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Prospects of the Malo-Chipiketsky quartz-bearing zone for quartz raw materials of high quality

L.Kh. Galiakhmetova[*]*, N.G. Bydtaeva, A.E. Nepryakhin*

Central Research Institute of Geology of Industrial Minerals (CNIIgeolnerud), Kazan, Russian Federation

Abstract. The article discusses the prospects of the Malo-Chipiketsky zone in the southern part of the Patomsky quartz-bearing region of the Baikal province, as a potentially probable new raw material base for granular and transparent quartz in the east of the country. The assessment of the area prospects was carried out according to the algorithm developed by FSUE TsNIIgeolerud for studying quartz objects, which includes a set of the most effective methods for assessing quartz raw materials, quartz concentrates and products from them. The research results showed high efficiency of the algorithm. The studies made it possible at the stage of prospecting to expressly, with a high degree of probability, sort out objects according to the quality of raw materials, identify ore-formation types of quartz and outline possible directions for the use of raw materials. The results were used in the selection and contouring of promising sections of quartz veins to assess the predicted resources of the selected ore-formation types of quartz.

Keywords: Patomsky quartz-bearing region, algorithm for studying quartz objects, quartz raw material, typomorphic quartz showings, ore-formation types

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Introduction

In the world practice, natural quartz raw materials remain the main strategic source for obtaining high-purity quartz products (concentrates, micro- and nanopowders) for high-tech industries. All quartz products of varying degrees of chemical purity are the basic components of semiconductor, optical, lighting, and other critical industries (Aksenov et al., 2012; Bur'yan et al., 2007).

The mineral resource base of quartz raw materials in Russia includes deposits of piezoelectric quartz, rock crystal, granular, transparent and opaque (milky white) vein quartz and quartzite. The need for piezoelectric quartz and rock crystal is currently virtually absent due to the replacement of natural raw materials with artificial analogues. The main sources for obtaining high purity quartz concentrates are granular and transparent vein quartz with the leading role of granular quartz (Aksenov et al., 2015). The main reserves and production of granular quartz are concentrated in the Ufaleisky quartz-bearing region of the Ural province.

This article discusses the prospects of the Malo-Chipiketsky zone in the southern part of the Patom quartz-bearing region of the Baikal province, as a potential object of granular and transparent vein quartz, expanding the mineral resource base of quartz raw materials in Russia. The work carried out by the employees of the former All-Russian Research Institute for the Synthesis of Mineral Raw Materials under the direction of A.G. Malyshev (1985-94) in the basin of the upper reaches of the river B.Patom and watersheds of adjacent basins. The prospectivity of the area is proved; a predictive assessment of the territory for quartz raw materials is given. But the insignificant extent of the geological and technological study required more comprehensive geological and geological and technological studies of quartz raw materials and its enrichment.

In 2017, under the state contract with the Federal Agency for Subsoil Use (Rosnedra), prospecting was completed in the southern part of the Patomsky quartz-bearing region, during which data were obtained that indicate the prospects for identifying new industrial facilities within the Malo-Chipiketsky quartz-bearing zone.

Research methods

The studies were conducted according to the previously developed by FSUE TsNIIgeolerudud algorithm for studying quartz objects, which includes a set of the most effective methods for assessing quartz

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[*] *Corresponding author: Lillya Kh. Galiakhmetova*
E-mail: gal-lilia@mail.ru

raw materials, quartz concentrates and products from them (Aksenov et al., 2015). The algorithm includes three blocks: I – geological study of quartz objects and natural quartz raw materials, II – development of an optimal technological scheme for enrichment of raw materials, obtaining and evaluating the quality of deeply enriched quartz concentrates, III – a set of methods for producing finished products (glass) in laboratory conditions, the closest to industrial, and methods for assessing its quality.

The first two blocks allow the quality of raw materials to be determined at the stage of prospecting, to predict possible directions for its use, to adjust enrichment schemes for obtaining high pure quartz concentrates, and to discard refractory raw materials. Positive results are the basis for the final stage (block III) of research with the receipt of finished products.

According to the algorithm, the first stage of research included field work and analytical studies of ordinary samples by the methods of mineralogical analysis, atomic emission and mass spectrometry with inductively coupled plasma, determination of light transmission coefficient, electron paramagnetic resonance, scanning electron microscopy and X-ray diffraction analysis. Field methods included a visual study of quartz veins, their parameters, the nature of the veins contacts with the host rocks, the presence and types of penetrating impurity mineral components and the degree of their development, the visual purity of the quartz itself, granulometry, as well as the study of the vein-containing complex. At the second stage, a technological assessment of the enrichment of quartz raw materials was carried out on laboratory technological samples in the Analytical and Technological Certification and Testing Center of the Central Research Institute of Geology of Industrial Minerals (CNIIgeolnerud) and on small technological samples on the experimental industrial line of Kyshtymsky GOK OJSC. The quality of the obtained concentrates was evaluated in accordance with the applicable specifications and standards of Russian and foreign manufacturers.

Results

The Baikal quartz-bearing province has great prospects for the resource base of granular and transparent quartz. The most promising is the Patomsky quartz-bearing region (Malyshev, 1987), which is located in the inner part of the arcuate Baikal-Patomsky fold-thrust belt north of the upper river B. Patom. From the north and east, the region is surrounded by an arc-shaped zone of uplifts, from the north-west and southeast it is limited by faults of the north-east direction. The Little Chipiketsky quartz-bearing zone is located in the southern part of the Patomsky quartz-bearing region and represents a suture shear zone with a set of corresponding structures (thrusts, domes, shears made by blastomilonites, blastocataclazites).

As a result of prospecting on the area of the Malo-Chipiketsky quartziferous zone, in addition to the previously identified quartz occurrences, more than 200 veins and their collapses were discovered. Quartz veins are concentrated in two tectonic blocks – the western Khaverginsky and the eastern Chipiketsky, separated by the Bugarikhtinsky fault of submeridional strike. Based on the morphostructural analysis carried out according to the well-known technique (Volchanskaya, 1990), a series of dome-ring structures of different rank and shape was identified on the area (Bydtaeva et al., 2018). Quartz veins are confined to these structures, to the annular and arc faults bounding them, to linear shear-overthrusts and vortical overthrusts.

Housing-bearing rocks belong to the Khaverginsky and Bugarikhtinsky formations of the Ballaganakh subseries of the Middle Riphean.

The Khaverginsky housing complex is highly diverse: shales with various petrographic-petrochemical and geochemical features predominate, interbedded with quartzites, quartzite-gneisses. The main mineral association of schists – biotite-muscovite – indicates the transformation of the host rocks under the conditions of the chlorite-muscovite subfation of the green shale facies to the epidote-amphibolite with the appearance of paragenesis: garnet+muscovite+biotite+quartz. Dynamometamorphic rocks are widely represented, which are characterized by structural heterogeneity, banded-lenticular and spotted appearance, the presence of metasomatic transformations, microporphyroblastic isolations. Brecciated rocks, as well as milonites, phillonites, blastomilonites, are noted. As a result of intensively manifested superimposed tectonic deformations, the Malo-Chipiketsky zone acquired a complex integumentary-folded structure with wide development of thrust structures. In this case, the rocks of the Khaverginsky Formation were pushed onto the Bugarikhtinsky Formation.

For metamorphic-hydrothermal deposits, which include deposits of quartz raw materials, the initial primary sedimentary rocks are considered as sources of matter and ore-forming fluids.

For the Khaverginsky complex, the compositions of mica schists fall into the fields of pelitic and aleuropelitic mudstones, pyrophyllitic, less often weakly carbonate and weakly ferruginous siallites. The initial compositions of chlorite and amphibole-containing schists are assigned to graywack siltstones, carbonate and ferruginous siltstones. It is known that pelitic sediments contain pore solutions with a high content of silica in an increased amount. Metamorphic transformations of the source rocks, mainly of the pelitic composition, lead to the release of preserved pore solutions containing silica, followed by its deposition in the areas of shales. The presence of extended thrusts within the Khaverginsky formation created favorable conditions for the screening of solutions, and the presence of carbonaceous shales in the composition of the formation apparently facilitated the deposition of a number of chemical elements from quartz-forming solutions, thereby ensuring the purity of quartz.

The Bugarikhtinsky complex is characterized by a predominance of plagiogneiss and quartzite with a subordinate role of shale. These are high siliceous rocks with reduced alkali content. The ubiquitous presence of pomegranate in the mineral association indicates an increased degree of metamorphism of the rocks of this complex. The initial rocks of plagiogneisses and quartzites of the Bugarikhtinsky complex are characterized as arkoses and polymict subarcoses, as well as graywack sandstones or medium-basic tuffites. The initial rocks of this composition are characterized by a reduced water content in pore solutions. During their metamorphic transformations, water fluids containing dissolved silica are released and deposited in tectonically prepared areas (shale zones). But the volume of the released fluid, based on the composition of the primary rocks, is small compared to the rocks of the Khayverginsky complex, therefore, the process of quartz formation is limitedly occured in the rocks of the Bugarikhtinsky complex.

First stage. A field study of the vein quartz of the Malo-Chipiketsky quartz-bearing zone showed its heterogeneity in terms of texture and structural features and material composition. The most widespread veins are folded by unevenly dynamometamorphosed quartz. The veins of granular quartz of a medium-fine-grained structure and primary crystalline quartz of a giant-grain structure are also distinguished (Bydtaeva et al., 2018; Galiakhmetova et al., 2019).

Quartz veins, composed of uneven-grained dynamometamorphized quartz, are confined mainly to gneiss-carbonaceous-shale rocks of the Khaverginsky formation. Veins are lenticular, rarely slab-shaped, lengths from 20 to 70 m and thickness 2-5 m. The largest veins reach 130 m with a thickness of 3-3.5 m. The veins are composed of light gray quartz with transparent and translucent grains of irregular shape from 1-10 mm to 2-3 cm in size.

The veins of granular quartz are confined mainly to quartzite-gneiss rocks of the Bugarikhtinsky Formation. Gently sloping, sub-consonant bedding of veins with is characteristic with a fall in the northern rumbas at angles of 10-30°. The veins are predominantly lenticular in shape; plate-shaped bodies are less common. Lenticular veins reach a length of 40-50 m, having a thickness in bulges to 5-7 m. The veins are composed of white, light gray quartz with transparent and translucent grains close to an isometric shape 1-5 mm in size.

Gigantic grained primary crystalline quartz is distributed sparsely; it composes low-thickness veins of small sizes. Macroscopically, quartz looks like confluent with indistinct outlines of individuals, composed of grains that are heterogeneous in transparency. With open cracks, quartz is broken into blocks of irregular shape. Healed cracks are represented by a system of subparallel extended zones in which gas-liquid inclusions are concentrated.

Quartz samples, which most fully characterize the structural and textural features of the selected types, were studied by scanning electron microscopy (SEM), since the study of the surface morphology of chips allows solving the genetic problems of quartz deposits and the technological aspects of evaluating quartz raw materials (Belkovsky et al., 1999).

On the fractograms of scanning electron microscopy, the surfaces of chips and cracks of various types of quartz significantly differ from each other. Recrystallization and regeneration sites of single small grains at the contact of larger ones were found in uneven-grained dynamometamorphosed quartz (Fig. 1a). Granular quartz is characterized by a homogeneous structure (Fig. 1b). Gigantic -grained primary crystalline quartz differs from the others by its perfectly smooth microrelief, on the surface of which fragments of the matrix are observed, held by a static charge and indicating the internal stress in the crystal (Fig. 1c).

The boundaries of quartz grains are areas of fluid infiltration and hydrothermal solutions, in which predominant redeposition of the substance occurs. Fracture surfaces often have a microporous structure or are covered with natural etching pits, which are pyramids with a pointed peak. Etching figures are noted in granular medium-fine-grained and uneven-grain dynamometamorphized quartz. In granular quartz, the degree of dissolution is insignificant (Fig. 1d). The grains of uneven-grained dynamometamorphosed quartz, in which the fracture surfaces are completely covered by etching pits and pores, were subjected to the most intensive dissolution (Figs. 1e, 1f). The latter are sites of localization of gas-liquid inclusions.

Despite the fact that quartz is one of the purest natural substances, it contains impurities that are subdivided according to the nature of their quartz incorporation into mineral, gas-liquid, and structural.

The largest amount of mineral impurities was found in uneven-grained dynamometamorphized quartz, in which iron hydroxides, muscovite, albite, chlorite, and biotite are present in decreasing order, magnetite, pyrite, ilmenite, and graphite are found (Fig. 2a). Muscovite, iron hydroxides, biotite, albite, chlorite, sericite, rutile, and magnetite comprise the bulk of inclusions in giant-grained quartz (Fig. 2b). Granular quartz is characterized

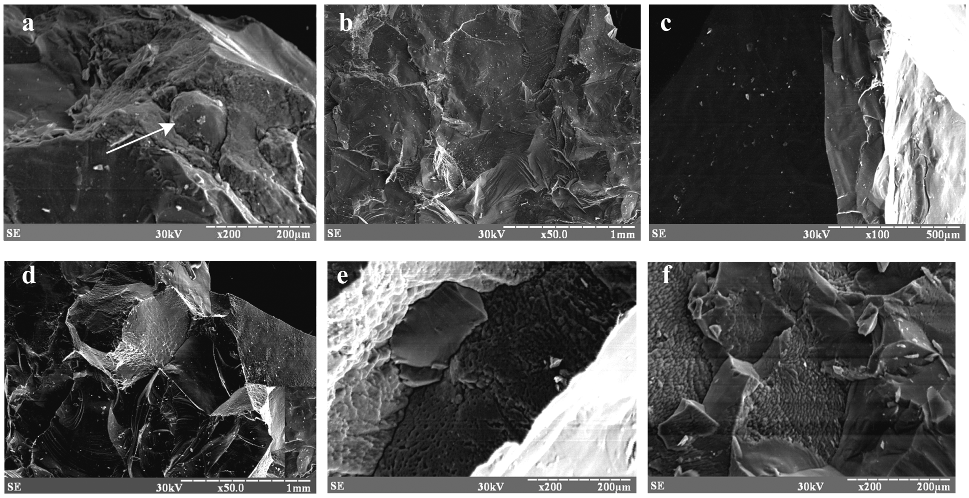

Fig. 1. Electron microscopic image: a – fresh cleaved uneven dynamometamorphosed quartz; b – fresh cleavage of medium-fine granular quartz; c – fresh cleavage of giant-grained primary crystalline quartz; d – surface fractures of granular quartz; pore (e) and etching pits (f) in uneven-grain dynamometamorphized quartz.

by the lowest content of mineral inclusions, the main share of which is muscovite, iron hydroxides, albite and chlorite (Fig. 2c).

In assessing quartz raw materials, in addition to the qualitative and quantitative characteristics of mineral inclusions, an important role is played by such important parameters as the form of occurrence of mineral impurities and the nature of their intergrowth with quartz. The identification of localization features of mineral inclusions in vein quartz opens up the possibilities of enrichment of quartz raw materials and contributes to the selection of the optimal enrichment scheme. In uneven-grain dynamometamorphosed quartz, mineral inclusions are located in intergranular space and cracks, less often inside quartz grains (Fig. 3a). In the giant-grained primary crystalline quartz, there are a large number of finely dispersed inclusions of muscovite and biotite, and thin rutile needles inside quartz grains (Fig. 3b, c). In the studied samples of granular quartz, mineral inclusions are located in intergranular space.

The technical conditions for certain types of quartz products are regulated by the coefficient of light transmission, which reflects the relative saturation of quartz with gas-liquid inclusions. High granular transmittance (69.2-82 %) is inherent for granular quartz; on the contrary, for light-grained quartz, they are low (from 35.3 %). It should be noted that highly transparent sections with a high transmittance (up to 80.2 %) are found in giant-grained quartz, but their volume does not exceed 15-20 % of the gross mass. The light transmission coefficient of uneven dynamometamorphosed quartz is 53.7-80.8 %.

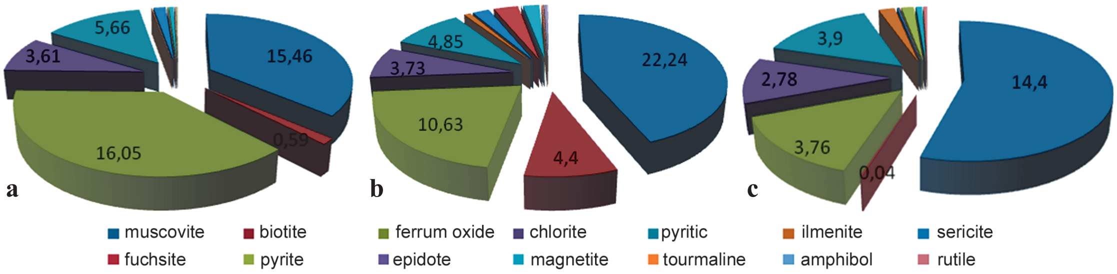

Fig. 2. The average content of mineral impurities (nx 10^{-3} %): a – in uneven-grain dynamometamorphosed quartz; b – in giant-crystalline primary crystalline quartz; c – in medium-fine granular quartz.

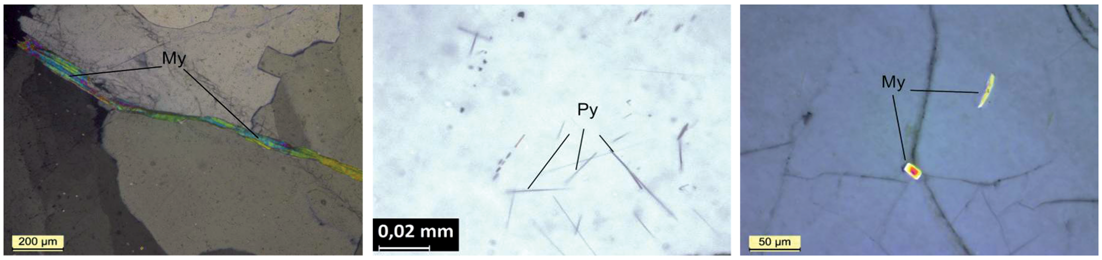

Fig. 3. Mineral inclusions in the vein quartz of the Malo-Chipiketsky zone: a – muscovite in the intergranular space of an uneven-grain dynamometamorphosed quartz; b – thin needles of rutile in giant quartz; c – finely dispersed muscovite in giant-grained quartz.

The composition of gas-liquid inclusions was determined by chromatographic analysis. According to the data obtained, the inclusions have a carbon dioxide-water composition. The total amount of gases released during the heating of the quartz powder in the corundum crucible at a rate of 10 °C/min was recorded in the temperature ranges 100-600 °C and 600-1000 °C. In the temperature range of 100-600 °C, the total amount of gases released is 35.97120.82 µg/g, of which H_2O accounts for 35.5-120.2 µg/g (90.399.8 %). The CO_2 content does not exceed 2.2 µg/g (7.7 %). A small amount of CO and CH_4 is also noted. In the high-temperature region, gas evolution is sharply reduced. The total amount of gases released is reduced to 12.7-35.1 µg/g. At the same time, the proportion of H_2O in the gas composition decreases (89.3-97.7 %), and the proportion of CO increases to 1.2 µg/g, which corresponds to 6.8 % of the total. CO_2 emission in the high-temperature and low-temperature ranges varies insignificantly.

The concentration of structural impurities makes it possible to assess the ultimate purity of raw materials, because purification of quartz from structural impurities with modern enrichment methods is not possible. In the quartz of the Malo-Chipiketsky zone, the main paramagnetic center is Al-O–. Granular quartz is characterized by low concentrations of Al-O–, giant-grained quartz – by high concentrations of this center. This parameter occupies an intermediate position in dynamometamorphosed quartz.

Defects associated with the entry of impurities of various elements into the structure of quartz lead to lattice distortions, which accordingly affects the unit cell parameters. To determine the degree of perfection of the crystal structure of quartz, the crystallinity index (CI) is used, which is taken as 10 rel. units for an ideal quartz crystal lattice. As a result of the performed studies, an increase in the degree of perfection of the crystal structure of quartz was established in the series: uneven-grained dynamometamorphized quartz (5.7) → giant-crystalline primary crystalline quartz (6.1) → medium-fine granular quartz (6.9).

Mineral inclusions in combination with gas-liquid and structural impurities determine the chemical composition of quartz. The main chemical elements-impurities of vein quartz of the Malo-Chipiketsky zone are Al, Fe, Na, K, Li, Ca, P, and Ti, the content of which was determined by atomic emission spectrometry (Table 1). The content of radioactive elements (U and Th) in quartz ranges from 0.002 to 4.581 ppm.

The results of studying the typomorphic features of the initial quartz raw materials of the Malo-Chipiketsky zone are shown in Table 2.

The totality of established typomorphic features of the identified natural types of quartz from the Malo-Chipiketsky zone allows predicting the quality of the

Type of quartz (number of analysis)	Average content of impurity elements, ppm															
	Al	Ti	Ca	Mg	Cu	Cr	Ni	Co	Mn	Na	K	Li	P	Fe	B	Σ_{el}
Unevenly dynamometamorphosed (n=19)	39.4	3.1	6.2	2.1	0.4	5.5	0.2	0.02	0.9	12.1	10.6	1.4	5.3	87.4	0.1	174.5
Medium-fine-grained, granular (n=24)	27.9	2.4	2.4	1.7	0.4	4.5	0.2	0.02	0.8	6.9	6.9	1.2	2.5	45.3	0.1	103.2
Primary crystalline quartz, giant-grained (n=11)	47.6	3.2	8.3	2.1	0.4	5.4	0.2	0.01	0.9	5.9	5.3	1.7	3.6	103	0.2	187.9

Table 1. The average content of impurity elements in the vein quartz of the Malo-Chipiketsky zone. The determination of impurity elements was carried out by the method of atomic emission and mass spectrometry with inductively coupled plasma in the laboratory of CNIIgeolnerud (analysts: O.V. Vishnevskaya, M.Sh. Dresher, R.R. Gilmutdinov).

Typomorphic features of quartz	Medium-fine granular quartz	Uneven-grained dynamometamorphized quartz	Giant-crystalline primary crystalline quartz
Structure	Medium-fine	Uneven-grained	Giant-grained
Mineral impurities	muscovite, ferrum oxide, albite, chlorite, biotite, magnetite	ferrum oxide, muscovite, albite, chlorite, biotite, magnetite, pyrite, ilmenite, graphite	muscovite, ferrum oxide, biotite, albite, rutile, cericil, magnetite
Distribution of mineral impurities	in intergranular space	in fractures, intergranular space, rarely inside the quartz grains	inside the quartz grains, in fractures
Light transmission, (T, %)	69-82 74	54-81 69	35-80 64
Concentration $[Al–O^-]$, ppm	8.1	10.1	13.5
∑ elements-impurities, ppm	132.9	189.03	188.2
Crystallinity index	6.9	5.7	6.1

Table 2. Typomorphic features of vein quartz from the Malo-Chipiketsky quartz-bearing zone. The studies were performed in the laboratories of CNIIgeolnerud.

quartz products obtained from them and to outline the main areas of their use. The most promising for obtaining high-quality quartz concentrates is recognized as quartz raw materials obtained from granular quartz veins, which is characterized by increased chemical purity, high light transmission, and low content of mineral and structural impurities. Quartz raw materials from veins of uneven-grained dynamometamorphized quartz are inferior in quality to granular quartz and are mainly suitable for the production of ordinary quartz glass. The raw material obtained from the veins of giant-grained primary crystalline quartz is difficult to concentrate, because it contains finely divided mineral inclusions inside quartz grains, a large number of gas-liquid and structural impurities.

The increased content of uranium and thorium in the sublattice product of the fraction (0.1 mm) of the studied samples does not allow the use of raw materials as highly pure special-purpose powders.

At the ***second stage***, a technological assessment of the enrichment of raw materials was carried out on laboratory technological (LTS) and small technological samples (STS), selected taking into account the results of analytical studies of ordinary samples.

The enrichment technological schemes used for the set of enrichment methods are generally similar and include: ore picking (only for STS samples) – crushing – fractionation – magnetic separation – flotation – acid treatment (leaching) – concentrate heat treatment – finishing magnetic separation (only for STS samples).

The quality of highly pure quartz concentrates is regulated by Technical Specifications (TS) No. 5726-002-11496665-97 "Quartz concentrates from natural quartz raw materials for the fusion of quartz glasses". In addition, manufacturers of quartz concentrates (Russian Quartz LLC) have developed their own technical requirements.

The quality of the quartz concentrates obtained from laboratory and technological samples of most of the studied veins falls within the ranges of norms regulated by TS-97 and the technical requirements of world and domestic manufacturers (Fig. 4). Average indicators of the chemical composition of the quartz concentrates of the studied veins by standardized elements, including individual indicators for such elements as Al, Ti, Fe, as well as group indicators: ∑Na, K, Li – the sum of alkaline impurity elements, the sum of indicators for other normalized elements – are comparable with the requirements of manufacturers (Table 3). The uniformity parameter of the quartz raw material of a particular vein was determined by the ratio of the number of high-purity concentrates to the total number of enriched furrow samples, expressed as a percentage. The quartz raw material of the predominant number of veins is characterized by a uniformity parameter in the range

Indicator, ppm	LTS 1	LTS 2	LTS 3	LTS 4	LTS 5	LTS 6	****RQ-3K***	***KGO-3***	***IOTA -STD***	***IOTA-CGU***
Al	17.5	9.73	8.39	13.44	12.64	9.23	*15*	*10*	*16.2*	*20*
Ti	1.25	1.97	1.06	3.12	2.01	1.69	*3*	*2*	*1.3*	*2*
$\sum_{Na.K.Li}$	20.80	8.02	5.13	6.95	5.07	8.07	*5.5*	*8*	*2.4*	*3.5*
Fe	9.65	0.19	0.22	0.62	0.78	0.36	*1.4*	*1*	*0.23*	*1*
∑ of other normalized elements	2.90	0.71	0.23	1.60	1.00	1.45	*4*	*3.3*	*2.23*	*1.65*
Uniformity parameter, %	15.4	64.7	100	100	83.3	81.8	-	-	-	-

Indicator, ppm	LTS 7	LTS 8	LTS 9	LTS 10	LTS 11	LTS 12	LTS 13	LTS 14	LTS 15	LTS 16	LTS 17	LTS 18
Al	7.80	14.75	14.41	10.46	6.35	9.40	10.00	23.60	17.62	13.34	14.26	14.91
Ti	1.94	1.83	1.99	1.36	1.75	1.78	1.35	2.61	2.34	1.51	1.64	1.65
$\sum_{Na.K.Li}$	6.08	3.36	3.86	4.60	4.08	10.39	5.80	5.61	2.81	3.14	3.10	2.97
Fe	0.21	0.33	0.15	0.23	0.47	0.44	0.65	0.39	0.21	0.23	0.00	0.24
∑ of other normalized elements	0.53	1.14	0.34	0.30	0.75	0.62	0.40	0.74	0.69	0.16	0.17	0.21
Uniformity parameter, %	83.3	93.8	80.0	100	80.0	81.8	28.6	32.3	-	-	-	-

*Table 3. The quality of quartz concentrates in chemical composition and the uniformity parameter of the studied quartz veins. * The quality of high-purity quartz concentrates from UNIMIN and Russian companies.*

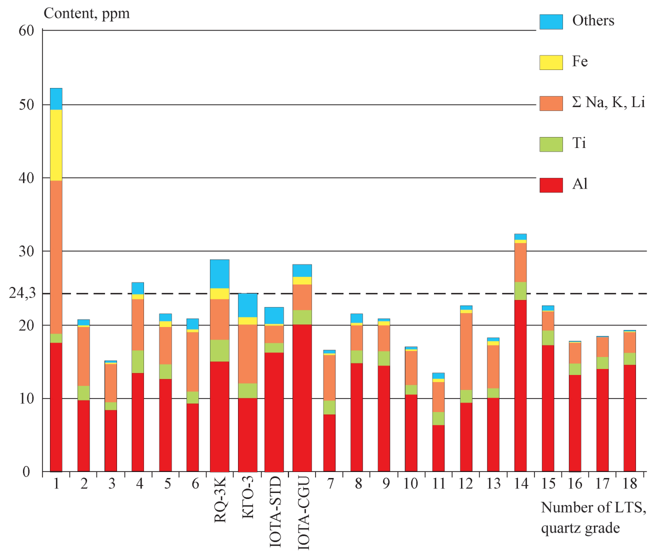

Fig. 4. Indicators of chemical purity of quartz concentrates from laboratory technological samples

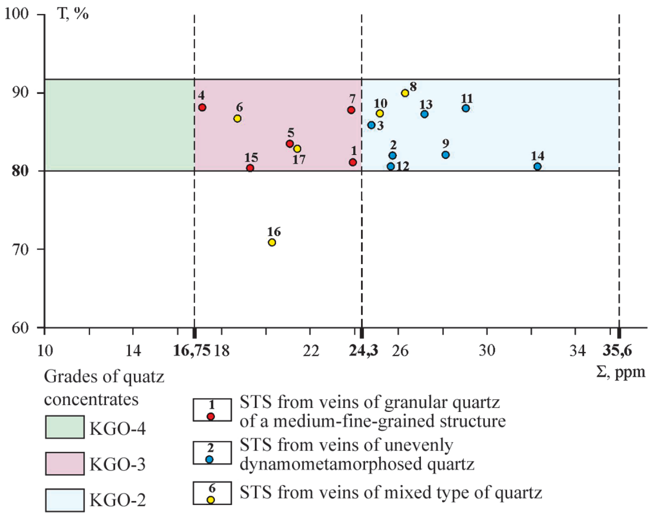

Fig. 5. Correspondence of the quality of quartz concentrates to the requirements of TS-97 according to the main indicators

of 80-100 %. This means that the quality of quartz concentrates obtained from raw materials of the edge parts of the vein is mainly consistent with the quality of concentrates of the central part of the vein.

During mass spectrometric studies of deeply enriched quartz concentrates of granular quartz, 5.4 ppm of water was released in the low temperature range, and 22 ppm in the high temperature range, which does not exceed the normalized amount of high temperature water according to TS-97.

Technological evaluation of the enrichment of quartz raw materials, performed on the pilot production line of Kyshtymsky GOK OJSC on small technological samples selected taking into account the results of analytical and laboratory technological studies, showed that the quality of the concentrates obtained corresponds to grades KGO-2 and KGO-3 according to TS-97 or grades RQ-3K, RQ-4K of the technical requirements of TT 7.04-13 Russian Quartz LLC. The results of comparing the quality of deeply enriched quartz concentrates obtained from STS samples with manufacturers' requirements are shown in Table 4 and Figure 5. Of the 17 samples tested in experimental conditions, 7 samples (41 %) correspond to KGO-3 grades according to TU-97 and RQ-3K according to TT 7.04-13 and can be recommended as high-quality melting raw materials; 9 samples (53 %) correspond to grades KGO-2 and RQ-4K and can be used as ordinary melting raw materials. One sample (6 %) does not meet the requirements for high-purity concentrates in terms of light transmission.

Based on the data obtained on the typomorphic features of quartz, the quality of quartz concentrates, and on the peculiarities of localization of quartz veins, two potentially promising ore-formation types are distinguished: granular and uneven-grain dynamometamorphosed. According to the qualitative characteristics and features of the vein-containing complex, granular quartz is assigned to the quartzite-gneiss formation of granular quartz and is recommended as a high-quality melting raw material. Uneven-grained quartz is assigned to the gneiss-carbon-shale formation of uneven-grained dynamometamorphosed quartz and is recommended for use as ordinary melting raw materials.

Conclusions

On the example of the Malo-Chipiketsky quartz-bearing zone, the objective effectiveness of the algorithm for studying quartz objects is shown. The studies made it possible at the stage of prospecting to expressly, with a high degree of probability, sort out objects according to the quality of raw materials, identify ore-formation types of quartz and outline possible directions for the use of raw materials. This approach avoids the unjustified costs of enrichment and experimental smelting of low-quality raw materials.

The results were used in the selection and contouring of promising sections of quartz veins to assess the forecast resources of two ore-formation types of quartz.

The above data allowed the authors to conclude about the high quality of the quartz raw materials of the Malo-Chipiketsky quartziferous zone and recommend more detailed studies using the III block of the algorithm.

The results of the work carried out increase the prospects of the Patomsky quartz-bearing region as a whole and the Malo-Chipiketsky quartz-bearing zone, in particular, to create a large raw material base for quartz in Eastern Siberia.

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Concentrate grades/ Number of samples	T, %	Content of impurities, ppm													
		Al	B	Na	K	Li	Ca	Mg	Fe	Mn	Cu	Ti	Cr	Ni	$\Sigma_{\text{эл}}$
TS 5726-002-11496665-97 quartz concentrates from natural quartz raw material for the fusion of quartz glasses															
KGO-2	80	15	-	5	3	3	3	2	2	0.3	0.3	2	-	-	35.6
KGO-3	80	10	-	5	2	1	2	1	1	0.2	0.1	2	-	-	24.3
Technical requirements to quartz concentrates from granular quartz of Russian Quartz LLC															
RQ-2KC	80	5.0	0.1	0.5	0.3	0.4	0.6	0.2	0.5	-	<0.1	3.0	0.1	0.1	10.9
RQ-3K	80	15.0	-	2.0	2.0	1.5	2.0	2.0	1.4	-	-	3.0	-	-	28.9
RQ-4K	80	20.0	0.2	9.0	5.0	1.0	5.0	8.0	3.0	0.3	0.3	3.0	0.3	0.3	55.4
Technical requirements to quartz concentrates of UNIMIN (USA)															
Iota STD		16.2	0.08	0.9	0.60	0.9	0.5	<0.05	0.30	<0.05	<0.05	1.3			20.93
Malo-Chipiketsky quartz-bearing															
STS-1	81.1	17.3	0.07	1.70	0.55	2.1	0.12	0.07	0.10	0.01	0.01	2.0	0.01	0.01	24.05
STS-2	82.0	19.3	0.06	0.77	0.10	3.1	0.11	0.04	0.08	0.01	0.01	2.2	0.01	0.01	25.80
STS-3	85.9	17.4	0.07	0.90	0.26	2.1	0.74	0.50	0.15	0.01	0.01	2.7	0.01	0.01	24.86
STS-4	88.1	12.7	0.06	0.61	0.35	1.9	0.10	0.08	0.16	0.01	0.01	1.2	0.01	0.01	17.04
STS-5	83.5	15.4	0.06	1.00	0.44	1.4	0.11	0.13	0.18	0.01	0.01	2.4	0.01	0.01	21.16
STS-6	86.7	13.4	0.11	0.89	0.70	2.1	0.20	0.10	0.12	0.01	0.01	1.2	0.01	0.01	18.86
STS-7	87.8	17.4	0.10	0.94	0.98	1.6	0.12	0.17	0.12	0.01	0.01	2.5	0.01	0.01	23.97
STS-8	90.0	20.0	0.08	0.68	0.78	1.8	0.14	0.18	0.12	0.01	0.01	2.6	0.01	0.01	26.24
STS-9	82.1	20.2	0.07	1.60	1.10	2.3	0.10	0.15	0.15	0.01	0.01	2.5	0.01	0.01	28.21
STS-10	87.4	18.4	0.07	1.20	0.82	1.5	0.05	0.09	0.08	0.01	0.01	3.0	0.01	0.01	25.25
STS-11	88.0	22.1	0.04	0.92	1.00	2.2	0.12	0.14	0.13	0.01	0..01	2.4	0.01	0.01	28.94
STS-12	80.6	19.9	0.09	0.77	0.70	2.0	0.05	0.13	0.09	0.01	0.01	2.0	0.01	0.01	25.77
STS-13	87.3	20.4	0.03	0.70	0.80	2.5	0.05	0.11	0.11	0.01	0.01	2.5	0.01	0.01	27.24
STS-14	80.6	24.0	0.09	1.90	0.64	2.8	0.12	0.21	0.11	0.01	0.01	2.5	0.01	0.01	32.41
STS-15	80.0	13.9	0.06	1.10	0.60	1.3	0.09	0.08	0.10	0.01	0.01	2.1	0.01	0.01	19.37
STS-16	70.9	14.7	0.10	1.50	0.74	1.0	0.10	0.11	0.12	0.01	0.01	2.0	0.01	0.01	19.34
STS-17	82.8	15.5	0.07	1.00	0.88	1.4	0.08	0.13	0.20	0.01	0.01	2.2	0.00	0.01	21.49

Table 4. Correspondence of the quality of deep enriched quartz concentrates to the requirements of domestic and foreign manufacturers

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About the Authors

Liliya Kh. Galiakhmetova – Researcher, Central Research Institute of Geology of Industrial Minerals (CNIIgeolnerud)
4 Zinina st., Kazan, 420097, Russian Federation
E-mail: gal-lilia@mail.ru

Nina G. Bydtaeva – PhD (Geology and Mineralogy), Leading Researcher, Central Research Institute of Geology of Industrial Minerals (CNIIgeolnerud)
4 Zinina st., Kazan, 420097, Russian Federation

Alexander E. Nepryakhin – PhD (Chemistry), Chief Technologist, Central Research Institute of Geology of Industrial Minerals (CNIIgeolnerud)
4 Zinina st., Kazan, 420097, Russian Federation

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