a series of orogenic belts retreating from north to south (Bogdanova et al. 2006; Korja et al. 2006). According to these views, the structurally different blocks of the Estonian orogenic basement are located in the internal part of the mosaic of 1.93–1.80 Ga amalgamated Palaeoproterozoic orogenic belts and microcontinents (Fig. 1). The structural architecture of the Estonian folded basement suggests that compressional tectonics towards the Karelian Protocraton was the likely cause of the continental crust-forming processes in this area.

In Northeast Svecofennia the oldest 1.93–1.91 Ga Lapland–Savo Orogenic Belt embraces the NW border of the Karelian 3.5–2.7 Ga Protocraton. In the SE continuation of the Savo Belt, in SE Finland and SW Russian Karelia, Kalevian schist basins spread towards the large Novgorod gravity and magnetic minima block (Fotiadi 1958; Gafarov 1963). Here we opine that the geophysical anomalies reflect the existence of a large granitoid-rich continental crustal block.

To the southwest of the Lapland–Savo Orogenic Belt and the Keitele microcontinent, 1.90–1.88 Ga dated latitudinally extending Fennian orogenic suites form the Tampere, Häme, and Uusimaa volcanic-sedimentary belts of island arc origin in southern Finland (Korja et al. 2006). As it was revealed by the interpretation of geophysical anomalies, and lithological and isotope age studies, the Tallinn Zone of northern Estonia belongs to this assemblage of accreted island arc belts (Puura et al. 1983, 2004; Koistinen 1996). However, recent geophysical and petrological studies suggest that the Häme orogenic zone bordered a microcontinent in the south, which is supposed to be a continuation of the Central Swedish Bergslagen microcontinent (Korja et al. 2006; Lahtinen et al. 2008). Thus orogenic rocks of the Tallinn Zone and the neighbouring seabed of the Gulf of Finland lie on the top or at the southern margin of this microcontinent. Following earlier understandings on the NE Estonian basement structure, the local Alutaguse Zone could be cosidered as a secondary rifted eastern part of the Tallinn Zone which formed during the extensional stage of the Fennian orogeny. In this case the expected age of metamorphic alumogneisses should be around 1.88 Ga or somewhat younger.

Another possible age of these gneisses is derived from the correlations of the Alutaguse Zone with the 1.93–1.91 Ga Lapland–Savo Orogenic Belt. Namely, around St Petersburg (NW Russia) a large area of siliciclastic alumina-rich migmatized gneisses with a granitoid massif in the Novgorod area has been mapped by drilling (Tikhomirov 1965; Koistinen 1996). We interpret the last structure of unknown age as an analogue of the Keitele granitoid microcontinent that is well documented in Central Finland (Lahtinen et al. 2005). In the western continuation of the Novgorod microcontinental block widespread migmatized siliciclastic (alumogneisses) complexes have been revealed in a number of drill cores in the Alutaguse Zone of NE Estonia (Puura 1980; Puura et al. 1983, 1992, 2004; Koistinen 1996; Soesoo et al. 2004). In this context the rocks of the Alutaguse Zone are possibly similar to those of the 1.93–1.91 Ga Lapland–Savo orogeny.

Further south the distribution of the Estonian–Latvian Granulite Belt corresponds to the Baltic gravity and magnetic high by Fotiadi (1958) and Gafarov (1963). The belt is predominantly composed of metamorphosed up to granulite facies mafic volcanic rocks. At early stages of research these rocks were believed to be analogues to the Archaean rocks of the Kola Peninsula, Volgo-Uralia, and Sarmatian protocratons (Puura et al. 1983). However, South Estonian granulite rocks belong to Palaeoproterozoic crustal units (Puura & Huhma 1993; Soesoo et al. 2004). The peak metamorphic conditions have been estimated to be 1.78–1.77 Ga (Soesoo et al. 2006). Yet, earlier metamorphic event(s) within these granulites are also possible between 1.87 and 1.82 Ga (Soesoo et al. 2006), reported also from northern Latvia (Mansfeld 1996). Due to very limited data this supposition cannot be proved or refuted here.

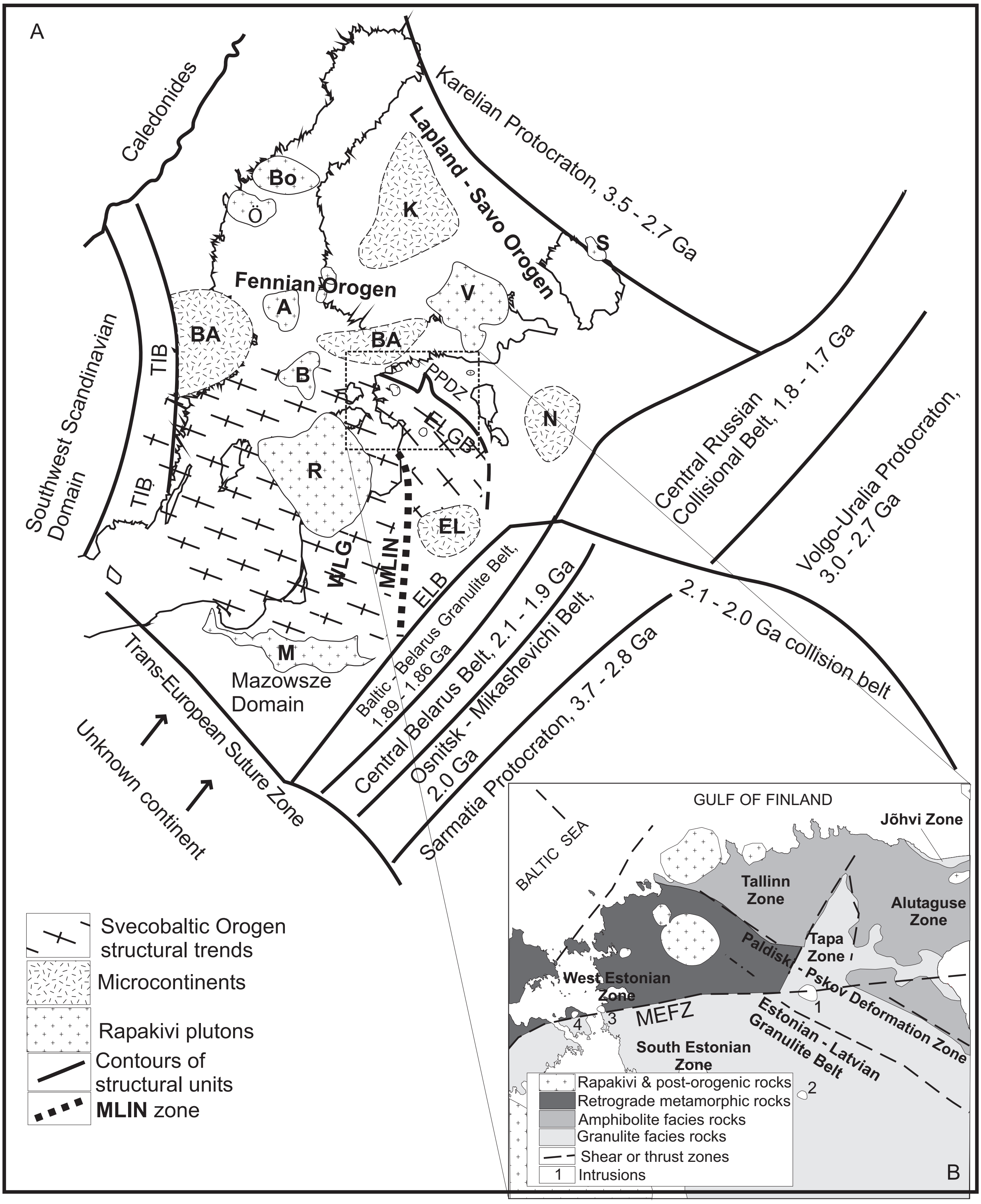

Fig. 1. (A) Late Palaeoproterozoic to Early Neoproterozoic tectonic complexes of the Baltic Sea Region (modified after Krzeminska et al. 2005; Bogdanova et al. 2008). TIB, Transscandinavian Igneous Belt. Microcontinents: BA, Bergslagen; K, Keitele; N, Novgorod; EL, East Latvia. Tectonic belts: ELGB, Estonian–Latvian Granulite Belt; WLG, West Lithuanian Granulite Belt; ELB, East Lithuanian Belt; MLIN, Mid-Lithuanian–Inčukalns Belt. Rapakivi plutons: Bo, Bothnia; Ö, Rödö; A, Åland; B, Baltic Sea; V, Wiborg; S, Salmi; R, Riga; M, Mazuri Complex. PPDZ, Paldiski–Pskov Deformation Zone. (B) Major units of the Estonian basement. Small shoshonitic intrusive plutons: 1, Taadikvere; 2, Abja; 3, Virtsu; 4, Muhu. MEFZ, Middle Estonian Fault Zone.

The 1.84–1.80 Ga metamorphosed Svecobaltic orogenic belts are revealed also in SE Sweden and western Lithuania (Mansfeld 1996; Mansfeld et al. 2005; Bogdanova et al. 2006, 2008). The Estonian–Latvian Granulite Belt contacts with the Fennian orogenic complexes through the transpressional Paldiski–Pskov Deformational Zone (All et al. 2004), which is obviously a major linear divide in the Estonian part of the Svecofennian Domain interior. In the SE the Estonian–Latvian Granulite Belt extends to the East Latvian granitoid-migmatite massif (Bogatikov & Birkis 1973; Puura 1980), which in geophysical potential field maps is very similar to the Novgorod block. This important structural and lithologic unit has been ignored in a number of publications since 1985. In analogy with the Novgorod and Keitele microcontinents, we treat it as a Palaeoproterozoic microcontinent-type terrain.

Other 1.84–1.80 Ga Svecobaltic orogenic suites in the Baltic Sea region are supracrustal complexes of SE Sweden, West Lithuanian Granulite Belt, and Mazowsze Domain in NE Poland (Skridlaite & Motuza 2001; Skridlaite et al. 2003; Krzeminska et al. 2005; Bogdanova et al. 2006). These suites traverse from NWW to SEE and are considered as assemblages of continental and oceanic volcanic arcs that have retreated and amalgamated from NE to SW in Svecofennia (Mansfeld 1996; Bogdanova et al. 2006; Korja et al. 2006). It should be mentioned that essentially older zircons with U-Pb ages down to 2.0–1.85 Ga supracrustal protolith ages have recently been obtained inside the West Lithuanian Granulite Belt (Motuza 2005; Motuza et al. 2008). Three other mainly SW–NE-trending orogenic belts of 2.0–1.86 Ga age in the southern Svecofennian Domain, forming the basement of western–NW Belarus and eastern Lithuania, have been interpreted as accreted parts with the north-northwestern border of the 3.7–2.8 Ga Sarmatian Protocraton (Mansfeld 1996; Krzeminska et al. 2005). However, in the tectonic model developed by G. Motuza, the East Lithuanian Belt together with the coeval Baltic–Belarus Granulite Belt, has been accreted towards the West Lithuanian Domain (as a possible microcontinent) along the Mid-Lithuanian Suture Zone (Motuza 2005; Linnemann et al. 2008).

In Fig. 1 the 1.89–1.86 Ga Baltic–Belarus Granulite Belt is not considered to be a continuation of the Svecobaltic South Estonian–North Latvian granulite zone as demonstrated also by Bogdanova et al. (2006). It is noteworthy that the tectonic discordance between these two zones was established already in the 1970s on the basis of geophysical data (Bogatikov & Birkis 1973; Puura 1980).

The N–S-directed, mostly mafic (with some felsic metavolcanics) Mid-Lithuanian Suture Zone, with ages of volcano-plutonic rocks around 1.84 Ga, is regarded as subduction-related collisional zone between the West Lithuanian and East Lithuanian belts (Wiszniewska et al. 2007; Linnemann et al. 2008). The mafic metavolcanites-dominated Inčukalns zone in the Latvian crystalline basement (Bogatikov & Birkis 1973) is interpreted by us as a northern continuation of the Mid-Lithuanian Suture Zone. The N–S-striking fault zones are also observed in geophysical anomaly fields in the Estonian basement. These are treated as far-reaching influence of this meridional zone via the northern Latvian and southern Estonian granulite terrain on the location of the Tapa Block, which is mainly composed of rocks similar to southern Estonian mafic metamorphics. In this context the age of the boundary between the Tallinn and Alutaguse zones, marked by the Tapa Block and a fault zone along its western–northwestern margin, remains generally unknown (as well as the age of the Alutaguse alumogneisses). The U-Pb age of zircons from tonalites of the eastern part of the Tapa Block is 1.824 Ga ± 26 Ma, while charnockites of the western part of the Tapa Block show zircon age of 1.761 Ga ± 11 Ma (Soesoo et al. 2006).

PRELIMINARY STRATIGRAPHIC SUBDIVISION OF ESTONIAN PALAEOPROTEROZOIC OROGENIC COMPLEXES

A simple lithostratigraphic correlation of deeply deformed rocks of rare drill core sections (as is the case in Estonia and the Baltic States) is of limited use. The geochemical-geochronological database for orogenic rocks is still incomplete. Mainly metamorphic (?) ages of zircons have been dated so far (Soesoo et al. 2004), with a few exceptions of magmatic ages (Soesoo et al. 2006; V. Petersell, unpublished data). The dating of the accompanying igneous assemblages, which in each structural zone probably have different ages, is even more complicated. Using the above structural and general lithological data, isotope age determinations of zircon fractions (Soesoo et al. 2004, 2006), and correlations of rock bodies with neighbouring areas within the Svecofennian Domain, a preliminary stratigraphic scheme of orogenic complexes of the Estonian basement is presented in Table 1. In this table the relative stratigraphic position of the three main lithostratigraphic units of the previously used stratigraphic scheme of the Estonian orogenic basement (Puura et al. 1983, 1997; Soesoo et al. 2004) is shown: (1) Alutaguse, (2) Jägala, and (3) a formally unnamed complex of metamorphics of the granulite and retrograde amphibolite facies in southern and western Estonia. The positioning of minor and local Tapa, Jõhvi, and Uljaste units (the last two

Table 1. Position of the main supracrustal and infracrustal complexes of the crystalline basement of Estonia and surrounding areas in the geochronological/stratigraphical chart by IUGS 2004 and their tectonic settings

Period Ga	Age, Ga	Volcanic **(V)**, sedimentary **(S)**, metamorphic sedimentary **(MS)**, and volcanic **(MV)** complexes	Intrusive **(I)** and metamorphic intrusive **(MI)** complexes	Isotopic age, Ga	Estonian and adjacent areas	Correlations with surrounding areas	Tectonic setting
		Subsequent erosion					
	1.40						
CALYMMIAN 1.60–1.40		Late Calymmian erosion					
		V: Qz-porphyries, Pl-porphyrites	**I:** rapakivi formation plutons of the Riga–Åland Subprovince: Riga pluton	1.59–1.54	**I:** Kurzeme, Saaremaa, Riga Bay **I, V:** Undva Peninsula and Baltic Sea	SW Finland and central Sweden	Uplift, fault and block tectonics, large intrusions and volcanic areas and erosion within the Svecofennian Orogenic Domain; extensional collapse
	1.60						
STATHERIAN 1.80–1.60		**V:** Qz-porphyries, Pl-porphyrites	**I:** rapakivi formation plutons of the Wiborg Subprovince: Märjamaa, Neeme, Ereda, Naissaare plutons	1.67–1.62	**V:** Suursaari **I:** N Estonia, Gulf of Finland	S and SE Finland	
		S: Qz-conglomerate			**S:** Suursaari		
			I: post-orogenic shoshonitic plutons: Abja, Märjamaa	1.63	Middle and N Estonia	S Finland, NW Ladoga	
	1.80	Amalgamation of Fennoscandian, Sarmatian, etc. megablocks					
OROSIRIAN 2.05–1.80			**I:** post-orogenic shoshonitic plutons: Virtsu, Taadikvere, Muhu	1.83	Middle and W Estonia	S Finland, NW Ladoga	Uplift, erosion, extensional collapse
		MV and MS: island arc complexes in granulite facies	Late orogenic Mi granites and charnockites **MI:** synorogenic plutonics	1.84–1.80	S and W Estonia	**Svecobaltic terrane:** SE Sweden (Sörmland basin), Central and S Baltic areas	Accretionary processes in active margins of the Svecobaltic orogeny
		MS and MV: Jägala complex in the **Tallinn Zone** island arc suites **Alutaguse complex** in the **Alutaguse Zone** back-arc suites in amphibolite to local granulite facies	Late orogenic Mi granites **MI:** synorogenic plutonics	1.90–1.88 ≤1.88 or 1.93–1.91	N and NE Estonia	**South Svecofennian terrane:** S Finland, NW Russia	Accretionary processes in active margins (or back-arc basins) of the Fennian (or in the Alutaguse Lapland–Savo ?) orogeny
	>2.05	Opening and spreading of the Svecofennian ocean					

bearing ore mineralizations) needs more detailed studies and discussion.

The three main orogenic complexes (as well as minor units) belong to the Orosirian system (IUGS chart 2004 – Gradstein et al. 2004), as confirmed by the whole database of Estonia and surrounding areas. On the basis of age distribution it can be concluded that the Estonian basement should be divided into two or three different orogenic or metamorphic units. Within the main structural units of the Estonian folded basement, the metamorphic rocks are accompanied by igneous rocks of mafic to felsic composition. Most likely the ages of the formation of these igneous rocks differ as well. Although geochronological data of these rocks are scarce, some general points can be mentioned:

– suites belonging to the 1.90–1.88 Ga Fennian Orogenic Belt may be observed in the Tallinn Zone;
– rock assemblages of the 1.84–1.77 Ga Svecobaltic Belt form the Estonian–Latvian granulites. The 1.77 Ga age of some charnockites of the Tapa Block may indicate that in places the orogenic development terminated as late as in the early Statherian.

Differences in the age of metamorphism of these two zones were discussed by Puura et al. (2004) and Soesoo et al. (2004). The position of the Alutaguse Zone in relation to the 1.93–1.91 Ga Lapland–Savo or the 1.90–1.88 Ga Fennian orogenic belts remains open.

POSTCOLLISIONAL AND ANOROGENIC, PALAEO-MESOPROTEROZOIC (STATHERIAN–CALYMMIAN) COMPLEXES IN THE ESTONIAN BASEMENT

After the Fennoscandian convergence with cratonic megablocks of Volga-Uralia in the east and northeast, Sarmatia in the southeast, Amazonia in the west, and an unknown continent in the southwest around 1.80 Ga ago (formation of the original East European Craton), Fennoscandia underwent a major stabilization period (Korja et al. 2006; Bogdanova et al. 2008). The overthickened juvenile crust of the Svecofennian Domain (Korja & Heikkinen 1995; Puura & Flodén 1999, 2000; Korja et al. 2006) experienced gravitational collapse together with rapid uplift and thermal resetting. A specific spectrum of ‘post-orogenic’ and ‘anorogenic’ igneous formations from the time span of 1.83–1.45 Ga survived mainly in plutonic facies. They formed specifically in the areas of the juvenile crust of the Svecofennian Domain, including the present Estonian territory. Stratified supracrustal suites are very rare in the whole domain and unique also in Estonia. Actually, in the sense of supracrustal deposition and especially because of poor survival of the last formations, the mentioned time interval belongs to the great sedimentary break preceding the latest Neoproterozoic and Phanerozoic sedimentation on the East European Craton. However, considering the amount of infracrustal rock formation, the time span of 1.63–1.45 Ga was a period of active rifting processes pointed out by the voluminous anorthosite-rapakivi (AMCG after Emslie et al. 1994) magmatism.

The representatives of postorogenic magmatism, small monzonite-type mafic-felsic plutons of shoshonitic geochemical affinity, originating from the enriched lithospheric mantle, intruded into southern Finland 1.82–1.77 Ga ago (Eklund et al. 1998; Väisänen et al. 2000) and also into Estonia in 1.83–1.63 Ga (Kirs & Petersell 1994; Petersell & Levchenkov 1994). Partly gneissic rock of the Muhu quartz-monzonite and Taadikvere granodiorite plutons of the Estonian basement shows a U-Pb isotope age about 1.83 Ga (Petersell & Levchenkov 1994; Petersell, unpublished data), whereas quartz-monzonite of the Abja pluton and granodiorite of the Märjamaa pluton yield a U-Pb zircon age of 1.63 Ga (Kirs & Petersell 1994; Rämö et al. 1996).

The Fennoscandian anorogenic anorthosite-rapakivi plutons developed in the time span of 1.67–1.45 Ga within the Svecofennian Domain juvenile crust (Puura & Flodén 1996, 1999; Andersson 1997; Skridlaite et al. 2003, 2007; Rämö & Haapala 2005). Several igneous rapakivi subprovinces of a similar association of mafic and felsic rocks from deep infracrustal intrusive to supracrustal volcanic facies have been distinguished (Åhäll et al. 2000; Puura & Flodén 2000; Dörr et al. 2002). The two largest subprovinces, Wiborg 1.67–1.62 Ga and Riga–Åland 1.59–1.54 Ga, occupy the interior position in the Svecofennian Domain of the extraordinarily thick (55–65 km) crust (Rämö et al. 1996; Puura & Flodén 2000; Rämö & Haapala 2005). In any large subprovince the main granitic composite batholith-type body is surrounded by minor granitic plutons as well as by marginal mafic dyke swarms. The formation of huge rapakivi granite-anorthosite igneous centres has been accompanied by fundamental reconstruction of the upper mantle and the whole crustal structure. This is reflected in the substantial rise of the Moho surface (Elo & Korja 1993; Puura & Flodén 2000) as well as in specific features of the regional Bouguer and magnetic anomaly fields (Korhonen et al. 1999; Puura & Flodén 2000). Four minor subprovinces, Salmi (1.56–1.54 Ga, Neymark et al. 1994) in the northeast, Ragunda (1.53–1.49 Ga, Andersson 1997) in the northwest, Mazury (1.55–1.51 Ga, Wiszniewska & Baginski 2003), and southern Sweden–western Lithuania (1.46–1.44 Ga, Skridlaitė et al. 2007) in the southwest, are located in the marginal parts of the Svecofennian Domain and do not stand out clearly in geophysical anomaly fields.

The Estonian territory is located in the central part of the Fennoscandian Rapakivi Province. Suites of the two largest rapakivi subprovinces – Wiborg and Riga–Åland – are found here (Puura & Flodén 2000). The southern portion of the central Wiborg granitic body is located in the Gulf of Finland, just off the NE Estonian coast. Using drilling and geophysical mapping, six stock-like rapakivi granite plutons were discovered under the 150–300 m thick late Neoproterozoic and Palaeozoic sedimentary cover in the continental part of Estonia, all belonging to the Wiborg Rapakivi Subprovince with ages around 1.63 Ga (Rämö et al. 1996). The zircons of leucogabbronorite and biotite-hornblende granite from the Riga batholith (NW Latvia) show U-Pb ages about 1.59 and 1.58 Ga (Rämö et al. 1996), respectively, suggesting connection to the Riga–Åland Subprovince. The basement in the bottom of the Gulf of Riga as well as on Ruhnu Island and western Saaremaa Island is represented by the northern portion of the Riga pluton. Off the western coast of Saaremaa and Hiiumaa islands, rapakivi plutons form the basement of the Baltic Sea floor (Puura et al. 1992). The Nd and Pb isotopic compositions of zircons from Estonian and Latvian rapakivi complexes demonstrate that the lower crust and lithospheric mantle are devoid of an essential Archaean component in the area (Mansfeld 1996; Rämö et al. 1996). This is another evidence of the juvenile Palaeoproterozoic age of the continental crust in the north and central East Baltic area.

Supracrustal, predominantly volcanic rocks in connection with rapakivi-anorthosite plutonic associations have so far been found only in the Wiborg and Riga–Åland Subprovinces. A classical outcrop of mafic (several types of plagioclase porphyrites, total thickness up to 15–20 m) and overlying much thicker felsic volcanic rocks (quartz porphyries, thickness 130–150 m) lying on the lens-shaped beds of post-Svecofennian quartz-conglomerate is known on Suursaari (Hogland) Island (Ramsay 1892; Niin 1997). This suite is located near the SW border of the Wiborg pluton and is possibly in tectonically uplifted position. The U-Pb zircon age from the lower part of the felsic lava unit yields an age of 1.635 Ga (Rämö et al. 2007). A similar section of rapakivi-related volcanic rocks from plagioclase porphyrites to quartz porphyries was penetrated by drilling (Undva 580 drill hole) on NW Saaremaa Island (Niin 1976). It is located near the northern border of the Riga pluton and its age is conventionally assumed to be similar to the age of the Riga and Åland plutons. In the central part of the Baltic Sea, NE of Gotska Sandon Island and south of the Åland archipelago, two types of volcanic-subvolcanic quartz porphyries – brown and red – crop out under the Quaternary deposits. From there large amounts of erratic material have been extracted and distributed by glacial drift over southern areas on the Baltic Sea shore and seabed. The U-Pb zircon age for both brown and red quartz porphyries yields a common concordant age of 1570 Ma (Kirs et al. 2006), which suites well to the time span of the formation of the Riga–Åland Subprovince.

STRATIGRAPHIC POSITION OF ESTONIAN POST- AND ANOROGENIC ROCK COMPLEXES

The Estonian postorogenic and anorogenic infracrustal igneous bodies formed 1.83–1.54 Ga ago, i.e. during the Orosirian, Statherian, and Calymmian periods (Table 1). The existing datings of Estonian postorogenic plutons of shoshonitic geochemical affinity show that they formed 1.83–1.63 Ga ago. The overlapping age of the youngest shoshonitic rocks (Abja quartz-monzonite, Märjamaa granodiorite) with rapakivi plutons infers long-lasting coexistence of crustal melting responsible for rapakivis and more restricted lithospheric mantle melting responsible for shoshonitic magmas. The anorogenic plutonic bodies of the Wiborg subprovince formed in the period of 1.67–1.62 Ga, or in the Statherian Period. The supracrustal, stratified quartzite and quartz conglomerate lenses and volcanic mafic and felsic sheets (Suursaari Island) represent the Statherian system in the basement in the near surroundings of Estonia. The plutonic bodies of the Riga–Åland Subprovince formed 1.59–1.54 Ga ago, i.e. during the Calymmian Period. Its supracrustal, volcanic mafic, and felsic sheets (Undva section and Baltic seabed) represent the Calymmian system in Estonia and the adjacent area. The supracrustal bodies of these periods are not influenced by metamorphic processes and form gently tilted sheets. However, the lateral distribution of these bodies is extremely restricted. The outcrop of the largest quartz porphyry body on Suursaari Island extends as a NNW–SSE belt for some 11 km. The break in the Estonian geological section before the Cryogenian deposition corresponds to the Ectasian, Stenian, and Tonian systems.

CONCLUSIONS

1. According to the up-to-date stratigraphic chart of the Precambrian issued by IUGS 2004 (Gradstein et al. 2004), the folded basement rocks of Estonia formed during the Orosirian Period of the Palaeoproterozoic. The Orosirian System of supracrustal sedimentary and volcanic rocks is represented by intensely folded and metamorphosed deposits, whose stratification and correlation between drill holes and between the

structural zones of the Estonian basement, as well as with the surrounding areas, is presently possible only in general terms. It is based on structural constraints and a few U-Pb isotopic age criteria. The infracrustal igneous bodies related to the metamorphic complexes are only occasionally dated.

2. Different structural zones of the Estonian basement probably developed at different times within the Orosirian Period. The age of the Alutaguse Zone is less obvious as it may have formed during the formation of either the 1.93–1.91 Ga Lapland–Savo Belt (the oldest in the assemblage of belts accreted to the Karelian Protocraton) or the 1.90–1.88 Ga Fennian Orogenic Belt. The Fennian Orogenic Belt enfolds the Tallinn Structural Zone in North Estonia. The South Estonian–North Latvian granulites and West Estonian amphibolites possibly belong to the 1.84–1.80 Ga Svecobaltic Belt. Only detailed age studies within each zone would clear up the history of their formation.
3. The 1.83 Ga dates of the ‘post-orogenic’ shoshonitic Muhu, Virtsu, and Taadikvere plutons, located in contours of the Svecobaltic Belt, actually fall into the time span of the formation of this belt in the Orosirian Period.
4. The two largest subprovinces of the Fennoscandian Rapakivi Province formed during two periods: the plutons and volcanic sheets of the 1.67–1.62 Ga Wiborg pluton during the Palaeoproterozoic Statherian Period and the 1.59–1.54 Ga Riga–Åland Subprovince in the Mesoproterozoic Calymmian Period.
5. The transition from orogenic tectonic and metamorphic processes to post-orogenic shoshonitic and further on to voluminous anorogenic magmatism has been substantially overlapping in time, thus demonstrating an evolutionary trend rather than distinct isolated events.
6. In order to establish firmly the position of the Estonian basement, main as well as minor ore-bearing structures in the general structure of the earth’s crust in the Baltic and circum-Baltic region, a wide spectrum of petrological and isotopic geochemical and age studies is required to achieve adequate stratigraphic division of the local basement rock assemblages.

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Eesti kristalne aluskord: paleoproterosoilised Orosiri ja Statheri ning mesoproterosoilised Calymmi ajastu kivimkompleksid ja regionaalne korrelatsioon

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Fennoskandia kilbi ja Baltikumi regiooni Eelkambriumi kivimite petroloogilis-geokeemilisel uurimisel viimastel aastatel saadud vanuselised andmed tekitavad uusi tõlgendusi ka Eesti aluskorra kivimkomplekside vanuse ning regionaalse korrelatsiooni vallas. Tallinna vööndi kivimite teke on seostatav Fennia orogeneesi käiguga Bergslageni mikrokontinendi ääre keskkonnas 1,90–1,88 miljardit aastat (Ga) tagasi. Alutaguse vööndi kivimite moodustumise aja kohta pole aga jätkuvalt otseseid vanusemääranguid. Regionaalgeoloogilise andmestiku baasil võiks nende teket seostada kas 1,93–1,91 Ga tagasi aset leidnud Lapi-Savo orogeeni arengu või hoopis Tallinna vööndi idaosa riftistumisega Fennia orogeeni protsessides. Lääne- ja Lõuna-Eesti granuliitide teke on seostatav 1,84–1,80 Ga tagasi väldanud Svekobalti orogeeni vulkaaniliste saarkaarte arenguga, kusjuures mitmekordse regionaalmoonde kulmineerumine toimus 1,78 Ga tagasi. Postorogeenset šošoniitset magmatismi esindavad väikesed plutoonid (Abja, Virtsu jt) moodustusid 1,83–1,63 Ga tagasi, Viiburi rabakivi subprovintsi kuuluvad väikesed graniitsed plutoonid (Naissaare, Neeme jt) 1,67–1,62 Ga ja gigantne Riia rabakiviplutoon aga 1,59–1,54 Ga tagasi.