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KAMENNYE MOGILY DYKE BELT OF NEAR-AZOVIAN REGION

(Recommended by Member NAS of Ukraine I. I. Chebanenko)

Наведені структурно-геологічні, вікові, петрологічні і геохімічні характеристики дайкових порід Кам'яномогільського поясу. Одержані нові дані свідчать про те, що дайки кварцових порфірів, онгонітів і граніти масиву Кам'яні Могили є генетично спорідненими утвореннями, які слід віднести до наймолодшої на Українському щиті формації рідкіснометалевих лейкократових гранітів. Встановлено, що ці комагматичні породи виникали багаторазово (кварцові порфіри – граніти – онгоніти) і при різних геодинамічних режимах. З пегматитами, гранітами, кварцовими жилами і дайками кварцових порфірів поясу зв'язані рудопрояви флюориту, олова, тантала, ніобію, літію та інших рідкісних і благородних металів.

Приведены структурно-геологические, возрастные, петрологические и геохимические характеристики дайковых пород Каменномогильского пояса. Полученные новые данные свидетельствуют о том, что дайки кварцевых порфиров, онгониты и граниты массива Каменные Могилы являются генетически родственными образованиями, которые должны быть отнесены к самой молодой на Украинском щите формации редкометалльных лейкократовых гранитов. Установлено, что эти комагматические породы появлялись многократно (кварцевые порфиры – граниты – онгониты) и при разных геодинамических режимах. С пегматитами, гранитами, кварцевыми жилами и дайками кварцевых порфиров связаны рудопроявления флюорита, олова, тантала, ниобия, лития и других редких и благородных металлов.

In terms of the present structure of the Near-Azovian region, the Kamennye Mogily dyke Belt is confined to the fracture tectonic zone of the north-west (NW 310°) strike of the same name. The formation of the belt dykes is closely connected with this weakened, zone being of regional value in the Precambrian foundation of the Ukrainian Shield (USh) Near – Azovian block. At the present level of the erosion section of the Precambrian crystalline foundation surface this zone is a discordant (NW 310°) band of schistose, brecciated and cataclastic gneiss-migmatite rocks of the north-east strike near the Kamennye Mogily Massif.

The Kamennye Mogily Belt is about 3 km wide, and about 50 km long (Fig. 1A). One cannot judge of the true length of the belt because the dykes have been reliably mapped only at the south-eastern outskirt of the Kamennye Mogily Granite Massif and along the Vodyanaya ravine (10-12 km south-eastwards the massif). There is no doubt that the dykes are also developed north-westwards of the Kamennye Mogily Massif and strike south-eastwards, i. e. towards the Azov Sea coast. But they are overlapped there by the Cenozoic sedimentary rocks, and comparatively low thickness and substance composition of the dykes, close to enclosing rocks, do not allow their thrustworthy mapping by geophysical methods. Available structural-geological data also evidence to the fact that subvertical dykes of the Kamennye Mogily Belt have a distinct discordant position in space: they cross the enclosing rocks almost at a normal angle in a plan and at an acute angle at a depth.

The belt is mainly composed by subparallel dykes of acid composition (quartz porphyries, sometimes granite-porphyries) about 20 m thick. These dykes are confined to the central parts of the belt (Fig. 1A). Dysoriented low-thickness pegmatite and quartz veins are also observed there. Low-thickness (about 3 m) proterozoic dykes of dolerites occur sporadically in the boundary parts of the belt and beyond its limits. A stock of andesites of Triassic age testified to Mesozoic state of tectono-magmatic activization of the Kamennye Mogily is localized in the immediate proximity to the southern belt near the village of Fedorovka on the right board of the Karatysh River.

We have studied in most detail the belt dykes in the Karatysh River basin near the south-eastern frame of the Kamennye Mogily

Granite Massif (Fig. 1B). The dykes mainly crop out here in two small sublatitudinal ravines developed on the left smooth slope of the Karatysh River. They occur more rarely within the right comparatively steep slope of the river. For example, northwards of the Ukrainka village only two dykes of quartz porphyries, 6 m thick each (exposure 268–270 on Fig. 1B, 1C), are traced in a form of rock outcrops and crests. One more dyke of quartz porphyries is exposed in a little quarry distributed in the south-western vicinity of the Ukrainka village, 100 m westwards of the river bed (exp. 272). A rather thick (20 m) dyke of quartz porphyries close to the massif of granites (exp. 266) is also traced in a form of brown rock fragments on the right slope of the Karatysh slope 5 km below the dam. The same dyke is traced in the exposures 265 and 267, i.e. at a distance of about 2 km on the left slope of the river.

Thus, in the south-eastern frame of the Kamennye Mogily Massif granites one can observe about 10 exposures of quartz porphyries dykes, which total thickness is about 100 m. All the dyke bodies have the zones of hardening. The width of the dyke hardening zones in their boundary parts reaches 0.3 m. Structural geological and geophysical data, aerophotographs, as well as the field observations of the dykes, evidence for the fact that the length of certain dyke bodies of the belt makes the first dozens of kilometers. The strike of comparatively thick (5–20 m) dykes of the belt is north-western, i.e. corresponds to elongation of the massif and orientation of the Kamennye Mogily fracture controlling the dykes. Several apophyses of main dykes have the north-eastern orientation and comparatively low (about 1.5 m) thickness (Table 1). Some dyke bodies (exp. 269 and 270) have a bent, horseshoe-like form, changing its strike from NW 300° to NW 345°. The dip of most dykes is steep, close to vertical (Fig. 1C). That is confirmed by the field observation of dykes and results of profile micromagnetic survey made by the authors of the paper jointly with M. I. Orlyuk.

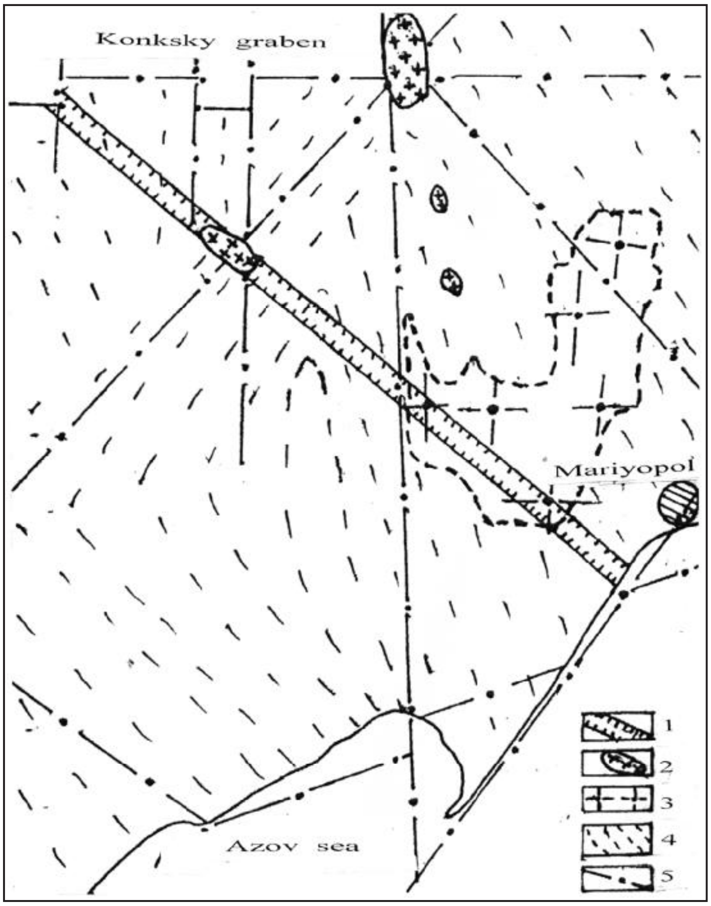

Fig. 1A. Structural-geological position of the Kamennye Mogily Dyke Belt of the Near-Azovian Region

1 – boundaries and structural geological position of the dyke belt; *2* – massives of granites of the Kamennye Mogily type; *3* – Yuzhny-Kalchik grano-sienite massif; *4* – enclosing gneiss-migmatite thicknesses of the Central-Near-Azovian series; *5* – fractured dislocations

As is seen on Fig. 1C, the area with the greatest localization of dykes as a whole is fixed by low values of regional anomalous magnetic field that, in our opinion, evidences not only for satiation with dykes, but also for high separateness, i.e. destruction of the given area of the Earth crust mainly along the Kamennye Mogily Fracture Zone, in which the "acid" magma, which formed the dykes, has been introduced. Magnetic susceptibility the of quartz porphyries as a whole is considerably lower than in gneisses and migmatites enclosed in them. Results of the profile micromagnetic survey evidence for the fact that all dyke bodies of acid composition (quartz porphyries, pegmatites, aplites) are fixed by nega-

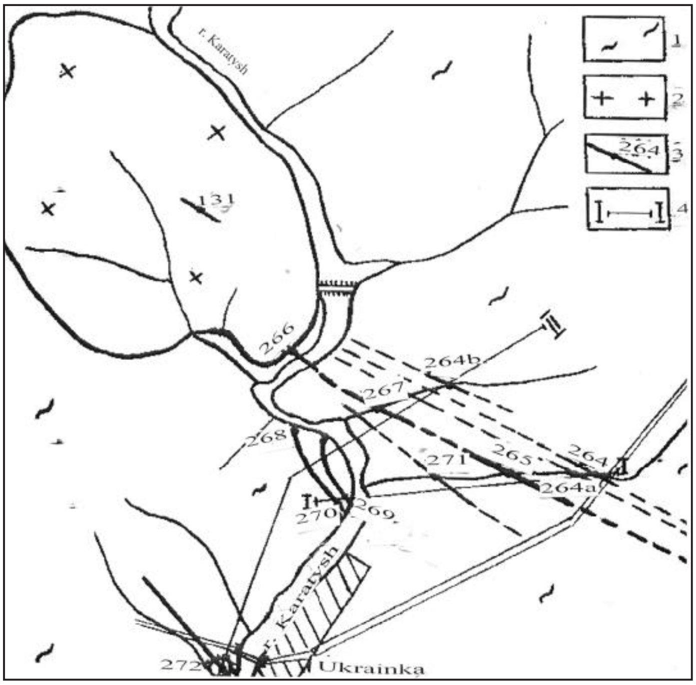

Fig. 1B. Scheme of the structure of the Kamennye Mogily Dyke Belt in the Karatysh River basin

1 – greisses and migmatites of the Central Near-Azovian series; *2* – the Kamennye Mogily Massif granites; *3* – the exposure of dykes of quartz porphyries, ongonites and their numbers; *4* – profiles of micromagnetic survey

Table 1. **Azimuthal orientation and thickness of dykes of the Kamennye Mogily Belt**

N	Numbers of dyke	Thickness of dyke (m)	Dyke strike azimuth (degree)
1	264	10	305
2	264 a	5	300
3	264 b	10	310
4	265	20	300
5	266	20	310
6	267	20	290
7	267/1	0,5	20
8	267/2	0,3	20
9	268	6	345
10	269	5	310
11	270	6	300
12	271	12	310
13	329	18	305
14	330	1,5	15
15	331	12	305

tive local, low-amplitude magnetic anomalies against a background of enclosing gneiss-migmatite thickness; in this connection the Za curve (Fig. 1C) is of saw form. Interpretation of Za curves allows, by geophysical data, to distinguish a number of additional dyke bodies overlapped by sedimentary rocks which never crop out.

One can observe directly in the granite massif the outcrops of the Precambrian rare-metal granite dykes close to Phanerozoic ongonites [1]. The weathering forms of ongonites dyke bodies often have a trough-like profile in the outcrops (Fig. 1D). The dykes are characterized by distinct crossing contacts with enclosing prophyre-like granites and contact zones of hardening. Within the Vityaz Mountain the ongonite dykes form a system of subvertical and complex branching bodies about 2.5 m thick (Fig. 1E). The thickest subvertical body of ongonites with NW 310° strike is traced over the length of 150 m and breaks through the Vityaz Mountain summit (Fig. 1F). The main dyke apophyses and other individual ongonite dyke bodies along the strike coincide rather distinctly in direction with jointing of enclosing migmatites, gneisses and granites: NW 300–310°, NE 40–45° and with sublatitudinal ones (Fig. 1E).

An analysis of structural-geological and radio-chronological data [2, 3, 7, 11, 12, 15, 17, 18–20, 22–27] demonstrates that the dykes of quartz porphyries from the Kamennye Mogily Belt were introduced before formation of the Kamennye Mogily Granite Massif, while ongonite dykes were introduced after that. The quartz porphyry dykes break through the Neoarchean gneisses and migmatites of the Central Peri-Azovian series, come right up to the massif of Kamennye Mogily granites, where they abruptly stop. Xenolites of quartz porphyries from 2x1 to 25x6 см in size by the data of V.I. Kuzmenko, V. N. Gladky, G. I. Konkov, L. G. Bernadsky and other geologists [3, 11, 15, 21] occur among granites on the right bank of the Karatysh River, in the south-eastern exo-contact of the massif. They are of grayish-ruddy colour and mainly elongated in submeriodinal direction.

A dyke contact of quartz porphyry with the Kamennye Mogily granites is exposed in the outcrop 266 (Fig. 1B); this evidences for the

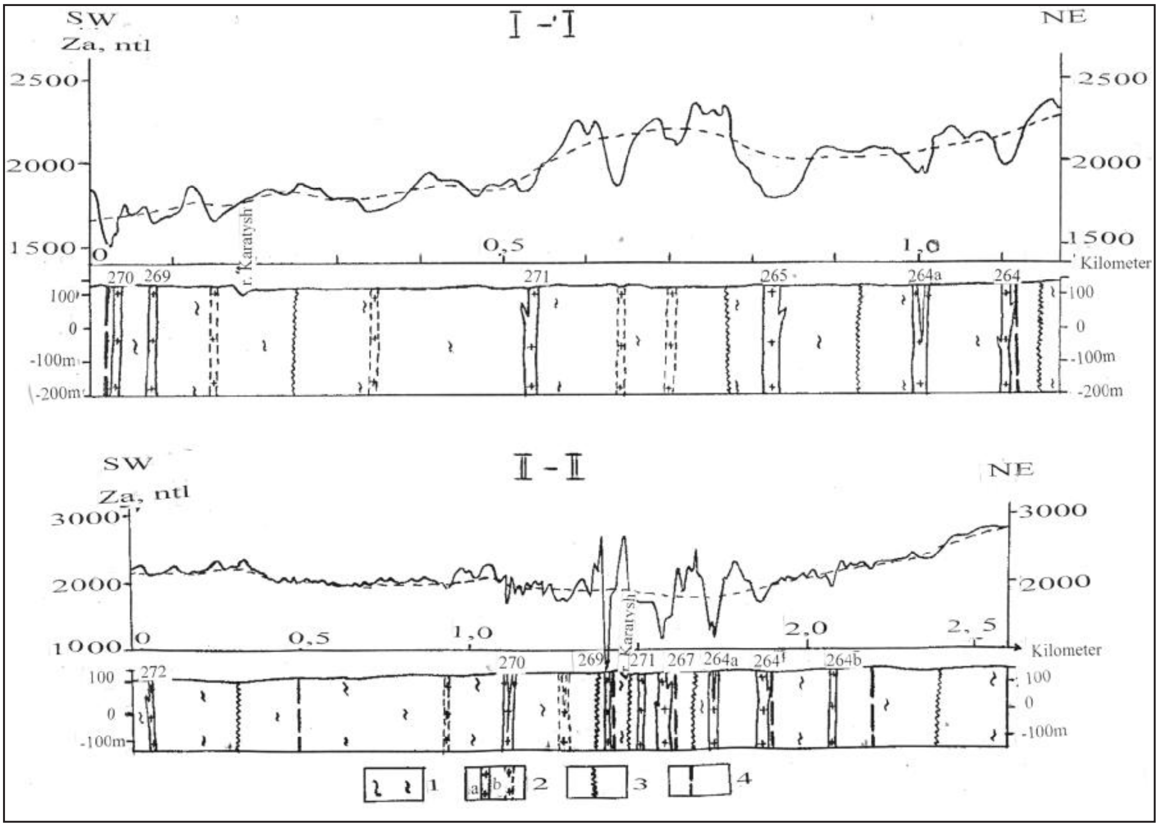

Fig. 1C. Geological-geophysical sections of the Kamennye Mogily Dyke Belt along I-I and II-II line

1 – enclosing gneiss-migmatite rocks; *2* – dykes of quartz porphyries: *a* – established, *b* – supposed by geophysical data; *3* – quartz veins; *4* – fractured dislocations

fact that granites are younger than the dykes. The described contact is sharp and intrusive, the quartz porphyry breaks on the contact, it becomes denser and acquires a brownish shade. A comparatively thick (about 20 m) dyke crops out approximately 1.2 km northwards of the vil. of Ukrainka (1 km south-eastwards of the granite massif) in a small ravine on the left bank of the Karatysh River (Outcrop 267 on Fig. 1B, 1C); two apophyses about 0.5 m thick with north-eastern (NE 20°) orientation are separated from the dyke. In this plane outcrop, distributed at the bottom of the ravine, approximately 50 m upwards the Karatysh River bed, the quartz porphyries are broken through by numerous low-thickness (about 0.3 m) veins of fine-grained pink granite of the Kamennye Mogily type. The vein strike is mainly north-western (NW 305°), and isotope K-Ag age of granite from the vein is 1150 Ma [3, 18, 19]. Quartz porphyries from the dyke 267, enclosing the granite veins, are of something "younger" age – 1070–1000 Ma because of superposed secondary processes. About 10

Fig. 1D. Tub-like weathering profile of ongonite dykes occurring among the Kamennye Mogily Massif granites on the peak of the Vityaz' mountain

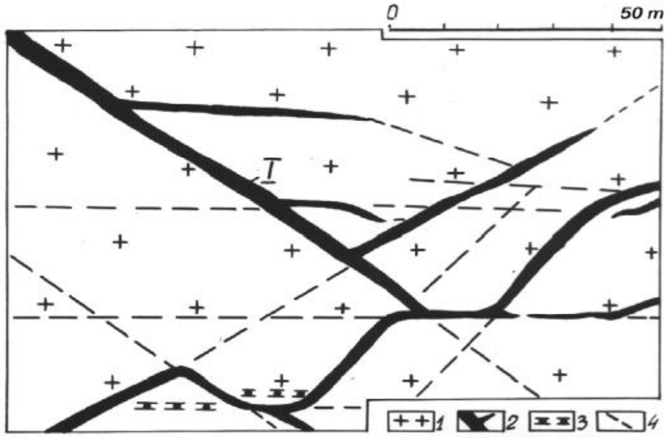

Fig. 1E. System of ongonite dykes in the Kamennye Mogily massif granites [12]

1 – biotite porphyry-like granites; *2* – ongonites; *3* – zones of cataclase and mylonitization; *4* – systems of cracks in granites


Fig. 1F. Subvertical exposure of two ongonite dykes on the peak of the Vityaz' mountain

determinations of isotope K-Ag age have been obtained by now for other dykes of quartz porphyries of the Karatysh River; these age values lie mainly in the time interval of 1420–1200 Ma [3, 7, 18, 19, 22].

The isotope age of the Kamennye Mogily granites, which break through the dykes of quartz porphyries and contain their xenolites, is 1880–1150 Ma. N.N. Zagnitko gives the isochronous date 1810 ± 15 Ma for the zirkone granites [7,19]. There are no satisfactory interpretations of such spread of digits. Mineralogical and petrographical investigations of the massif rocks evidence for considerable tectonic-metasomatic transformations of granites, that has probably told on determinations of isotope ratios calculated for the given rocks. The datings 1810 ± 15 Ma reflects the crystallization age of the granite, and lower datings display K-Ar system in the K field spats. Structural-geological, petrochemical and geochemical data evidence unambiguously for the fact that quartz porphyries and granites of the Kamennye Mogily Massif are the comagmatic formations. The dykes have been introduced in the first phase, and granites – in the second one. The ongonite dykes were formed at the third completing magmatic stage of formation of hypabyssal granitoids of the Kamennye Mogily complex. They break through granites on the Vityaz Mountain and form a net of disoriented dyke bodies (Fig. 1E).

Within the Near-Azovian block of the USh the dykes of quartz porphyries of the Kamennye Mogily Belt the granites and ongonites of the Kamennye Mogily Massif are, undoubtedly, the youngest Precambrian formations and were, apparently, formed in Neoproterozoic – 1850–1700 Ma ago.

As is known [7, 8, 10, 11, 13, 16, 20, 21] the hornblende-biotite, biotite, biotite-albite-microcline, muscovite-albite, pegmatoid and other varieties of granites are distinguished among the Kamennye Mogily Massif rocks. Pink middle- and coarse-grained porphyry-like biotite granites prevail. Their structure is hypidiomorphogranular. They consist of plagioclase (acid relict oligoclase N 12 and a later albite N 6-8) – 25–30%; two generations of microcline which forms porphyry-like secretions – 30–35%; quartz – 30–35%, biotite 205%. A later association of minerals – secondary quartz, muscovite, topaz and fluorite – is present in inconsiderable amounts. Accessory minerals are presented by cyrtolite, xenotime, zircon, apatite, sphene, thorite, cassiterite, magnetite and lithium mica (zinvaldite). Biotite granites are metasomatically changed to some extent: they are kalispared, albitized and greizenized.

Quartz porphyries of the Kamennye Mogily Belt are close in their chemical composition to granites and the rock with the same names from other regions of the USh and its frame [16]. Microscopically, they are dense, fine-grained rocks of typical pinky-brown color and porphyry-like structure. Impregnations (0–20%) are presented by quartz, plagioclase and potash feldspar which occur in various contents in the rocks (Table 2). The amount of quartz in them is from 2–5 to 15%, plagioclase, from 0 to 10%, potash feldspar – 0–11%. Porphyry impregnations are mainly absent in the contact parts of all dikes of quartz porphyries developed here. Quartz is present in impregnations in a form of separate, more or less idiomorphic, differently melted and corroded (sometimes with inflows of crystals of the main mass) grains of 0.1 to 2 mm. Quartz impregnations occur singly, and sometimes they form accumulations and intergrowths of two grains. As to their form the quartz porphyry impregnations are different – irregular, isometric, square. Quartz impregnations are often "impured" by the finest inclusions of accessory minerals, and as a rule, they are characterized by sharply expressed wavy extinction. Thin micrographic rims are sometimes seen around the quartz impregnations. Separate quartz grains are cracked by fissures filled with very fine scales of sericites.

Pragioclase is mostly observed in impregnations in glomerulo-porphyry intergrowths and is presented by andesine (rarely, by albite). It is of prismatic, tabular, sometimes, broad-tabular form. The length of impregnations varies from 0.1 to 2 mm. Plagioclase grains are often twinned poly-synthetically, but twinning bands are indistinct. Judging by the refraction index, which is less than in quartz and close to that of the Canadian balm the impregnation plagioclase is of acid composition. In the dyke of exp. 264 (Fig. 1B) the plagioclase, judging by the lower refraction index, than that of Canadian balm, has the composition of albite. Plagioclase of impregnations is richly sericitized in practically all dykes of quartz porphyries of the Karatysh River basin. Chlorite, brownish-green biotite also often develop in plagioclase, epidote and muscovite develop more rarely. Grains of ore minerals of 0.5–1 mm in size and inconsiderable impurities of biotite and hornblende are closely associated with single impregnations of plagioclase (exp. 267). Fine grains (about 0.03 mm) of green hornblende are often suboriented and confined to the jointing of plagioclase crystals. In interstices of intergrown grains of plagioclase one can sometimes notice fine (hundredth parts of a millimeter) fluorite irregular grains. Fluorite grains are isotropic, colourless, with low birefringence and weak violet shade.

Potash feldspars (PFS) in impregnations (orthoclase, sometimes microcline) are weakly pertitized, are of tabular and irregular form, grain size – about 2.5 mm. PFS impregnations also form sometimes glomeruloporphyry intergrowths and accumulations of tabular grains of 0.5–1.5 m. Some coarse grains contain fine quartz secretions, micrographically intergrown PFS. Fine impregnations of PFS often represent

Table 2. **General characteristic of mineral composition of impregnations of dyke quartz porphyries of the Kamennye Mogily Belt**

Impregnations	Numbers of dykes							
	264	265	266	267	267/3	269/1	269/6	270
Quartz	3	3	2	2	2	5	5	5
Potash spar	1	10	-	-	-	10	1	11
Plagioclase	0,5	1	5	2	10	0,5	0,5	-

completely the micrographic intergrowths with quartz or are surrounded by a thin rim of micrographic intergrowths of quartz and PFS. Polite, chlorite sericite, albite, fine-aggregate calcite, fine-scale brownish-green biotite and fluorite develop in PFS impregnations. Peripheral PFS zones often contain in abundance the finest (thousandth parts of a millimeter) grains of carbonate and fine grains of muscovite.

Structure of the basic mass of quartz porphyries is micrographic, partially micropoikilitic. The basic mass is mainly composed of fine (100^{th} parts of a millimeter) grains of PFS, micrographically intergrown with quartz. Fine scales of chlorite and brownish-green biotite are spread in the basic mass, those of muscovite, carbonate, fluorite, epidote, sericite and ore mineral grains occur more rarely. Fine xenomorphic grains of green hornblende in association with small amount of brown biotite and ore minerals are scattered in the basic mass of dyke rocks from exp. 265–267 and 270. More considerable in quantity and dimension accumulations (from 0.6 to 2 mm) of fine amphibole plates of 0.1 mm in association with a variable quantity of ore minerals and fine-scale biotite occur rarely in separate dykes, e.g. in exp. 270. Amphibole is green, with a strong shade, an elongation is positive, C: Ng = 16°. Ore minerals in the described dyke are of scale and irregular shape and are from 100^{th} parts to 0.3 mm long. In this connection the samples from dykes of the exp. 269 and 270 are characterized by high magnetic parameters, in which the values of In and X are 15–20 fold higher than in all others, as a whole, weakly magnetic quartz porphyries of the Karatysh River basin [18].

It should be noted that ore minerals are present in the basic mass of low-magnetic dykes in small quantities and spread through all the rock in a form of fine grains in association with biotite. Minerographic investigations evidence to the fact that magnetization carriers in quartz porphyries are magnetized, to different extent, magnetite and titanium-magnetite with a high Curie point.

Table 3. **Average chemical composition of quartz porphyries, ongonites and granites of the Kamennye Mogily Massif (%)**

Component	1	2	3	4	5
SiO_2	72,36	73,10	70,54	74,26	74,00
TiO_2	0,33	0,14	0,34	0,06	0,009
Al_2O_3	14,17	12,70	12,69	13,43	14,81
Fe_2O_3	1,55	1,25	1,72	0,72	0,11
FeO	1,01	1,62	3,12	1,17	0,34
CaO	1,38	1,10	1,35	0,76	0,66
MgO	0,52	0,20	0,69	0,15	0,07
MnO	0,09	0,01	0,04	0,015	-
Na_2O	2,85	2,86	2,66	3,73	4,14
K_2O	4,56	5,00	5,23	4,70	4,20
Li_2O	-	-	-	-	0,03
Rb_2O	-	-	-	-	0,09
P_2O_5	0,09	0,02	0,14	0,04	0,08
SO_3	-	-	0,05	-	0,01
CO_2	-	-	0,17	-	0,30
H_2O	1,09	0,16	0,16	-	0,43
F	-	-	0,04	0,54	0,69
п.п.п.	-	1,39	1,27	0,30	-
Total	100,00	99,53	100,20	99,88	99,97
Na_2O+K_2O	7,41	7,84	7,89	8,43	8,34
Na_2O/K_2O	0,63	0,57	0,51	0,79	1,00
K. a	0,68	0,79	0,78	0,85	0,77
al	4,60	4,14	2,30	6,58	28,48

Note: 1 – quartz porphyry along the Deli River [6]; 2 – analysis of the averaged sample of quartz porphyries of Near-Azovian area (100 samples) [18]; 3 – quartz porphyry from the dykes exposed along the Karatysh River (average from 8 analyses); 4 – biotite granite from the Kamennye Mogily Massif (av from 25 analyses) [8–13]; 5 – ongonite from dykes breaking through the granites of the Kamennye Mogily Massif (average by 4 analyses) [12, 18]. A dash – al component – coefficient of alumina content (Al_2O_3 + FeO + MgO).

Accessory minerals are mainly represented by apatite, monazite, zircon, fluorite.

Apatite (shares of %) forms rare fine grains of prismatic and irregular shape, from 100^{th} parts to 0.1 mm in size. Sometimes apatite grains form accumulations. Apatite associates with sphene and often occurs between quartz-feldspar grains of the main mass of rocks.

Sphene is partially leucoxenized and is associated with chlorite, biotite and monazite plates. Sphene also occurs in a form of aggregate, partially leucoxenized accumulations near cavities, formed at the expense of impregnations.

Fluorite (shares of %) mainly occurs sporadically and mainly in a form of low-violet grains the 100ths parts of a millimeter in size.

Sometimes quartz porphyries, e.g. in exp. 267, are crossed by quartz veins of about 1 mm. Quartz grains in them are of irregular form and often have fine-toothed limitation. Grain sizes are from 0.2 to 1.5 mm long. The extinctionof quartz grains is sharply expressed, wavy. Quartz has the finest impurities of accessory and ore minerals. Very fine grains of ore minerals of irregular form are noticed in quartz veins in single intergrain interstices.

Zircon, fluorite, monazite, sphene, rutile, apatite, malachite pyrite, ilmenite, magnetite are found in the grindings of porphyry quartz samples.

Macroscopically, the ongonites from dykes, which break through granites of the Kamennye Mogily Massif, are dence, fine-grained pinkish-grey rocks. Dykes in the quenching zones are composed by grey, bluish-grey fine-grained rocks.

When observed with a microscope, ongonites are of porphyry structure. Albite and topaz phenocrystals of 1 mm are observed among the main mass. Potash feldspar, leists of finely twinned albite, quartz, topaz, ore minerals and micas of biotite-zinwaldite type are developed in the main fine-grained mass. The appearance of microcline-pertite, fluorite, clevelandite, amazonite and muscovite is connected with superposed processes in the rock. Ortite, cassiterite, pyrochlore, columbite, xenotime, phenakite, zircon are present as accessory minerals of ongonites. According to the data of the work [12] the average mineral composition of ongonites (wt. %): quartz – 28; PFS – 27; albite – 39; mica – 3.5; fluorite – 2.5; topaz – shares of %.

Chemical composition of quartz porphyries, ongonites and Kamennye Mogily granites is presented in Table 3. All the considered rocks have acid granite composition, belong to potassium-sodium series and are rather leucocratic rocks. They are characterized by low contents of titanium, high contents of silica, alumina and potassium under its predomination over sodium. Quartz porphyries exposed in the Karatysh River basin are most close to normal granites by R. Deli and A. N. Zavarnitsky [6, 9].They have the lowest concentrations of SiO_2, Al_2O_3, Na_2O and the highest concentrations of TiO_2, Fe_2O_3, FeO, CaO, MgO, K_2O, P_2O_5 among the rocks under consideration. Under these conditions the amount of K_2O in them exceeds almost twice the amount of Na_2O. It should also be noted that concentrations of silica, alumina, fluorine and alkali as a whole increase regularly from old quartz porphyry to younger ongonite while concentrations of TiO_2, Fe_2O_3, FeO, CaO, MgO, K_2O, P_2O_5 decrease, that is illustrated in Fig. 2A.

Ongonites are the most leucocratic rocks of the described series. In respect of petrochemistry they are the rocks oversaturated by silicic acid (SiO_2 – 74%), subalkali ($Na_2O + K_2O >$ $> 8.1\%$) rocks. In contrast to genetically relative enclosing granites, they are characterized by lower concentrations of Ti, Fe, Mg, Ca, P oxides and higher concentrations of Si, Al, Na oxides. Concentrations of K_2O and Na_2O in ongonites are approximately equal, K oxides prevail over Na oxides in the central parts, while in the contact parts vice versa, Na oxides prevail over K oxides, that makes Proterozoic ongonites of the Kamennye Mogily Massif closer to Phanerozoic ongonites of Mongolia and Transbaikal region [1]. The most important peculiarity of topaz-bearing ongonites from the

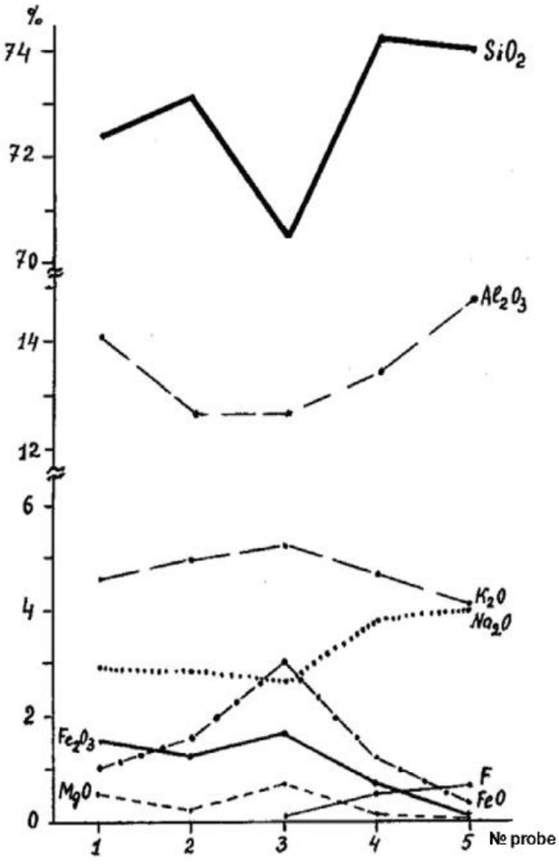

Fig. 2A. Change of contents of chemical compositions of the Kamennye Mogily Massif granites and genetically relative of the dyke rocks. Numbers of analyses correspond to the numbers of Table 3

Table 4. **Average content of chemical elements in quartz porphyries, ongonites and granites of the Kamennye Mogily Massif (g/t)**

Element	1	2	3	4	5	6	7
K (%)	3,78	4,15	4,34	4,38	4,06	3,82	3,49
Na(%)	2,11	2,10	1,97	2,00	1,95	2,66	3,06
Ca (%)	0,98	0,78	0,96	0,89	0,77	0,69	0,47
Mn	600	260	525	600	350	260	245
Ni	8	4,5	4	4	2	1	2,1
Co	5	1,8	1,8	2	1	1	1
Ti	2300	1800	4250	4355	600	100	104
V	40	3	6	4,5	1	1	2,8
Cr	25	8	8	10	1	1	8,3
Mo	1	3,2	3	1	1	1	0,7
W	1,5	2	2	2	3,5	3,5	3,5
Zr	200	500	780	935	245	122	40
Nb	20	130	52	75	54	63	333
Ta	-	-	6	8,6	6,5	7,9	37,3
Cu	20	10	25	25	35	38	12,8
Pb	20	54	40	41	44	68	183
Ag	0,05	0,11	0,05	0,05	0,06	0,06	0,04
Zn	60	70	70	70	73	64	85
Sn	3	14	14	5	10	20	100
Ga	20	32	25	25	27	36	51
Ge	1,4	1,4	1	1	1,1	1,1	8
Y	34	84	63	60	90	146	120
La	60	68	70	77	25	34	35
Ce	100	122	122	120	152	120	61
Sr	300	31	120	120	13	63	3,9
Ba	830	340	325	265	298	63	100
Pb	200	433	585	600	324	610	792
Li	40	25	21	20	58	138	283
Cs	5	3	3	3	3	-	-
Tl	1,5	3	3	3	-	-	4,4
B	15	3,8	3,8	3,8	20	20	-
Be	5,5	5,4	2	4	6,7	8,8	5,6
Sc	3	10	10	10	-	1	6,3

Note: 1 – average content of trace elements in the acid rocks of the Earth's crust by A.P. Vinogradov [5]; 2 – analysis of the averaged sample (100 samples) of quartz porphyries of the Near-Azovian region [18]; 3 – quartz porphyry of the Kamennye Mogily Belt, the Karatysh River (average by 6 analyses); 4 – quartz porphyry, Vodyanaya ravine (average by 7 analyses); 5 – mesocratic granite from the Kamennye Mogily Massif [1, 8]; 6 – leucocratic granite from the Kamennye Mogily Massif [8–13]; 7 – ongonite (average by 3 analyses).

Kamennye Mogily area is high content of alumina (coefficient al[1] = 24.48) and comparatively high concentrations of fluorine.

The above individual features of chemism of the considered rocks are presented on classification diagram [1], where quartz porphyries of the Karatysh River basin are distributed in the field of normal granites, and granites and ongonites of the Kamennye Mogily massif – in the field of families of subalkali leucogranites (Fig. 2B).

Average contents of trace elements in quartz porphyries, granites and ongonites of the Kamennye Mogily Massif are given in Table 4, and some their ratios – in Table 5. A comparison of average concentration values of trace elements in the described rocks with their average contents in acid rock by A. P. Vinogradov [5] shows that quartz porphyries granites and ongonites, as a whole, are enriched by W, Zr, Ga 1.5–2 times; Pb, Y, Rb, Tl, Sc – 2–3 times; Nb, Ta, Sn, Li – 3–30 times. Mo, Cu, Ag, Zn, Ge, La, Ce, B are found in contents close to the clark ones. They are approximately twice impoverished with Mn, Ni, Co, T, Cr, Ba, Cs. V and Sr are noticed in them in considerably lower (approx. 10 times) concentrations. Consequently, metallogenic specialization of quartz porphyries, granites and ongonites, normalized in respect of regional clarks, is determined by contents in them of Ta, Nb (2.6–16.7 clarks), Sn (1.7–33.3), Zr (204), Pb (2–9.1), Y (1.8–3.5), Rb (1.6–4), Sc (2.2–3.3), and leucocratic granites and ongonites (besides) – Li (3.5–7) and Be (1–1.6).

An analysis of geochemical peculiarities and chemical compositions (Table 3–5) of genetically bound series of rocks (quartz porphyries-granites-ongonites) also evidence to some differences between them. Thus, it is important to find out how trace element concentrations vary in the process of evolution of magmatic melt, of which the Kammennye Mogily complex rocks were formed, what changes are observed in the process of their partial metasomatic transformation. First, turn to the figures given in

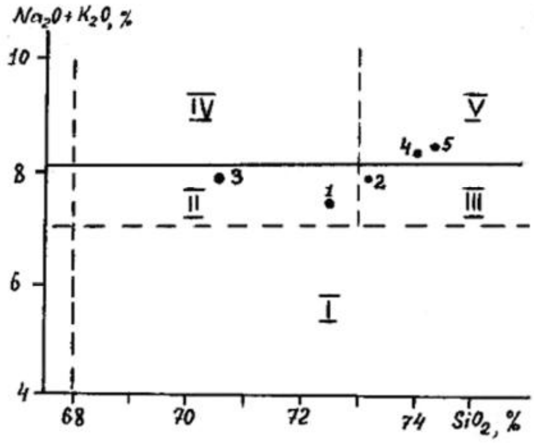

Fig. 2B. Position of granites of the Kamennye Mogily Massif and genetically relative dyke rocks in coordinates SiO_2 – ($Na_2O + K_2O$)

I – family of low-alkali granites; II – family of normal granites; III – family of leucogranites; IV – family of subalkali granites; V – family of subalkali leucocratic granites

Table 5. **Ratio of some elements in the dykes of quartz porphyries, ongonites and granites of the Kamennye Mogily Massif**

	Rocks	K/Na	K/Rb	K/Ba	Ca/Sr	Ba/Sr	Ba/Rb	Rb/Sr	Ti/Zr	Ti/V	Co/Ni	V/Cr	Zr/Nb	(La+ + Ce)/Y
1	Granites (average) [5]	1,8	189,0	45,5	32,7	2,8	4,1	0,7	11,5	57	0,6	1,6	10,0	4,7
2	Quartz Porphyries of Near-azovian area (average) [18]	2,0	95,8	122,0	251,6	11,0	0,8	14,0	3,6	600	0,4	0,4	3,8	2,3
3	Quartz porphyries of the Karatysh River	2,2	74,2	133,5	80,0	2,7	0,6	4,9	5,5	708	0,5	0,8	15,0	3,0
4	Quartz porphyries Vodyanya Balka	2,2	73,0	165,3	74,1	2,2	0,4	5,0	4,6	963	0,5	0,5	12,0	3,3
5	Mesocratic granite Kamennye Mogily	2,1	125,3	136,2	592,3	22,9	0,9	25,0	2,5	600	0,5	1,0	4,5	2,0
6	Leucocratic granite Kamennye Mogily	2,1	62,6	606,3	109,5	1,0	0,1	9,7	0,8	100	1,0	1,0	1,9	1,0
7	Ongonites, Kamennye Mogily	1,1	44,1	349,0	1205,1	25,6	0,1	203,0	2,6	37	0,5	0,3	0,1	0,8

Tables 3 and 4. They show that in the melt from which quartz porphyries, granites and ongonites are formed; Si, Al, Na, W, Nb, Ta, Pb, Zn, Sn, Ga, Ge, Y, Li, Rb, F were accumulated in the process of the melt evolution. And vice versa, Ti, Fe, Ca, Mg, K, Mn, I,Co, V, Zr, La, Sr, Ba Sc concentrations decreased as a result of the increase of acidity, alumina content and alkalinity in the rocks. Peculiarities of accumulation and decrease of concentrations of some trace elements (Rb, Nb, Sr, Li, Sn, Zr, Be) in the process of evolution of magmatic melt are illustrated on Fig. 2C.

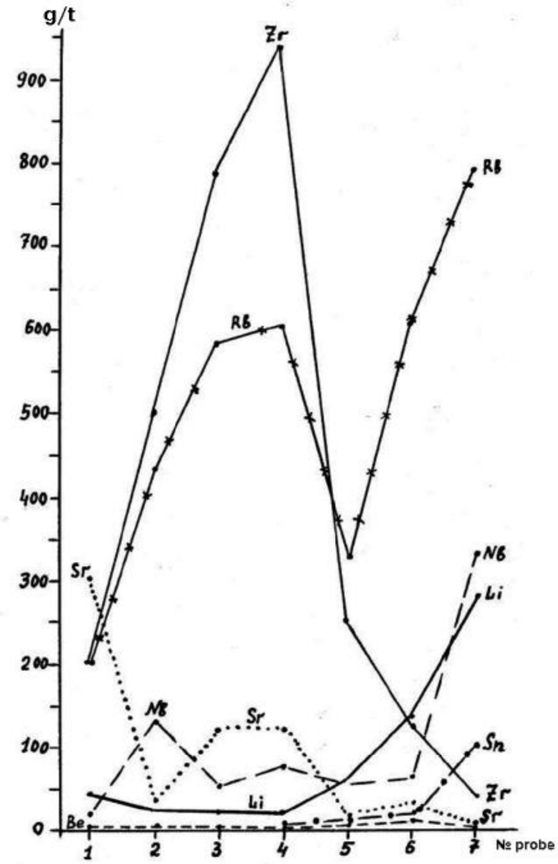

Fig. 2C. Variation diagram of the change of contents of rare elements in the quartz porphyry, ongonite and granite dykes of the Kamennye Mogily Massif. The numbers of samples correspond to the numbers in Table 4

Quartz porphyries compared with granites of the Kamennye Mogily Massif contain something higher amounts of K, Ca, Mn, Ni, Co, Rb, considerably higher amounts of Ti (10 times), Sc (10), Cr (9), V (45), Mo (3), La (2.5), Sr (2), Ba (2), approximately similar concentrations of Nb, Ta, Pb, Ag, Ce, Zn, Ga, Ge and lower concentrations – W (2), Cu, Sn, Y, Li, B, Be. As to contents of elements-impurities the quartz porphyries are most similar to mesocratic, and ongonites to leucocratic granites of the Kamennye Mogily Massif.

As to granites, more young and leucocratic ongonites are more enriched by Sn, Ge, Se, Cr – 6-7 times, Nb, Ta – 5.5 times; Pb, Li, V – 3 times; Ga and Rb – 2 times, Na – 1.5 times. Ongonites are impoverished with Sr (9 times), Zr (4.5),Ti (4),Cu (3), Ce (2), Mn, K, Ca. Ni,Co, Mo, W, Ag, Zn, Y, La, Ba, Be are present in them in similar concentrations. Consequently, metallogenic specialization of ongonites is determined by high concentrations of Nb, Ta (Nb/Ta = 9–20), Sn, W, Pb, Ge,Sc, Rb, Li, F and other elements-impurities in them. The above geological-chemical data permit considering ongonites the intrusive hypabyssal rocks, changed by autometasomatic processes. Comparatively high concentrations of Nb, Ta, Sn, Li, Rb, Be, F in them evidence that they should be related to rare-metal subvolcanic rocks of Li-F type, by V. I. Kovalenko [1].

The found out regularities of elements-impurities accumulation in the described rocks can also be established rather positively by the relations of conpled ratios of a whole number of elements presented in Table 5. The ratios K/Rb, K/Ba, Ca/Sr, Ba/Sn, Ba/Rb, Rb/Sr, Ti/V, Zr/Nb proved to be most informative. Under these conditions the quartz porphyries, granites and ongonites are distinguished by the ratios of rare lythophylic elements (Sr, Ba, Rb). In particular, the contents of silicic acid, alumina and alkali in granites and ongonites, i.e. in the final derivates of magmatic melts, being increased, the values of paired ratios K/Ba, Ca/Sr, Ba/Sr, Rb/Sr increase as a whole, while those of K/Na, K/Rb, Ba/Rb, Ti/V, Zr/Nb considerably drop (Table 5).The rocks under consideration are also distinguished by the ratio K/Rb which serves a criterion of the depth of the rocks formation. Following this criterion the quartz porphyries and mesocratic granites are the most deep-seated rocks, while leucocratic granites and ongonites are less deep-seated ones. A decrease in the values of K/Rb ratio proceeds in this direction that is in rather good agreement with available structural-geological notions.

So, the structural-geological, age, petrological and geochemical data evidence for the fact, that the quartz porphyries, granites and ongonites of the Kamennye Mogily Massif are genetically relative formations which belong to the youngest Precambrian formation of rare-metal leucocratic granites on the USh. The dyke bodies and granite massif are, unfortunately, comagmatic, they have been formed from a single and evolving with time magmatic focus. These rocks are differentiates of the single magma, which enclosing was not a one-act process, but proceeded with several impulses and in different geodynamic conditions. For example, the formation of dykes of quartz porphyries of the Kamennye Mogily Belt, in our opinion, occurred in the conditions of general upheaval of the described plot of the Earth crust, its expansion and breaking that was determined by the intrusion of the abyssal magmatic diapir in lower horizons of the Earth crust. The Kamennye Mogily Massif was, probably, formed under the conditions of descending tectonic movements of the Central Near-Azovian Region. As a result of these movements the upper parts of the Earth crust underwent a relative compression and, consequently, were low-permeable for the fissure magmatic injections. Probably, that is why the comparatively differentiated granite magma from intermediate magmatic foci intruded only in the structure point of intersection of large fractured zones with formation of a northwardly extended massif. A new upheaval of the Earth crust, its extension and fracturing characterize the rare-metal dykes of ongonites and pegmatites intruded here. Consequently, the quartz porphyries, ongonites pegmatites dykes and granite massif as a whole can serve as an indicator of geodynamic conditions and change of the tectonic field of stresses which existed at certain stages of evolution of the fractured tectonic zones to which they are confined.

The intrusion of the dykes and the Kamennye Mogily Massif took place in the Riphean [14]. They have intruded from independent, continuously evolving magmatic foci enriched with volatile components and rare elements (Ta Nb, Zr, Sn, Li, F etc.) connected with them. The forming of these rocks mainly proceeded in the structure points, during the platform period, at the stage of existence of the comparatively thick and mature ("granitized") Earth's crust of continental type. Quartz porphyries, granites and ongonites were differently subjected to metasomatic transformations which intensity was, probably, intensified by the final stages of their formation. The appearance of metasomatites and greisens is connected here with arrival of ore-bearing fluids which penetrated to the upper areas of the Earth's crust along the zones of abyssal fractures and structural points. Their penetration was stimulated by the abyssal heat and mass flows, which proceeded from the same foci.

The above data prove that one can directly find the ore manifestations and deposits of fluorite, tin, tantalum, niobium, lithium and other rare and noble metals under the unfavorable tectonic conditions with hydrothermally and metasomatically changed granites of the Kamennye Mogily Massif and its Belt dykes.

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