
MINERAL
DRESSING

Dressing Technology for the East Sayan Quartzites

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Abstract—The research results are presented for dressability of quartzites from the Garga quartzite region of the East Sayan. From the detailed analysis of the structure, texture, mineral and fluid inclusions in the chemical constitution, bright veined quartzites and coaly veined quartzites were distinguished in the Urda-Gargan block. Both kinds are readily dressed up quartz concentrates of deep concentration. The first quartzite kind can be used in manufacturing of transparent optical quartz glass, whereas the second variety is a promising feedstock for carbothermal production of silicon.

Keywords: Quarts, mineral impurities, fluid inclusions, quartz concentrate, quartz glass.

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INTRODUCTION

Natural quartz raw material serves for the production of high-purity and ultra high-purity quartz concentrates. These concentrates are used in manufacturing of optical quartz glass for the visible and near infrared spectral regions and high-temperature silica ceramics for all purposes. Any kind of raw material processing depends on the properties and ore mixture mineral composition [1]. Traditionally, quartz concentrates are produced using clear quartz and vein quartz varieties of various geological and industrial types [2]. As a rule, vein-shaped quartz bodies have limited reserves and are very inhomogeneous. The Kyshtym deposit is a unique operated deposit of granular quartz in Russia. Quartz mining is performed by the underground method requiring continuous improvement of mining technology in order to reduce quartz losses [3, 4].

In contrast with vein quartz varieties, high-purity quartzites from the East Sayan were studied in detail, using the Oka–Urik block including the Bural-Sardyk deposit as an example [5, 6]. They are highly-homogeneous and pure. Based on a high-purity variety of quartz raw materials from the Bural-Sardyk deposit which was earlier named superquartzites [5], KI type of optical quartz glass was produced [6].

Two types of compact quartzites taken from the Urda-Gargan block of the Gargan quartzite-bearing region were studied (Fig. 1). For comparison, the data on the dressability of the quartzites from the Bural-Sardyk deposit [6] and compact quartzites from the Oka-Urik block were presented (Fig. 1) [7].

The Irkut suite of the Urda-Gargan block mostly comprises gray, dark-gray fine-grained quartzites. Carbonaceous rocks (dolomites and limestones) are less common, quartz-chlorite and carbon-micaceous schists are of secondary importance.

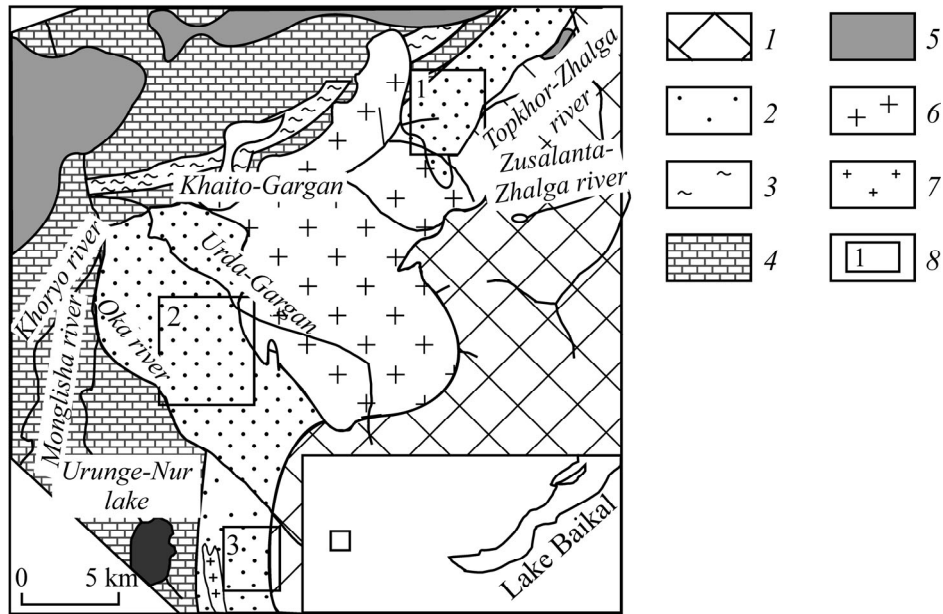


Fig. 1. Geological structure of the eastern part of the Gargan block: 1—basement; 2–4—sedimentary cover: 2—quartzites; 3—schists; 4—carbonates; 5—poorly defined ophiolite complex; 6—Sumsunur complex granitoids; 7—Munku-Sardyk complex granitoids; 8—the borders of quartzite-bearing blocks and their numbers: 1—Oka-Urik; 2—Urda-Gargan; 3—Urengener.

Within the borders of the Urda-Gargan block there are several prospecting areas: Semerka, Belaya Sopka, Okinsky 1 and Okinsky 2. The most studied site is Semerka, located on the flat watershed of the Oka and the Urda-Gargan rivers (Fig. 2). The productive quartzite bodies are extended in the north-east direction at 750 m and the width of its exposure is 70–150 m. On the surface they are represented by block eluvial-deluvial debris and sparse bed-rock exposures.

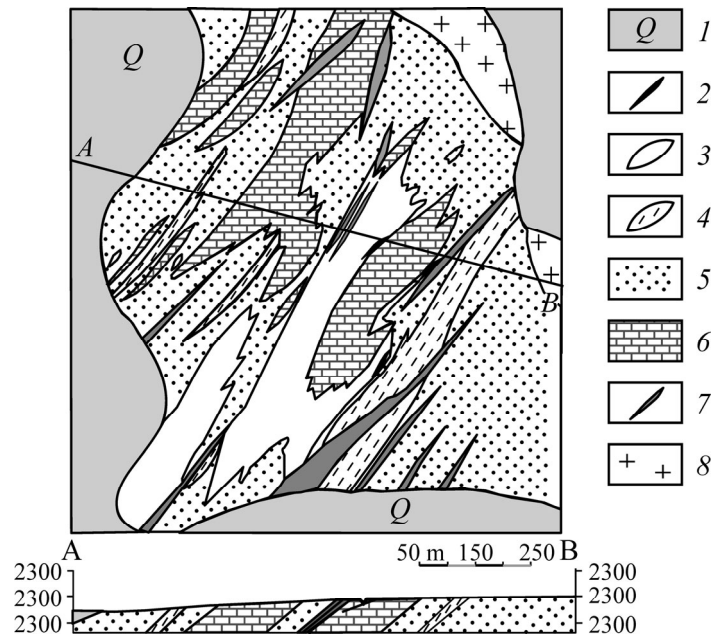


Fig. 2. Geological contour map of the Semerka Urda-Gargan block area: 1—quarternary deposits; 2—superquartzites; 3—bright quartzites; 4—quartz-chlorite and carbon-quartz-micasceous schists; 5—dark-gray quartzites; 6—carbonates; 7—gabbro-porphytic dykes and sills of the Urda-Gargan complex; 8—granitoids of the Sumsun complex.

A detailed study of the productive bodies of high-purity quartzites in the Urda-Gargan block shows that they can be formed in the central part of a dark-gray fine-grained quartzite block and depend on certain conditions within the quartzite formation, due to tectonic deformations and displacements. The boundaries between dark-gray and bright quartzites (until the occurrence of porphyric quartzites in central parts), for relatively large bodies, are predominantly gradual. Thin bodies (several tens of centimeters) are characterized by considerably sharp boundaries. The color change of rocks from dark to white can be observed on the sites from the first centimeters up to several tens of centimeters—for thin interbeds and up to the first meters—for thick bodies.

1. RESEARCH METHODS AND STUDY OBJECT

Petrographic study of the rocks were carried out in transmitted and reflected light by means of BX 51 (Olympus) microscope at the instrumental base of the IGC SB RAS Center for Collective Usage (CCU) Isotop and Geochemical Researches. In order to take the photos of the samples, PixeLink 1394 and QImagingMicroPublisher 5.0 RTV cameras were used.

The impurity elements concentrations were determined by the inductively coupled plasma mass spectrometry [6]. Quartz glasses were obtained at the upgraded unit for single-crystal growth OKB-8093, using the method of vacuum-compression melting at maximum pressure up to 5 bar [6]. Chemical enrichment of quartz concentrates was performed in the mixture of hydrochloric and hydrofluoric acids.

Carbon content was determined in the CCU Baikal Analytical Center of Irkutsk Institute of Chemistry SB RAS. The analyses were carried out at the element analyzer Flash EA 1112 CHNS. The technological samples (TS) of quartzites collected on the Semerka Urga-Gargan block area of the Gargan quartzite-bearing region in the Eastern Sayan were studied.

2. CHARACTERIZATION OF SAMPLES

The most common rock group of the Urda-Gargan cluster is quartzites. They are represented mainly by dark-gray, gray mottled and striped and massive microgranular types, grading from gray and light-gray to white micro-medium-grained quartzites. High-purity quartzite types (gray and light-gray compact and white porphyric—superquartzites) are found in thin lenticular forms and interbeds. On a macroscopic level, compact quartzites are represented by light-gray rocks with white shear and up to mottled gray-colored rocks with a massive structure without visible mineral inclusions, except for rarely occurred sericite thin flakes on the surface of grains. Despite of the fact that the samples of quartz are opaque, their thin chips are transparent and represent a clouded pure quartz monocrystal, for that reason they were called compact quartzites. The content of major elements in the purest types from light-colored types to dark-gray ones slightly varies. There are two types of compact quartzites: bright veined (compact 1, MTP-10) and coaly veined (compact 2, TP3) (Fig. 3), they are the most representative among high-purity quartzites in concentration degree assessment and production of high-purity quartz concentrates. The technological samples weighing more than 100 kg were collected by ditching on the site of the Semerka Urda-Gargan block.

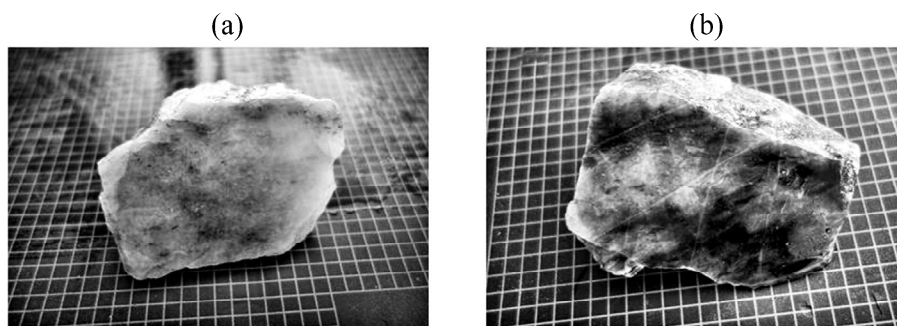


Fig. 3. Compact quartzites: (a) the first type—bright veined; (b) the second type—coaly veined.

The first type of quartzites (Fig. 3a) is characterized by massive microtexture. At a micro-level in this type of quartzites linear structures are observed. The rock has a heterogranoblastic microstructure, from fine to coarse blastic structures, sometimes porphyroblastic ones. Percentage ratio of mineral aggregates: 10–20%—giant blastic, 30–40%—large blastic, 20%—medium blastic, 20–40%—fine blastic texture. The rock consists of quartz aggregates 99.9–99.5%. The samples may also contain unevenly distributed fibers, flakes and needles of sericite with the size of less than 0.1 mm. Sericite can also fill the cross cracks in the rock. Fluid inclusions form sequences stretching across several grains. These chain-like sequences often intersect, less frequently they run parallel. The width of these sequences is 5–20 μm (Fig. 4). The inclusions can quite frequently form wide bands and ribbons. The width of these bands reaches 150 μm . Inside the quartz aggregates, in their central part, fluid inclusions are presented in small quantities, mostly they are located at the grain edges and to the intergranular space. The inclusions of water-salt composition predominate in this type of quartzites. Two-phase (fluid and gas) inclusions (with the size 20–43 μm) are the most common, single-phase inclusions are found less frequently. The melting point of two-phase inclusions is defined within the limits from -9.2 to -7.9 $^{\circ}\text{C}$, the total homogenization temperature: for one inclusions is 170–175 $^{\circ}\text{C}$, for the others—350–390 $^{\circ}\text{C}$.

To determine the composition of the fluid inclusions aqueous solution, the method of laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) was used. The analysis of seven largest (20–43 μm) and morphologically suitable (with three-dimensional, almost regular shape) inclusions was performed. Finally, the registered strong analytic signals pointed to the presence of Na in all the inclusions. According to the data obtained in the course of microcryothermometric analysis and LA-ICP-MS, it is found that sodium is the main alkali element of the fluid saline system. Therefore, salinity of NaCl–H₂O system was determined using the melting points values and homogenization temperatures for inclusions with the similar phase ratio [8], and it was 12–13 wt. % NaCl eqv. The main mineral inclusions are carbonates and single sericite flakes.

The second type of quartzites (Fig. 4b) is characterized by layered, layered-mottled and mottled structure. Quartzite layered structure represents the alteration of quartzite aggregates in the form of bands and lenses with varied sizes. There is no consistency in the length and width of the bands. The boundaries of the layers are not always distinguishable. Sometimes the aggregates of one dimension are interchanged with the aggregates of other dimension. This type of quartzites contain thin layers of coaly matter easily discernible at a micro-level between parallel polarizers (Fig. 4c). The main mineral inclusions are sericite flakes and coaly matter, probably, in the form of finely dispersed graphite.

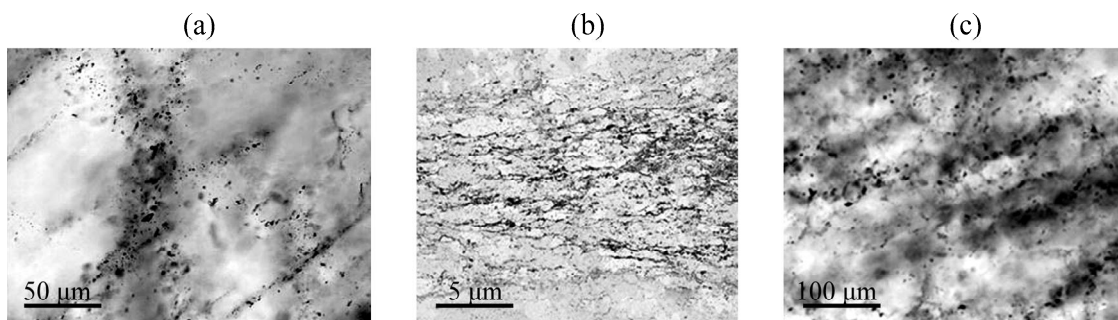


Fig. 4. Chain-like distribution of fluid inclusions in quartz aggregates: (a) type 1; (b) type 2; (c) uneven distribution.

Table 1. Weight fractions of impurities in the initial samples, ppm

Quartz type	Fe	Al	Ti	Ca	Mg	Cu	Mn	Na	K	Li	Σ10
Compact 1	17	59	3.2	20.0	10.0	0.3	0.90	6.0	22.0	0.1	138
Compact 2	29	84	3.6	6.7	6.4	0.2	0.90	6.5	34.0	0.1	171
Superquartzite	6	27	1.7	0.8	1.0	0.2	0.02	3.5	6.3	0.1	47
The Oka–Urik block compact quartzite	4.9	10	0.3	7.3	0.9	0.2	0.10	19.0	6.2	0.3	49

Table 1 provides the weight fractions of impurities in the initial sample of both types of compact quartzites from the Semerka Urda-Gargan block area, as well as superquartzites of the Bural-Sardyk deposit and the Oka–Urik block compact quartzites. Elemental composition of impurities was determined by inductively coupled plasma mass spectrometry [6]. Test samples were prepared by thermal crushing and represented the form of quartz grit ranging in particle size from 175 to 450 μm. The analysis of Table 1 reveals that both types of compact quartzites from the Urda-Gargan block are similar in the sum of ten regulated impurity elements, however, they are far below the Oka–Urik block superquartzites and compact quartzites in terms of purity.

2. QUARTZ CONCENTRATES

The following processes were used to obtain quartz concentrates. Quartzite was crushed up to the grain size of +2–15 mm in a roll-jaw crusher with tungsten-carbide jaws. The beneficiation results for the first type of quartzites (MTP-10) are given in Table 2. The next step was hand sorting with further treatment of the quartzite lump with hydrochloric acid (sample 481 and 482). A considerable part of impurities was removed with fines (<2 mm) after sieving (sample 480). Then, the grinding in a quartzite sample grinder was performed with further classification to the grain size of +100–300 μm. It was noted that almost double amount of impurities was removed (sample 483). Apparently, the greater part of mineral inclusions is removed with the fine fraction (<100 μm).

Table 2. Weight fractions of impurities in quartz concentrates, ppm

Sample number	Fe	Al	Ti	Ca	Mg	Cu	Mn	Na	K	Li	Σ10
First type											
480	140.0	142.0	8.1	22.0	20.0	0.60	8.40	17.0	39.0	0.10	397.0
481	41.0	72.0	4.3	16.0	11.0	0.50	2.20	7.0	26.0	0.10	180.0
482	17.0	59.0	3.2	20.0	10.0	0.30	0.90	6.0	22.0	0.10	138.0
483	11.0	41.0	1.9	4.6	5.3	0.12	0.70	5.2	15.0	0.10	85.0
485	0.2	7.3	1.0	2.8	0.4	0.10	0.01	4.4	1.0	0.10	17.0
486	0.1	7.1	0.8	1.9	0.3	0.10	0.01	1.6	0.3	0.40	12.3
Second type											
509	109.0	157.0	13.5	8.4	12.7	0.34	14.200	8.9	69.6	0.14	393.8
511	29.2	83.8	3.6	6.7	6.4	0.19	0.870	6.5	34.0	0.11	171.4
517	18.7	69.6	3.8	3.1	6.3	0.13	0.910	5.4	27.2	0.15	135.3
520	0.3	10.0	2.4	2.7	0.6	0.09	0.049	4.5	1.8	0.15	22.6
524	0.4	9.0	2.0	5.4	0.9	0.20	0.120	3.4	0.6	0.27	22.3

480—fines STS-10, size fraction 1.7 mm; 481—size fraction 1.7–15 mm after hand sorting; 482—STS-10 after hand sorting and treatment with 10% hydrochloric acid; 483—STS-10 after crushing to size fraction 100–300 μm; 485—STS-10 grit after hand sorting, treatment with hydrochloric acid and chemical enrichment in a mixture of 20% HCl and hydrofluoric acid (3 : 1) at 70° for 2 h; 486—the grit of 485 after calcination at 1450 °C for 3 h and chemical enrichment; 509—TS3 after hand sorting, size fraction 1.7–15 mm; 511—TS3 after hand sorting and etching with 10% HCl, size fraction 1.7–15 mm; 517—sample 511 after grinding to size fraction 100–300 μm; 520—TS3 after sorting, etching, size fraction 100–300 μm, chemical enrichment in HCl (20%): HF (20%) = 3 : 1; 524—TS3 after sorting, etching, size fraction 100–300 μm, chemical enrichment in 20% HCl, open-air calcination at 400°C—3 h, 1450 °C—3 h and chemical enrichment in HCl (20%): HF (20%) = 3 : 1.

The next stage was chemical enrichment in a mixture of acids (high purity) with deionized water, HCl (20%) : HF (20%) = 3 : 1; L : S (liquid to solid) = 2 : 1 at 700 °C for 2 h. Chemical enrichment considerably lowers the total concentration of iron, aluminum, magnesium, manganese, potassium, but with the exception of sodium (sample 485). This is consistent with the conclusion that sodium is presented in fluid inclusions, moreover, it is partially stored inside quartz grains, however, in lower quantities as compared to compact quartzites from the Oka-Urik block [7]. The etching at temperature of 1450 °C leads to the opening of fluid inclusions and to a considerable reduction of sodium concentration (sample 486). The etching of quartz grit in quartz through-type furnace may reduce Na concentration to ppm fractions.

The same procedures for quartz concentrates production were carried out using the second type of quartzites (carbonaceous quartzites TS3, Fig. 3b). As it follows from Table 2, the mentioned type of quartzites are easily enriched to quartz concentrates of deep concentration. However, unlike the first type of quartzites, the grinding and further size classification do not show considerable upgrading of 100–300 μm size fraction. Moreover, quartz concentrates obtained from quartzites of the second type retain gray color after chemical enrichment. In order to find out carbon content, the analysis of samples 517 (C—0.61%; ash content—97.52%) and 524 (C—0.65%; ash content—98.75%) was carried out at the elemental analyzer Flash EA 1112 CHNS. The obtained results reveal that the second type of quartzites differ from the first ones in a high content of coaly matter that binds mineral inclusions at grain boundaries. This explains the difference in the level of enrichment for quartz concentrates after grinding procedure and size classification. A flowsheet of quartzite enrichment is presented in Fig. 5.

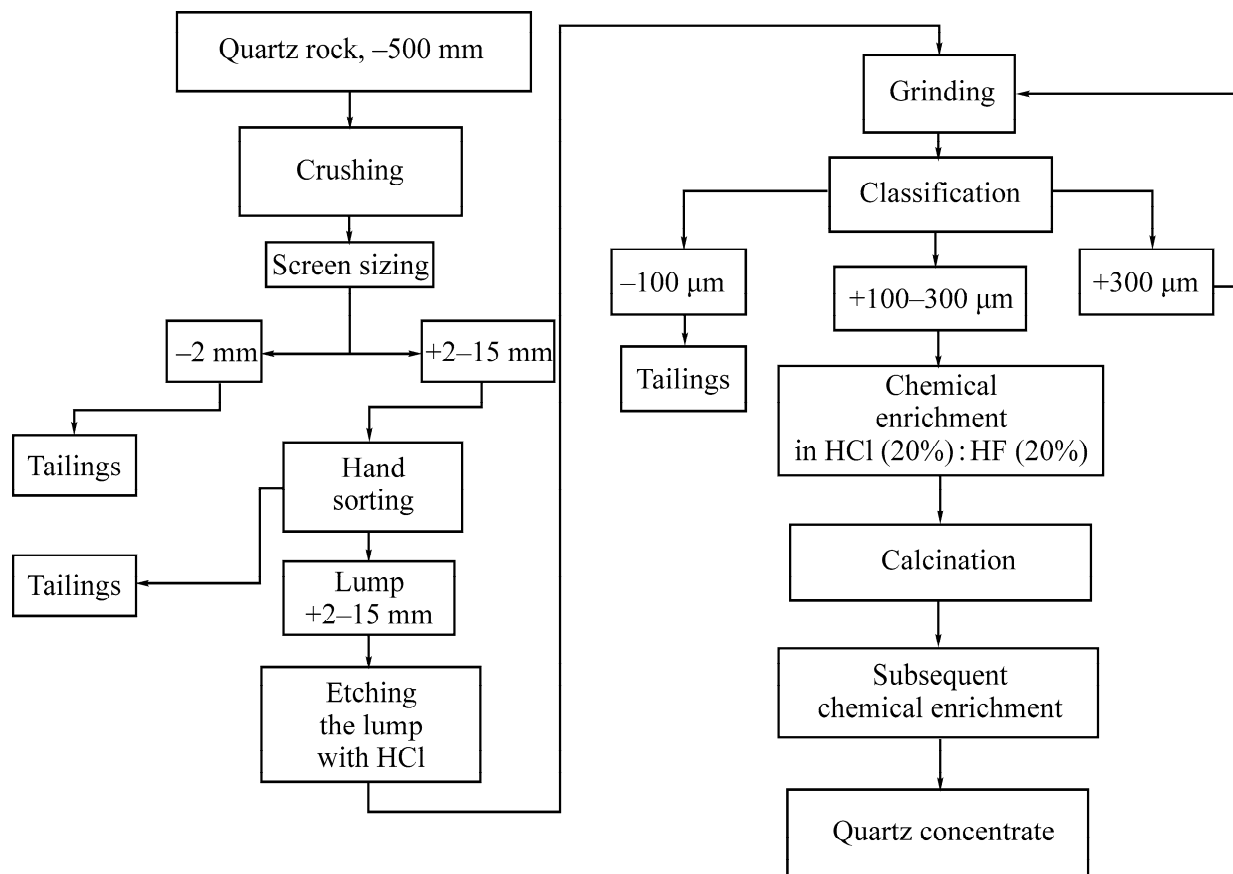


Fig. 5. A flowsheet of quartzite enrichment.

Table 2. Weight fractions of impurities in quartz concentrates, ppm

Quartz type	Fe	Al	Ti	Ca	Mg	Cu	Mn	Na	K	Li	Σ10
Compact 1	0.1	7.1	0.8	1.9	0.3	0.10	0.010	1.6	0.3	0.40	12.3
Compact 2	0.4	9.0	2.0	5.4	0.9	0.20	0.120	3.4	0.6	0.27	22.3
Superquartzite	1.1	4.0	0.6	0.4	0.2	0.18	0.006	0.2	0.3	0.18	7.2
Compact quartzite from the Oka–Urik block	6.9	5.3	0.2	2.0	0.5	0.11	0.050	1.1	0.9	0.40	17.0

The concentrates were obtained in the course of chemical enrichment, etching at 1450°C for 3 h.

Table 3 presents weight fractions of impurities in the quartz concentrates obtained from superquartzites of the Bural-Sardyk deposit [6], compact quartzites of the Oka-Urik block (compact) [7], compact quartzites taken from the southwestern part of the Oka–Urik block and both types of compact quartzites from the area of the Semerka Urda-Gargan block. As we can see from Tables 1 and 3, all the analyzed types of quartzites from the East Sayan region are easily dressed.

Superquartzites can be used to obtain quartz concentrates of an ultra-deep level of concentration without high-temperature chlorination, and compact quartzites from the Urda-Gargan an Oka-Urik blocks can be used to obtain quartz concentrates of a deep level of concentration [9].

Figure 6 represents a photo of quartz glass samples made of quartz concentrates—samples 486 and 524 (Table 2) obtained from the Urda-Gargan block compact quartzites of type 1 and type 2, respectively.

It can be seen that quartz concentrates obtained from the quartzites of type 1 give the possibility to produce transparent optical silica glass. Carbonaceous quartzites of type 2 are not suitable for production of transparent optical silica glass. This may be due to a high content of coaly matter. However, this type of quartzites will show high activity in carbothermal reduction reaction, which is essential for production of silicon.

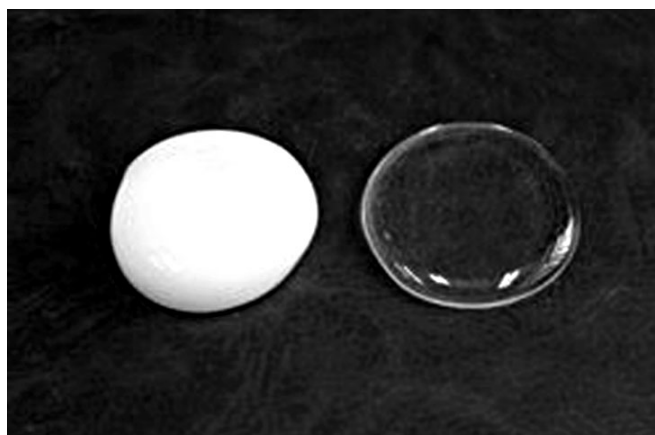


Fig. 6. Photos of glass samples made of quartz concentrates obtained from compact quartzites of type 1 (right) and type 2 (left).

CONCLUSIONS

From the detailed analysis of the structure, texture, mineral and fluid inclusions in the chemical composition, two types of the Urda-Gargan block quartzites were distinguished: bright veined quartzites and coaly veined quartzites.

Chemical enrichment in a mixture of hydrochloric and hydrofluoric acids can considerably reduce the concentration of inclusions. High-temperature calcination makes it possible to open the fluid inclusions. Chemical enrichment performed prior to calcination procedure is required to reduce the total concentration of impurities, subsequent chemical enrichment makes it possible to open and remove fluid inclusions.

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