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Tuffisite rocks in the basement of the early Proterozoic Pechenga Structure

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Abstract. The problematical Early Proterozoic fluidizite-explosive tuffisites have been considered in the Televi Sedimentary Fm of the Northern Pechenga volcano-sedimentary complex. Fluidizite-explosive "pseudoconglomerates" occur as irregular clastic rocks, without evidence of sorting by size and shape. Clastic fragments are represented by plagiogranites, granodiorites, diorites and quartz pebbles. Fragments have an angular or subround shape. There are a number of the plastic picrobasaltic lava fragments that were deformed by hard granitic clasts. This fact indicates high-temperature conditions of tuffisite-forming process. These conditions are also confirmed by a fact of volumetric decompaction processes in tuffisite fragments. Quartz grains from the granitic clasts are partly replaced by diaplectic glass. Such decompaction processes and quartz transformations are typical of latest diamond-bearing tuffisites of Polar Ural and Timan Area. The matrix of the Pechenga tuffisites is enriched in such compatible elements as Ni, V, Cr, and Co, that is typical for tuffisitic rocks and for endogenic "pseudoastroblems". Rb-Sr isochrone with the age of 2595 ± 79 Ma has been received for these rocks.

Аннотация. Охарактеризованы раннепротерозойские породы возможного флюидизит-эксплозивного происхождения из осадочной телевинской свиты Северопеченгского вулканогенно-осадочного комплекса. Флюидизит-эксплозивные "псевдоконгломераты" представляют собой хаотичные кластиты без признаков сортировки по размеру и форме. Кластические фрагменты представлены плагиогранитами, гранодиоритами, диоритами и кварцевыми гальками. Обломки имеют угловатую и округленную форму. Наблюдаются обломки пластичной пикробазальтовой лавы, которые деформируются твердыми обломками гранитоидов. Этот факт указывает на высокотемпературные условия туффизитового процесса, что подтверждается также процессами объемного разуплотнения фрагментов. Зерна кварца из обломков гранитоидов частично замещаются диаплектовым стеклом. Такие процессы разуплотнения и преобразования кварца типичны для позднейших алмазоносных туффизитов Полярного Урала и Тимана. Матрикс печенгских туффизитов обогащен такими некогерентными элементами как Ni, V, Cr и Co, что типично для туффизитовых пород и для эндогенных "псевдоастроблем". Для этих пород была получена Rb-Sr изохрона с возрастом 2595 ± 79 млн лет.

Key words: Kola Peninsula, Pechenga Structure, Early Proterozoic, fluidizite-explosive processes, tuffisite, pseudoconglomerate, diamond-bearing mineralization

Ключевые слова: Кольский полуостров, Печенгская структура, ранний протерозой, флюидизит-эксплозивные процессы, туффизит, псевдоконгломерат, алмазоносность

1. Introductrion

Early Proterozoic volcano-sedimentary rocks within the N-W Kola Peninsula in Russia form a part of the larger Polmak-Pechenga-Varzuga Greenstone Belt (PV Belt). The Pechenga Structure is the best investigated fragment of the PV Belt due to the presence of a well known unique Cu-Ni sulfide deposits connected with gabbro-wehrlitic intrusions, due to location and boring of the Kola Superdeep Borehole (SG-3), being the world's deepest borehole (12261 m) and due to some peculiarities of its geological structure. The last-mentioned factor includes a great thickness of supracrustal rocks forming the Pechenga Area; a well representation of sedimentary and especially volcanic parts of the Pechenga rock sections; a slight deformation of rocks and a comparatively weak metamorphism of the Northern Pechenga rocks. The most important papers on the Pechenga Area include those by (*Zagorodny et al.*, 1964; *Predovsky et al.*, 1976; 1987; *Skuf'in*, 1998; 2002; *Balashov*, 1996; *Smol'kin et al.*, 1995).

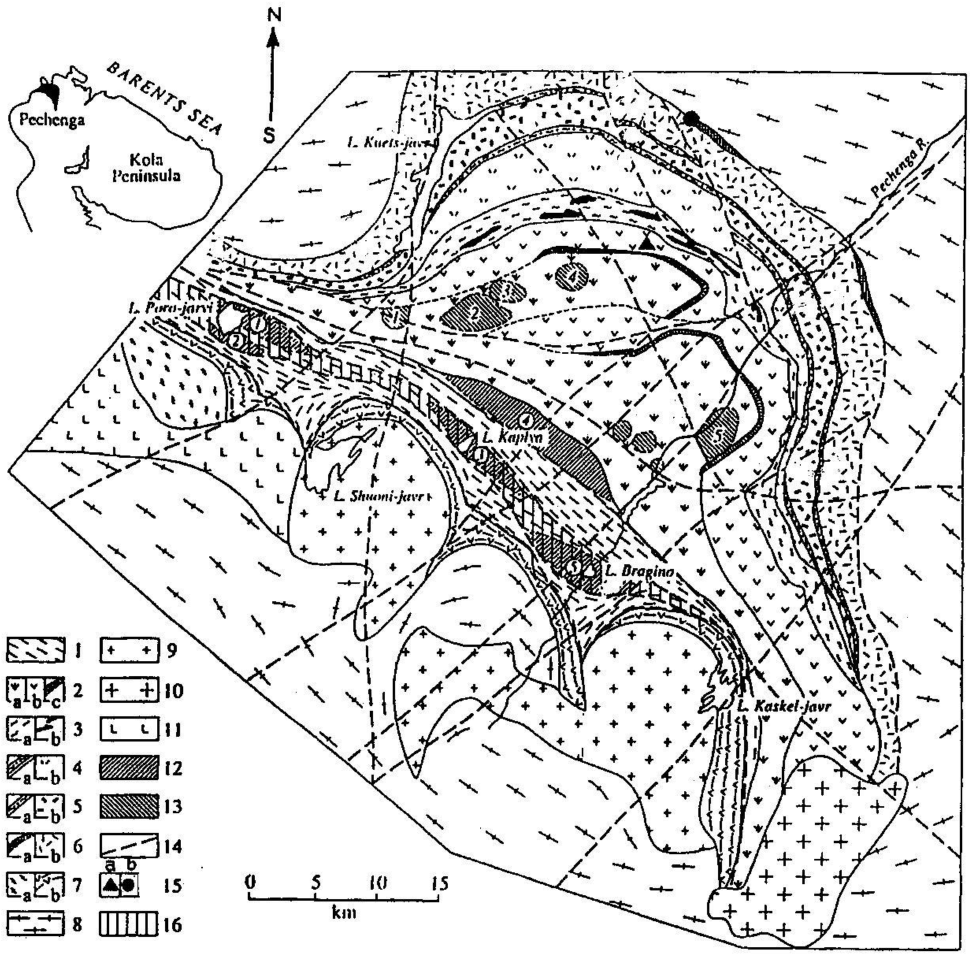

Fig. 1. Geological and palaeovolcanological sketch map of the Pechenga Structure:

1 – volcano-sedimentary rocks of the Southern Pechenga Complex (1905-1700 Ma); 2-6 – volcano-sedimentary rocks of the Northern Pechenga Complex (2500-1905 Ma): 2 – volcanites of the Suppvaara and Matert Volcanic Fms (1980±34 Ma): a – basaltic, less ferropicritic lavas and pillow-lavas, b – basaltic lavas and pillow-lavas, c – felsic lavas and tuffs; 3 – Zhdanov Tuffaceous-Sedimentary Fm: a – tuffaceous-sedimentary rocks, b – gabbro-wehrlites; 4 – sedimentary and volcanic rocks of the Luchlompolo Sedimentary and Zapolyarny Volcanic Fms (2114±52 Ma): a – sediments, b – volcanites; 5 – sedimentary and volcanic rocks of the Kuvernerinjoki Sedimentary, Pirttijarvi Volcanic and Orshoaivi Volcanic Fms (2214±54 Ma): a – sediments, b – volcanites; 6 – sedimentary and volcanic rocks of the Televi Sedimentary and Majarvi Volcanic Fms (2324±28 Ma): a – sediments, b – volcanites; 7 – supracrustal rocks of uncertain stratigraphic position: a – schistose gneisses, b – schistose amphibolites; 8 – Archaean gneiss-granitic complex of the basement; 9 – diorites and plagiogranites of the Early Proterozoic Kaskeljavr and Shuonijavr granite domes (1940 Ma); 10 – microcline granites of the Litsa-Araguba Intrusive Complex (1765 Ma); 11 – gabbros of the Archaean Kaskama-Shuort Intrusive Complex; 12 – eruptive volcanic centres in the Southern Pechenga Zone (1-5); 13 – eruptive volcanic centres in the Northern Pechenga Zone (1-5); 14 – faults; 15: a – position of the Kola Superdeep Borehole (SG-3); b – position of the tuffisite rocks; 16 – Porojarvi Fault Basin.

The Pechenga Structure represents morphologically a subisometric synclinorium, its northern part is a fragment of primary Early Proterozoic volcano-tectonic palaeodepression, that was filled by the rocks of the Northern Pechenga Complex, 11 km thick (development age is 2550-1940 Ma); sedimentary and volcanic rocks of the Southern Pechenga Complex (development age is 1940-1700 Ma) formed the sublinear discordant fault structure, that cut the S-W margin of the palaeodepression (Fig. 1). The rock sections of the Northern Pechenga Complex are represented by four groups (the group names are those from the Finnish stratigraphic nomenclature) – Sariola (Televi Sedimentary and Majarvi Volcanic Fms), Lower Jatuli (Kuvernerinjoki Sedimentary and

Pirttijarvi Volcanic Fms), Upper Jatuli (Luchlompolo Sedimentary Fm), Ludia (Zapolyarny Volcanic Fm, Zdanov Tuffaceous-Sedimentary Fm, Matert Volcanic and Suppvaara Volcanic Fms).

2. Results of investigations

More ancient Sariola rocks at the northern border of the Pechenga Area immediately lie on the Archaean granite-gneissic basement; these rocks are represented by basal horizon of eluvial conglomerate-breccias and polymictic conglomerates of the Televi Sedimentary Fm. We can suppose that at least a part of these clastites is a product of the Early Proterozoic fluidizite-explosive system.

These problematical tuffisites are connected with an ancient palaeorelief hollow at the northern border of the Pechenga Area, along a large West-Chihnajarvi Fault, having N-E strike (Fig. 1). Cross sections of tuffisites and their gigantic eluvial blocks are located at the northern coast of Pityevoe Lake N-W of the town of Zapolyarny. Fluidizite-explosive "pseudoconglomerates" occur as irregular clastic rocks, without evidence of sorting by size and shape (Fig. 2, 1). Clastic fragments are represented by massive and trachytoid medium-grained and fine-grained plagiogranites, granodiorites and diorites, that are not analogous to the surface granite-gneissic basement rocks of the Pechenga Structure. Fragments have an angular or subround shape. There are also a lot of round and subround quartz fragments and some clasts of peculiar high-silica quartz-plagioclase magmatic rocks that contain about 70-80 % of quartz grains and only 20-30 % – plagioclase grains (Figs. 2, 4). Clastic rocks of the Televi Fm in this region are traditionally discussed as sedimentary ones similar to fluvial conglomerates and gritstones. But a number of textural, mineralogical and geochemical rock features do not respond to this exogenetic origin hypothesis. Firstly, in these rocks more than 30 % of cobbles have numerous structural inclusions of smaller fragments of pebble size; that is why they differ from ordinary conglomerates. Similar events were not observed in true sedimentary conglomerates. But conglomeratic inclusions of "breccias into breccias" type are extremely peculiar to the intrusive pyroclastic rocks or tuffisites that it is determined by the explosion recurrence (*Reynolds*, 1954). Secondly, there are a number of the plastic picrobasaltic lava fragments that were deformed by hard granitic clasts. This fact indicates high-temperature conditions of tuffisite-forming process. These conditions are also confirmed by a fact of volumetric decompaction processes in tuffisite fragments (Fig. 2, 2). Such a volumetric decompaction phenomenon is very typical of the present volcanic ignimbrites and was described by (*Golubeva, Makhlaev*, 1994) in Ordovician diamond-bearing tuffisites of Polar Ural. Thirdly, the degree of pebbles and cobbles' roundness is much high in the considered conglomerate-like rocks. Even fragments in marine conglomerates with the roundness coefficient CR (ratio of the radius of the inner circle to the radius of the outer) 0.7 and more are scarce (an average of 1 per 100), and fragments with CR 0.85-1.0 are absent (*Bilibin*, 1955). In cobbles and pebbles of river conglomerates the CR value does not exceed 0.2. But in Pechenga tuffisites every 10^{th} fragment, especially quartz fragments, has the CR value not less than 0.7 and on every square meter of the cross section surface of these rocks several fragments with CR equal to 0.8-0.9 in spectrum can be seen. Just such a high level of fragments rolling is quite usual for fluidizites and tuffisites (*Reynolds*, 1954). Fourthly, quartz grains from the granitic clasts are replaced by diaplectic glass (Fig. 1, 3). Analogous phenomenon in the quartz grains from Jatulian tuffisitic "conglomerates" was described in Northern Onega Depression (*Kasak, Zaizev*, 2002). Such quartz transformations are typical of diamond-bearing tuff-lavas Ichetinsko-Umbinskaya "fluidizite-explosive system" of Middle Timan (*Rybalchenko et al.*, 1997) and for a number of pseudo-astroblems that can have endogenic nature (*Marakushev*, 1993; 1995).

The matrix of the Pechenga tuffisites is enriched in such compatible elements as Ni, V, Cr, and Co (Table), it is typical for tuffisitic rocks and for endogenic "pseudoastroblems" (*Marakushev*, 1993; 1995). Quartz pebbles are enriched in Fe, Mg, Ca, Cu, Ni, Cr, V and other mantle elements. In this regard the composition and content of microelements in fragments and matrix appeared to be similar, which confirms the genetic nature of this sameness.

Thus, the totality of the facts allows us to consider these "pseudoconglomerates" with possible diamond-bearing mineralization to be endogenous, most likely mantle derived. They may be more ancient than the other formations of diamond-bearing tuffisites.

Geochronological studies on fluidizites of the Televi Fm were performed by the Rb-Sr isochrone method on rocks as a whole.

Methodology of sample analysis by means of Rb-Sr method

For the sample decomposition distilled acids HCl, HF, HNO_3 and H_2O (bidistillate) were used. The decomposition of the analyzed samples (200 mg of rock) was performed in 4 ml of HF and HNO_3 (5:1 ratio) in closed teflon weighing bottles in a thermostat at the temperature of 200° C during 24 hours. Then the resultant solution was divided into two aliquots to determine the isotopic composition and concentrations of Rb and Sr. The latter was determined by isotope dilution using a mixed tracer $^{85}Rb/^{84}Sr$. Isolation of Rb and Sr was carried out by eluent chromatography on resin "Dowex" 50 × 8 (200-400 mesh). We used 1.5 N and 2.3 N HCl as an eluent. The volume of resin used in the columns was ~7 cm^3 and ~4 sm^3. The isolated fractions of Rb and Sr were evaporated to dryness and then treated with a few drops of HNO_3. The isotopic composition of Sr and the content of Rb and Sr were determined in a mass spectrometer MI-1201-T in one-tape mode on tantalum tapes.

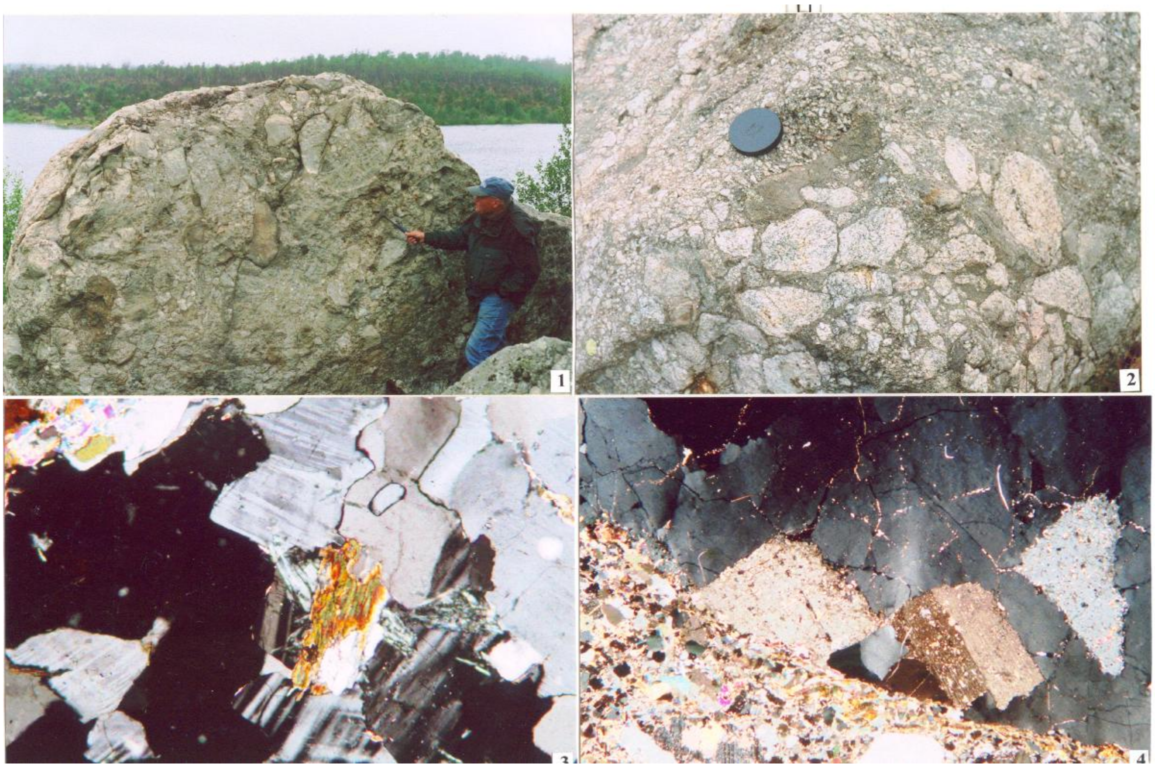

Fig. 2. Fluidizite-explosive tuffisites in the Televi Fm section. Pictures of the cross sections (1, 2) and micro-sections (3, 4). 1 – tuffisites at the northern coast of the Lake Pityevoe; 2 – plastic fragment of the picrobasaltic lava (in the centre) that was deformed by a granitic clast. Granite fragments have symptoms of volumetric decompaction; 3 – pseudomorph of the diaplectic glass (dark) after the quartz grains in the granitic fragment. Micro-section is 5 mm wide, nicols +; 4 – contact of the high-silica quartz-plagioclase magmatic rock with the fine-grained tuffisitic matrix. Micro-section is 5 mm wide, nicols +

The prepared samples were applied on the tapes in the nitrate form. The isotopic composition of Sr in all samples was normalized to the value recommended by the NIST SRM-987, equal to 0.71034 ± 26. The errors in the Sr isotopic composition (95 % confidence interval) did not exceed 0.04 %, the determinations of Rb-Sr relations – 1.5 %. Pollution within the laboratory was equal to 2.5 ng for Rb and –1.2 ng for Sr. The adopted decay constants of rubidium were used when calculating the ages. Calculation of the isochrone parameters was conducted by K. Ludwig's programmes (*Ludwig*, 1991). The results obtained are shown in Fig. 3. In this case, the resulting Rb-Sr isochrone with the age of 2595 ± 79 Ma dates the age of superimposed Proterozoic (Sumian) thermal events that are manifested locally in the structural-formational Northern Pechenga zone. The resulting age of the Early Proterozoic tuffisite-forming processes in the northern framing of the Pechenga Structure correlates with the age of Mustavaara dikes (2555 ± 65 Ma) determined by the Sm-Nd method (*Fedotov, Amelin*, 1992), as well as with the age of nepheline syenite of the Sahariyok massif in the Keyvy block (2562 ± 10 Ma) determined by the Pb-Pb method (*Zozulya, Eby*, 1999).

3. Discussion

Formation of pyroclastic rocks and eruptive breccias in the Pechenga structure having contrast subalkaline compositions (*Skuf'in*, 1998), touches upon a very interesting problem of fluidizite-explosive systems, which in recent years attracted attention of specialists in ore deposits and deposits of diamonds (*Golubeva, Makhlaev*, 1994; *Rybalchenko et al.*, 1997; *Petrovsky et al.*, 2010). These publications show the close relationship of ore mineralization with a wide range of explosive-eruptive breccias associated with fluid high-thermal mantle flows. The problem of fluidisite-explosive systems also affects the modern view on the basal conglomerates and quartz conglomerates at the basement of the Early Proterozoic Baltic Shield formations as a kind of "basal pyroclastic pseudoconglomerates" and "monomictic quartz-pyroclastites" (*Kazak, Zaitsev*, 2002) related with active treatment, rounding and partial melting of deep granitic and quartz fragments by a superheated thermal fluid flow.

Table. Major (wt %) and trace (ppm) elements of the Pechenga tuffisitic rocks

	1	2	3	4	5	6	7	8	9
SiO_2	71.98	70.78	77.59	76.64	73.90	71.78	91.19	92.42	94.73
TiO_2	0.10	0.64	0.03	0.005	0.17	0.59	0.25	0.03	0.00
Al_2O_3	12.49	14.87	11.88	12.82	13.92	13.27	1.52	0.51	0.34
Fe_2O_3	0.42	0.59	0.18	0.21	0.29	0.29	0.10	1.03	0.53
FeO	2.00	2.29	1.49	1.29	2.18	4.44	3.28	4.69	1.78
MnO	0.04	0.02	0.01	0.01	0.2	0.03	0.03	0.04	0.01
MgO	0.68	0.75	0.38	0.16	0.67	1.41	1.05	0.49	0.18
CaO	2.85	1.27	0.55	0.49	0.53	0.51	0.64	0.13	0.80
Na_2O	3.08	3.03	3.42	3.11	3.55	2.99	0.49	0.17	0.10
K_2O	3.16	4.00	3.63	4.45	3.27	2.75	0.11	0.18	0.03
H_2O^-	0.02	0.10	0.12	0.04	0.08	0.04	0.08	0.01	0.06
H_2O^+	0.76	0.59	0.25	0.32	0.66	1.24	0.32	0.45	0.35
P_2O_5	0.11	0.09	0.05	0.10	0.08	0.10	0.02	0.02	0.00
CO_2	1.81	0.42	0.00	0.00	0.14	0.00	0.42	0.16	0.59
S_{tot}	0.12	0.25	0.02	0.05	0.13	0.13	0.05	0.02	0.40
Sum	99.62	99.69	99.60	99.70	99.59	99.57	99.55	100.35	99.90
Cu	18	140	50	44	31	64	20	25	–
Ni	41	20	26	25	26	67	8	0.5	100
Co	28	5.4	2.2	2.1	2.6	10	0.20	0.15	10
Cr	74	34	65	62	60	230	39	31	190
V	27	68	7.2	4.5	18	50	150	26	–
Rb	111	144	84	103	111	158	18	3	–
Ba	540	1090	610	750	740	200	80	20	–
Sr	130	176	143	189	140	52	20	5	–
Nb	13	22	15	12	16	19	16	46	–
Zr	92	520	84	51	198	223	0.20	0.20	–

Note: 1 – tuffisitic matrix; 2-6 – fragments in tuffisitic matrix: 2 – fine-grained gneissic granodiorite; 3 – gneissic aplite; 4 – medium-grained aplite; 5 – medium-grained granite; 6 – fine-grained granite; 7, 8, 9 – quartz fragments.

Thus, we can conclude that the formation of eruptive breccias, and a variety of lavoclastic rocks and "pseudoconglomerates" that have a contrast alkaline ultrabasic and mafic-felsic composition, including also high-silica differentiates, and the formation of carbonaceous sedimentary formations in the Early Proterozoic rock sections of the region, is related to the plume fluid systems of the Eastern Baltic Shield, which also include fluidizite-explosive systems.

Taking into account the association of plume magmatic, metasomatic and fluidizite-explosive systems with a wide range of sulfide and oxide ores, including noble metals and PGE, the emergence of such eruptive breccias and tuffisites in close contact with basalt-picritic Pechenga rocks, and carbonaceous rocks of the Productive Fm of the Northern Pechenga Complex and Ni-bearing Pechenga intrusives, is quite natural and understandable.

Considering also the polygenic, including fluidizite-explosive origin of the basal arkosic and monomictic Early Proterozoic quartz-conglomerates of Karelia, which was partially proved for Segozero, Kumsa, Lechtino and other structures, it should be taken into account that diamondiferous rocks can be related to such "pseudoconglomerates" and "tuffisites". We can add that fluidizite-explosive rocks of basal "conglomerates" in the region have not been truly tested on possible concentrations of diamonds.

The Pechenga Structure and the whole Pechenga-Varzuga Belt should be considered not just as Early-Proterozoic rift-structures of long-term development, but as an area of long-term formation of deep-mantle plumes manifestations. Considering stages of plume-tectonic processes in the Early Precambrian of the Eastern Baltic Shield, we can say that large-scale manifestations of highly differentiated sub-alkalic and picrite-basaltic magmatism, accompanied by powerful fluidizite-explosive processes, occur simultaneously with certain stages of plume-tectonic activity.

Pseudoconglomerates-tuffisites in the Pechenga Structure basement are associated with the Sariola cycle of Karelia-tectogenesis, tracing the border between the Karelia Complex and its Archaean basement in the Pechenga Area. The Sariola plume-tectonic cycle in the eastern Baltic Shield means a destruction of the continental crust, the origin of rift structures that inherit the network of Archaean faults, filling these structures with endogenous tuffisites, accompanied by powerful eruptions of Sariola andesibasalts several kilometres thick. *V.Z. Negrutsa* (1990) studied Sariola quartz "conglomerates" in Karelia and noted "tuffitic" genesis of these rocks and the cloak-like nature of their primary occurrence. However, these typical quartz tuffisites form a "diluted" type of clastites (a mixture of quartz pebbles with tuff material). There is a complete analogy with the Sariola Pechenga tuffisites!

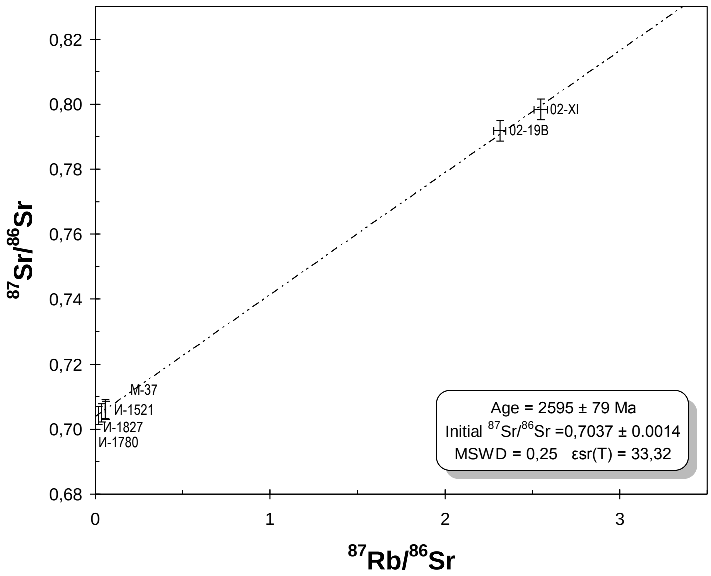

Fig. 3. Isotopic Rb-Sr isochrone for the Televi Fm tuffisitic rocks

4. Conclusion

1. The problematical Early Proterozoic fluidizite-explosive tuffisites are considered in the Televi Sedimentary Fm of the Northern Pechenga volcano-sedimentary Complex. Fluidizite-explosive "pseudoconglomerates" occur as irregular clastic rocks, without evidence of sorting by size and shape. Clastic fragments are represented by plagiogranites, granodiorites, diorites and quartz pebbles. Fragments have an angular or subround shape.

2. There are a number of the plastic picrobasaltic lava fragments that were deformed by hard granitic clasts. This fact indicates high-temperature conditions of tuffisite-forming process. These conditions are also confirmed by a fact of volumetric decompaction processes in tuffisite fragments. Quartz grains from the granitic clasts are partly replaced by diaplectic glass. Such decompaction processes and quartz transformations are typical of latest diamond-bearing tuffisites of the Polar Ural and Timan Area.

3. The matrix of the Pechenga tuffisites is enriched in such compatible elements as Ni, V, Cr, and Co, that is typical for tuffisitic rocks and for endogenic "pseudoastroblems".

4. The resulting Rb-Sr isochrone with the age of 2595 ± 79 Ma for these rocks dates the age of superimposed Proterozoic (Sumian) thermal events that are manifested locally in the structural-formational Northern Pechenga zone. The resulting age of the Early Proterozoic tuffisite-forming processes in the northern framing of the Pechenga Structure correlates with the age of Mustavaara dikes (2555 ± 65 Ma), as well as with the age of nepheline syenite of the Sahariyok massif in the Keyvy block (2562 ± 10 Ma).

5. The Pechenga Structure and the whole Pechenga-Varzuga Belt should be considered not just as Early-Proterozoic rift-structures of a long-term development, but as an area of long-term formation of deep-mantle plumes manifestations. Accounting stages of plume-tectonic processes in the Early Precambrian of the Eastern Baltic Shield, we can say that large-scale manifestations of highly differentiated sub-alkalic and picrite-basaltic magmatism, accompanied by powerful fluidizite-explosive processes, occur simultaneously with certain stages of plume-tectonic activity.

6. Pseudoconglomerates-tuffisites in the Pechenga Structure basement are associated with the Sariola cycle of Karelia-tectogenesis, tracing the border between the Karelia Complex and its Archaean basement in the Pechenga Area. The Sariola plume-tectonic cycle in the eastern Baltic Shield means a destruction of the

continental crust, the origin of rift structures that inherit the network of Archaean faults, filling these structures with endogenous tuffisites, accompanied by powerful eruptions of Sariola andesibasalts several kilometres thick.

7. Our investigations allow us to consider these "pseudoconglomerates" with possible diamond-bearing mineralization to be endogenous, most likely mantle derived.

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