

Geology and Genesis of the Cheremshanka Silica Deposit, Western Transbaikal Region, Russia

D. I. Tsarev^a, V. K. Khrustalev^a, V. I. Gal'chenko^b, and D. Ts. Ayurzhanova^a

^a *Geological Institute, Siberian Division, Russian Academy of Sciences, ul. Sakh'yanyovoi 6a, Ulan-Ude, 670047 Russia*

^b *Cheremshanka Mine, ZAO Kvartsit, Turuntaevo, 671260 Russia*

Received March 26, 2007

Abstract—The geology and genesis of a large high-grade silica deposit is considered. It occurs in the form of a quartzite layer, 20–50 m thick, extending for 8 km in conformity with the host Upper Proterozoic silicate–carbonate metasedimentary rocks. The average content of SiO₂ is 99.2%. It has been established that quartzite was formed by metasomatic silicification of sandstone during metamorphism of the carbonate–silicate sequence. The rocks were silicified by infiltration acid leaching, whereas long-term refinement of quartzite was provided by diffusion in finely dispersed capillary–porous systems, where the energy of the solution–solid phase interface was important. In the course of metasomatic migration of components, Au, Ag, Pb, Zn, Fe, and other elements were removed from quartzite and formed gold–sulfide mineralization in contact zones of the quartzite body. This opens up opportunities for discovering economic Au–Ag and Pb–Zn ores in the ore field.

DOI: 10.1134/S1075701507040046

INTRODUCTION

The demand for high-technology silica is growing due to its increasing consumption in metallurgy for production of dinas refractory, ferrosilicon, silicomanganese, silumin, and transformer steel; manufacture of abrasives, cutting materials, and electronic devices on the basis of silicon carbide; production of solar batteries using ultrapure silicon; etc.

Silica is obtained from quartz sandstone and high-purity quartzite with an insignificant amount of impurities. Only raw material that contains >99% SiO₂ is profitable for mining. To obtain the crystalline silicon of high purity that is used in electronics and for solar batteries, the SiO₂ content in the starting material should be no less than 99.99%.

The Cheremshanka deposit, a large industrial source of silica, is situated in the Western Transbaikal region (Fig. 1) 80 km from Ulan-Ude. The deposit was discovered in 1966 by the Buryat Geological Survey as a layer of quartz sandstone fit for making glass (Ignatovich et al., 1972). The deposit was officially recognized and highly evaluated by the Second Regional Conference of Founders of Eastern Siberia in 1968. Since 1992, the Cheremshanka deposit has been mined by the open pit method. According to exploration data, the average chemical composition of the silica raw material is as follows (wt %): 99.2 SiO₂, 0.02 TiO₂, 0.35 Al₂O₃, 0.02 Fe₂O₃, 0.02 MgO, 0.03 CaO, 0.02 Na₂O, 0.02 K₂O, 0.10 LOI, total 99.94.

To meet consumer requirements, lump quartzite must contain (wt %) 99.2–99.6 SiO₂, <0.14 Fe₂O₃, <0.40 Al₂O₃, and <0.03 CaO.

Studies carried out by the authors in 2000–2004 in the main open pit, in prospect pits and trenches in the northern part of the quartzite block, and at natural and artificial outcrops at the periphery of the deposit showed that the quartzite body is quartz metasomatic rock rather than quartz sandstone. Promising gold–silver–base-metal mineralization is localized near the quartzite layer, showing a paragenetic relation to its formation.

GEOLOGY OF THE CHEREMSHANKA DEPOSIT

The quartzite layer, 20–50 m thick, is traced from north to south for 8 km, being hosted in the Upper Proterozoic metasedimentary sequence that consists of the Itantsa silicate and the Burla carbonate formations. The quartzite layer is localized at the boundary of these formations, lying conformably with folded host rocks that dip at angles from 20° to 60° (Fig. 2). Tsarev and Khrustalev (2002) showed that the sheetlike body is composed of metasomatic quartzite rather than of quartz sandstone as was suggested previously by geological exploration. The member of black carbonaceous sericite–quartz schist of the Itantsa Formation at the contact with the Burla Formation is 300 m thick. This is foliated rock with lepidogranoblastic microtexture, schistose structure, and quartz veinlets. The modal mineral composition of this rock is as follows (vol %): 50–60 quartz, 30–35 sericite, 3–5 plagioclase, 7 coaly–graphite material, and 1–3 ore minerals.

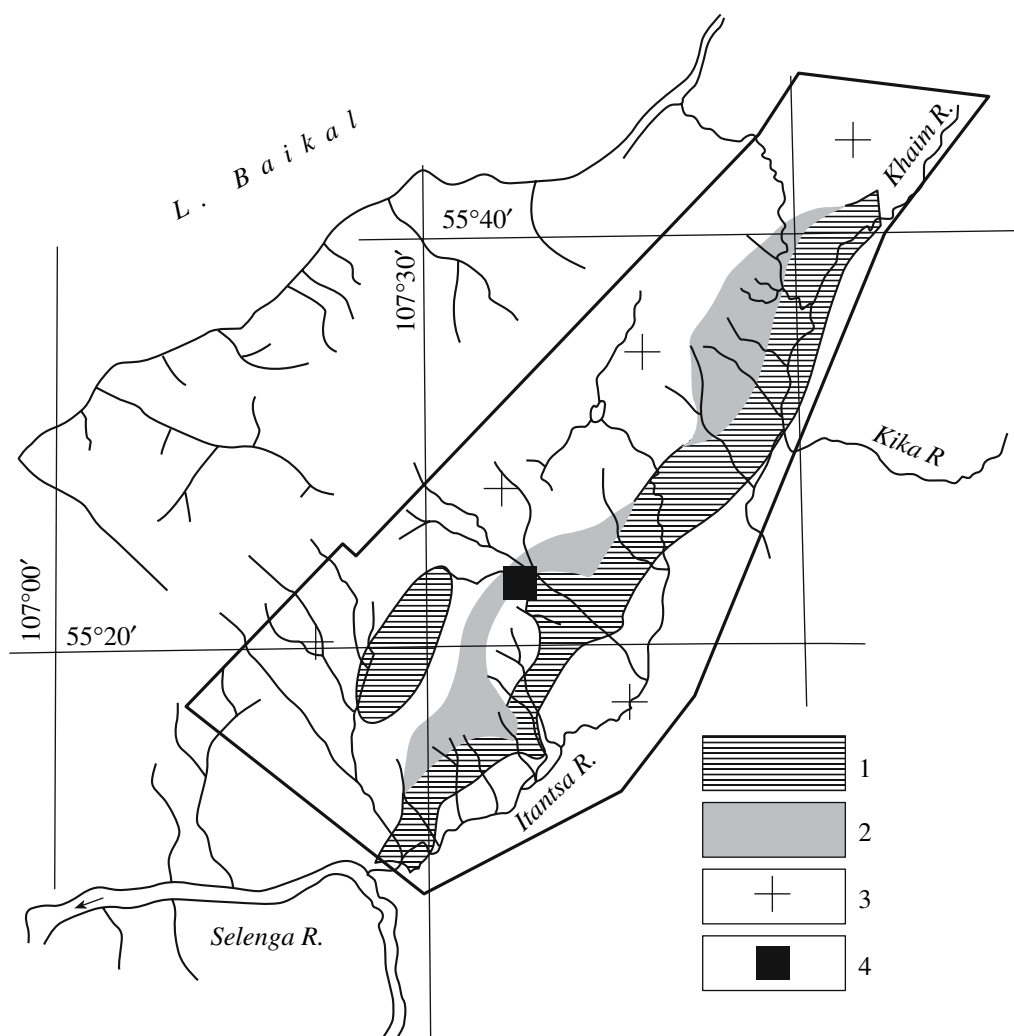


Fig. 1. Geological sketch map of the district of the Cheremshanka silica deposit. Upper Proterozoic metasedimentary rocks: (1) Burla Formation; (2) Itantsa Formation; (3, 4) granitoids of the (3) Late Proterozoic Barguzin and Early Paleozoic Vitimkan complexes; (4) Cheremshanka deposit.

Sandstone relics replaced incompletely by quartz are retained in the roof of the quartzite layer. Patches of ocher, dark brown and brown iron hydroxides, and locally developed manganese hydroxides are observed in gray sandstone. The psammitic fine- to medium-grained massive rock consists of rounded quartz grains and sericite flakes (5–10%). Virtually all cement has been leached out, and, therefore, the sandstone is porous in appearance. In the brown varieties, secondary iron hydroxides serve as basal cement. The initial cement probably was clayey–carbonaceous. Insignificant amounts of sericite in interstices of quartz grains testify to the presence of clayey minerals. Ovoid relics of sandstone impregnated or not impregnated with iron hydroxides frequently occur in white quartzite, resembling pebbles in shape. Occasionally, they cluster into conglomerate-like segregations. The quartzite layer is commonly overlain by dolomite of the Burla Formation

and locally by sericite and carbonate–quartz–sericite schists that underlie dolomite (Fig. 3).

The observations carried out in trenches, adits, and open pits revealed a complicated structure of the basal unit of the Burla Formation. The lowermost portion of the section (130 m) studied in detail at the deposit is composed of dark gray and gray, passing into light gray, massive pelitomorphous dolomites with coarsely crystalline calcite veinlets and interbeds (10–50 cm) of gray-colored quartz–sericite–carbonate and sericite–carbonate schists, as well as units of brecciated massive and algal dolomites with interbeds enriched in organic matter. The average chemical composition of dolomite is as follows (wt %): 2.30 SiO₂, 0.01 TiO₂, 2.08 Al₂O₃, 0.69 Fe₂O₃, 1.0 FeO, 0.01 MnO, 19.01 MgO, 32.07 CaO, 0.01 Na₂O, and 0.15 H₂O.

The modal mineral composition of dolomite is as follows (vol %): 96–99 dolomite, 2–3 quartz, 3 sericite,

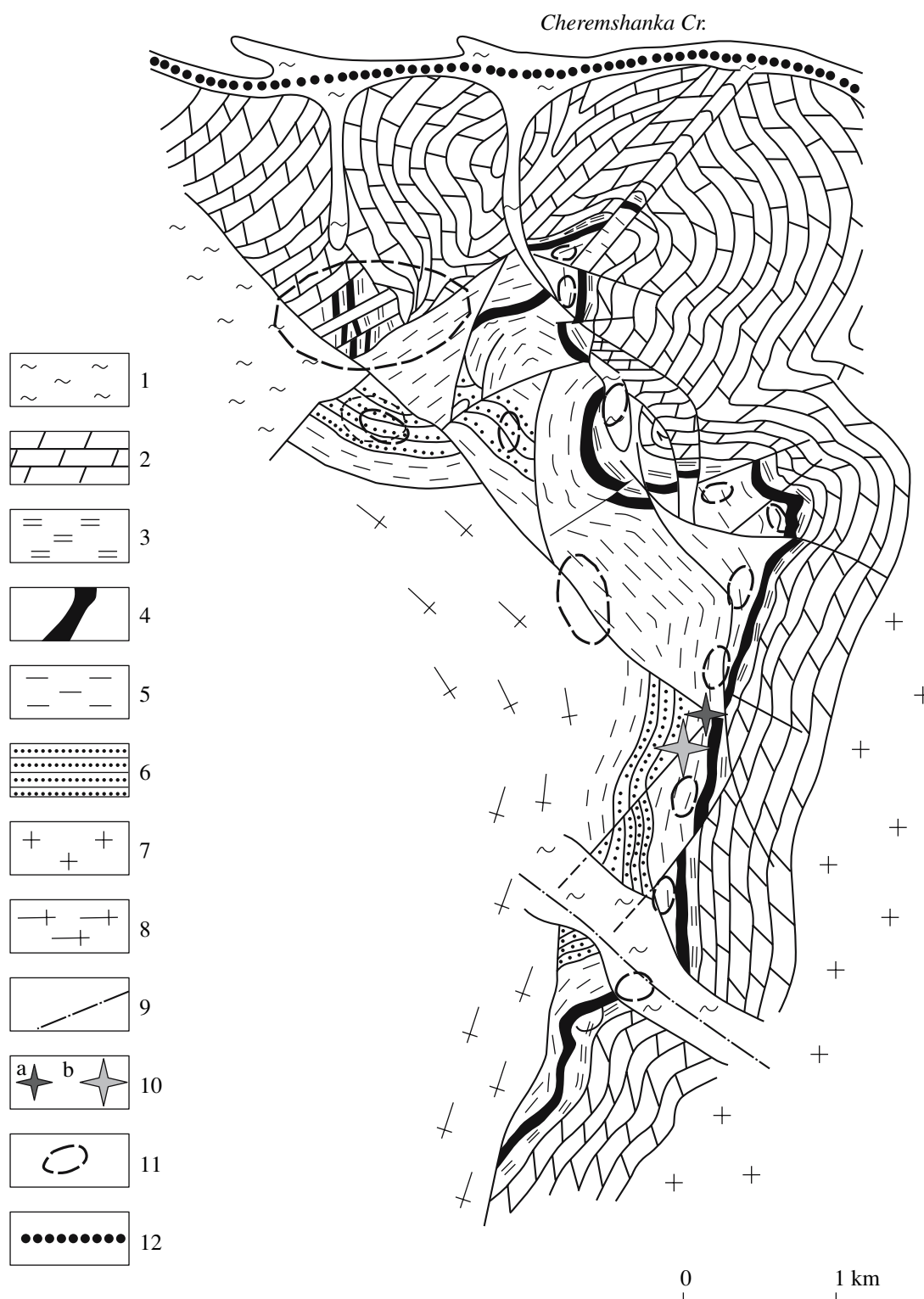


Fig. 2. Schematic geological map of orebody at the Cheremshanka quartzite deposit with secondary Au halos. (1) Quaternary and Neogene sediments; (2) Upper Proterozoic dolomite of the Itantsa Formation; (3–6) Upper Proterozoic rocks of the Burla Formation: (3) shale, (4) quartzite, (5) carbonaceous quartz–sericite schist, (6) sericite–quartz sandstone; (7) Early Paleozoic granites of the Vitimkan Complex; (8) Late Proterozoic gneissose granite of the Barguzin Complex; (9) fault; (10) samples containing (a) 1–72 g/t Au and (b) 5000 g/t Ag; (11) secondary geochemical halos (0.001–0.1 g/t Au); (12) gold placer with potential resources of 250 kg of gold in category P_1 and inferred reserves of 50 kg of gold in category C_2 , average grade 1 g/t.

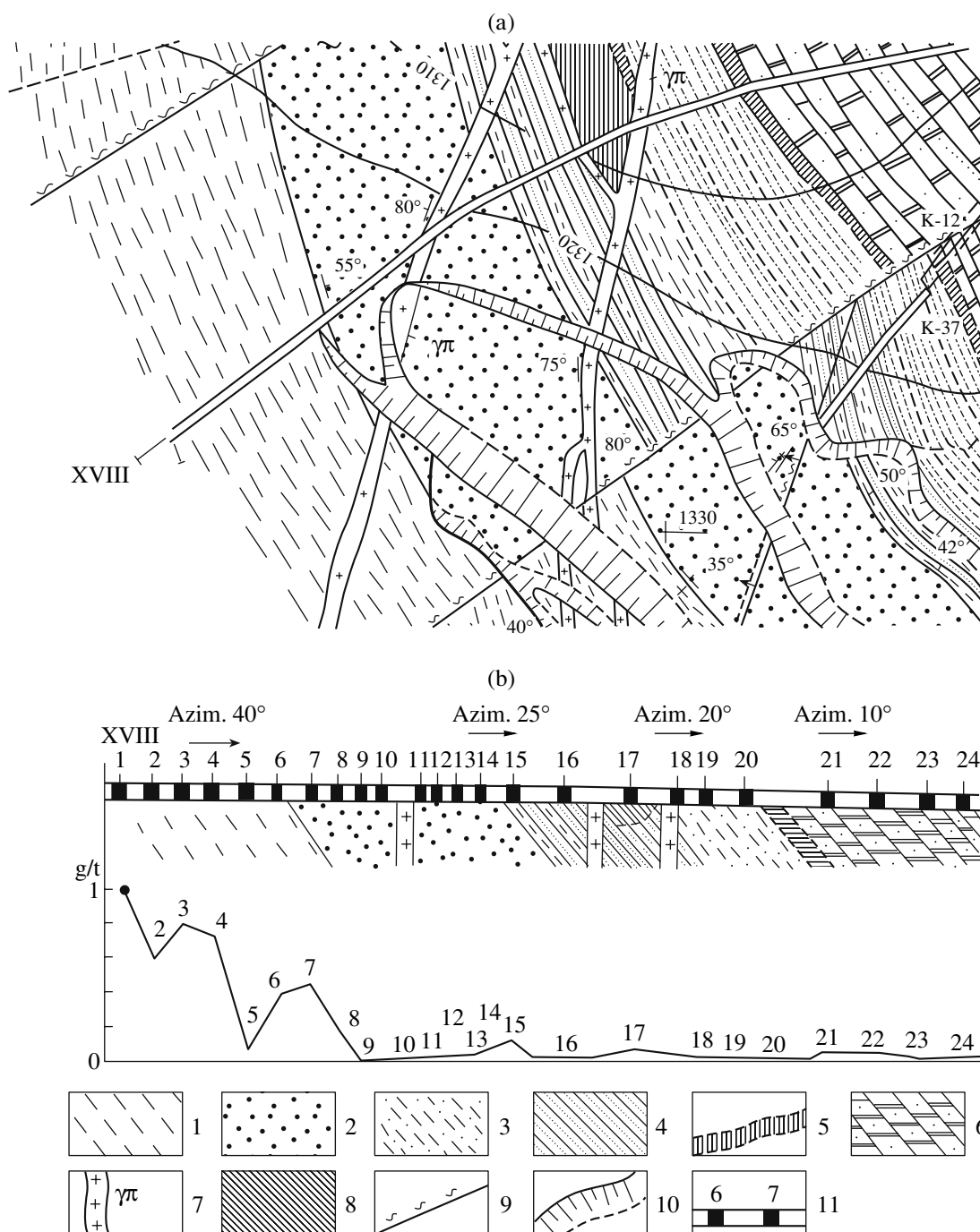


Fig. 3. (a) Geological plan of a fragment of the main open pit and (b) section along exploration line XVIII with results of trench sampling for gold. (1) Carbonaceous quartz-sericite schist; (2) quartzite; (3) quartz-mica-feldspar schist with lenses and interbeds of iron oxide ore; (4) alternating sandstone, siltstone, and carbonaceous quartz-sericite schist; (5) limonitized clayey linear zone of weathering; (6) dolomite; (7) plagiogranite porphyry and quartz porphyry (dikes); (8) weathered rocks; (9) fault accompanied by milonitization; (10) working bench of open pit; (11) samples and their numbers.

and 1.5 ore minerals. In the basal part of the formation, dolomite is silicified and contains interbeds of carbonate-quartz sandstone. Granitoid rocks of the Late Proterozoic Barguzin and the Early Paleozoic Vitimkan intrusive complexes crop out at the deposit.

The Barguzin granitoids are gneissose and locally foliated and silicified. Small remnants of gabbro and gabbrodiorite of the Ikat Complex occur in these granitoids. The fine- to medium-grained granitoids of the Vitimkan Complex vary in composition from leucog-

Table 1. Silica and impurity contents in quartzites (1–4) and sandstone (5)

Variety of high-silica rocks	Content, wt %						
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	MnO	CaO	MgO
1	99.61	0.110	0.028	0.002	–	0.005	–
	99.68	0.120	0.027	0.004	–	0.004	–
2	99.40	0.110	0.058	0.004	–	0.002	–
	99.30	0.130	0.059	0.004	–	0.004	–
3	99.30	0.200	0.070	0.005	–	0.010	–
4	98.50	0.276	0.463	0.013	0.057	0.15	0.07
	98.71	0.270	0.120	0.007	–	0.01	–
5	75.60	0.424	2.930	0.019	0.119	11.90	8.65
	68.30	0.373	3.760	0.020	0.218	15.01	11.10

Note: See the legend of Fig. 4 for varieties of quartzites.

ranite to granodiorite and are accompanied by diverse dikes.

Anticlines and synclines composed of metasedimentary rocks reveal undulation and virgation of their axes, and their limbs dip at different angles northwestward and southeastward (up to vertical). Folds are broken and displaced by faults trending northeastward and occasionally in other directions. Numerous dikes mostly of acid composition, longitudinal and transverse, are controlled by faults. The southern part of the quartzite body is cut along its strike by two parallel leucogranite dikes 2.5 km in extent. These dikes are displaced along faults and locally transformed into boudins.

The rocks were metamorphosed under conditions of mica schist facies at $T = 600\text{--}650^\circ\text{C}$ and $P = 7.5\text{--}10$ kbar. Metamorphism was most intense along the NE-trending master faults. Effects of contact metamorphism related to granitoid intrusions have been obliterated by dynamometamorphism and are poorly discernible. However, typical hornfels and skarn may be observed at the contacts with Vitimkan granitoids.

Almost all rocks of the deposit are foliated to a variable degree. Silicate sedimentary rocks are foliated most intensely in comparison with carbonate and igneous rocks. The granitoids of the Barguzin Complex were transformed into gneissose rocks and foliated along fault zones.

Metasomatic alteration has affected all rocks of the deposit. The most intense bimetasomatic alteration is confined to the contact between silicate and carbonate rocks. Silicate rocks are liable to carbonation, whereas carbonate rocks are replaced by silicate minerals, and both underwent silicification. Metasomatic processes are widespread in the framework of granitoids pertaining to the Vitimkan Complex. The contact metasomatism related to the older intrusive complexes is obscure.

PETROGRAPHY AND GENESIS OF QUARTZITE

Quartzites at the Cheremshanka deposit are massive compact rocks of white, yellow-white, and gray color (Fig. 4). Small brown and black pocks, a few millimeters in size, filled with iron and manganese hydroxides, are identified in white and yellowish quartzites (Fig. 5). Brown and white ovoids of relict sandstones are abundant in contact zones of the quartzite body (Fig. 6).

Four quartzite varieties are recognized: (1) white medium- to fine-grained; (2) white fine-grained to some degree transformed into marshallite; (3) yellow-white and yellow; and (4) gray.

White quartzite largely occurs as blocks in the central portion of the layer. The pocks filled with iron hydroxides and relict ovoids of primary sandstone are sporadic. The relict ovoids are surrounded by dark brown rims colored with iron hydroxide and, in some cases, with black manganese hydroxide as a result of removal of impurities in the process of quartzite refinement (Fig. 5).

The white quartzite is massive, with granoblastic, mosaic hornfels, and rarely observed porphyroblastic microstructures. Quartz grains are closely packed. Scarce and small interstices contain sericite, goethite, sulfide and rutile micrograins, and occasional zircon grains (Fig. 7).

The chemical composition of the rock is given in Tables 1 and 2.

White fine-grained quartzite to some degree transformed into marshallite is distinguished by the highest silica content and the lowest contents of impurities (Fe, Al, Ca, and Mg). This quartzite is almost completely devoid of relict quartz grains. The newly formed quartz grains are clear-cut and pure with irregular outlines, about 0.3 mm in size, and slightly fractured. A nematoblastic quartzite structure is observed in some places. Sericite flakes and iron hydroxide films occasionally occur in the interstices.

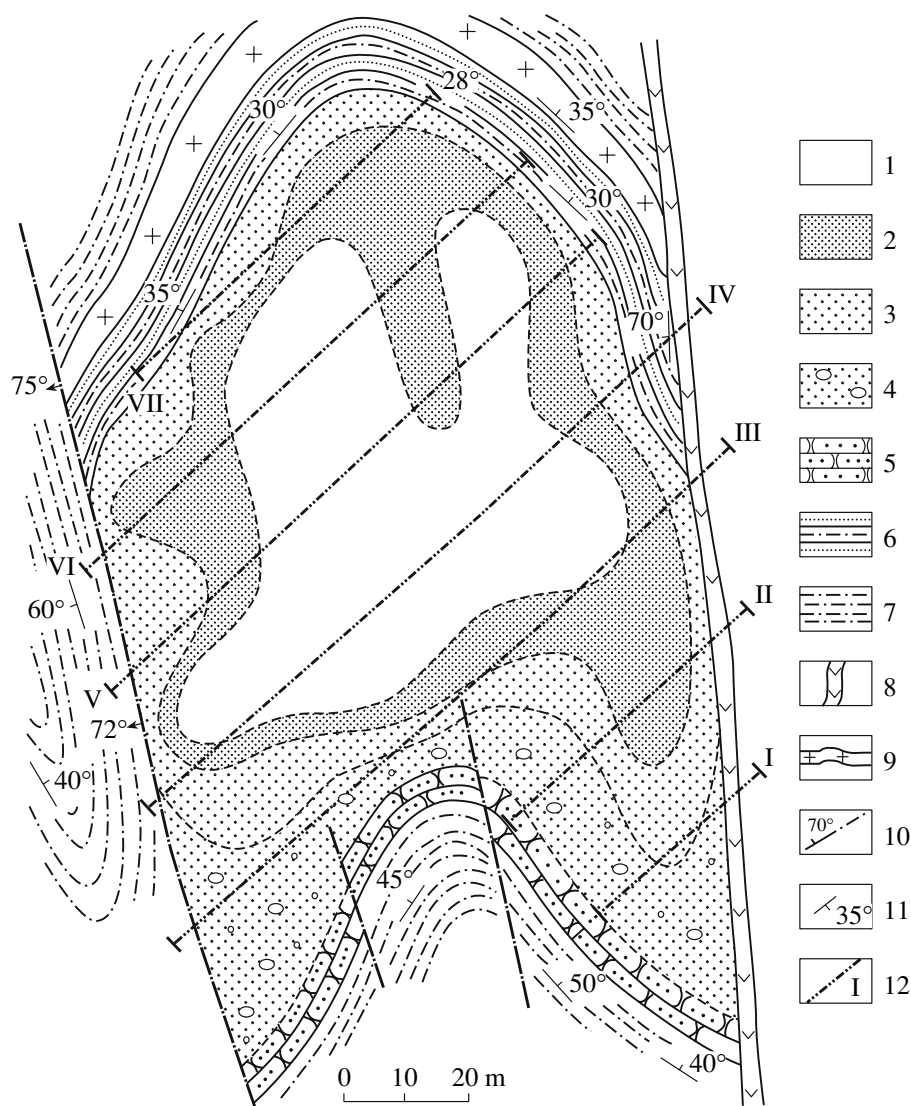


Fig. 4. Zoning of the body of silica-rich rocks and distribution of iron oxides. (1–4) Varieties of quartzites with different contents of iron oxide: (1) white fine-grained to some degree transformed into marshallite (0.04%), (2) white fine- to medium-grained (0.04–0.06%), (3) yellow-white and yellow with occasional “shadows” of replaced sandstone (0.06–0.08%), (4) yellow and spotty with numerous ovoid relics of replaced sandstone (0.08–0.28%); (5–9) host rocks: (5) quartz sandstone with carbonate cement, (6) alternating sericite-bearing quartzite and sericite schist, (7) sericite-quartz schist, (8) dike of porphyritic diorite, (9) sill of kaolinized aplite-like granite; (10) faults and their dip azimuth and angle; (11) strike and dip of foliation; (12) lines of trench sampling.

Yellow-white and yellow quartzites are abundant in contact zones of the quartzite body and in the walls of tectonic fractures that outline rock blocks. These fine-grained rocks often display supergene linear, concentric, and fan-shaped banding of iron and manganese hydroxides. The ovoids of supergene iron hydroxides as relics of altered sandstone (Figs. 4, 7) and hydroxide pocks are more abundant in these rocks than in other quartzite varieties. This variety of quartzites contains more detrimental impurities than the white varieties, whereas the SiO_2 content is lower. At contacts with dikes, the silica content in yellow quartzite is the lowest

(93.40–96.24%) and the amount of impurities is relatively high (Tables 1, 2).

Gray quartzite occurs as irregular lenses in white varieties, often at contacts with silicate schists. This is a fine- to medium-grained rock, whose appearance resembles thawing ice. The gray color is caused by an elevated content of sericite (~2%). Quartz grains are 0.2–0.4 mm in size. They are irregular in shape and are characterized by undulatory extinction. Interstices between quartz grains are filled with rutile, leucoxene, sphene, pyrite, and limonite. Such quartzite is a silicified schist in marginal zones of the productive sheetlike body.

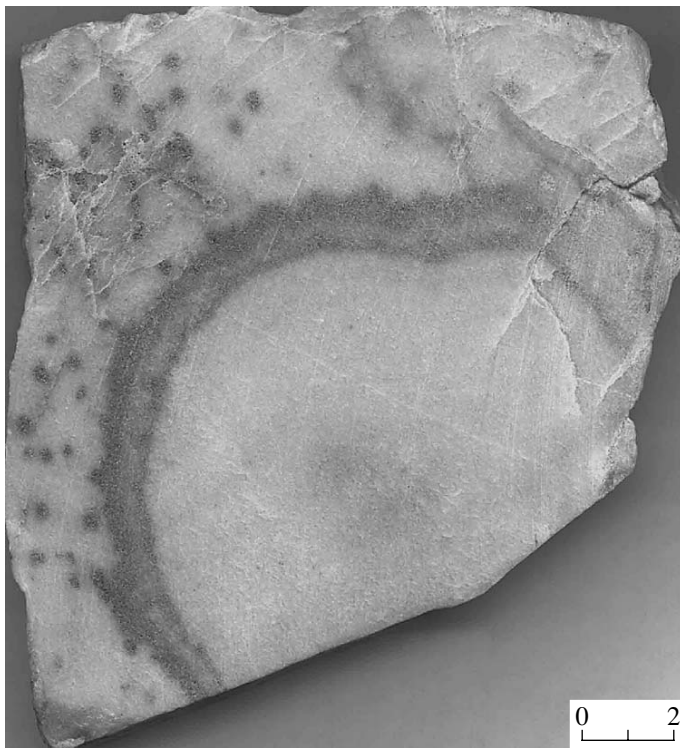


Fig. 5. A rounded fragment of the Cheremshanka quartzite. Quartzite refined by diffusion is located in the center. The rhythmic outer rim is composed of material removed from the replaced sandstone and fixed in goethite, hydrogoethite (the major mineral), galena, sphalerite, chalcopryrite, fahl-ore, and pyrite, which were identified as micrograins of crushed rocks. Elements contained in these minerals are as follows: 0.15% Fe and W, >10% Pb, 0.6% Zn, 2% Cu, >10 ppm Ag, 10 ppm Au, >1% Sb, 3% Bi, and 6% As. Sandstone with hydrogoethite pocks replaced by quartz is seen at the left margin of the photograph.

Sandstone relics are retained in quartzite as linear fragments or brown ovoids largely consisting of quartz grains with irregular wavy contours and a yellowish color.

The rock is massive and has blastopsammitic, regenerative texture. Iron hydroxides, magnetite, chalcopryrite, and oxidized pyrite are located between quartz grains. Cement has been leached out or replaced by iron hydroxides. Rare sericite flakes and broad hollow interstices suggest that clayey carbonate material initially cemented quartz grains.

The main mass of silica was introduced into quartzite by infiltration and diffusion in pore and fracture solutions. The silicate rocks of the Itantsa Formation are enriched in silica, and the rocks of the overlying Burla Formation, in CaO and MgO. A sandstone layer sandwiched between the silicate and carbonate (dolomite) formations served as the main fluid conduit, being more coarse-grained than the adjoining rocks. The transverse and longitudinal fractures arising as a response of brittle rock to pressure increased the trans-

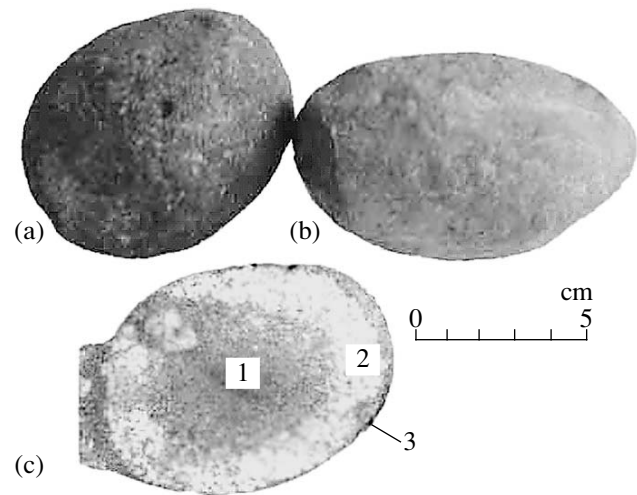


Fig. 6. Relict sandstone ovoids from metasomatic quartzite at the Cheremshanka deposit, resembling conglomerate pebbles in outer appearance. (a, b) Ovoids, side view; (c) ovoid, view in section: (1) relic of incompletely replaced sandstone, (2) silicified outer portion of sandstone ovoid, (3) hydroxide rim of components removed from the sandstone by diffusion.

mission capacity of the sandstone. While compression of silty and clayey rocks results in their foliation, psammitic layers react to such deformation by brittle failure. This is confirmed by numerous dikes that occur in the quartzite layer (former sandstone).

When pore solutions in carbonate rocks of the Burla Formation are heated, they overflow into the permeable, porous and fractured sandstone. Filtration of solutions into the silty and clayey rocks is hampered by their low porosity. Experiments have shown that the filtration rate of aqueous solutions through pores with a radius $<10^{-4}$ cm is only 10^{-9} cm/s (tens of centimeters over 1000 years), and, therefore, nonfiltration mechanisms dominate in mass transfer (Trukhin, 1973; Pospelov, 1973).

In terms of physical chemistry, all rocks and minerals are porous bodies and their behavior obeys the laws of the thermodynamics of capillary-porous systems. Capillary-porous bodies are dispersion systems, in which the rigid frame may be regarded as a dispersion medium and the pores filled with gas or liquid as an immobile dispersion phase. The smaller the dimensions of the dispersion phase, the more actively it behaves with respect to the dispersion medium, in our case, to the pore walls. In addition to temperature and pressure, this activity also depends on dispersity, i.e., on the curvature of pores filled with solution or gas (Tsarev, 2002).

In connection with the different size of pores, the dissolution of silica in alkaline solutions proceeds more actively in fine porous siltstone and claystone than in coarse porous sandstone. In capillary dispersed systems, the walls of fine capillaries are dissolved and the

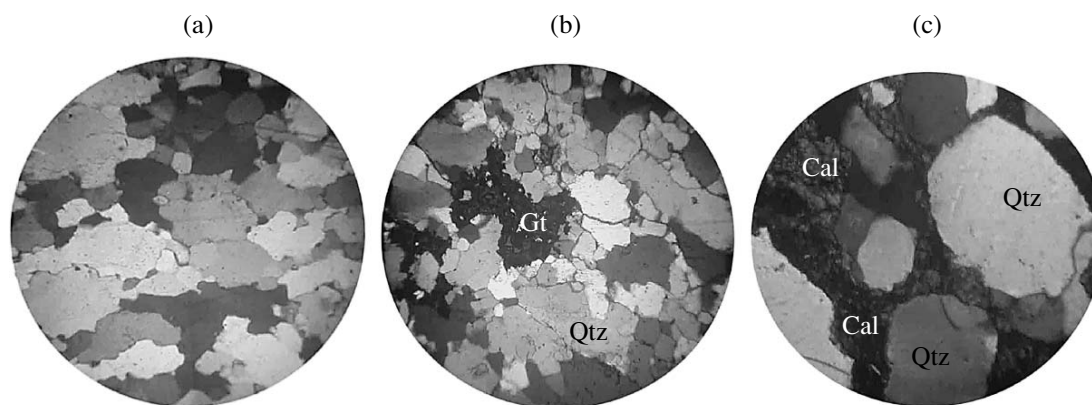


Fig. 7. Textural varieties of quartzite at the Cheremshanka deposit. Magn. 54. (a) Quartzite refined by diffusion; (b) infiltration quartzite: Gt, goethite; Qtz, quartz; (c) quartz sandstone cemented with carbonate: Qtz, quartz; Cal, calcite.

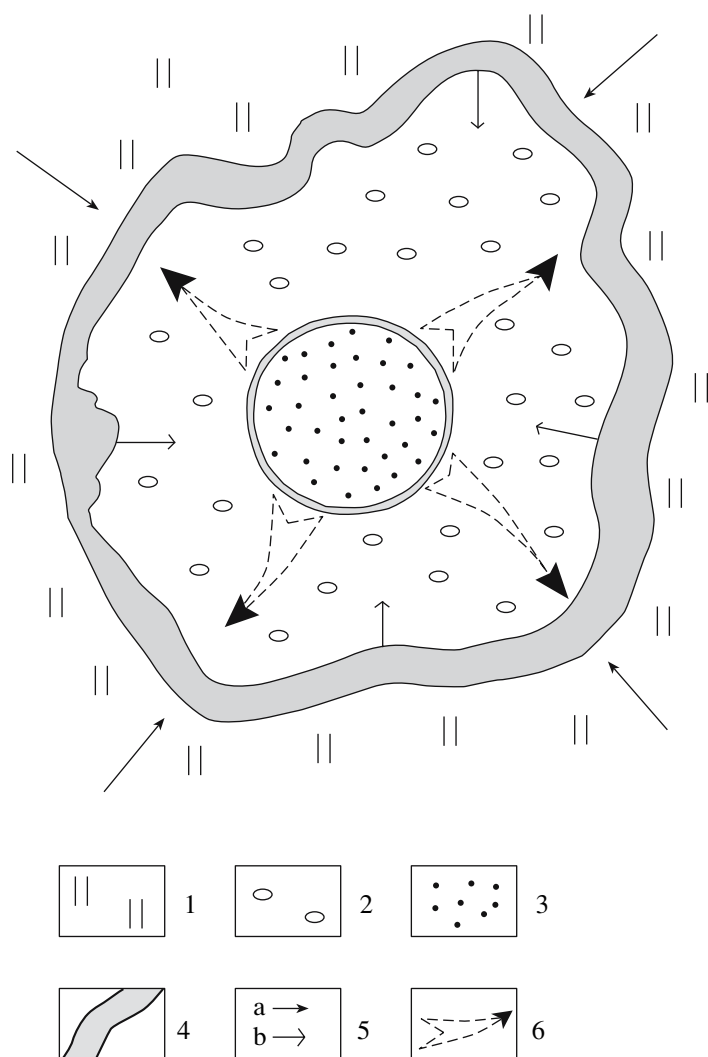


Fig. 8. A conceptual scheme of self-refinement of quartzite. (1) Infiltration quartzite; (2) diffusion quartzite; (3) relic of sandstone; (4) iron hydroxide selvage; (5) direction of matter migration: (a) infiltration and (b) diffusion; (6) direction of diffusion removal of matter.

Table 2. Chemical composition of quartzite varieties, wt %

No.	Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Σ
<i>White medium-grained quartzite</i>														
1	TsT-15	99.30	0.03	0.30	0.06	0.44	0.01	0.02	<0.01	<0.01	0.02	0.01	0.12	100.32
2	TsT-16	99.40	0.03	0.30	0.06	0.44	0.02	0.03	<0.01	<0.01	0.02	0.01	0.12	100.33
3	TsT-17	99.50	0.03	0.30	0.06	0.44	0.03	0.04	<0.01	<0.01	0.02	0.01	0.12	100.34
4	TsT-22	99.10	0.03	0.30	0.06	0.44	0.08	0.09	<0.01	<0.01	0.02	0.01	0.12	100.39
5	TsT-23	99.11	0.03	0.30	0.06	0.44	0.09	0.10	<0.01	<0.01	0.02	0.01	0.12	100.40
Average		99.28	0.03	0.30	0.06	0.44	0.05	0.06	<0.01	<0.01	0.02	0.01	0.12	100.36
<i>White fine-grained quartzite to some degree transformed into marshallite</i>														
6	DCh-11	99.52	0.02	0.08	0.09	0.12	0.03	<0.10	<0.10	<0.01	0.04	<0.05	0.08	99.98
7	DCh-12	99.69	0.03	0.08	0.07	0.08	0.01	<0.10	<0.10	0.01	0.05	<0.05	0.04	100.06
8	DCh-13	99.72	0.02	0.07	0.08	0.08	0.05	<0.10	<0.01	<0.01	0.05	<0.05	0.06	100.13
9	DCh-14	99.83	0.03	0.05	0.06	0.07	0.04	<0.10	<0.01	<0.01	0.04	<0.05	0.04	100.16
10	DCh-15	99.92	0.02	0.05	0.06	0.07	0.03	<0.10	<0.01	<0.01	0.04	<0.05	0.02	100.21
Average		99.74	0.02	0.07	0.07	0.08	0.03	<0.10	0.04	<0.01	0.04	<0.05	0.05	100.11
<i>Yellow-white and yellow quartzites</i>														
11	TsT-15b	97.30	0.04	0.30	0.90	0.81	0.01	0.03	0.03	<0.01	0.02	0.01	0.18	99.63
12	TsT-16b	98.20	0.04	0.20	0.53	0.52	0.01	0.03	<0.01	<0.01	0.02	0.01	0.13	99.69
13	TsT-17b	98.80	0.03	0.20	0.52	0.30	0.02	0.02	<0.01	<0.01	0.02	0.01	0.17	100.09
14	TsT-18b	98.30	0.03	0.25	0.55	0.37	0.01	0.04	<0.01	<0.01	0.02	0.01	0.19	99.77
15	TsT-19b	98.80	0.04	0.10	0.39	0.59	<0.01	0.01	<0.01	<0.01	0.02	0.01	0.14	100.10
Average		98.20	0.04	0.21	0.58	0.52	0.01	0.03	0.03	<0.01	0.02	0.01	0.16	99.86
<i>Gray quartzite</i>														
16	ChR-6	89.84	0.22	5.35	0.30	0.34	<0.01	0.16	0.01	0.19	1.65	0.01	1.54	99.64
17	ChR-7	85.75	0.31	7.69	0.48	0.93	0.01	0.35	0.02	0.38	2.03	0.01	1.87	99.83
18	ChR-8	86.52	0.29	6.92	0.59	0.96	0.01	0.28	0.02	0.32	1.83	0.01	1.46	99.21
19	ChR-9	87.57	0.34	7.01	0.29	0.89	0.01	0.23	0.02	0.34	1.03	0.01	1.63	99.37
20	ChR-10	88.65	0.28	6.89	0.37	0.68	0.01	0.19	0.02	0.26	1.09	0.01	1.15	99.60
Average		87.67	0.29	6.77	0.41	0.76	0.01	0.24	0.02	0.30	1.53	0.01	1.53	99.53

Note: The analyses were performed at the Geological Institute, Siberian Division, Russian Academy of Sciences, analysts G.I. Buldaeva, I.V. Borzhonova, I.V. Bardamova, and A.A. Tsyrenova (2001–2003).

dissolved material precipitates in larger capillaries (Frolov, 1982).

The alkaline pore and fracture solutions most likely were polygenetic and combined transmagmatic and magmatic (Korzhinsky, 1953) and formation waters of carbonate rocks of the Burla Sequence that were activated on saturation with Ca and Mg.

The solutions were supplied into the sandstone layer from both a magmatic source and fine porous silty rocks by squeezing as a result of tectonic compression or by film capillary transfer. The saturation of alkaline solutions with silica caused their acidation. The acid solutions, moving from fine porous rocks to coarse porous sandstone, became oversaturated because of a release of pressure and precipitated silica. This process, which is called acid leaching (Korzhinsky, 1953), pro-

vided the transformation of sandstone into quartzite. Dolomites and granitoids that had undergone cataclasis, brecciation, and foliation were locally transformed into quartzite as well. Sandstone beds intercalated with schists of the Itantsa Formation were also silicified.

The fluid inclusions in quartz of metasomatic quartzite and silicified sandstone from the Cheremshanka deposit were studied at the Laboratory of Petrogenesis and Ore Genesis of the Geological Institute of the Siberian Division of the Russian Academy of Sciences by standard techniques of thermometric analysis (Roedder, 1984).

The metasomatic quartzite contains primary and secondary fluid and solid–fluid inclusions. The homogenization temperature of primary fluid inclusions was estimated at 268°C and that of secondary inclusions, at

170°C. For primary solid–fluid inclusions, $T_{\text{hom}} = 344^\circ\text{C}$. For primary inclusions in sandstone, $T_{\text{hom}} = 345^\circ\text{C}$.

The infiltration-type silicification of sandstone and other rocks was accompanied by diffusion redistribution of silica along with their refinement by removal of impurities. The infiltration and diffusion occurred against the background of tectonic deformation concurrently with migration of fracture and pore solutions, which gave rise to recrystallization of quartzite and related removal of impurities. More intense refinement was caused by diffusion recrystallization. The removed impurities accumulated at the front of the solution filtering through. The basic and other components that were removed during these process precipitated in silicate and carbonate rocks underlying and overlying sandstone. As a result, the dolomite and schist that host the quartzite body contain lenses of hematite and sulfides, small quartz lenses and veinlets, and ferruginous–siliceous aggregates that resemble jaspilite, as well as elevated contents of Au, Ag, Pb, Zn, and relevant minerals (see below).

The decreasing pressure gradient brought the solution to a stop. This event was preceded by deposition of removed impurities (shifted components after Korzhinsky) and the formation of magnetite, hematite, pyrite, pyrrhotite, chalcopyrite, arsenopyrite, fahlore, galena, sphalerite, etc. These minerals mark the boundary of the infiltration frontal removal (Fig. 5). The frontal recrystallization and removal started from tectonic fractures that contour quartzite blocks and from cross-cutting dikes, i.e., from linear channels of solution filtration. In this connection, contours of the zones enriched in newly formed mineral aggregates are often closed. As the perimeter of a separate contour approached the center, it acquired a more regular spherical shape.

The counter diffusion flow of impurities was directed from the inner zone of the sphere towards the contour of newly formed minerals. The contour of impurities removed by diffusion merged with the infiltration contour or was localized nearby. Relics of incompletely replaced sandstone were retained in the center of the diffusion sphere (Figs. 6, 8). The diffusion varieties of quartzites are best refined, as indicated by their chemical composition (Table 1).

GOLD–BASE-METAL MINERALIZATION AT THE CHEREMSHANKA DEPOSIT

As was mentioned above, gold–base-metal mineralization associated with the quartzite layer is known in the Cheremshanka ore field. This mineralization has been documented at the flanks of the quartzite body, largely on the side of its footwall (Fig. 2). The scope of this mineralization has not yet been constrained, though possibilities of discovering gold–base-metal deposits are quite real.

Several ore-bearing zones have been traced at the deposit: (1) zones of gold–sulfide mineralization in black shales; (2) stringer–disseminated and stockwork zones in various rocks at contacts of dikes that crosscut quartzite; and (3) zones of mica–quartz–carbonate metasomatic alteration (beresitization) with sulfide disseminations and quartz and quartz–sulfide veinlets and pockets.

An alluvial gold placer is also known along the Cheremshanka River (Fig. 2).

The black shale sequence in the Cheremshanka ore field, several hundred meters thick, was traced for tens of kilometers. A foliated zone, from 10 to 16 m wide, was traced along the contact between the black shale sequence and the economic quartzite body, abruptly waning in quartzite. The zone consists of black and gray compact fine- and medium-grained rocks. The modal mineral composition of this rock (except carbonaceous matter) is as follows (vol %): 40–70 sericite, 15–90 quartz, 5–10 chlorite, 1–5 carbonates, 0–1 muscovite, and 0–3 biotite. Sulfides, magnetite, garnet, andalusite, rutile, and apatite are secondary minerals, while kaolinite, goethite, and hydrogoethite were formed under supergene conditions.

According to the trench sampling, the Au content in these rocks (in areas enriched in pyrite) varies from 0.001 to 0.10 ppm (Fig. 3).

Judging from numerous geochemical anomalies detected in the ore field, the gold–sulfide mineralization of the black shale type is widespread. The presented data allow us to suggest that the gold now localized along the footwall of the quartzite body was leached out from sandstone and other rocks as a result of the hydrothermal metasomatic process that created the silica deposit.

CONCLUSIONS

On the basis of the evidence presented above, it may be concluded that the Cheremshanka deposit is a body of metasomatic quartzite that replaced a layer of quartz sandstone in the process of silica gain from host silicate silty–clayey rocks and removal of components of the replaced carbonate–clayey cement to the roof and bottom of the layer. The metasomatic silicification largely was an infiltration process. Various impurities were removed by diffusion.

The removed Pb, Zn, Au, and Ag precipitated in the contact zones of host rocks and in quartzite itself with formation of ore mineralization; in certain zones, this mineralization might be of economic importance.

ACKNOWLEDGMENTS

We thank the management of the Cheremshanka Mine for their permission to study the deposit and F.G. Reif for his consultations on mineral thermometry.

REFERENCES

1. Yu. G. Frolov, *Treatise on Colloid Chemistry: Surface Events and Dispersed Systems* (Khimiya, Moscow, 1982) [in Russian].
2. V. I. Ignatovich, O. V. Sokolov, Yu. V. Plotnikov, and V. V. Novikov, "Quartz Sandstones of the Cheremshanka Deposit: A High-Quality Raw Material for Glass Industry," in *Geology and Exploration of Mineral Deposits* (VIEMS, Moscow, 1972) [in Russian].
3. D. S. Korzhinsky, "Essays on Metasomatic Processes," in *Main Problems of the Geology of Magmatic Ore Deposits* (Akad. Nauk SSSR, Moscow, 1953), pp. 332–475 [in Russian].
4. D. S. Korzhinsky, *Metasomatic Zoning* (Nauka, Moscow, 1982) [in Russian].
5. A. N. Novikova and N. A. Suranova, "Mineralogical and Petrographic Characteristics of Quartz and Quartzite Sandstones of the Cheremshanka Deposit," in *Proceedings on Mineralogy, Geochemistry, and Petrography of the Transbaikalian Region* (Ulan-Ude, 1971), No. 3, pp. 81–86 [in Russian].
6. G. L. Pospelov, *Metasomatism: Paradoxes, Geological–Geophysical Nature, and Mechanisms* (Nauka, Novosibirsk, 1973) [in Russian].
7. E. Roedder, *Fluid Inclusions in Minerals* (Reviews in Mineralogy, Mineral. Soc. Amer., 1984, Vol. 12; Mir, Moscow, 1987).
8. Yu. P. Trukhin, "Pore Solutions and Causes of Heterogeneities of Their Chemical Composition (with Reference to Hydrothermal Deposits of Kamchatka)," in *Problems of Pore Solutions in Geology* (Nauka i Tekhnika, Minsk, 1973), pp. 169–172 [in Russian].
9. D. I. Tsarev, *Metasomatism* (Buryat Sci. Center, Siberian Division, Russian Acad. Sci., Ulan-Ude, 2002) [in Russian].
10. D. I. Tsarev and V. K. Khrustalev, "New Aspects of the Integrated Processing of Quartzite from the Cheremshanka Deposit," in *Economic Problems and New Technology for the Integrated Processing of Minerals* (Chita, 2002), pp. 147–155 [in Russian].