ARTU ÜLIKOOLI
TOIMETISED
CTA ET COMMENTATIONES UNIVERSITATIS TARTUENSIS

972

EESTI ALUSPÕHJA GEOKEEMIA JA MINERALOOGIA KÜSIMUSI

Töid geoloogia alalt
XIV

TARTU 1994

ON THE GEOLOGICAL STRUCTURE OF THE CRYSTALLINE BASEMENT OF THE SOUTHERN SLOPE OF THE BALTIC SHIELD

Valter Petersell, Oleg Levchenkov

Introduction

The southern slope of the Baltic Shield (SSBS) belongs to the transitional area between the shield in the north and Poland–Lithuania depression and Latvia saddle in the south. It comprises the territory of Estonia and the western part of the Leningrad and the northwestern part of the Pskov regions, also North Latvia (Fig. 1). Its territory on the continent exceeds 66 thousand square km. The western border lies under the Baltic Sea. The northern border proceeds by the contact of the Baltic Shield and Russian Plate along the southern part of the Gulf of Finland. Here the crystalline basement has subsided for 20–40 m. The southern boundary of the slope has not been defined exactly. At present it proceeds by the zone of sublatitudinal subsurface tectonic faults along the slopes of the Lokno–Valmiera basement dome (Tect. map.., 1980). By data of seismic studies this fault ranges into the upper mantle and the displacement of the Mohorovicic discontinuity can reach 6 km and more. SSBS is covered by Vendian, Paleozoic and Quaternary sedimentary rocks with a total thickness from a few meters in the Gulf of Finland up to 400–600 m and more in South Estonia. The relief of the crystalline basement is weakly rugged, in the greatest part of the territory dipping southward for 2–4 m/km (Fig. 2). Near the Lokno–Valmiera basement dome the southward inclination of the basement relief decreases gradually and is replaced by the zone of Lokno–Valmiera domes, with the relative height reaching 37 m.

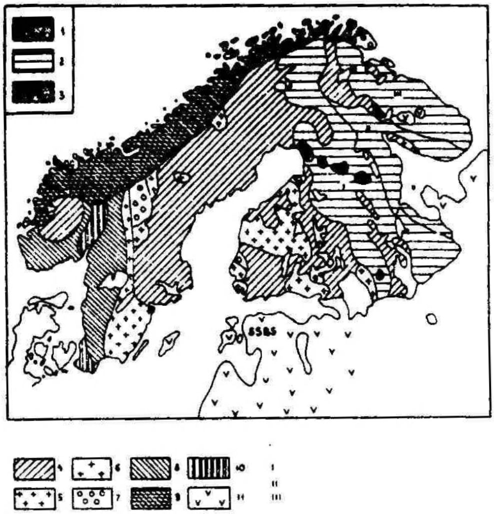


Fig. 1. Geochronological chart of the Precambrian Baltic Shield, compiled by results of U-Pb age dating of zircon in rocks. (By Tugarinov and Bibikova, 1980, with supplements of authors).
1 – main rock mass of Chuna-Moncha-Volchi tundra; 2 – Archean of the Baltic Shield (3.00–2.60 Ga): I – Karelian region, II – White Sea region, III – Kola region; 3 – deep magmatism (2.40 Ga); 4 – Sveco-Karelian formations (2.40 – 1.85 Ga); 5 – Svecofennian magmatism (1.90–1.75 Ga); 6 – rapakivi granites (1.67–1.54 Ga); 7 – Jotnian and Sub-Jotnian formations (1.75–1.67, 1.54–1.27 Ga); 8 – Dalslandian activization zone (1.10–0.90 Ga); 9 – Caledonides; 10 – post Riphean cover of the East European Platform; 11 – Phanerozoic platform Formations.

The units and views on the geological structure of the crystalline basement

Regionalization of the crystalline basement of the SSBS has been carried out by A. Öpik (Öpik, 1935), E. Fotiadi (Fotiadi, 1958), R. Gafarov (Gafarov, 1962), E. Pobul (Pobul, 1960) and by other researchers on the basis of magnetometric and gravimetric data in the years 1936 to 1963. These geological and geophysical source materials allow to subdivide the SSBS into two different structural facies regions — Tallinn–Novgorod and Estonian–Latvian ones which roughly coincide with the subdivision by E. Fotiadi. Considering the geophysical fields, composition, genesis and degree of metamorphism of the rocks, these regions are subdivided into zones and other structural units. As for their age and structure, views differ considerably and are often contradicting (Dedejev, 1974; Zander et al, 1967, Puura, 1974, Petersell, 1976 etc.).

In the Tallinn–Novgorod region the Tallinn, Alutaguse, Jõhvi and Tapa zones are distinguished. The Estonian–Latvian region is subdivided into the Paldiski–Pskov zone and West and South Estonia with North Latvia (Fig. 2).

In the Tallinn zone in the form of subsurface belts there can be observed mostly metavolcanic quartz-feldspathic, biotite and biotite amphibole gneisses and amphibolites, also metasedimentary biotite and aluminiferous gneisses with interbeds of graphite- and sulphide-bearing varieties ("black" shale). All these belong to the Jägala rock massif (Petersell, 1974).

In the Alutaguse zone there are widely distributed biotite and aluminiferous, more rarely biotite-amphibole gneisses, quartzite and other rocks, interbedded with "black" shale. These different rocks form the Alutaguse rock massif. In the Uljaste Member and its analogues there are distinguished quartzites, interbedded with carbonate rocks, "black" shale, biotite-amphibole gneisses, etc., occurring in the lowermost part of the Alutaguse rock massif (Vaher et al, 1962).

The Jõhvi zone is characterized by mineralogically diverse Mn-rich ferruginous quartzites occurring in biotite and aluminiferous gneisses and acid, intermediate and basic metavolcanites. They all form the Vaivara rock massif (Puura, 1974; Vetrennikov et al, 1986).

In the submeridional Tapa zone the granitized basic rocks border with biotite- amphibole gneisses and amphibolites, also as with the "black" shale interbedded aluminiferous gneisses (Petersell, 1976).

The Estonian–Latvian structural facies region is considerably less studied. The Paldiski–Pskov zone is dominated by metavolcanic quartz-feldspathic, biotite and biotite-amphibole gneisses, more rarely by amphibolites and carbonate rocks. In South Estonia and North Latvia there occur often granulites and charnockites, but also biotite and biotite-amphibole gneisses, more rarely aluminiferous gneisses and other rocks. In Northwestern Latvia Mn-rich ferruginous quartzites were discovered by boring at Staicele locality (Vetrennikov et al, 1986). In West Estonia there prevail biotite and biotite-amphibole gneisses.

Quartz-feldspathic and aluminiferous gneisses and amphibolites occur more rarely. From the Undva core (b.h. 508) on West Saaremaa the subplatform stage (Gothian) quartz-porphyry and plagioclase porhyrites have been recorded (Niin, 1976).

The Estonian crystalline basement supracrustal rocks were metamorphized in the amphibolite facies, those of the South Estonia, Tapa and Jõhvi zones partly also in the granulitic facies of metamorphism, which is represented by the sillimanite-andalusite type (Krist. fund..., 1983) The Pre-Gothian supracrustal rocks are penetrated by metabasites, more rarely by metaultrabasites and granitoids. The whole complex is, in turn, penetrated by late Svecofennian granites causing migmatization and intense, but uneven K-metasomatism. Na- metasomatism has been recorded only in small areas. Intrusive rocks of the subplatform Gothian complex are represented by gabbroids and granitoids of anorthosite- rapakivi formation.

Basing on magnetometric data and on those obtained from single drill cores in North Estonia, in 1935 A. Öpik (Öpik, 1935) suggested the extension of Svecofennian structures and rocks on the territory of Estonia from Central Sweden and South Finland.

L. Vardanjants (Vardanjants, 1960) and S. Tihomirov (Tihomirov, 1966) correlated the above-mentioned rocks with Svecokarelian rocks of the Baltic Shield. A principally similar viewpoint was expressed also by other Soviet scientists (Dedejev, 1974, Zander et al, 1967). However, part of paragneisses in Northeastern Estonia they assigned to the Novgorod Archean massif. V. Petersell (Petersell, 1976) supported the opinion that rocks of the crystalline basement of the SSBS belong to svecofennides-karelides. In 1974–1976 several publications appeared, edited by V. Puura (Puura, 1974; Puura et al, 1976; Koppelmaa et al, 1978) where for the first time rocks of the crystalline basement of South and West Estonia, as also of the Paldiski–Pskov, Tapa and Jõhvi zones were attributed to the Archean. More recently these views have been widely supported and developed by V. Puura, M. Niin, H. Koppelmaa and V. Klein (Geol. map .., 1980; Tect. map.., 1980; Krist. fund.., 1983; etc.). Unfortunately the data, such as the isotopic age, mineralogical, petrochemical and other correlations have not been published by these authors. Archean age was mostly based on high degree of metamorphism and similarity of these rocks with granulites of the Russian Plate and the Kola peninsula.

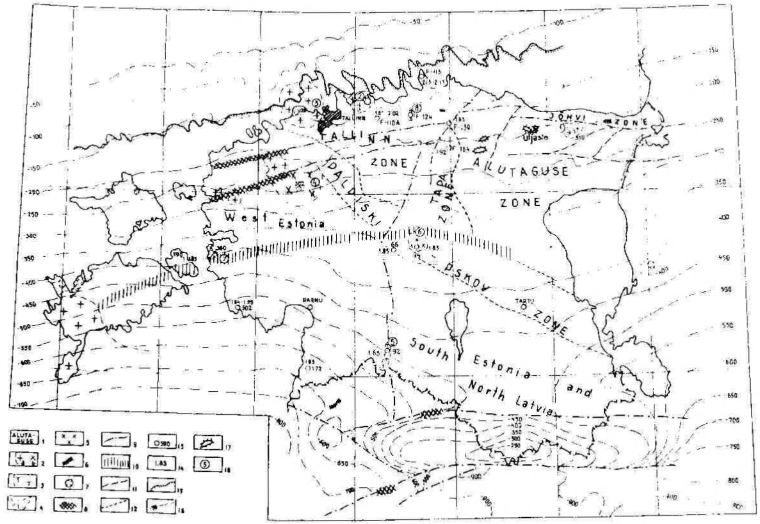


Fig. 2. Scheme of the geological structure of the crystalline basement of the Southern slope of Baltic Shield.
1 – structure zone; 2–4 – anorthosite-rapakivigranite formation, 2 – potassic porphyraceous granite (a) and granodiorite (b), 3 – gabbro-diorite and gabbro-norite, 4 – plagioclase porphyrite and quartz porphyries; 5–6 – Svecofennian complex (5-granodiorite and quartz-diorite, Mn-rich ferruginous quartzites); 7 – ring-shaped structure; 8–9 – faults ranging into the upper mantle surface, 8 – by seismic studies, 9 – by geological features); 10 – zone of fracture and mylonitisation; 11 –proved platform faults; 12 – boundary of zone; 13 – location of samples for U-Pb isotopic age-dating; 14 – isotopic age, Ga; 15 – boundary of Vendian deposits; 16 – contour line of the basement surface; 17 – local rise of the basement; 18 – number of small intrusions (1 – Ereda, 2 – Jägala, 3 – Naissaar, 4 – Märjamaa, 5 – Abja, 6 – Taadikvere, 7 – Virtsu, 8 – Sigula)

As was said before, the "Archean", as well as the Proterozoic, rocks are subjected to intense K-metasomatism and migmatization. This is often accompanied by numerous veins and small "dirty" intrusions of potassic granites with xenoliths of adjacent rocks. In the areas of "Archean" rocks charnockitization as also small charnockite massifs were recorded. All these granites, including charnockite, were not subjected to metamorphism.

By the supporters of the "Archean" age such intense migmatization accounts for the high degree of metamorphism. Ultrametamorphism, in turn, accounts for intense migmatization and charnockitization. Potassium-rich magma and fluids, originated from deeper sources acted as one possible reason for K-metasomatism and migmatization, also charnockitization. These processes, however can be widely observed in the classical Svecofennian area effecting basic and other potassium-deficient rocks (Miner. mest..., 1982, Tugarinov et al, 1980).

Thus, the main problems discussed during the last 30–40 years are the determination of the geological position of the SSBS in the structure of the East-European Platform and the age relations betweeen the regions and structural zones distinguished in the crystalline basement of the SSBS. Only correctly established age relations of rock complexes of the region allow to estimate reliably the perspective of the area as a mineral deposit. This concerns particularly the subsurface territories which are neighbored by well-studied different-aged areas of the shield with different ore perspectives.

Material and methods of the study

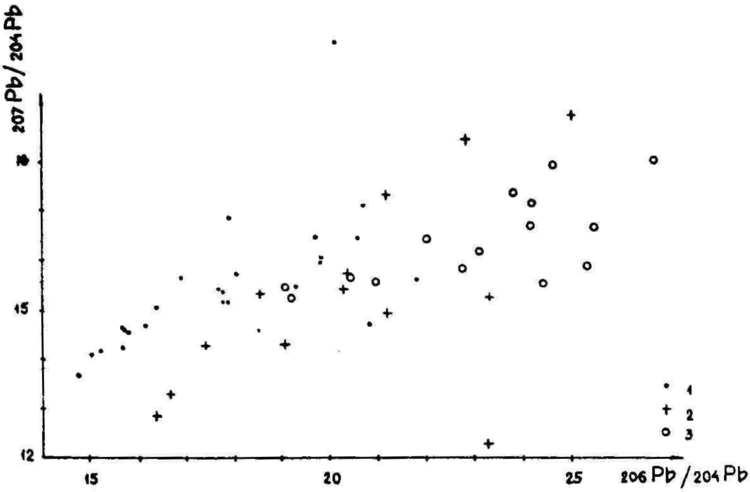
The factual material for this paper has been collected during the geological study of the crystalline basement of the SSBS in the years 1965–1990, permanently assisted by one of the author (V. Petersell). Results of spectral, X-ray spectral, atomic-absorption, silicate etc. analyses had been applied together with data on mineralogical, petrographic, petrophysical etc. investigations. Additional samples were taken for determination of the trace elements, REE, gross isotopic composition of Pb in rocks and for U-Pb isotopic age dating of zircon.

Material for establishing gross isotopic composition of Pb in rocks was obtained from duplicates of samples taken for geochemical investigations. The samples were collected by point method from petrographically similar rock intervals of drill cores with the total weight of 150–250 grams and ground up to grain size of 200 mesh.

Samples for U-Pb isotopic age dating were taken from acid metavolcanites, aluminiferous gneisses and intrusive rocks. The samples comprised pieces of drill core without any noticeable marks of migmatization and K-metasomatism, except for the sample from borehole 502. In this borehole aluminiferous gneisses are all migmatized or subjected to K-metasomatism. Therefore also all rock samples bear traces of K-metasomatism. The weight of a sample depended on the zircon content in the rock ranged from 2 kg to 6 kg.

The isotopic analysis of Pb in the rocks was performed by isotopic spectral method in the laboratory of IGFM of the Ukrainian Academy of Sciences by means of a unified interference spectral analyzer (type UISA-2). The relative error of measuring by the concentration of isotopes 208Pb higher than 40%, also 206Pb and 207Pb higher than 20%, does not exceed 1.5 and 2.5%, respectively. The relative error by determination of the isotope 204Pb by the concentration 1.4% does not exceed 5–7% (Zukov, Lesnoi, 1982).

The isotopic age dating of rocks by Pb and U isotopes from zircon was carried out in the laboratory of Vassiliostrov association "Ostrov" by IGGD in St. Petersburg. Decomposition of zircon and extraction of Pb and U were performed by Krogh's method (Krogh, 1973). Pollution with laboratory Pb did not exceed 3 ng. The content of Pb and U isotopes was measured by means of the mass spectrometer Finnigan MAT, model 261. Fractionation coefficient of this device is 0.001 to 1 per unit of at. mass. Error by measuring the isotopic ratios 206Pb/238U and 207Pb/235U was up to 1.5%. Establishing of isotopic relations, finding of their analytical points in the concordia diagram and calculation of isochron ages were performed according to K. Ludwig (Ludwig, 1980). By calculating the age the following constant values were used: $\lambda_{238} = 0.155125 \times 10^{-9}$ years, $\lambda_{235} = 0.984850 \times$ $\times 10^{-9}$ years, 238U/235U = 137.88. In meaning of correctional lead the isotopic composition calculated by the model of J. Stacey and J. Kramers (Stacey, Kramers, 1975) was used.



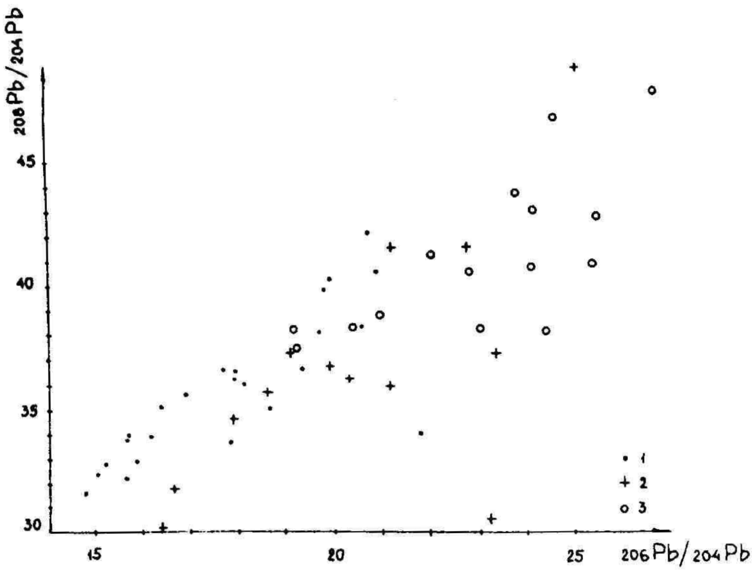
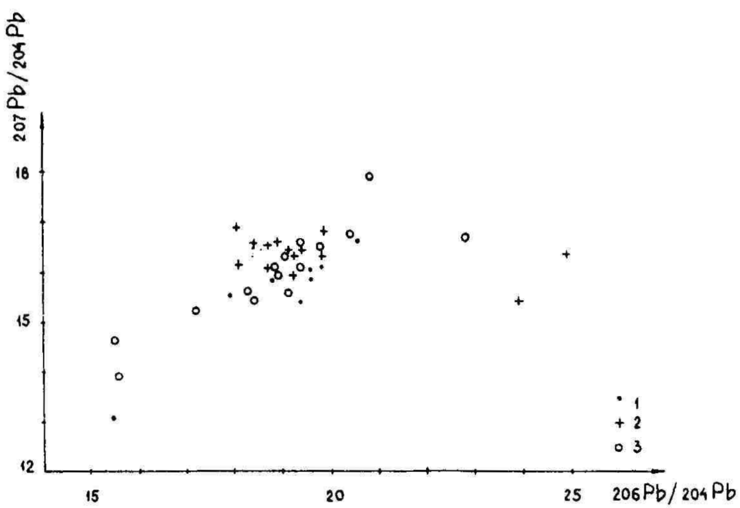


Fig. 3. 207Pb/204Pb – 206Pb/204Pb (a) and 208Pb/204Pb – 206Pb/204Pb (b) diagrams illustrating the Pb isotopic ratios in rocks of the Tallinn and Alutaguse zones;
1 – aluminiferous gneisses; 2 – potassic granites causing migmatization; 3 – metavolcanic quartz-feldspar, biotite and amphibole-biotite gneisses.



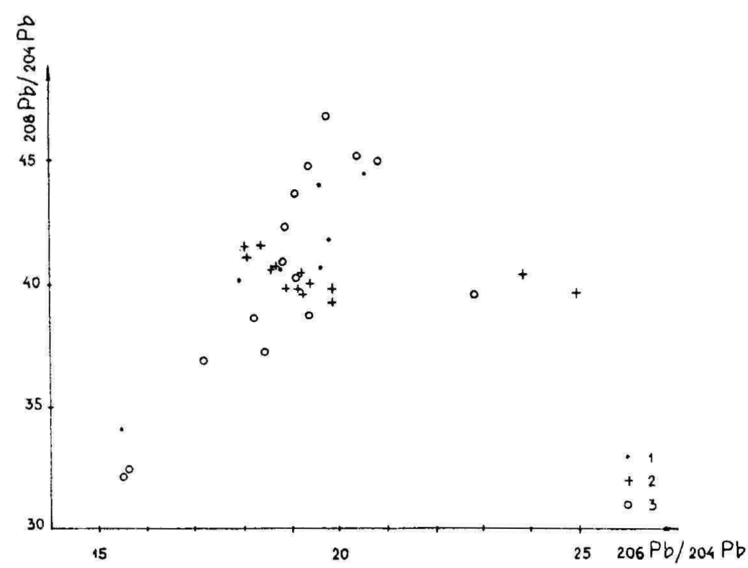


Fig. 4. 207Pb/204Pb – 206Pb/204Pb (a) and 208Pb/204Pb – 206Pb/204Pb (b) diagrams illustrating the Pb isotopic ratios in rocks of West and South Estonia.

1 – aluminiferous gneisses; 2 – potassic granites causing migmatization; 3 – metavolcanic quartz-feldspar and biotite gneisses.

Results

Data on the isotopic composition of Pb from aluminiferous gneisses, metavolcanites and migmatiteforming plagio-microcline granites are plotted in the diagrams 207Pb/204Pb – 206Pb/204Pb (Fig. 3) and 208Pb/204Pb – 206Pb/204Pb (Fig. 4). The fields and trends of points in those diagrams are clearly different.

In the diagram Fig. 3 the fields of Pb isotopic relation points of aluminiferous gneisses from different regions almost coincide, but differ noticeably from those of migmatite-forming granites and metavolcanites. The last-mentioned fields are quite similar and overlapping. Those regularities are followed, although less clearly, in the diagram Fig. 4.

The factual material obtained in this way allows to suggest, that the supposed formation of migmatite plagio-microcline (or orthoclase) granites of the SSBS during metamorphism and ultrametamorphism of aluminiferous and other gneisses seems ungrounded. The most reasonably they correlate with the migmatites and pegmatites of post-folded Svecofennian plagio-microcline granites in the Baltic Shield, intrusion of which took place after the main stage of folding and metamorphism at the interval of 1.850 1.750 Ga at the time of Svecofennian tectono-magmatic activisation (Miner. mest..., 1982, Tugarinov et al, 1980). Certainly this does not exclude the occurrence of ultrametamorphic migmatites.

Petrochemical and geochemical analysis of "Archean" and Proterozoic metavolcanic and intrusive rocks of the SSBS has shown, that by those characteristics they are widely varying — from acid to basic composition — whereas metavolcanites form often differentiated series.

The wide range of variation of petrochemical and geochemical characteristics is also proper to metasedimentary rocks from these regions. Among those in various "Archean" complexes the rocks, similar to rock types, characteristic to the Fennoscandian Svecofennian area (not known from other areas of the Russian Plate) are common. These are: Mn-rich, often sulphide- bearing ferruginous quartzites, recorded from the Jõhvi and Tallinn zones, as also from Northwestern Latvia (Vetrennikov et al, 1986). Such specific rock types include also pre-Gothian P-rich metavolcanites and intrusions in West and South Estonia and beds of calcite-dolomite rocks in metavolcanic sections of the Paldiski–Pskov zone (Petersell, 1976, Krist. fund., 1983). The latter have typical sedimentary marine isotopic composition of C ($\delta^{13}C$ varies from -0.6 to -1.9% pro).

To determine the real stratigraphic position of the observed rocks, of principal importance has the isotopic U-Pb age dating of zircon. Results of those datings are given in Table 1 and in Fig. 5. From this material it can be seen, that in the concordia plot the analytical points of U-Pb age dating by zircon from metavolcanites of amphibolite facies, as well as from granulite facies and from synorogenic granites approximate to a straight line. The isotope ages of rocks are very similar, ranging from 1.833 to 1.827 Ga, by 207Pb/206Pb ratio: from 1.833 to 1.812 Ga. The age of metavolcanites from the Tapa zone, particularly at the granulite facies of metamorphism, is somewhat higher, about 1.918 Ga (Fig. 5), but by 207Pb/206Pb ratio ranges from 1.889 to 1.884 Ga.

At the present time the data that could show the rocks "rejuvenation" during regional metamorphism are still lacking. Results of the studies (Höltta, 1988, Tugarinov, Bibikova, 1980) have not revealed considerable "rejuvenation" of rocks during metamorphism up to amphibolite facies conditions inclusive. Indisputably, the isotope ages show, that the metamorphism of rocks in West and South Estonia has Svecofennian age and there is no reason to attribute these rocks to the Archean.

The analytical points of U-Pb age dating of zircon from aluminiferous gneisses are quite dispersed and they did not approximate to a straight line in the concordia plot (Fig. 5). The age of zircon dated by 207Pb/206Pb ratio ranges from 2.175 to 1.841 Ga (Table 1). The age of aluminiferous gneisses from South Estonia (sample 5026220) is considerably lower than in the Tallinn zone. This may be caused by rejuvenation or partially by the occurrence of younger zircon connected with K-metasomatism of rocks. By zircon the U-Pb age of aluminiferous gneisses is close to that of greywacke from Tampere region (Wetherill et al, 1962) and of quartzite from southeastern Sweden (Aberg, 1978), being also Svecofennian. It is notable that the age of gneisses is older and changeable. The problem whether this was caused partly by an older source of removal or by uneven "rejuvenation" of rocks, remains unsolved.

Thus, the data presented allow most certainly to attribute the supracrustal complexes of West and South Estonia, but also of the Paldiski–Pskov, Tapa and Jõhvi zones to svecofennides and to correlate them with the corresponding rocks of the Baltic Shield.

U-Pb dating of the age of Svecofennian metavolcanites and synorogenic granitoids – gabbroids of the Baltic Shield has shown, that the age of these rocks decreases from the northeast to the southwest, from 2.100–1.950 Ga in Outokumpu–Oravaara region (Huhma, 1986; Wetherill et at, 1962) to 1.940–1.830 in West and South Estonia. Supporting the opinions of G. Gaal and R. Gorbatschev (Gaal, Gorbatschev, 1987) and A. F. Park et al. (Park et al, 1984) we consider that such age trends reflect the direction of the origin of the Svecoennian crust also on the SSBS. The estimated rate of the formation of the Svecofennian crust of the Baltic Shield was about 1 cm per year.

For establishing the geologic structure of the SSBS of great interest are also small intrusions of gabbroids and granitoids (Fig. 2).This group includes gabbro-norites of Sigula (b.h. F-124), gabbro diorites of Abja (b.h. 92), granodiorites of Taadikvere (b.h. 94), Virtsu (b.h. 360) and Märjamaa (b.h. 302), but also potassium granites from Naissaare, Jägala (Neeme) and Ereda stocks. These rocks form a specific association, characterized by the increased content of trace elements (Petersell, Kirs, 1992). Granites of the mentioned massifs, as well as Märjamaa granodiorites, are not subjected to metamorphism. Granites of the Neeme massif are intersected by aplitic, microsyenitic veins. Undoubtedly they belong to rapakivi-granite formation. Gabbro-norites of the Sigula massif are not metamorphised either, but till now assigned to svecofennides (Geol. map.., 1980; Krist. fund., 1983).

Gabbro-diorites of the Abja massif have sporadically weak gneissic texture. Granodiorites of the Taadikvere and Virtsu massifs are as a whole weakly gneissous. Besides, rocks of the first massif are intersected by thin veins of plagiomicrocline granites. They have been considered as Svecofennian or older (Geol. map..., 1980). The age dating by U-Pb method, however, show that granodiorites are of Svecofennian, gabbro diorites of Gothian age (Table 1, Fig. 5). In accordance with the age and geochemical data gabbro-diorite correlates with gabbroids of anorthosite — rapakivi formation of the Baltic Shield and also by geochemical data with gabbro-norite of Sigula massif (b.h. F-124) (Petersell, Kirs, 1992). The occurrence of veins of plagiomicrocline granites in gabbro-diorites of the Abja massif, in turn, gives evidence of post gabbro-diorite intrusion taking place in South Estonia. This may account for the Gothian age of some plagio-microcline granites established by K-Ar method (Krist. fund..., 1983).

Table 1. Pb and U isotopes in the zircons from the rocks of the crystalline basement of the SSBS

No	Fraction mcm	Concentration, ppm		Measured			Atomic ratio		Age, Ma	Zones	Descripton of samples
		U	Pb	206 Pb / 204 Pb	207 Pb / 206 Pb	208 Pb / 206 Pb	206 Pb / 238 Pb	207 Pb / 235U	207 Pb / 206 Pb		
1	2	3	4	5	6	7	8	9	10	11	12
	Borehole 590 (Muhu), sample 5904420, interval 442–452 m										
1	120–250	304.4	94.70	3820	0.1145	0.1280	0.2889	4.431	1820	West Estonia	Finegrained amphibolebiotite gneiss (metavolcanite). Amphibolite facies of metamorphism
2	140–250	316.4	102	3180	0.1154	0.1253	0.3038	4.677	1826		
3	200–250	279.3	101.1	1175	0.1224	0.1668	0.3227	4.973	1828		
4	80–200	295.0	93.34	10340	0.1124	0.1276	0.2956	4.544	1824		
5	150–200	316.7	97.89	3385	0.1152	0.1482	0.2824	4.362	1832		
							Concordant age		1827 ± 7		
	Borehole 066 (Vaki), sample 0664680, interval 468–489 m										
6	100–200 (4)	1051	319	21250	0.11233	0.06157	0.3006	4.639	1830	South Estonia	Finegrained quartz-feldspar gneiss (metavolcanite). Amphibolite facies of metamorphism
7	100–200 (5)	744	217	17225	0.11139	0.06515	0.2883	4.431	1824		
			sample 0664800, interval 480–489 m								
8	100–200 (5)	982	297	44780	0.11204	0.05772	0.3002	4.629	1829		
9	60–80 (z)	518	149	9780	0.11323	0.06740	0.2828	4.370	1833		
							Concordant age		1828 ± 8		
	Borehole 172 (Häädemeeste), sample 1726990, interval 699–702 m										
10	70–150 (3)	658	208	10490	0.11225	0.20056	0.27934	4.2795	1817	South Estonia	Finegrained quartz-feldspathic gneiss (metavolcanite). Granulite facies of metamorphism
11	70–100 (z)	1553	462	6679	0.11206	0.15039	0.27366	4.1566	1802		
12	70–100 (6)	2802	266	3769	0.10215	0.24816	0.08157	1.1092	1598		
13	50–70	483	354	6273	0.11361	0.22212	0.25369	3.9028	1825		
14	50–70	412	143	7889	0.11342	0.20737	0.30452	4.6954	1829		
							Concordant age		1832 ± 22		

1	2	3	4	5	6	7	8	9	10	11	12
	Borehole F-164, sample 1643580, interval 358–396 m										
15	80–200 (1)	404	118	4255	0.11553	0.07585	0.2846	4.422	1844	Tapa zone	Finegrained quartz-feldspathic and
16	80–100 (z)	479	133	1575	0.12078	0.0945	0.2648	4.116	1844		amphibole-biotite gneiss, in places
17	80–200 (2)	415	121	8330	0.11468	0.06525	0.2886	4.515	1856		with rare pyroxenes (metavolcanite).
18	50–80 (3)	571	176	1380	0.12373	0.09687	0.3011	4.798	1889		Granulite facies of metamorphism
							Concordant age	1918 ± 10			
	Borehole F-139, sample 1394050, interval 405–408 m										
19		728	211	7310	0.11437	0.11454	0.2744	4.272	1847	Tallinna zone	Rich of quartz aluminiferous gneiss
	Borehole F-113, sample 1134090, interval 409–413 m										(metasedimentary rock). Amphibolite
20	80–100	752	700	4983	0.39572	0.82576	0.3338	6.086	2128		facies of metamorphism
21	60–100 (4)	652	233	1590	0.14039	0.11945	0.3292	5.999	2127		
22	60–100 (5)	460	169	2200	0.14121	0.11921	0.3402	6.370	2175		
	Borehole F-110A, sample 110A3400, interval 340–344 m										
23	80–100 (5)	706	209	7730	0.12581	0.08002	0.2857	4.894	1847		
24	60–100 (4)	510	152	3950	0.12174	0.06283	0.2960	4.866	2018		
25	60–100 (4)	964	284	5890	0.11966	0.03078	0.2993	4.867	1944		
	Borehole 502 (Varbla), sample 5026220, interval 622–628 m										
26	50–100	631	187	2705	0.11789	0.07976	0.2884	4.510	1855	South Estonia	Aluminiferous gneiss (metasedimen-
27	50–100	529	161	6980	0.11506	0.06496	0.3035	4.736	1856		tary rock), in places weakly subjected
				sample 5026030, interval 603–615 m							to migmatization. Granulite facies
28	50–100 (3,4)	351	103	3570	0.11827	0.03786	0.3115	5.080	1930		of metamorphism
29	50–100 (5)	550	166	4650	0.11446	0.04035	0.3082	4.781	1841		
30	50–100 (5)	582	178	1115	0.12335	0.10514	0.3019	4.4761	1870		
	Borehole 92 (Abja), sample 926064, interval 606–610 m										
31	80–200	267.7	74.07	4015	0.1029	0.2081	0.2433	3.351	1624	South Estonia	Mediumgrained gabbro-diorite,
32	200–250	250.6	69.82	6140	0.1019	0.2244	0.2431	3.360	1628		weakly gneissic
			sample 92611, interval 611–617 m								
33	80–200	237.9	70.39	3855	0.1032	0.2693	0.2484	3.439	1632		
34	200–250	194.5	63.85	1175	0.1114	0.3291	0.2594	3.589	1630		

Table 1 (continued)

1	2	3	4	5	6	7	8	9	10	11	12
35	80–200	216.3	83.22	241.7	0.1569	0.4296	0.2620	3.622	1629		
							Concordant age	1635 ± 7			
	Borehole 94 (Taadikvere), sample 944040, interval 404–424 m										
36	200–250	426	119	9780	0.11256	0.14987	0.2586	3.975	1824	South Estonia	Potassic porphyraceous granodiorite, weakly gneissic
37	80–200	364	109	5725	0.11331	0.14937	0.2775	4.262	1822		
38	80–200	438	127	2030	0.11750	0.16408	0.2610	3.999	1818		
			sample 944540, interval 454–464 m								
39	200–250	372	114	7530	0.11273	0.14227	0.2852	4.381	1823		
40	80–200	390	106	3090	0.11477	0.14920	0.2509	3.831	1812		

Remarks:

Characterization of zircons: 1 – long-prismatic, 2 – short-prismatic, 3 – prismatic corroded, 4 – prismatic, 5 – rounded, 6 – opaque, Z – yellowish, AO – abrasive treatment

Borehole 590 (Muhu), sample 5904420

Zircons subtransparent, prismatic and rounded. Size of grains 0.05–0.2 mm, rarely more, elongation 1.5–2.1. Zoning of crys tals is not observed.

Borehole 066 Vaki), samples 0664680 and 0664800

Zircons subtransparent,often yellowish prismatic and rounded, frequently fractured, but not transformed. Size of grains 0.05–0.2 mm, elongation 1.5. Zoning of crystals is not observed.

Borehole 172 (Häädemeeste), sample 1726990

Zircons from transparent to opaque, yellowish, greenish, prismatic, often rounded (corroded). Size of grains 0.05–0.1 mm, rarely more, elongation 1.5. Zoning of crystals is not observed.

Borehole F-164, sample 1643580

Zircons subtransparent, prismatic, often corroded and rounded. The grains with turbid zoning of crystals are represented, also with nodules of apatite, quartz and ore minerals. Size of grains 0.05–0.25 mm, elongation 2–3.

Borehole F-139, sample 1394050

Zircons subtransparent, prismatic, rounded and corroded. Size of grains 0.1mm. Elongation 2–2.5

Borehole F-113, sample 1134090

Zircons from subtransparent to opaque, prismatic, rounded and corroded, rolled and fine. Size of grains 0.05–0.1 mm. The grains are often fractured, rarely weakly zoning, elongation 2.

Borehole F-110A, sample 110A3400

Zircons subtransparent, often yellowish, prismatic, corroded and rounded. Size of grains 0.05–0.1 mm. In the biggest grains turbid zoning is observed, often also nodules. Elongation 2–2.5.

Borehole 502 (Varbla), samples 5026220 and 5026030

Zircons from subtransparent to opaque, prismatic and rounded, corroded with marks of roundness. Size of grains 0.05–0.07mm, rarely up to 0.1 mm, fractured, elongation 1.5. Some grains have the turbid dark nucleus.

Borehole 92, samples 926060 and 926110

Zircons transparent, light rose-coloured (brownish), pris matics, idiomorphic. Rare grains are weakly zoned. Size of grains 0.05–0.3 mm, elongation 1.5. Rare fine nodules in zircons are observed

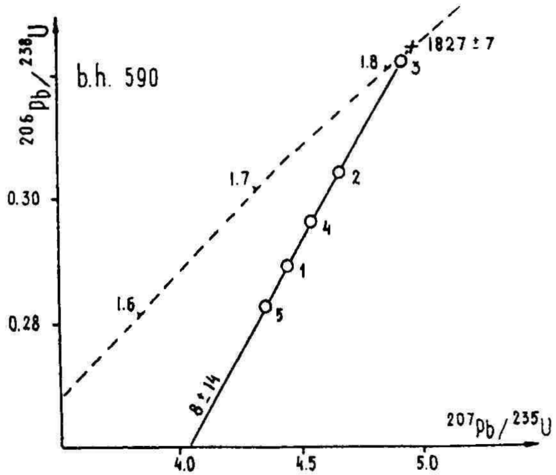
Borehole 94 (Taadikvere), samples 944040 and 944540

Zircons greyish transparent and subtransparent, prismatic, often with uneven indented crystal edges and fractured, but not transformed. Size of grains mostly 0.1–0.3 mm, elongation 1.5–3. In the centre of crystals the nodules of ore minerals are observed.

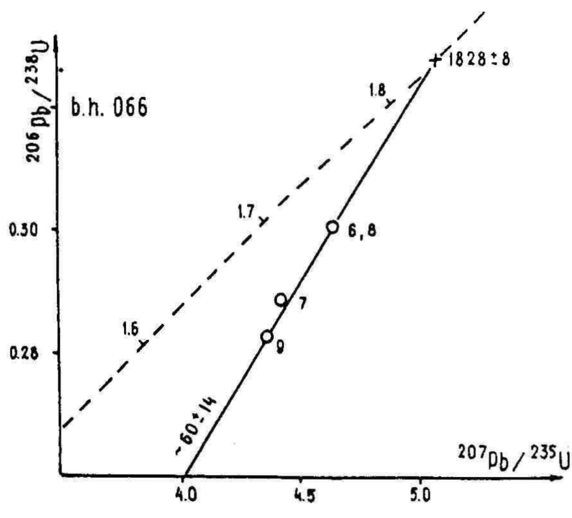
Fig. 5. Concordia diagrams of U-Pb isotopic zircon data of rocks from the Estonia crystalline basement

a–d – metavolcanite: West Estonia, b.h. 590 (a); South Estonia, b.h. (066 (b), b.h. 172 (c); Tapa zone, b.h. F-164 (d); e–f – aluminifwerous gneisses: Tallinn zone, b.h-s F-110A, F-113, F-139 (e); South Estonia, b.h. 502 (f); g–h – intrusive rocks: gabbro and diorite Abja, b.h. 92 (g), granodiorite Taadikvere, b.h. 94 (h); 1–40 – numbers of dating in table 1

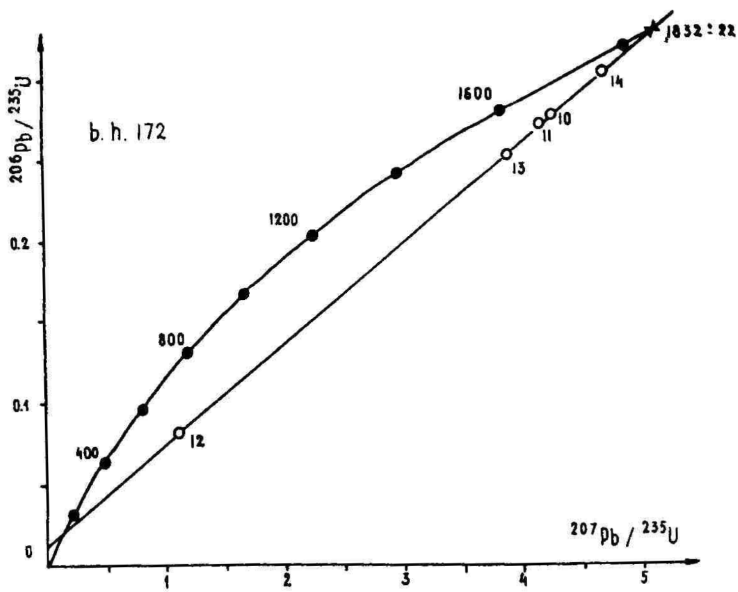
a



b

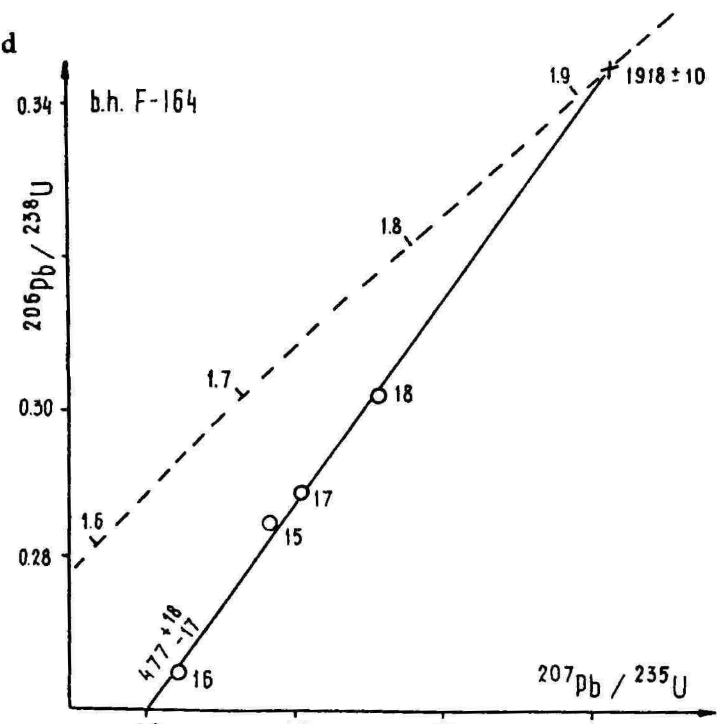


c



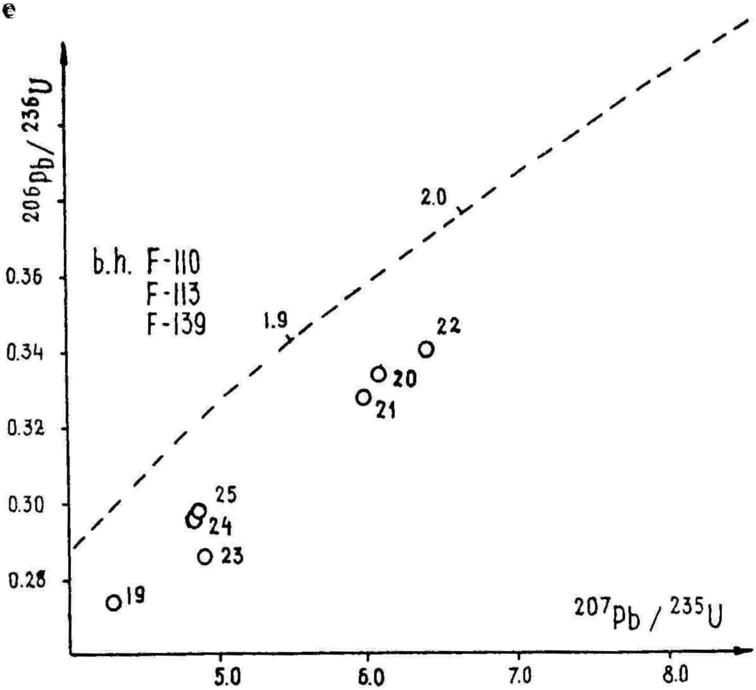
b. h. 172
^{206}Pb / ^{235}U
^{207}Pb / ^{235}U
0.2
0.1
0
1
2
3
4
5
400
800
1200
1600
1832 ± 22
10
11
12
13
14

d



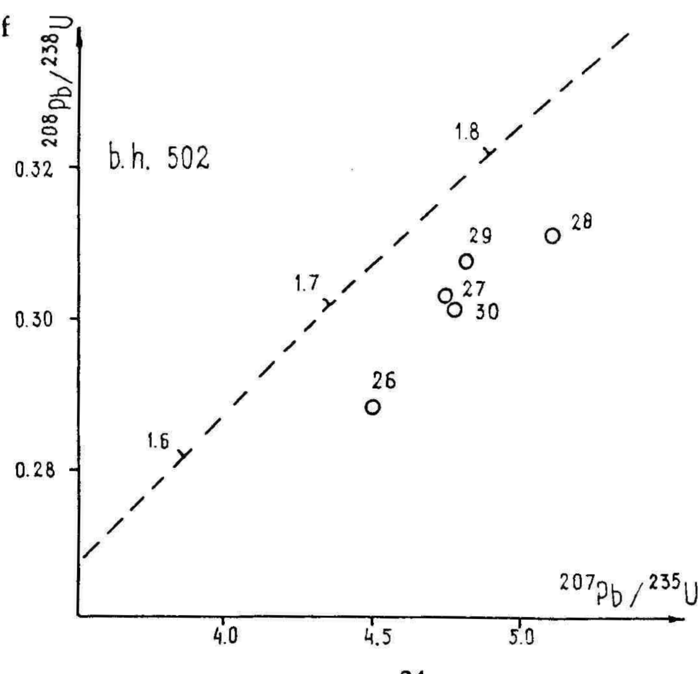
b.h. F-164
^{206}Pb / ^{238}U
^{207}Pb / ^{235}U
0.34
0.30
0.28
4.0
4.5
5.0
5.5
1.6
1.7
1.8
1.9
1918 ± 10
477 +18 −17
15
16
17
18

e



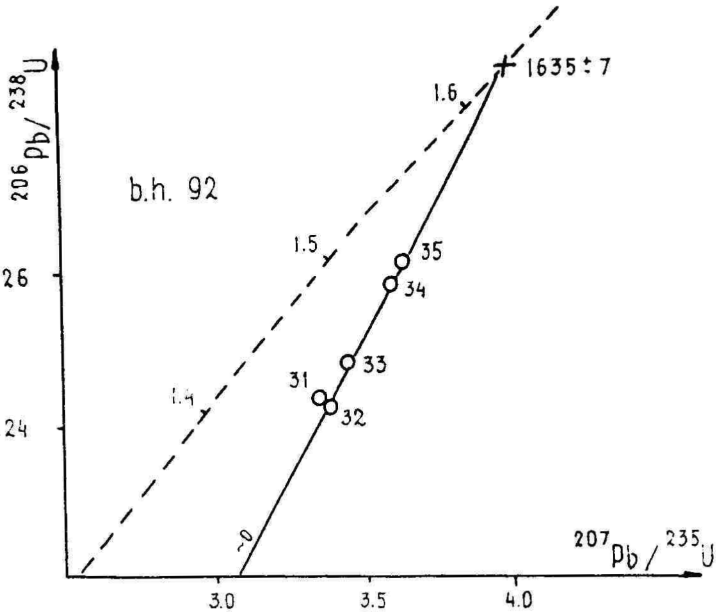
206Pb/236U
b.h. F-110
F-113
F-139
2.0
1.9
22
20
21
25
24
23
19
0.36
0.34
0.32
0.30
0.28
207Pb / 235U
5.0
6.0
7.0
8.0

f



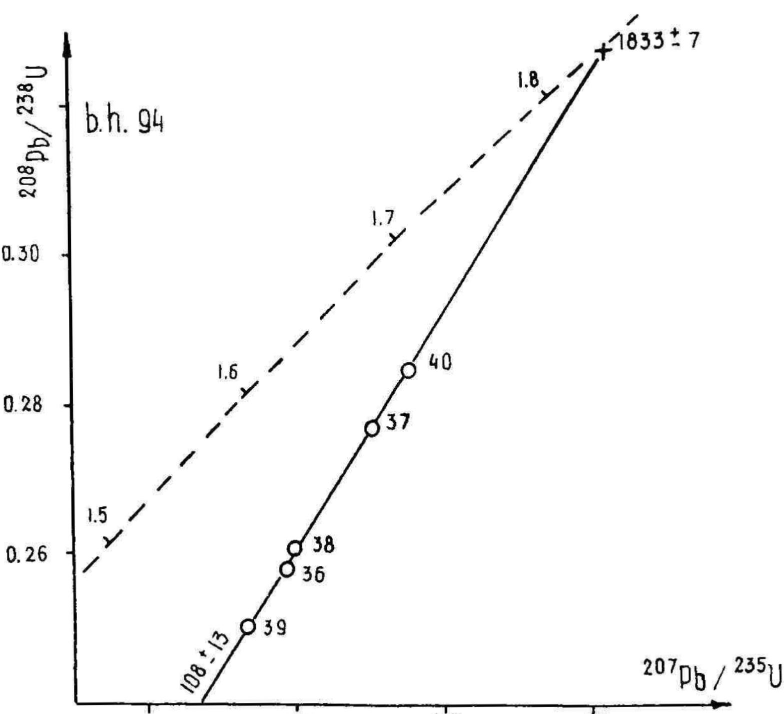
208Pb/238U
b.h. 502
1.8
1.7
1.6
28
29
27
30
26
0.32
0.30
0.28
207Pb / 235U
4.0
4.5
5.0

g



206Pb/238U
b.h. 92
1635 ± 7
1.6
1.5
1.4
35
34
33
31
32
~0
0.26
0.24
207Pb/235U
3.0
3.5
4.0

h



208Pb/238U
b.h. 94
1833 ± 7
1.8
1.7
1.6
1.5
40
37
38
36
39
108 ± 13
0.30
0.28
0.26
207Pb/235U
3.5
4.0
4.5
5.0

9*

Acknowledgements

The authors thank the geologists- researchers of the crystalline basement of Estonia, Dr-s V. Klein and J. Kivisilla, geologists H. Koppelmaa, M. Niin, K. Suuroja, E. Kala, and also the lecturer of the Tartu University J. Kirs for kindly providing unpublished data on geology and useful discussions about the structure of the crystalline basement of Estonia.

We greatly acknowledge the help of Dr. F. I. Zukov from the Ukr. Acad. Sci., who initiated and guided isotopic Pb datings. The authors are also indebted to Prof. A. Loog from Tartu University, thanks to whom the publication of this paper was possible.

References

Aberg G., 1978. Precambrian geochronology of southeastern Sweden. Geol. fören. förhandl. 100, p. 1–37.

Dedejev, 1974 – **Дедеев В. А.**, 1974. Раннедокембрийские складчатые структуры и массивы фундамента Русской плиты. В кн.: Структура фундамента платформенных областей СССР. Л.: Наука.

Gaal G., Gorbatschev R., 1987. An outline of the Baltic Shield.

In: Precambrian Geology and Evolution of the Central Baltic Shield, Gaal, G. and Gorbatscev, R. (eds.). Precambrian Res. 35, 15–52.

Gafarov, 1962 – **Гафаров Р. А.**, 1962. Строение складчатого фундамента Восточно-Европейской платформы по геофизическим данным. Изв. АН СССР. Сер. геол. 8 с. 56–67.

Geological map of the Crystalline basement of the Soviet Baltic Republics. Scale 1 : 500000. 1980. Leningrad. NEDRA.

Fotiadi, 1958 – **Фотиади Э.Э.**, 1958. Геологическое строение Русской платформы по данным региональных геофизических исследований опорного бурения. М.: Гостеоптех издат. 244 с.

Huhma H. 1986. Sm-Nd, U-Pb and Pb-Pb isotopic evidence for the origin of the Early Proterozoic Svecokarelian crust in Finland. Geol. Surv. of Finland. Bull. 337. 52 p.

Höltta P. 1988. Metamorphic zones and the evolution of granulite grade metamorphism in the early Proterozoic Pihlavesi area, central Finland. Geol. Surv. of Finland. Bull. 344. 50 p.

Koppelmaa et al., 1978 – **Коппелмаа Х, Клейн В. М., Пуура В. А.**, 1978. Метаморфические комплексы кристаллического фундамента Эстонии. – В кн: Метаморфические комплексы фундамента Русской плиты. Л. Наука с. 43–76.

Krogh T. E. 1973. A low-contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determinations. Geochim. Cosmochim. Acta 37. N.3. p. 485–494.

Krist. fund. ..., 1983 – **Кристаллический фундамент Эстонии. 1983. М.: Недра. 208 с.**

Ludwig K. R. 1980. Calculation of uncertainties of U-Pb isotope data. Earth Planet. Sci. Lett. 46. p. 212–220.

Luha A. 1946. Eesti NSV maavarad. R.K. Teaduslik-tehniline kirjandus. Tallinn. 178 lk.

Miner. mest ..., 1982 – **Минеральные месторождения Европа. Северо-Западная Европы. 7, М. Мир. 583 с.**

Niin, 1976 – **Нийн М. И.** 1976. К стратиграфии хогландской серии среднего протерозоя Северной Прибалтики. В кн.: Материалы по стратиграфии Прибалтики. Вильнюс: ЛитНИГРИ. с. 15–17.

Park A. F., **Bowes** D. R., **Halden** N. M., **Koistinen** T. J. 1984. Tectonic evolution at an Early Proterozoic continental margin: The Svecokarelides of eastern Finland. J. Geodynamics 1. p. 359–386.

Petersell, 1974 – **Петерселль В. Х.**, 1974. О сульфидной минерализации в кристаллических породах ягалаской толщи Изв. АН ЭССР. Геология. 2, с. 142–148.

Petersell, 1976 – **Петерселль В. Х.**, 1976. Основые черты геологии и рудоносности кристаллического фундамента южного склона Балтийского шита. Автореф. дисс. .. канд. геол-мин. наук АН ЭССР. Таллинн ИГ АН ЭССР, 28 с.

Petersell, V., **Kirs**, J., 1992. Geochemical Character of Estonian Subplatform Granitoids and Gabbroids. Tartu Ülikooli Toimetised. 956. Töid geoloogia alalt XIII, p. 27–43.

Pobul, 1962 – **Побул Э. А.**, 1962. О строении кристаллического фундамента Эстонии по данным геофизики Тр. Ин-та геология АН ЭССР, т. 10. Геология палеозоя. Таллинн, с. 309–318.

Puura, 1974 – **Пуура В. А.**, Структура Южного склона Балтийского щита. Автореф. дисс. канд. геол-мин. наук. Таллинн, ИГ АН ЭССР, 28 с.

Puura et at., 1976 – **Пуура В. А., Куусвалу Т. И., Биркис А. П.**, 1976. Главные черты геологического строения докембрийского фундамента Прибалтики. В кн.: Геология, петрология и металлогения кристаллических образований Восточно-Европейской платформы. ТШМ. Недра. с. 27–40.

Stacey J. S., **Kramers** J. D., 1975. Approximation of terrestrial lead isotope evolution by a two-stage model. Earth Planet. Sci. Lett. 26. p. 207–221.

Tectonic map of the Soviet Baltic Republics. Scale 1 : 500000. 1980. Leningrad. NEDRA.

Tihomirov, 1966 – **Тихомиров С. Н.**, 1966. Геологическое строение докембрийского фундамента в пределах Ленинградской области и Прибалтики. Автореф. дисс. ... канд. геол.-мин. наук Л: ВСЕГЕИ, 24 с.

Tugarinov, Bibikova, 1980 – **Тугаринов А. И., Бибикова Е. В.**, 1980. Геохронология Балтийского щита по данным цирконометрии. М: Наука, 132 с.

Vaher et al., 1962 – **Вахер Р. М., Пуура В. А., Эрисалу Э. К.**, 1962. Тектоническое строение Северо-Восточной Эстонии. – Тр. Ин-та геологии АН ЭССР, т. 10, с. 319–335.

Vardanjants, 1960 – **Варданянц Л. А.** 1960. Геологическая карта докембрийского кристаллического фурдамента Русской платформы м-ба 1 : 500000. Обьяснительная записка. М: Госгеолтехиздат. 48 с.

Vetrennikov et al., 1966 – **Ветренников В. В., Петерселль В. Х., Пылдвере А. А.**, 1986. Марганценосная железорудная формация докембрия и происхождение горных пород кристаллического фундамента Белоруссии и Прибалтики. Минск. с. 86–97.

Öpik A. 1935. Eine mögliche geologische Deutung der magnetischen Anomalien Estlands. – In: C.r. Comiss. Geodes. Baltiq. reunie a Tallinn et Tartu 20–30 about 1935. p.287–288.

Zander et al., 1967 – **Зандер В. Н., Томашунас Ю. И., Берковский А. Н.**, 1967. Геологическое строение фундамента Русской плиты. Л: Недра, 122 с.

Zukov, Lesnoi, 1982 – **Жуков Ф. И., Лесной Д. А.**, 1982. Изотопы серы и углерода в стратиформных месторождениях складчатых областей. Киев. „Наукова Думка". 160 с.

Wetherill G. W., Kouvo O., Tilton G. R., Gast P. W. 1962. Age measurements on rocks from the Finnish Precambrian. – J. Geol. 70. N 1. p. 74–88.

BALTI KILBI LÕUNANÕLVA KRISTALSE ALUSKORRA GEOLOOGILISEST EHITUSEST

Valter Petersell, Oleg Levchenkov

Resümee

Balti kilbi lõunanõlva piiridesse arvatakse Eesti territoorium, Leningradi oblasti lääne- ja Pihkva oblasti loodeosa ning Põhja-Läti. Nõlva kristalses aluskorras levivad valdavalt metavulkaniidid ja metasedimendid. Intrusiivsete kivimite levik on tunduvalt tagasihoidlikum.

Gneisilised kivimid on enamasti metamorfiseeritud regionaalse metamorfismi amfiboliitse ja granuliitse faatsieste tingimustes, ning on sageli mõjustatud K-metasomatoosist, migmatiseeritud ja granuliitse faatsiese levilas ka tšarnokiidistunud.

Viimastel aastakümnetel on osa Eesti ja Läti geolooge käsitlenud migmatisatsiooni ja tšarnokiidistumist kivimite osalise sulamise tulemusena *in situ* tingimustes mitte ainult kivimite kõrge metamorfismiastme tõendina, vaid ka nende arhailise vanuse peamise kriteeriumina. Nii korreleeritakse Balti kilbi lõunanõlval suurtel aladel varem svekofenniidide struktuurivööndisse loetud varaproterozolisi kivimeid Koola poolsaare ja Vene lava arhailise vanusega kivimitega.

Metasedimentide, metavulkaniitide ja migmatiite moodustavate K-rikaste graniitide Pb isotoopkoosluse eripära ja sarnasus (jn. 3 ja 4) lubavad migmatiite moodustavaid K-rikkaid graniite rööbistada Balti kilbil paljanduvatele svekofenniididele omaste kurrutusjärgsete K-rikaste, samuti migmatiitemoodustavate graniitidega.

Tsirkoonide järgi määratud metavulkaniitide ja granitoidide U-Pb isotoopvanused nii amfiboliitse kui granuliitse metamorfismi vööndite arhaikumi kivimitest näitavad, et tegemist on tüüpiliste varaproterozoiliste svekofenniidide kurrutusvööndi kivimitega. Nende samaaegsust svekofenniididega rõhutavad ka ainult viimastele Ida-Euroopa platvormil iseloomulike Mn-rikaste rauakvartsiitide jt. kivimitüüpide esinemine ning metasedimentide teistest veidi kõrgem isotoopvanus sõltumata metamorfismi faatsiesest (jn. 5, tabel 1).

U-Pb isotoopvanuse määrangud kinnitavad ka Balti kilbi lõunanõlva P-rikaste subleeliseliste gabroidide anortosiit-rabakiviformatsiooni kivimitega üheaegset teket.

Seega jätkuvad Balti kilbi lõunanõlval vähemalt valdavas enamuses kilbil paljanduvate svekofenniidide analoogid. Esitatud kivimite U-Pb isotoopvanuse määrangud tunnistavad svekofenniidideaegse kontinentaalse koore kasvu lõuna- ja edelasuunas.