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New data on the granite pedestal of the monument to Peter the Great "The Bronze Horseman" in Saint Petersburg

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Abstract. In order to expand and popularize knowledge about the stone decoration of Saint Petersburg, we present new data on the mineralogy and petrography of the famous Thunder-Stone, the parts of which were the basis for the monument to Peter the Great – the legendary "Bronze Horseman". In the course of studying geological documentation of the monument's granite base, we examined the mineral composition and internal structure of granite, as well as the fragments of a pegmatite vein and veinlets found in it. 25 single-mineral samples were collected from the available microscaled shear fractures within the pedestal surface and studied by electron microscopy, electron probe and X-ray phase analysis. It was established that K-Na feldspar in the granite composition was represented by microcline, whereas micas were represented by annite-siderophyllite and muscovite. Accessory minerals included monazite, xenotime, thorite, zircon, rutile, apatite, fluorite, Ti-, Nb-, Ta-bearing minerals, uranium phosphates. The presence of topaz is characteristic of pegmatites. The revealed structural and textural features of four granite boulders in the monument pedestal, as well as mineralogical and chemical composition of their rock-forming and accessory minerals, showed the similarity of this rock to Precambrian biotite-muscovite granites and topaz-containing pegmatites (stockscheiders) of the late formation phase of the Vyborg rapakivi granite massif. The research results are considered as the basis for further geological and mineralogical study of the Thunder-Stone origin and determining the place of its separation from the primary source.

***Key words*:** Saint Petersburg; Thunder-Stone; Peter the Great; granite; rapakivi; topaz; Vyborg massif

Dear Readers! Here is one of the last publications by the honorary professor of the Saint Petersburg State University Andrei Glebovich Bulakh (*1933-2020*)*, the greatest connoisseur of natural stone in the architecture of Saint Petersburg. In his works, A.G.Bulakh sought to combine the interests of historians, architects, restorers and geologists to show the importance of accurate mineralogical and geological information in the diagnosis of stone in works of art and in historical reconstructions. By publishing this article, we pay tribute to the memory of a wonderful person, a brilliant teacher, a bright and original scientist.*

Introduction. It is known that the huge boulder Thunder-Stone, used as the material for the monument to Peter the Great ("The Bronze Horseman"), was discovered in Konnaya Lakhta near the Gulf of Finland in 1768. It is described in detail how the boulder was found, dug up, processed, installed on Senate Square and how the equestrian statue of the emperor was prepared and cast from bronze [4, 5]. It is indicated that the huge rock under the horseman is monolithic and made of Finnish granite. But both facts should be checked and clarified in order to expand knowledge about the stone decoration of Saint Petersburg and its preservation [3, 4, 15]. This is especially important in the time of 350th anniversary of Peter the Great.

The authors, with the participation of the staff of the State Museum of Urban Sculpture, had a unique opportunity to work with the pedestal of the monument, examine and photograph its condition, collect and study micro samples of the stone. For the first time, the granite was reliably diagnosed, its minerals were studied, the block structure and turns of the Thunder-Stone's blocks during the pedestal creation were established. It was revealed that the Thunder-Stone's granite clearly differs both from the vyborgites and piterlites, traditionally used in the stone decoration of Saint Petersburg, and from the facing slabs of the pavement around "The Bronze Horseman".

The structure of the pedestal. A careful examination of the monument reveals that the "rock" underneath is made up of four blocks of complex configuration [2, 8] (Fig.1). The largest block is marked as N 1, the smallest is N 4. One more block, marked as N 5, is 30 cm long and can be seen at the base of the pedestal at the border of blocks N 1 and N 2. Three types of rocks have been identified in these blocks. Firstly, the pedestal is composed mainly (about 90 %) of granite. Secondly, it contains three inclusions (xenoliths) of another rock – fine-grained granite (named so conventionally, according to the visual assessment). Inclusions are visible at the very top of block N 1, under the horseman's feet. Their shape is angular, visible dimensions are 50×30, 20×10 and 40×20 cm (Fig.2). Thirdly, in granite of the block N 1, one can see fragments of a pegmatite vein, about 50 cm thick. Not all of it is visible, since its main part is cleaved and covered by block N 2 (Fig.3). In addition, the granite contains thin pegmatite veinlets, 3-5 cm thick. They are visible in block N 1 on the left side of the pedestal, and in block N 2 at the front of the pedestal.

Different shades of color of granite blocks N 1-4 suggest that the color of the Thunder-Stone was not uniform. It is evident that, first of all, the most durable material was chosen and color shades were not taken into account. A detailed study of the orientation of granite trachytoid structure, the position of pegmatite veins and veinlets made it possible to determine from which part of the original boulder these blocks were made, how much they were processed and how exactly they were turned to give the pedestal the appearance of a "single rock" according to Falcone's idea [2]. Three-dimensional computer modeling showed that only 1/3 of the original Thunder-Stone was used for the pedestal, the total volume of which is estimated at 675 m^3, which corresponds to ca. 1,755 tons of granite [2]. But the authors have not yet been able to identify location of the remaining parts of the original boulder.

Fig.1. Block structure of the Bronze Horseman pedestal. Photo credit to G.N.Popov, 2016
1-4 – numbers of granite blocks

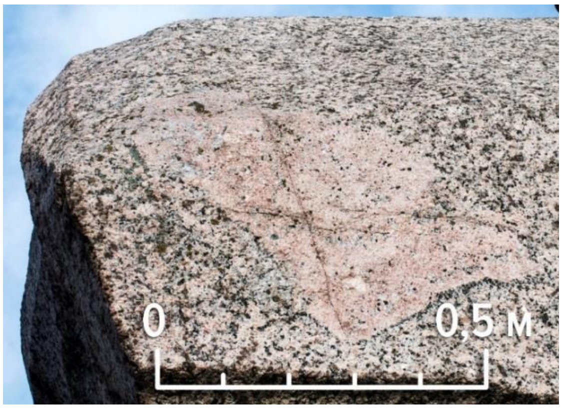

Fig.2. One of the inclusions of fine-grained granite in block N 1, left side.
Photo credit to G.N.Popov, 2020

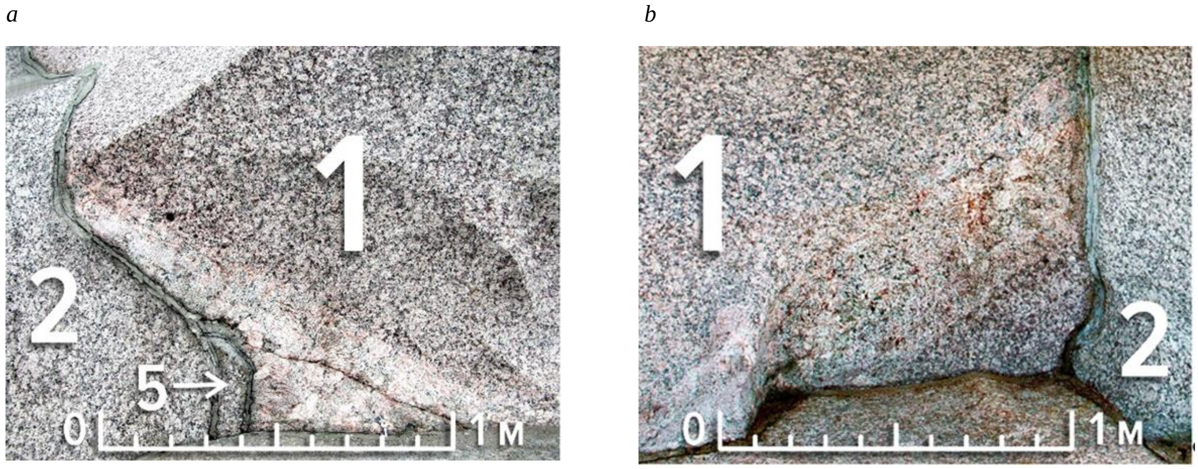

Fig.3. Pegmatite vein in block N 1. Left part of the pedestal, photo credit to A.G.Bulakh, 2002 (*a*) and right part of the pedestal, photo credit to G.N.Popov, 2019 (*b*)
1, 2, 5 – numbers of granite blocks

Granite. The granite is light pink with different shades of gray. In the block N 1, granite is clearly pink with different color variations over the block volume. In the block N 2 it is pinkish-gray, in the block N 3 – light pink, in the block N 4 – grayish-pink. The main granite minerals are K-Na feldspar, plagioclase and quartz. Mica is presented by biotite and muscovite. According to [2], the composition of granite (in vol.%) is the following: feldspar – 68 %, quartz – 29 %, dark-colored minerals (mica) – 3 %. Among feldspars, the predominant one is K-Na feldspar (approximate ratio of K-Na feldspar to plagioclase is 3:1).

The granite is coarse-grained, with an average grain size of about 1.5-3 cm. Feldspar crystals are subeuhedral, the average grain size is about 0.5-2 cm, in some places there are K-Na feldspar aggregates, 3-5 cm in size. The size of quartz grains varies from 0.3 to 0.5-1 cm. Mica crystals are euhedral, from 0.5 to 2 cm in size. The texture is trachytoid due to the parallel orientation of flattened feldspar crystals. Depending on the sections, the granite looks different in different blocks of the pedestal – in some cases it is almost massive, sometimes porphyric, sometimes clearly trachytoid (Fig.4).

Pegmatite. In the front Neva-facing part of the granite block N 1, one can see two fragments of a pegmatite vein, about 50 cm thick. According to the mineral composition (K-Na feldspar, plagioclase, quartz, biotite and muscovite), this pegmatite is a granite one. The pegmatite vein is characterized by clearly expressed contacts with the host granite, graphic and pegmatoid structure, as well as zonal texture [8]. It is composed of a parallel-columnar aggregate of large (up to 15 cm long) feldspar crystals with small ingrowths of quartz, forming a graphic structure. In the axial part of the vein, feldspar crystals do not contain quartz and are euhedral with respect to the quartz core.

Pegmatite veinlets are mainly composed of feldspar (2-4 cm across) and quartz crystal aggregates. The contacts between the veinlets and granite are not sharp. The structure is partly zonal with xenomorphic segregations of quartz nests in the axial parts of veinlet bodies. In block N 1, the veinlets are parallel to each other and stretch along the block. In block N 2, the same veinlets stretch across its elongation.

Materials and methods of laboratory research. 25 single-mineral samples, collected from the available micro-scaled shear fractures within the pedestal surface, were examined in this study. Topaz was diagnosed in two samples, collected in 2002 [8]. In 2016, five samples were taken: 1) two pieces of pink K-Na feldspar from the granite chip, 2.3×3.9 mm in size; 2) one lamella of mica, 0.5×2 mm in size; 3) another mica fragment, 2×2 mm in size; 4) many small fragments of different minerals, 2×3 mm in size; 5) two grains measuring 1.2×2 mm and 0.02 mm. In 2018, 18 mineral samples were collected (Fig.5).

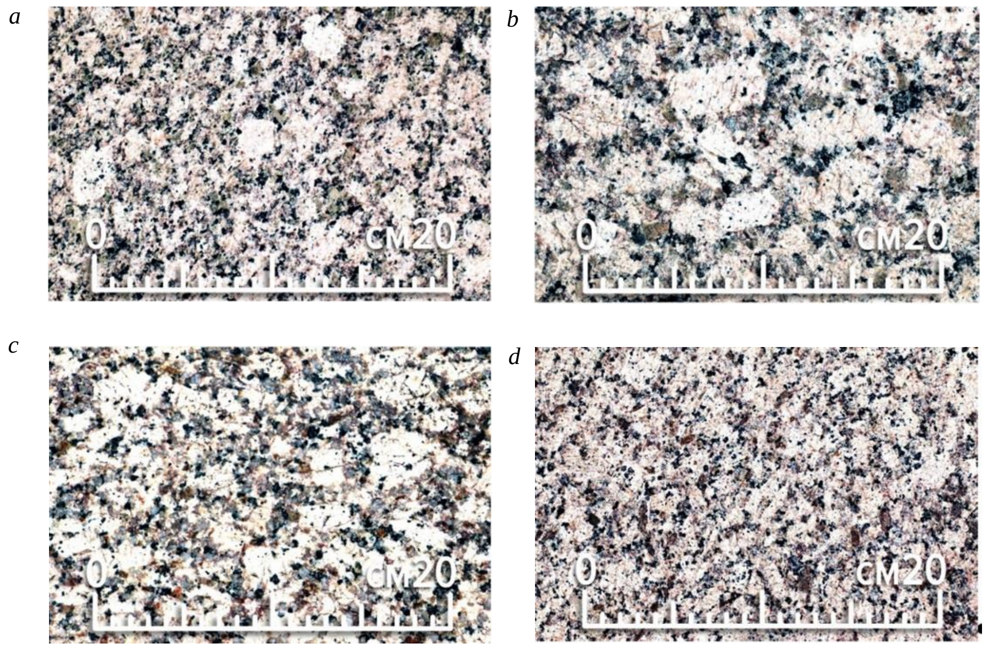

Fig.4. The structure and texture of granite as seen in different sections on the pedestal surface (*a*), in block N 1 (*b*); in block N 3 (*c*, *d*). Photo credit to G.N.Popov, 2020

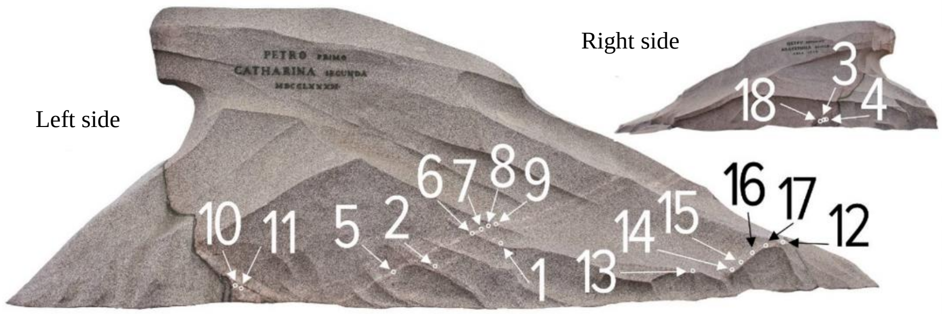

Fig.5. Sampling locations and numbers of micro-samples in block N 1 (sampling in 2018)

Samples taken in 2016 and 2018 were examined at the Research Park of St. Petersburg State University [8, 13]. The morphology of grains, their intergrowth and inclusions in them were studied in the Resource Center “Microscopy and Microanalysis” using a microscope microanalyzer Hitachi TM3000 (Japan), equipped with an energy dispersive microanalysis attachment OXFORD (UK), a system with focused electron and ion probes QUANTA 200 3D (FEI, Netherlands) and the analytical complex Pegasus 4000 (EDAX, USA). We obtained SE and BSE images of the studied samples. Electron probe microanalysis was carried out on a Pegasus 4000 energy dispersive diffractometer (SDD ApolloX, resolution at 5.9 KeV Mg Kα – 125.7 eV). The measured samples were rough and polished, covered with carbon in a high vacuum at an accelerating voltage of 15-20 kV. The degree of triclinicity of feldspar was determined by the powder method using an X-ray diffractometer UltimaIV (Rigaku), X-ray tube radiation $CuK\alpha_{1+2}$; wavelengths $\lambda_{CuK\alpha1}$ = 1.54059 Å and $\lambda_{CuK\alpha2}$ = 1.54443 Å; tube operating mode 40 kV/30 mA; sample rotation speed 20 rpm; temperature 25 °C, atmosphere – air.

Results obtained. In total, more than 20 mineral phases have been identified, 15 of them have been reliably diagnosed (Table 1).

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Table 1

Minerals diagnosed in the rocks of the Bronze Horseman pedestal

Rocks of the pedestal	Granite	Pegmatite (vein)	Pegmatite (veinlets)
Rock-forming minerals			
K-Na feldspar	+	+	+
Plagioclase (oligoclase)	+	+	+
Quartz	+	+	+
Less abundant minerals			
Biotite	+	+	+
Muscovite	+	+	+
Magnetite	+		+
Topaz		+	+
Fluorite	+		+
Accessory minerals			
Monazite	+		
Apatite	+		
Xenotime		+	
Thorite	+		
Zircon	+		
Rutile-anatase	+		+
Barite	+		+

Note. In addition to the listed minerals, Fe-, Ti-, Nb-, Ta-bearing minerals, U phosphates, TRR were found in the monument pedestal, but not precisely diagnosed. Inclusions of iron and nickel were not indicated either, as their origin in the rocks of the pedestal has not been identified.

Rock-forming minerals – include feldspars and quartz. *K-Na feldspar* has a light pink color and an almost stoichiometric chemical composition $KAlSi_3O_8$ (Table 2). In three analyses, FeO impurity of up to 1-2 % was determined in the mineral. The degree of triclinicity at the two analyzed points was 87.6 % (in granite) and 86.1 % (in a pegmatite veinlet). The mineral is substantially homogeneous and contains rare perthites composed by albite N 5-10. *Plagioclase* in the granite has a lilac-gray color and is represented by oligoclase N 15-20. Albite was found in pegmatite. *Quartz* has not been studied in the laboratory. Here are examples of chemical formulas of the indicated minerals:

Sample N 1 – $(K_{0.84}Na_{0.08})_{0.92}(Si_{3.00}Al_{1.02}O_8)$ – microcline.
Sample N 9 – $(Na_{0.84}Ca_{0.15}K_{0.01})_{1.00}(Si_{2.85}Al_{1.15}O_8)$ – plagioclase N 15.

Table 2

Feldspars (element contents normalized to 100%)

Analyses	K-Na feldspar				Plagioclase
	from granite			from pegmatite (vein)	from granite
Sample number	1	3	5	7	11
SiO_2	65.70	54.77	64.20	65.73	61.15
Al_2O_3	11.98	29.05	19.20	18.72	25.15
FeO	–	1.23	–	–	–
K_2O	14.41	14.95	16.51	15.37	09.45
Na_2O	0.92	–	–	0.18	9.85
Year	2016	2018	2018	2016	2018
Numbers of analysis points	1_1_1	12_2_6	11_1_1	5_1_1	12_2_4

Less abundant minerals. We have found mica (biotite and muscovite), magnetite, topaz, and fluorite. *Biotite* is represented by annite-siderophyllite with variable values of FeO to MgO ratio (Table 3). *Muscovite* is significantly enriched in Fe. Li was not detected in any micas.

Table 3

Micas (element contents normalized to 100 %)

Analyses	Biotite		Muscovite					
	from granite	from pegmatite (veinlets)	from granite		from pegmatite (vein)	from pegmatite (veinlets)		
Sample number	16	19	21	22	18	24	25	20
SiO_2	39.42	55.18	54.65	49.27	49.20	50.62	49.57	49.31
TiO_2	0.78	–	0.58	0.26	0.43	–	–	–
Al_2O_3	21.99	21.79	24.62	34.43	29.61	37.02	37.64	32.62
FeO	27.71	8.10	6.96	4.89	9.52	2.14	1.35	7.48
MgO	0.65	10.39	11.05	0.40	0.59	–	–	–
K_2O	9.56	4.38	10.35	10.75	10.65	9.10	10.96	10.59
Na_2O	–	–	–	–	–	1.13	0.28	–
Year	2016	2018	2016	2016	2016	2018	2016	2018
Numbers of analysis points	2_1_1	2_3_6	2_1_2	2_1_3	2_1_4	16_1_1	5_1_2	2_2_6

Examples of mineral formulas:

Sample N 16 – $K_{0.90}(Fe^{2+}_{1.68}Al_{0.82}Mg_{0.07}Ti_{0.04}Fe^{3+}_{0.02})_{2.63}(Al_{1.09}Si_{2.91}O_{10})(OH)_2$ – biotite.
Sample N 18 – $K_{0.84}(Fe^{2+}_{1.87}Al_{0.84}Mg_{0.07}Ti_{0.04}Fe^{3+}_{0.02})_{2.64}(Al_{1.10}Si_{2.90}O_{10.00})(OH_{1,86})$ – biotite.
Sample N 21 – $K_{0.85}(Al_{1.53}Fe^{2+}_{0.37}Ti_{0.03}Mg_{0.10})_{2.03}(Al_{0.48}Si_{3.52}O_{10})(OH)_2$ – muscovite.
Sample N 22 – $K_{0.88}(Al_{1.77}Fe^{2+}_{0.25}Mg_{0.04}Ti_{0.01}Fe^{3+}_{0.01})_{2.08}(Al_{0.84}Si_{3.16}O_{10})(OH)_2$ – muscovite.

Magnetite was found in two forms. It was identified in the form of flattened crystals with cleavage cracks. Based on a single analysis, it contains Cr (0.77 %) and Ti (1.37 %). Magnetite with a special morphology was found in the form of tiny spheres with a diameter of about 0.08 mm, containing impurities of Mg, Al and Si (about 3 % in total). Such magnetite spheres are encountered worldwide, and there are ongoing discussions about their origin.

Topaz was found in pegmatite veinlets in the form of single grains and in a pegmatite vein in the form of clearly visible clusters, where each individual grain varies in size from 0.3 to 2.5 mm, with an average value of about 1.5 mm. Topaz is transparent, colorless, bluish and greenish; it associates with quartz and feldspar (Fig.6). In two topaz samples we detected impurities of FeO (1.47 and 3.32 %). According to the analysis, the composition of topaz corresponds to formula $Al_{2.01}Si_{O.99}O_{4.00}(F_{1.86}OH_{0.14})$. *Fluorite* was found in granite and pegmatite veinlets.

Accessory minerals. Seven minerals were identified in microsamples. In addition, 18 more mineral phases were identified but could not be diagnosed. *Zircon, monazite, thorite and apatite* were found in granite, *xenotime* – in pegmatite. Their chemical compositions were standard. *Rutile* (and equally possible *anatase*) was found in granite and pegmatite veinlets. Some of their grains had an ideal stoichiometric TiO_2 composition, but more often they were enriched with isomorphic impurities. The presence of Nb and Ta in undiagnosed phases is worth noting, which indicates either special varieties of rutile or such minerals as titanosilicates.

a *b*

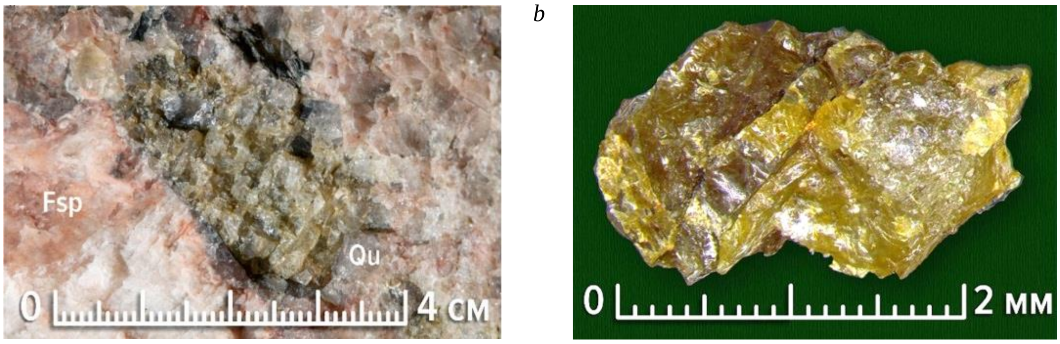

Fig.6. Topaz grains from a pegmatite vein.
Photo credit to G.N.Popov, 2020 (*a*) and S.Yu.Yanson, 2018 (*b*); Fsp – feldspar; Qu – quartz

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Uranium and copper phosphates. Five phosphates were identified, four of them were radioactive. They were found in pegmatite and pegmatite veinlets (Table 4) in the form of accumulations of very small (first microns) lamellar, tabular crystals with square or rounded outlines, as well as powder on the surface of feldspar, quartz and topaz grains. Analysis of samples N 59 and N 60 suggests that these can be torbernite and cheralite, respectively. Unambiguous identification of the indicated minerals has not been achieved.

Table 4

Phosphates of Th, U and Cu (element contents normalized to 100 %)

Analyses	Mineral phases				
	from pegmatite (veinlets)				from pegmatite (vein)
Sample number	56	57	58	59	60
P_2O_5	15.57	16.05	15.30	15.22	23.24
SiO_2	17.67	17.93	19.40	19.39	4.58
UO_2	44.05	45.29	42.75	42.69	5.91
ThO_2	0.00	0.00	0.00	0.00	45.77
Al_2O_3	10.61	10.56	11.37	11.37	3.94
MgO	4.61	4.46	5.12	5.12	0.00
CuO	3.63	3.67	3.97	3.91	0.00
FeO	1.98	2.04	2.09	2.31	4.99
CaO	0.00	0.00	0.00	0.00	11.56
K_2O	1.88	0.00	0.00	0.00	0.00
Year	2016	2016	2016	2018	2018
Numbers of analysis points	5_3_1	5_3_1a	5_3_1b	9_9_1	11_1_6

Undiagnosed minerals. According to the analytical data, samples N 61, 62, 63 and 64 (Tables 5, 6) correspond to Fe silicates and aluminosilicates, whereas sample N 65 corresponds to a special Ti oxide. The presence of Nb and Ta titanosilicate was detected in samples N 66, 67 and 68.

Table 5

Silicates and aluminosilicates of Fe and Ti (element contents normalized to 100 %)

Analyses	Mineral phases				
	from granite			from pegmatite (veinlets)	
Sample number	61	62	63	64	65
SiO_2	15.33	26.67	26.41	32.99	10.95
TiO_2	1.22	–	–	–	78.58
Al_2O_3	7.71	23.57	22.95	3.03	8.53
MgO	1.66	2.65	2.87	3.03	–
MnO	–	–	–	0.87	–
FeO	73.24	46.62	47.77	59.53	–
CaO	0.85	–	–	–	–
K_2O	–	0.29	–	0.55	–
Na_2O	–	–	–	–	1.94
Cl	–	0.20	–	–	–
Year	2018	2016	2018	2018	2018
Numbers of analysis points	12_5_1	1_1_3	16_1_3	9_3_1	9_2_1

Table 6

Titanosilicates of Nb and Ta (element contents normalized to 100 %)

Analyses	Mineral phases		
	from granite		
Sample number	66	67	68
Nb_2O_5	6.39	6.52	3.69
Ta_2O_5	18.80	14.87	7.99
SiO_2	14.73	14.57	8.22
TiO_2	47.15	52.06	69.97
Al_2O_3	2.04	22.41	1.65
FeO	10.89	9.57	8.49
Year	2016	2018	2018
Numbers of analysis points	2_2_4	3_4_1	3_4_2

Metals are represented by lamellar inclusions of nickel and iron in microcracks of feldspar crystals. The issue of the origin of such inclusions, whether they are natural or technogenic [13], remains controversial.

Discussion. First, let us pay attention to the ratio of the main rock-forming minerals, as well as structural and textural features of the Thunder-Stone. It is obvious that the volumetric ratios of quartz, feldspars and dark-colored minerals characterize the rock as biotite-muscovite K-feldspar granite. The uniform crystallinity, pronounced trachytoid texture and complete absence of rounded (ovoid) segregations of alkaline feldspar allow to exclude the similarity of this rock to the typical rapakivi granite – vyborgite (Baltic-Brown) and peterlite (Carmen-Red) – in accordance with the contemporary perception of the rocks from the rapakivi granite formation [17]. The idea of the Thunder-Stone as a “Finnish” rapakivi granite, common among historians and art experts, is apparently explained by its external resemblance to rapakivi, widely represented in the architecture of Saint Petersburg in the 18th – early 20th centuries [18].

In terms of structure and texture, the Thunder-Stone is not identical to the Olginsky boulder, located on the shore of the Gulf of Finland in the area of Konnaya Lakhta, where the former was once discovered. The Olginsky boulder is considered to be a part of the Thunder-Stone. However, this is a misperception – the boulder is composed of a completely different rock, ovoidal rapakivi granite. Three boulders on the banks of the Petrovsky Pond can neither be considered fragments of the Thunder-Stone. Observations suggest that this is also ovoidal rapakivi granite.

Secondly, the mineral composition, structure, texture, the presence of fluorite, monazite, apatite and other accessory minerals in the Thunder-Stone, as well as topaz and fluorite in pegmatites, allow us to draw attention to its similarity to coarse-grained trachytoid biotite-muscovite granites of the late magmatism phase, which occurred during the formation of the Vyborg rapakivi granite massif. This refers to biotite-muscovite granites, identified by D.A.Velikoslavinsky (1953) in the study of geological structure of the Vyborg massif and later attributed by A.M.Belyaev [1] to rare-metal biotite-muscovite topaz-bearing granites. The Kymi Massif (southeastern Finland) is given as a regional example of a geological object composed of such rocks. Trachytoid granites of this type, the so-called “even-grained rapakivi granites” of the Lappeenranta region, are described and studied in detail by Finnish researchers [14, 15, 16]. The age of the rocks in this massif is estimated as the Lower Proterozoic (1.5-1.6 Ga).

Genetic similarity of the Thunder-Stone to such rocks is also indicated by the presence of pegmatite veinlets. In terms of mineral composition and structure, they are similar to the so-called stockscheiders – topaz-bearing pegmatites, developed in the marginal zones of topaz-bearing granitoid bodies of the Vyborg massif [1]. Both in stockscheiders and in pegmatites, topaz is represented by intergrowths of tiny crystals.

In particular, the issue of topaz presence in the granite that composes the Thunder-Stone remains open. This mineral is found in biotite-muscovite granites of the Vyborg massif, and it would be important to check the similarity of the Thunder-Stone to such rock in this respect. For this purpose, it is necessary to study the stone pedestal of “The Bronze Horseman” in petrographic thin sections. For obvious reasons, it is not yet possible to carry out such study in practice.

The noted similarity of the rocks does not settle the questions of Thunder-Stone origin, but definitely directs on the way to further search for their solution. Of course, the natural outcrops of rapakivi granite in the Vyborg massif are located relatively close to the place of Thunder-Stone discovery, and the conclusion about their spatial proximity seems to suggest a conclusion about their genetic affinity. Nevertheless, it is wrong to exclude from consideration other rapakivi granite massifs, known in the mainland of Finland [20], on the Aland Islands and in other regions of Northwest Russia and neighboring countries. Moreover, the processes of destruction and movement of crystalline basement rock fragments on the Baltic shield during the last glaciation covered vast territories of Northern Europe [6, 10]. So, the noted mineralogical and petrographic similarity of rocks should be considered only as a precondition for determining the desired direction in further research. It can clearly be stated that in the future there is a need for a detailed comparative analysis between the rocks in the monument stone base, the rocks of the rapakivi granite formation and the granites of other formations in the northwestern region of Russia, Finland and Sweden [7, 9]. Examples of rapakivi granite studies [11, 12] show that for the correlation of this type of rocks it is especially important to take into account individual typomorphic features of accessory minerals.

For obvious reasons, petrochemical comparison of the rocks is impossible. Therefore, further study of "The Bronze Horseman" pedestal should focus on physiographic analysis of the compared rock structure and texture, as well as on electron-probe analysis of chemical (including isotopic) composition and age of accessory minerals, specifically, zircon. The authors recommend taking into account the following mineralogical features of the Thunder-Stone: the K content according to the results of radiometry is 6.4 %*, which in terms of K_2O corresponds to 7.4 %; the K/Na ratio is greater than 1, which is evident from the ratio of the main rock-forming minerals; the content of Fe and Mg in granite is low, which follows from a small amount of dark-colored minerals; the Fe/Mg ratio is high, which is evident from the chemical composition of biotite; the gamma activity of granite varies between 31and 38 mcR/h [8]; the content of radioactive elements is 10^{-4} for Ra and 10^{-4} for 65 Th. In granites and pegmatites of the Thunder-Stone, biotite is represented by annite-siderophyllite. At the same time, in mica from granite (Table 3) the $Fe^{2+}/(Fe^{2+} + Mg)$ ratio is 0.96, the $Fe^{2+}/(Fe^{3+} + Mg)$ ratio is 94.5/4.2/1.2, the annite/phlogopite/muscovite ratio is 65.4/2.7/31.9. The authors believe that these indicators are typical for micas from the late formation phases of the Vyborg rapakivi granite massif, the chemical composition of which is well studied [15, 19].

Conclusions. Thus, the famous Thunder-Stone, the four main parts of which make up the pedestal for "The Bronze Horseman", is a boulder of biotite-muscovite K-feldspar granite. The structure of the granite boulder is complicated by the inclusions of xenoliths of other finer-grained granites. On one edge, it is composed of pegmatite lying in granites in the form of a vein, half a meter in thickness, which is only partially preserved. Numerous pegmatite veinlets are also developed in granites. The structural and textural features of granite, its mineral and chemical composition of the rock-forming and accessory minerals, together with the same characteristics of the pegmatites developed in it, indicate their similarity to trachytoid biotite-muscovite granites and topaz-bearing pegmatites (stockscheiders) of the late formation phase of the Vyborg rapakivi granite massif, hard rock outcrops of which are known in southern Finland. The presumed age of the Thunder-Stone formation of granite and pegmatites, as well as the rocks of the Vyborg massif, is estimated as 1.5-1.6 Ga.

The article explores Thunder-Stone origin, as well as other completely unexplored aspects of its history, in particular, how it was separated from the primary rocks, weathered and moved to the coast of the Gulf of Finland, where it was found in 1768. All these questions are undoubtedly interesting for both professional historians of Saint Petersburg and for a wide range of curious and inquisitive enthusiasts. After all, the Thunder-Stone and "The Bronze Horseman" monument to Peter the Great in Saint Petersburg are a part of the historical and cultural heritage of Russia.

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Dedicated *to the memory of the geologist, rapakivi granites researcher Alexei Dmitrievich Shebanov (1968-2017).*

* Average value across 14 point measurements, spectrometer RPK-106, operator G.V.Romanov, Russian Geoecological Center, Saint Petersburg.

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