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Genesis of Metasomatic Rocks and Mineralized Veins at the Berezovskoe Deposit, Central Urals: Evidence from Fluid Inclusions and Stable Isotopes

I. A. Baksheev*, V. Yu. Prokof'ev**, and V. I. Ustinov***

* Faculty of Geology, Moscow State University, Vorob'evy gory, Moscow, 119899 Russia

** Institute of the Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences, Staromonetnyi per. 35, Moscow, 109017 Russia

*** Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, ul. Kosygina 19, Moscow, 117975 Russia

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Abstract—The Berezovskoe gold deposit near the town of Yekaterinburg in the Central Urals is controlled by an array of granitoid porphyry and lamprophyre dikes. Individual fluid inclusions in quartz from veins accompanying metasomatic rocks of the propylite, gumbeyite, and beresite–listwanite associations were examined by microthermometric techniques, and aqueous extracts of these inclusions were analyzed by ICP-MS techniques. The isotopic compositions of quartz, tourmaline, scheelite, and carbonates were analyzed, and it was established that mineralized quartz veins associated with the metasomatic rocks of the beresite–listwanite association at the Berezovskoe deposit were produced by at least two pulses of hydrothermal activity. The first of them was responsible for the origin of the early (scheelite + quartz I) assemblage, and the second formed the productive ore mineralization. The early assemblages crystallized at temperatures of 365–270°C under pressures of 3460–1470 bar from solutions with salt concentrations of 14.9–2.4 wt % equiv. NaCl and a CO₂ concentration of 6.3–3.1 mol/kg of solution. The density of the solution was 1.10–1.00 g/cm³, and the density of the carbon dioxide phase was 1.04–0.78 g/cm³. The quartz of the productive association crystallized at temperatures of 335–255°C and pressures of 2860–810 bar from solutions with salt concentrations of 9.0–2.0 wt % equiv. NaCl and a CO₂ concentration of 5.3–3.1 mol/kg of solution. The density of the solution was 1.08–0.96 g/cm³, and the density of the carbon dioxide phase was 0.99–0.62 g/cm³. The ore mineralization was deposited as a consequence of fluid boiling and devolatilization, which were caused by local tectonic motions. Gold-bearing mineralized veins developed at weak vertical variations in the physicochemical parameters, which was favorable for a great depth interval of ore deposition and a high ore potential at the lower levels of the deposit. The calculated oxygen isotopic composition of the aqueous phase in the fluid that produced quartz I ($\delta^{18}\text{O}_{\text{H}_2\text{O}}$ from +3.6 to +6.5‰) and scheelite ($\delta^{18}\text{O}_{\text{H}_2\text{O}}$ from +2.8 to +5.4‰) testify that the fluid was of magmatic and/or metamorphic provenance.

INTRODUCTION

The study and exploitation of Russia's gold deposits is currently systematically shifted from placer to lode types, with the latter considered to serve as the sources of several placers. This causes closer attention to be paid to lode deposits regarded as typifying certain gold-bearing ore associations.

Significant gold reserves are accommodated in deposits of the plutogenic gold–quartz association, which can be typified by the Berezovskoe deposit, 5 km north of the town of Yekaterinburg. The geology and mineralogy of the deposit, which has been mined for more than 250 years, were described by several researchers, who up to recently recognized only two types of metasomatic rocks at the deposit: propylite and beresite–listwanite [1]. In 1998, Spiridonov *et al.* [2]

demonstrated that another type of metasomatic rock widespread at the deposit belongs to the gumbeyite association and includes the accompanying veins.

In studying lode mineral deposits, much attention is commonly paid to fluid inclusions and stable isotopes contained in minerals of the metasomatic rocks and mineralized veins. These results may provide unique information on distinctive features of the mineralizing processes that operated during the development of the deposits. The information includes the temperature, pressure, and chemical composition of the mineralizing solutions, concentrations of chemical elements in them, and their probable sources.

In spite of the fact that the Berezovskoe deposit was described in numerous papers, there are practically no available data on fluid inclusions and the isotopic com-

position of minerals from the metasomatic rocks of the propylite association and accompanying veins. The only research devoted to fluid inclusions and the isotopic composition of minerals of the gumbeyte association is [2]. Scarce and unsystematic data on fluid inclusions and stable isotopes in minerals from the beresites–listwanites and associated veins are available from literature published in various years [3, 4], but this information is far from sufficient for adequate understanding of the processes that produced this deposit. Since the deposit contains metasomatic rocks of different associations, it is important to reveal the differences between the genetic conditions of the propylites, gumbeytes, beresites–listwanites, and associated veins.

The deposit is cut by several mine and exploration workings, which expose it from the surface to a depth of –712 m and allow one to detect possible variations in the physicochemical parameters of the origin of gold-bearing quartz veins over this depth interval and, thus, to characterize the ore potential of the lower levels of the deposit.

GEOLOGY OF THE DEPOSIT AND MINERALOGY OF METASOMATIC ROCKS AND MINERALIZED VEINS

The geologic structure of the Urals is subdivided into two megazones: miogeosyncline (Western Zone) and eugeosyncline (Eastern Zone). The Eastern Megazone includes three synclinoriums (Magnitogorsk, Eastern Ural, and Tyumen'–Kustanai) and two anticlinoriums (Eastern Ural and Transuralian) [5]. The Berezovskoe gold ore field is localized in the central portion of the Sverdlovsk tectonic zone in the western flank of the Eastern Ural anticlinorium [6]. The zone is composed of a thick succession of sedimentary rocks and basaltoids of Silurian–Devonian age, which are cut by numerous intrusions of variable age and composition.

The Berezovskoe ore field is hosted by a weakly eroded Berezovskii tectonic block (Fig. 1) and is dominated by Silurian–Devonian volcano-sedimentary and terrigenous rocks. The stratified sequence contains numerous sheet- and laccolith-shaped bodies of serpentinized hyperbasites, is deformed into gentle folds, and dips to the west and northeast at angles of 20°–30° [7]. The central part of the block is intruded by the granitoids of the weakly eroded Shartash pluton, which is exposed as an oval approximately 7 km across. The southern contact of the intrusion is steep, whereas its northern contact dips at small angles beneath the Berezovskoe gold deposit. The Rb–Sr age of the granitoids is 350–355 Ma, i.e., Early Carboniferous [8].

Numerous dikes cut across both the Shartash granitoids and the stratified succession and consist of granite porphyries and lamprophyres, which were emplaced after the granite porphyries. The dikes extend for a few kilometers along the strikes and compose swarms that fan in a northerly direction. The dikes of individual

swarms are spaced at 5–10 m, with distances between swarms ranging from 80 to 100 m. Most of the dikes are restricted to north-striking faults, which dominate within the ore field (Fig. 1).

The Berezovskoe gold deposit is hosted by metasomatic rocks of at least three types.

The metasomatic rocks of the propylite association develop after acid, intermediate, and mafic rocks and consist of chlorite, epidote, amphibole, albite, quartz, tourmaline, carbonates, and hematite; those which develop after serpentinized ultramafic rocks consist of talc, magnesite, and hematite.

The metasomatic rocks of the gumbeyte association developed after acid, intermediate, and mafic rocks consist of quartz, potassium feldspar, calcite, dolomite, sericite, pyrite, and scheelite. The analogous rocks replacing serpentinite are composed of talc, hydroxyl-phlogopite, magnesite, and hematite. The gumbeytes and related ore mineralization were described in detail in [2].

Most of the metasomatic rocks affiliate with the gold-bearing beresite–listwanite association. The beresites developed after acid rocks and consist of quartz, sericite, dolomite, calcite, and pyrite. The listwanites replacing hyperbasites contain magnesite and fuchsite in place of calcite and muscovite, respectively. The beresite–listwanite developed along contacts between silicic and serpentinized ultramafic rocks and consist of quartz, sericite, Fe-magnesite, Fe-dolomite, and pyrite. Gold-bearing carbonate–quartz veins are related to the beresite–listwanite association, which occurs as 1.5-m-thick aureoles around the veins.

The carbonate–quartz gold-bearing veins can be classified into two types: (1) ladder veins localized within granite and plagiogranite porphyry dikes at high angles with respect to the contacts of the dikes and (2) veins in volcanic sedimentary rocks and serpentinized hyperbasites. The veins of both types are coeval and dip southward or, rarely, northward at high angles. The gold grades in the veins of the first group are much lower than those in the veins of the second group.

The veins are sheet-shaped, and there are often *en-echelon* arrays of short lens-shaped veinlets in them. Coarse-grained quartz of several generations is the main gangue mineral. The ore minerals are pyrite, scheelite, galena, chalcopyrite, aikinite, fahlores, and native gold, which fill pockets and interstices between quartz grains.

The four main mineral assemblages distinguished in the mineralized gold-bearing veins are as follows: (1) quartz I + carbonate + scheelite; (2) pyrite + carbonate; (3) quartz II + carbonate + fahlores + galena + aikinite + native gold (productive assemblage); and (4) carbonate. Gold is unevenly distributed in the veins, is accompanied by fahlores and aikinite, and is 800–930 fine.

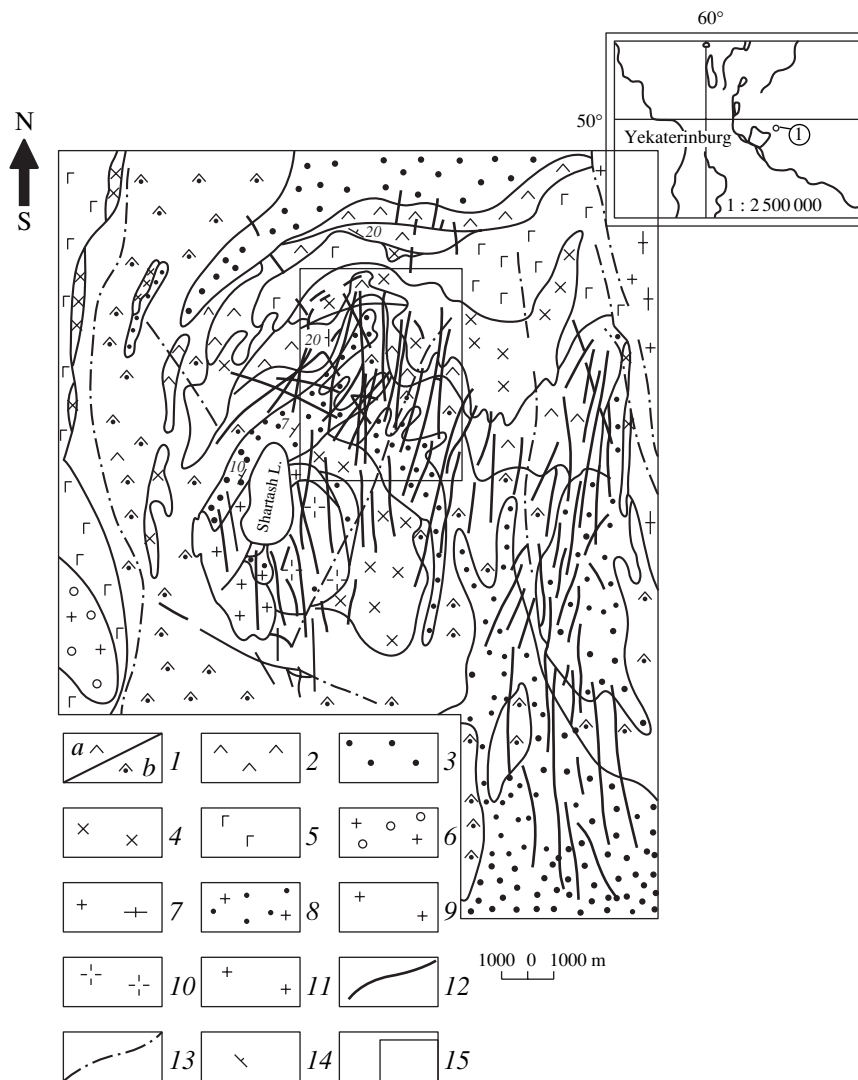


Fig. 1. Schematic geological map of the Berezovskoe gold ore field, Central Urals (modified after [7]). The inset demonstrates the location of the ore field (denoted by *I*). (*Ia*) Microgabbro-dolerite, (*Ib*) aphyric basalts and their breccias; (2) metamorphosed microgabbro-dolerite and basalt porphyrites; (3) terrigenous rocks (S); (4) serpentinites and talc-carbonate rocks; (5) gabbro; (6) granitoids of the Verkhnyaya Iset' Massif; (7) granite-gneisses of the Murzinka Massif; (8–11) rocks of the Shartash Massif: (8) adamellites; (9) fine-grained adamellites; (10) medium-grained adamellites; (11) coarse-grained adamellites; (12) granitoid dikes; (13) faults; (14) strike and dip symbols of schistosity; and (15) boundaries of the Berezovskoe gold deposit.

METHODS

Individual fluid inclusions were examined under a microscope in doubly polished platelets 0.3–0.5 mm thick. The chemical composition of the fluids and their density were assayed from the data of cryometric studies. The eutectic temperatures were determined accurate to $\pm 1.5^\circ\text{C}$, the melting temperatures of ice and CO_2 homogenization temperatures were determined accurate to $\pm 0.2^\circ\text{C}$, and the accuracy of the CO_2 melting temperatures was $\pm 0.5^\circ\text{C}$. The fineness of liquid CO_2 was determined from the decrease in the melting temperature relative to the triple point (-56.6°C). The concentrations of salts were evaluated using the melting temperatures of the gas hydrates according to the data

from [9]. For euhedral inclusions, we additionally assayed the volume of the gaseous phase (accurate to ± 20 vol %) and calculated the CO_2 concentration in an aqueous solution based on the CO_2 solubility in an aqueous solution of NaCl (using data from [10]). Simultaneously, we calculated also the overall density of the aqueous fluid. The homogenization temperatures of fluid inclusions were measured accurate to $\pm 2^\circ\text{C}$ (the corresponding values in the tables are rounded to 5°C).

Aqueous extracts were analyzed by inductively coupled plasma techniques (ICP-MS) on a VG-Plasma Quad 2 (VG Instruments) device. The extracts were obtained from aggregates of quartz grains 0.5–0.25 mm in size weighing 10–15 g. The background

solution was prepared prior to the opening of the vacuoles; then, the inclusions were opened thermally (at a temperature of 450°C) with simultaneous determination of H₂O (by means of absorption with P₂O₅) and preparation of the respective sample solution. The volume of the sample solution was equal to that of the background solution: 30–45 ml depending on the sample weight (at a 1 : 3 dilution). The concentrations of elements were calculated as the difference between these concentrations and were then recalculated to the masses of solutions in the inclusions.

Replicate analyses for Na and K concentrations were conducted by titration. These data were further treated as their more precise because of the technical specialties of the ICP analysis for being major components.

The **isotopic composition** of quartz, scheelite, and tourmaline was analyzed with the use of the fluoride technique of O₂ separation and further mass spectrometric determination of $\delta^{18}\text{O}$ with a precision of $\pm 0.2\%$ [11]. The $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ of carbonates were determined by CO₂ extraction by SnCl₂ melt from the samples [12].

The **chemical composition** of minerals was analyzed on a CamScan scanning electron microscope equipped with a LINK 10000 analytical set at the Department of Petrology, Geological Faculty, Moscow State University, at an accelerating voltage of 15 kV, beam current of $1\text{--}6 \times 10^{-9}$ E, with a beam 3 μm in diameter. Corrections were introduced in accordance with the ZAF routine.

RESULTS OBTAINED ON FLUID INCLUSIONS

Description of fluid inclusions. In order to obtain information on the ore deposition conditions, we used normal inclusions (which were not necked and were trapped from an originally homogeneous phase of fluid) that were selected as groups of inclusions with similar phase relations.

In selecting inclusions for this study, we paid much attention to the identification of their genetic type [13, 14]. This paper presents our results obtained on primary and pseudosecondary types of inclusions. It was relatively rarely possible to reliably distinguish primary inclusions, and they were used as reference objects. The criteria utilized as pointing to their primary nature were as follows: inclusions should have been either evenly distributed over the volume of the host mineral, restricted to its growth zones (such inclusions were rare), or else be situated behind a crystal inclusion, which hampers the growth of the crystal. The pseudosecondary inclusions were restricted to cracks, which terminated within the host crystal and reflected the growth condition of the crystal during later stages.

The quartz and scheelite of veins related to the metasomatic rocks of the propylite, gumbeyite, and beresite associations were determined to contain two types

of coeval inclusions: (1) an aqueous solution with a gas bubble, which accounted for 35–18 vol % of the inclusions and contained liquid carbon dioxide (sometimes with a solid phase), and (2) gas-dominated inclusions, which were syngenetic with inclusions of the first type and filled with high-density carbon dioxide with 5–15 vol % aqueous solution. This combination of inclusions suggested that the mineralizing fluid was heterogeneous. In other words, the minerals crystallized on a two-phase equilibrium line and the homogenization temperatures of the inclusions corresponded to the temperatures of mineral crystallization; i.e., inclusions of this type can be utilized in pressure estimates [14].

Most of the water–carbon dioxide inclusions were depressurized before their homogenization, so that we managed to measure the homogenization temperatures of only a few smallest inclusions (no more than 10% of all inclusions). To obtain statistically significant number of measurements, in studying each inclusion group we selected large swarms of coeval inclusions, among which large vacuoles occurred with similar phase relations. The largest inclusions of these groups were first examined cryometrically, because these inclusions became unsealed when heated due to their high internal pressure, and then the platelet was heated to determine the homogenization temperatures of the smallest inclusions, most of which remained intact during heating. Because several inclusions were depressurized before homogenization, we examined large numbers of platelets of each sample to obtain an overall large number of measurements, in spite of the apparent laborious character of this procedure.

Pressure estimates. The entrapment of heterogeneous fluid provides a principal possibility of assaying the pressure under which a mineral crystallized [14]. To evaluate the pressure, we used the FLINCOR computer program (version 1.21) [15]. The total pressure was calculated as the sum of the partial pressures of water and carbon dioxide. The pressure of CO₂ (which was practically pure in our samples) was estimated from the intersection of CO₂ isochores and isotherms. The isochores were drawn with the aid of the aforementioned program, based on the results obtained for gas-dominated inclusions and with the utilization of equations for pure CO₂ from [16]. The isotherms were calculated from data on the homogenization temperatures of aqueous inclusions. The water pressure was calculated from the homogenization temperatures of aqueous fluids in the H₂O–NaCl system with the use of the equation from [16].

Our thermo- and cryometric results obtained for individual fluid inclusions in quartz and scheelite are summarized in Tables 1–3 and are illustrated in a series of histograms (Fig. 2). For each sample, two groups of results are reported: for its water-dominant and high-density carbon dioxide phases. As can be seen from these data, quartz veins related to metasomatic rocks of various associations at the Berezovskoe deposit were

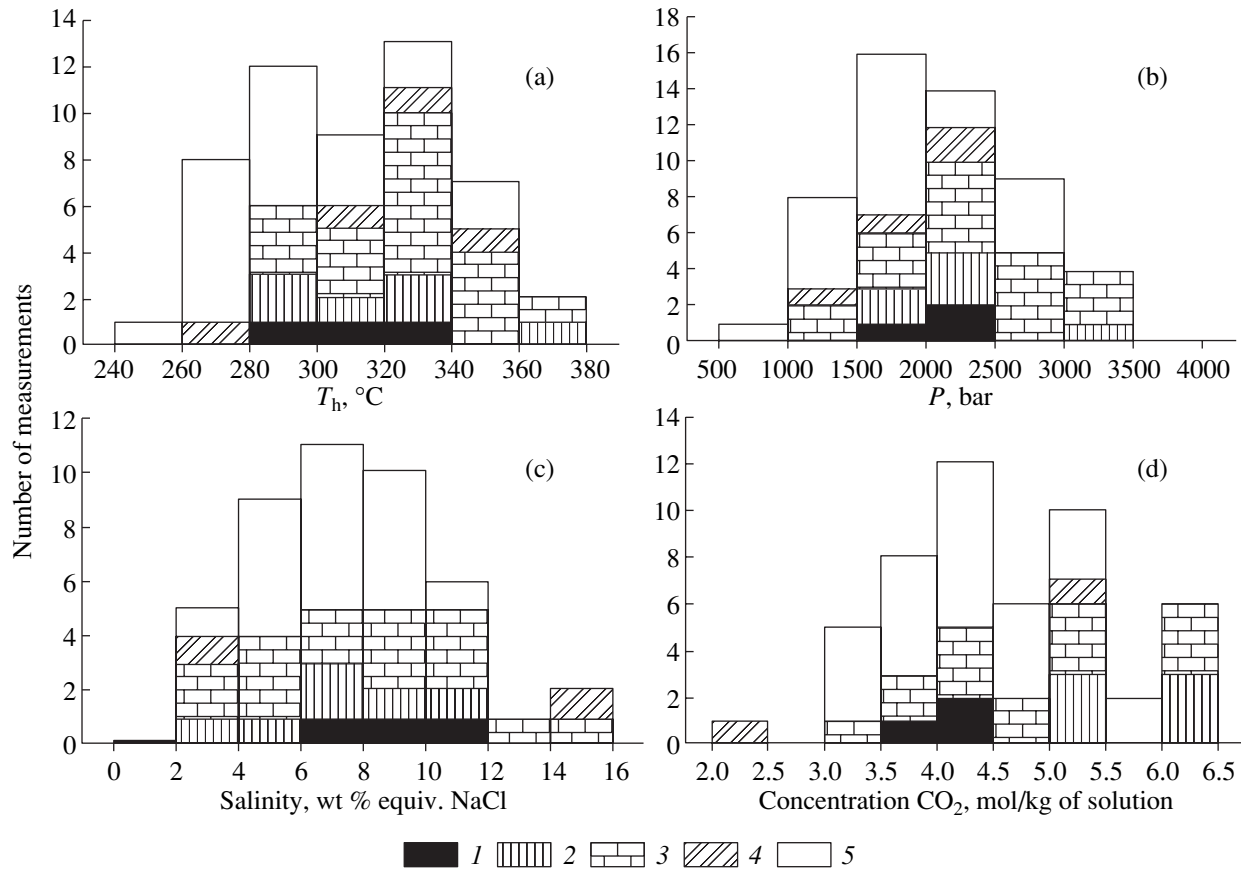


Fig. 2. Histograms for (a) homogenization temperatures, (b) pressures, (c) salinities, and (d) CO_2 concentrations of fluid inclusions in quartz and scheelite from the Berezovskoe gold ore field. (1) Propylites; (2) gumbleites; and (3–5) beresites–listwanites: (3) quartz I, (4) quartz II, and (5) scheelite.

formed by chloride-rich solutions. The concentrations of salts were 14.9–2.0 wt % equiv. NaCl. The solutions were also rich in carbon dioxide (6.3–2.4 mol/kg of solution). The intervals of the homogenization temperatures and pressures are 365–265°C and 3460–810 bar. The carbon dioxide contained virtually no admixtures, as follows from its melting point (from –56.6 to –57.5°C) being near the carbon dioxide triple point. The density of the liquid phase ranged from 1.10 to 0.93 g/cm³, and the density of CO_2 of gas-dominated inclusions was from 1.04 to 0.62 g/cm³.

The propylites and related quartz veins developed at temperatures of 330–290°C and pressures of 2310–1710 bar with concentrations of salts varying from 10.4 to 7.0 wt % equiv. NaCl and CO_2 concentrations of 4.4–3.9 mol/kg of the solution. The density of the solution was 1.05–1.03 g/cm³, and the density of the carbon-dioxide phase was 0.90–0.85 g/cm³ (Table 1).

The gumbleites were formed at 360–295°C and 3390–1630 bar from solutions with salt concentrations of 10.7–3.4 wt % equiv. NaCl and rich in CO_2 (6.1–5.2 mol/kg of solution). The density of the solution was

1.10–0.88 g/cm³, and the density of the carbon dioxide phase was 1.00–0.82 g/cm³ (Table 1).

We determined the conditions of the origin of two mineral assemblages in quartz veins related to the metasomatic rocks of the beresite–listwanite association: the early scheelite + quartz I association (based on inclusions in quartz I and scheelite; these conditions reflect the genesis of the metasomatic rocks) and the later productive association (data were derived from inclusions in quartz II), which represents the bulk of the economic ore mineralization.

Quartz I crystallized at temperatures of 365–290°C and pressures of 3460–1470 bar from solutions with salt concentrations of 14.1–2.4 wt % equiv. NaCl and CO_2 concentrations of 6.3–3.1 mol/kg of the solution. The density of the solution was 1.10–1.00 g/cm³, and the density of the carbon dioxide was 1.04–0.78 g/cm³ (Table 2).

The scheelite was deposited at temperatures of 345–270°C and pressures of 2470–1470 bar from solutions with salt concentrations of 14.9–4.0 wt % equiv. NaCl and CO_2 concentrations of 5.2–2.4 mol/kg of the solution. The density of the solution was 1.02–0.93 g/cm³,

Table 1. Results obtained on individual fluid inclusions in minerals from veins related to propylites and gumbeyites at the Berezovskoe gold deposit

Sample	Mineral	<i>n</i>	Temperature, °C							Concentration		Density, g/cm ³	Pressure, bar
			homogenization	eutectic	ice melting	CO ₂ melting	CO ₂ homogenization	gas hydrate melting	salts, wt % equiv. NaCl	CO ₂ , mol/kg of solution			
Tzh-2	Quartz	40	330–290	–36...–33	–6.2...–6.1	–56.7...–56.6	13.2–26.1L	6.3–4.1	10.4–7.0	4.4–3.9	1.05–1.03	2310–1710	
	"	20	–	–	–	–56.7...–56.6	4.1–12.1L	–	–	–	0.90–0.85		
Shartash-1	Quartz	25	360–295	–32...–30	–11.9...–8.3	–56.6	–4.7–5.4L	8.0–5.9	9.1–4.4	6.1–6.0	1.10–1.06	3390–1630	
	"	63	–	–	–	–56.6	–13.9–14.8L	–	–	–	1.00–0.90		
SHV-1	Quartz	6	335–295	–28	–9.2...–8.2	–56.6	–7.2–16.9L	8.3–5.0	10.7–3.4	5.4–5.2	1.09–1.05	2500–1670	
	"	31	–	–	–	–56.7...–56.6	0.6–13.9L	–	–	–	0.93–0.83		

Notes: In all cases, fluid boiled during the heating of the inclusion, *n* is the number of inclusions measured; L and G mean CO₂ homogenization to liquid and gas, respectively.

Table 2. Results obtained on individual fluid inclusions in quartz I and scheelite from veins related to beresites–listwanites at the Berezovskoe gold deposit

Sample	Mineral	n	Temperature, °C							Concentration			Density, g/cm ³	Pressure, bar
			homogenization	eutectic	ice melting	CO ₂ melting	CO ₂ homogenization	gas hydrate melting	salts, wt % equiv. NaCl	CO ₂ , mol/kg of solution				
2D	Quartz	10	350–325	-32...-31	-7.8...-7.2	-57.3...-56.9	-7.2–26.1L	8.8–3.8	10.8–2.4	6.2–3.8	1.09–1.02	2980–1680		
	"	92	-	-	-	-57.3...-56.6	-7.3–17.7L	-	-	-	0.97–0.80			
	Scheelite	3	335	-32	-6.6	-58.1	19.9L	0.6	14.9	5.2	1.02	2190		
	"	4	-	-	-	-57.3	7.7L	-	-	-	0.88			
32a	Quartz	17	350–330	-32...-31	-11.1...-8.8	-57.3...-57.0	-13.0–26.2L	8.7–6.1	10.0–2.6	6.3–4.5	1.10–1.00	3240–1920		
	"	73	-	-	-	-57.3...-57.0	-12.7–13.0L	-	-	-	0.97–0.82			
36	Quartz	47	340–300	-30	-10.2...-7.7	-56.8...-56.6	5.5–27.6L	7.6–4.6	9.6–4.7	6.3–5.4	1.06–1.00	2590–1470		
	"	71	-	-	-	-56.8...-56.6	-0.5–19.4L	-	-	-	0.93–0.78			
8d	Quartz	31	365–345	-35...-33	-11.3...-10.8	-56.9...-56.6	-3.2–15.4L	4.5–1.8	14.1–9.8	5.3–4.3	1.09–1.07	3210–2440		
	"	52	-	-	-	-57.1...-56.6	-9.2–3.8L	-	-	-	0.98–0.91			
42	Quartz	21	335–290	-30	-7.5...-6.0	-56.6	11.0–29.7L	6.9	5.9	4.9–3.1	1.06–1.02	2930–1500		
	"	43	-	-	-	-56.6	-8.9–17.4L	-	-	-	0.97–0.80			
Ber-2	Scheelite	11	345–270	-28	-4.6	-56.8	29.9G	8.0	4.0	2.4	0.93	2470–1470		
	"	43	-	-	-	-56.9...-56.8	3.1–15.4L	-	-	-	0.91–0.82			
Ber-35	Quartz	11	320–290	-37...-35	-13.0...-12.0	-57.5...-57.3	20.0–21.4L	4.4–2.1	13.1–9.9	4.1–3.6	1.09–1.07	3460–1520		
	"	64	-	-	-	-57.5...-56.8	-22.1–16.9L	-	-	-	1.04–0.81			

Note: See Table 1 for notation.

Table 3. Results obtained on individual fluid inclusions in quartz II of the productive association at the Berezovskoe gold deposit

Sample	Mineral	<i>n</i>	Temperature, °C							Concentration			Density, g/cm ³	Pressure, bar
			homogenization	eutectic	ice melting	CO ₂ melting	CO ₂ homogenization	gas hydrate melting	salts, wt % equiv. NaCl	CO ₂ , mol/kg of solution				
3G-1	Quartz	8	275–255	–32	–63...–5.4	–57.3	19.8–27.4L	6.1	7.3	4.2–3.2	1.03–1.02	1800–1470		
	"	7	–	–	–	–57.3	7.6–13.1L	–	–	–	0.84–0.88			
4d	Quartz	19	335–265	–33	–6.9...–6.1	–57.4...–56.9	0.3–21.9L	9.0–8.6	4.1–2.0	5.2–3.4	1.07–1.04	2860–1420		
	"	54	–	–	–	–57.4...–56.9	–7.4–16.0L	–	–	–	0.97–0.82			
1D	Quartz	31	320–275	–33...–32	–81...–6.5	–56.9...–56.7	–2.7–28.6L	7.1–6.2	8.4–5.6	4.8–3.6	1.08–1.01	2710–1320		
	"	23	–	–	–	–56.9...–56.7	–6.7–19.8L	–	–	–	0.96–0.78			
37	Quartz	11	300–275	–30...–33	–9.6...–7.2	–56.8...–56.6	17.7–26.9L	6.5–5.5	8.3–6.6	5.3–4.8	1.05–1.00	2040–1520		
	"	39	–	–	–	–56.6	5.6–14.7L	–	–	–	0.88–0.81			
38	Quartz	11	305–270	–31...–30	–9.0...–7.2	–57.3...–56.9	19.9–29.8L	5.7–5.0	9.0–7.9	4.3–3.2	1.05–1.02	2780–1370		
	"	29	–	–	–	–57.0...–56.7	–11.1–17.8L	–	–	–	0.99–0.80			
43	Quartz	5	285–280	–32	–9.6	–56.6	24.4–26.8L	5.5	8.3	4.3–4.2	1.04–1.03	2490–1400		
	"	32	–	–	–	–56.6	–7.9–18.3L	–	–	–	0.97–0.79			
3D	Quartz	74	310–265	–31...–30	–7.2...–5.6	–57.3...–56.9	28.6L–30.9G	7.9–6.6	6.5–4.1	4.7–3.1	1.01–0.96	1590–810		
	"	76	–	–	–	–57.3...–56.9	17.7–29.3L	–	–	–	0.80–0.62			

Note: See Table 1 for notation.

Table 4. ICP-MS analyses of aqueous extracts from veined quartz of the Berezovskoe gold deposit

Element	Concentration in the solution of inclusions, g/kg of H ₂ O					
	Tzh-2	42	3G-1	level 262 m	4d	37
Li	0.0015	–	–	0.00014	–	0.0015
B	0.027	0.012	0.020	0.011	0.015	0.012
Na (tit.)	37.78	7.58	8.17	4.52	7.96	7.68
Na (ICP)	27.70	6.45	7.27	3.98	5.95	5.53
Mg	0.22	0.005	0.002	–	0.0075	0.22
Al	–	0.0007	–	–	0.0046	0.0011
Si	–	0.19	0.48	0.20	0.18	0.43
Cl	25.75	17.82	0.45	–	–	–
K (tit.)	7.59	0.64	0.56	1.07	1.03	1.26
K (ICP)	3.38	0.36	0.54	0.68	0.76	0.82
Ca	2.51	–	–	–	0.126	–
Sc	0.0007	0.000007	0.00018	0.00009	0.00007	0.0007
Ti	0.0024	–	–	–	–	–
V	0.0017	–	5 × 10 ⁻⁶	–	–	–
Cr	0.054	0.006	0.024	0.0006	–	–
Mn	–	–	–	–	0.0037	0.0025
Fe	0.024	0.017	–	–	–	–
Co	–	0.0036	0.00005	0.00014	0.00024	0.0037
Ni	–	0.014	0.0006	0.0041	0.0067	0.0076
Cu	–	–	–	–	0.014	–
Zn	0.17	–	0.039	–	–	0.17
Ge	0.0028	–	0.00087	0.00019	–	0.00018
As	–	0.0099	0.039	0.027	0.0093	0.030
Se	–	–	0.00017	–	0.00007	0.000125
Rb	0.0083	0.0017	0.0024	0.0022	0.0035	0.0034
Sr	0.031	0.0092	0.016	–	0.011	0.009
Mo	0.00037	–	0.0001	–	–	–
Ag	–	–	–	0.00085	0.074	0.0270
Sn	0.0018	0.00007	–	–	–	–
Sb	0.00007	0.00055	0.00022	0.0020	0.0034	0.1423
Cs	0.0019	0.00046	0.0016	0.00027	0.0014	0.0009
Ba	0.0763	–	–	–	0.0025	0.0051
La	0.00004	–	0.00008	0.0014	–	–
Ce	0.0001	–	0.000002	–	–	–
Pr	0.000007	–	–	–	–	–
Nd	0.000004	–	–	–	–	–
Gd	0.00003	–	–	–	–	–
W	0.0009	–	–	–	–	–
Au	–	5.8 × 10 ⁻⁶	–	2.05 × 10 ⁻⁶	8.4 × 10 ⁻⁶	6.5 × 10 ⁻⁵
Pb	0.0016	–	–	–	–	–
Bi	–	–	0.00012	0.00024	–	–
Th	–	0.000002	–	–	–	–
U	0.0001	0.00007	–	–	–	–
T _h , °C	310	320	265	285	300	290
P, bar	2060	2260	1380	1750	2340	1690
C _{salts} , wt % equiv. NaCl	9.4	9.8	9.0	12.7	9.3	12.1
C _{CO₂} , mol/kg of solution	4.2	4.0	3.7	4.8	4.4	5.1
Density, g/cm ³	1.04	1.04	1.02	1.02	1.06	1.03
Sample mass, g	16.07995	15.3974	15.0597	15.18135	13.8047	15.00125
Aqueous extract volume, ml	48.24	46.19	45.18	45.54	41.41	45.0
H ₂ O concentration in sample, wt %	0.09	0.13	0.18	0.19	0.21	0.12
H ₂ O mass in sample, g	1.4472 × 10 ⁻²	2.0017 × 10 ⁻²	2.7107 × 10 ⁻²	2.8845 × 10 ⁻²	2.8990 × 10 ⁻²	1.800 × 10 ⁻²

Table 5. Oxygen isotopic composition of coexisting quartz and scheelite from various deposits of the plutogenic gold–quartz association

No.	Sampling locality	Quartz			Scheelite			$\Delta^{18}\text{O}, \text{‰}$	$T_{\text{calc.}}, \text{°C}$
		$\delta^{18}\text{O}, \text{‰}$ (SMOW)	$T_{\text{h}}, \text{°C}$	$\delta^{18}\text{O}_{\text{H}_2\text{O}}, \text{‰}$	$\delta^{18}\text{O}, \text{‰}$ (SMOW)	$T_{\text{h}}, \text{°C}$	$\delta^{18}\text{O}_{\text{H}_2\text{O}}, \text{‰}$		
1	Lev. –301 m, d II.	16.0	335	10.3	6.6	335	8.7	9.4	261
2	Lev. –314 m	9.1	280	1.5	6.2	310	7.9	2.9	–
3	Lev. –314 m, d VP	12.4		4.8	5.4		7.2	7.0	390
4	Lev. –512 m, d PP	13.3	284	5.8	3.7	320	5.6	9.6	253
5	Lev. –512 m, d Sev	10.9	320	4.7	4.0		6.0	6.9	397
6	Lev. –512 m, v	14.1	355	8.9	5.8	355	8.1	8.3	310
7	Dump	13.2	305	6.5	5.4	323	7.4	7.8	337
8	Dump	11.4	308	4.8	2.0		4.0	9.4	260
9	Dump	10.2	305	3.6	3.6		5.5	6.6	422
10	Dump	10.8	308	4.2	2.8		4.8	8.0	326
11		9.6	335	3.9	3.5	355	5.8	6.1	469
12	Lev. –115 m	16.5		9.7	4.2		5.9	12.3	174
13	Lev. –430 m	16.6	303	9.8	5.4	308	7.2	11.2	202
14	Lev. –475 m	13.9		7.1	4.2		5.9	9.8	249
15	Lev. –205 m	15.2	303	8.4	5.2	318	7.1	10.0	239
16	Lev. –430 m	15.1		8.3	5.5		7.4	9.6	253
17	Lev. –250 m	14.8	285	7.4	4.6	295	6.2	10.2	232
18	Lev. –350 m	15.7	275	7.9	5.6		7.2	10.1	235
19		11.9	338	6.2	3.7	343	5.9	8.2	315
20		11.7		6.1	3.4		5.6	8.3	310
21		16.8	315	10.4	4.8	320	6.7	12.0	181
22		16.7		10.3	5.1		7.0	11.6	191
23		11.9	298	5.0	3.7	307	5.4	8.2	315
24		14.1		7.2	4.8		6.5	9.3	265

Note: Notation: lev.—level, d—dike, PP—Petropavlovskaya, Sev—Sevastopol'skaya, II—II'inskaya, VP—Vtoropavlovskaya, v—vein; 1–20 analyses conducted by the authors: (1–10) Berezovskoe deposit, Central Urals, (11) Shershnevskoe deposit, Southern Urals, (12–16) Bestyube deposit, northern Kazakhstan (12–14—central prospect, 15–16—western prospect), (17–20) Dzhelambet deposit, northern Kazakhstan (17–18—central prospect, 19–20—southern prospect), (21–22) Glenorchy deposit, New Zealand [30], (23–24) Hollinger deposit, Canada [31]. The homogenization temperatures of fluid inclusions are compiled from [32].

and the density of the carbon dioxide phase was 0.91–0.82 g/cm³ (Table 2).

Quartz II crystallized at temperatures of 335–255°C and pressures of 2860–810 bar from solutions with salt concentrations of 9.0–2.0 wt % equiv. NaCl and CO₂ concentrations of 5.3–2.1 mol/kg of the solution. The density of the solution was 1.08–0.96 g/cm³, and the density of the carbon dioxide phase was 0.99–0.62 g/cm³ (Table 2).

Analyses of aqueous extracts by ICP-MS techniques indicated that the solutions contained Na, K, Cl, Ca, Mg, Al, Si, Ti, Au, Ag, Pb, Zn, Cu, Sb, Bi, As, B, Fe, Mn, V, Cr, Co, Ni, Li, Rb, Cs, Sr, Ba, Mo, W, Sn, Sc, Ge, Se, La, Ce, Pr, Nd, Gd, Th, and U (Table 4). Our data have revealed certain regularities in the behavior of some elements and justified the use of the bulk anal-

ysis of aqueous extracts in, at least, semiquantitative characterization of the mineralizing fluid.

The solutions that caused propylitization were evidently enriched in Cl, Na, K, Mg, Ca, B, Ti, V, Cr, Fe, Rb, Sr, Mo, Sn, W, Cs, Ba, REE, Pb, and U.

Compared with fluid inclusions in quartz from propylites, fluid inclusions in quartz from veins related to beresites and listwanites are generally poorer in Cl, Fe, U, Cr, B, Sn, and Ba (although the concentrations of these elements remain relatively high); contain no Ca, Ti, V, Mo, Ba, and REE; but bear Si, Ni, Th, Co, Au, and As and higher concentrations of Sb.

The fluids responsible for the origin of the productive associations additionally contain Se, Mn, Cu, Ag, and Bi and are characterized by higher concentrations

Table 6. Oxygen and carbon isotopic composition of carbonates from veins related to beresites and listwanites at the Berezovskoe deposit, Central Urals

No.	Sampling locality	$\delta^{18}\text{O}$, ‰ (SMOW)	$\delta^{13}\text{C}$, ‰ (PDB)
1	Mine Severnaya, dump	20.0	-6.5
2	Mine Yuzhnaya	18.3	-6.1
3	Zolotaya Gorka quarry	21.4	-5.6

of Au, As, and Sb; i.e., these fluids were enriched in the same elements that compose the ore mineralization.

ISOTOPIC COMPOSITION OF MINERALS

Isotopic data on coexisting quartz and tourmaline from the veins of the propylite association and quartz and scheelite from veins related to the beresites–listwanites are listed in Table 5, and analogous data on the beresites–listwanites are given in Table 6.

Crystals of quartz and tourmaline from veins related to the propylites display surfaces of concurrent growth, a fact suggesting their simultaneous crystallization from the same fluid. The $\delta^{18}\text{O}$ values of these minerals are, respectively, +12.2 and +8.2‰ (Table 5) and correspond, according to [17, 18], to the crystallization of this assemblage at a temperature of 283°C. This value is virtually identical to the homogenization temperature of fluid inclusions.

Quartz and scheelite from veins related to the gumbesites and beresites–listwanites also have concurrent growth surfaces. The $\delta^{18}\text{O}$ for the quartz and scheelite of the gumbesite associations vary from 2.1 to 5.8‰ and from 11.0 to 12.6‰, respectively [2], and the analogous values for quartz I and scheelite of the beresites–listwanites are 2.0–6.6‰ and 9.1–16.0‰, respectively (Table 5, analyses 1–10). The isotopic temperature (calculated based on [19]) of the crystallization of the quartz I + scheelite assemblage was $329 \pm 63^\circ$ and was

in good agreement with the homogenization temperatures.

In order to compare the Berezovskoe deposit with analogous deposits in other provinces, we studied the oxygen isotopic composition of quartz and scheelite from deposits in northern Kazakhstan (Bestyube, Stepnyak, and Dzhelambet) and the Southern Urals (Sher-shnevskoe). Their $\delta^{18}\text{O}$ values range from +3.5 to +5.6‰ and from +9.6 to +16.6‰, respectively (Table 5, analyses 11–20).

The oxygen and carbon isotopic composition of carbonates from the Berezovskoe deposit vary from +18.3 to +21.4‰ and from -6.5 to -5.6‰, respectively (Table 6).

CHEMICAL COMPOSITION OF MAGNESITE AND DOLOMITE

In order to assay the temperatures of the beresite–listwanite metasomatic rocks based on mineralogical data, we analyzed the chemical composition of coexisting Fe-magnesite and Fe-dolomite, which are the main minerals of these rocks (Table 7). The iron mole fractions of the Fe-magnesite and Fe-dolomite vary from 43.9 to 50.1 and from 33.1 to 35.1%, respectively. Both carbonates pervasively contain Sr, Mn, Zn, and Co.

The temperature of the origin of metasomatic rocks (assayed by a thermometer [20]) was approximately 340°C and is in good agreement with the homogenization temperatures of fluid inclusions in vein quartz from the same sample (365–345°C; Table 2, Sample 8d).

DISCUSSION

When considered together with geological and mineralogical data, our results obtained on the fluid inclusions and isotopic composition of minerals make it possible to reveal the characteristic features of the mineralizing process, the most important of which is the heterogeneous state of the fluid, when the inclusions were captured from a mixture of two immiscible fluids.

Table 7. Chemical composition (wt %) of magnesite and dolomite from beresites and listwanites at the Berezovskoe deposit, Central Urals

Component	MgO	FeO	CaO	MnO	ZnO	CoO	SrO	CO ₂	f, %
1	12.83	12.28	29.32	0.60	0.00	0.00	0.00	44.96	36.0
2	13.35	12.23	28.69	0.45	0.00	0.25	0.00	45.04	35.2
3	13.62	12.02	28.34	0.75	0.00	0.00	0.20	45.06	34.5
4	13.34	12.87	28.31	0.48	0.00	0.00	0.00	45.00	35.9
5	20.59	34.37	0.57	0.30	0.00	0.00	0.00	44.18	48.6
6	19.94	35.70	0.21	0.20	0.00	0.00	0.00	43.95	50.2
7	22.72	31.77	0.17	0.34	0.25	0.00	0.00	44.76	44.4
8	20.86	34.26	0.43	0.21	0.00	0.00	0.00	44.24	48.1

Note: CO₂ was calculated as a difference. Minerals: (1–4) dolomite, (5–8) magnesite.

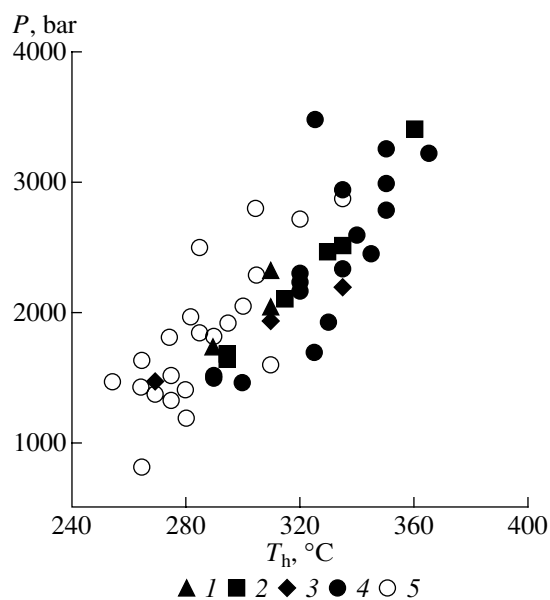


Fig. 3. Correlation between the pressures and fluid homogenization temperatures in mineralizing system of the Berezovskoe deposit. (1) Quartz from veins related to propylites; (2) quartz from veins related to gumbleites; and (3–5) quartz and scheelite from veins related to beresites–listwanites: (3) scheelite, (4) quartz I, and (5) quartz II.

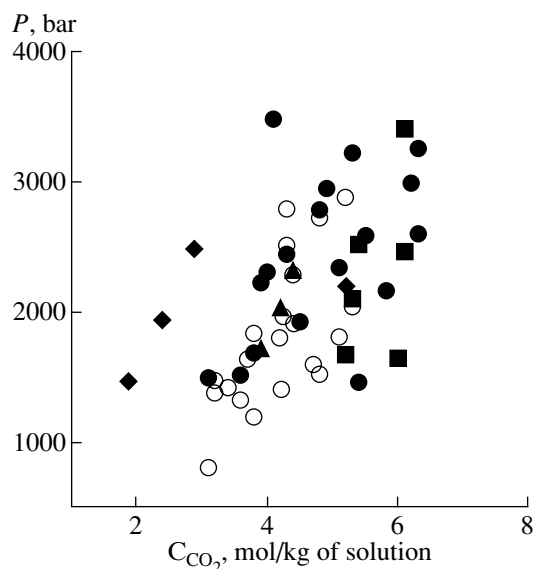


Fig. 4. Correlation between the pressures and carbon dioxide concentrations of the fluid, demonstrating a decrease in the latter with decreasing pressure. See Fig. 3 for symbol explanations.

We believe that the main reason for the heterogenization of the mineralizing fluid was the fact that the solution was saturated with respect to carbon dioxide and occurred under a high pressure (above the lithostatic pressure), which drastically decreased due to tectonic motions. The maximum pressure values were appar-

ently higher than the lithostatic pressure and were caused by the excess pressure in the source of the mineralizing fluid. This, in turn, suggests that the source was located at a significant depth. Fracturing and faulting opened pathways for the gas-saturated fluid and caused its heterogenization (i.e., the release of dissolved carbon dioxide in the form of bubbles). However, the fractures and cracks were not connected with the surface (tapered at depth), so the whole hydrothermal system remained closed, as follows from the occurrence of gaseous inclusions of dense CO₂ (1.04–0.62 g/cm³) and the high pressure values calculated from the data on fluid inclusions.

Observations of fluid inclusions indicate that the minerals crystallized on a two-phase equilibrium line, and, thus, corrections for pressure should be equal to zero [14]. If the crystallization occurred away from the equilibrium line, corrections for pressure (in our case, no more than 100°C) should have been introduced into the calculated temperatures, and the crystallization temperatures would be >400°C. However, similarities between the homogenization temperatures and those of isotopic thermometers justify the use of the former as the crystallization temperatures of the minerals.

We also believe that the high pressures, ca. 3500 bar, as calculated from fluid inclusion data for all three types of metasomatic rocks (propylites, gumbleites, and beresites–listwanites) and related veins, were caused by the excess fluid pressure in the source. It is possible that quartz started to crystallize under these pressures. The lower limit for the pressure seems to be determined by the lithostatic pressure and corresponds to depths of 5.6, 5.3, 4.6, and 2.6 km for the propylites, gumbleites, early beresitic association (quartz I + scheelite), and productive gold-bearing association, respectively.

Our data suggest that gold-bearing quartz veins of the Berezovskoe deposit developed simultaneously with a drastic pressure decrease due to tectonic motions. This process was associated with the boiling and heterogenization of the mineralizing fluid because of CO₂ release. Simultaneously, the pressure also decreased, along with the concentrations of salts and gases in the solution (Figs. 3, 4). Geological observations (quartz veins fill fractures in granitoid dikes and volcanic sedimentary rocks) and the wide pressure interval provide evidence that the pressure drop was caused by the opening of fractures and cracks. A similar style of fluid behavior was described at the Sigma gold deposit in Canada [21], which is also hosted by beresites and listwanites.

The early quartz I + scheelite assemblage of the beresites–listwanites was formed at temperatures and pressures decreasing, respectively, from 365 to 270°C and from 3460 to 1470 bar. The salinity varied from 14.9 to 2.4 wt % equiv. NaCl at a CO₂ concentration changing from 6.3 to 2.4 mol/kg of the solution. The similarities between the homogenization temperatures of inclusions and the “isotopic temperatures” yielded by min-

erals from the metasomatic rocks suggests simultaneous crystallization of the wall-rock beresites–listwanites and the quartz I + scheelite assemblage.

The productive association was initially deposited at increasing temperature and pressure to 335°C and 2860 bars, respectively, which testify to a new pulse of hydrothermal activity.

The mineral assemblages of gold-bearing quartz veins at the Berezovskoe deposit were produced in at least two stages of hydrothermal activity.

From the surface to the level of –712 m, no significant variations in the homogenization temperature were observed (Fig. 5), which points to the absence of vertical zoning and, perhaps, a significant depth interval of ore mineralization.

Bortnikov *et al.* [4] cite a somewhat narrower range of temperature and pressure for the Berezovskoe deposit (295–270°C and 2500–900 bar) and a different interval of salt concentrations (18.2–7.6 wt % equiv. NaCl). These data are close to the values that we previously obtained on quartz II from various mineralized veins. We also evaluated the maximum temperature and pressure values for veins related to the premineralization metasomatics (propylites, gumbeites, and beresites–listwanites), which were not examined by Bortnikov *et al.* Nevertheless, the general regularities of the variations in the fluid composition and the physicochemical conditions of the hydrothermal process (heterogeneous fluid, high carbon dioxide concentrations, etc.) were determined similarly in this paper and in [4]. The differences between the values of some parameters can be regarded as a widening of their intervals based on a more detailed study of the deposit.

The homogenization temperatures and the lower pressure limits set for quartz I and II from the Berezovskoe beresite–listwanites are similar to those determined at other deposits of the plutonogenic gold–quartz association. According to [22], the P – T parameters of the well-known Mother Lode gold deposit in California are 290–350°C and 1–2 kbar and the analogous parameters of the Bralorne deposit in Canada are 350°C and 1.75 kbar [23].

Data from various research conducted on analogous deposits abroad indicate that gold was most probably contained in the solutions in the form of chloride and hydrosulfide complexes [24, 25, and others]. Moreover, positive linear correlations between the gold and antimony concentrations in the fluid of the Berezovskoe deposit suggest that gold–antimony complexes could be involved (along with gold–sulfide compounds) in gold transport. The segregation of CO₂ resulted in an increase in fluid pH [24], which, in turn, caused the decomposition of gold–sulfide, -chloride, and -antimony complexes and the deposition of gold and associated minerals [25]. The drastic decrease in the concentrations of salts in the solution from early to late mineral assemblages (from 14.9 to 2.0 wt %) can be explained by the dilution of the hydrothermal fluid with

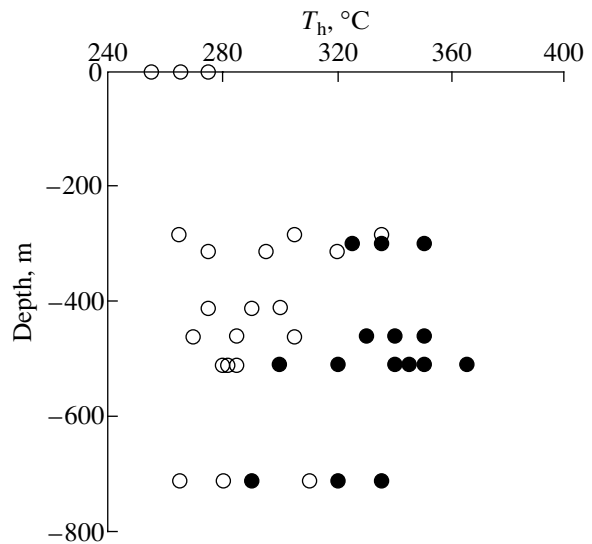


Fig. 5. Variations in the homogenization temperatures of fluid inclusions in quartz from veins related to beresites–listwanites. See Fig. 3 for symbol explanations.

low-salinity waters from other sources (conceivably, pore waters). The dilution of the hydrothermal fluid should also have resulted in a decrease in the solubility of ore components and their deposition. The determined concentrations of Au, Ag, and other elements are also consistent with analogous data available from the literature [26, 27, and others].

Our data on the composition of the solutions testify to the fact that their composition systematically varied during the evolution of the hydrothermal process from propylite to the early scheelite–quartz association and then to the productive association of the beresites and listwanites. An increase in the concentrations of both lithophile (Li, Rb, Cs, B, Sn, W, Ba, and Sr) and chalcophile elements in the solution suggests that the mineralizing fluid and metals in the solution originated from different sources. At the same time, the occurrence of certain elements (such as Se, Mn, Cu, Ag, and Bi) in the fluids that produced the productive ore associations indicates that the composition of the solution that came from the main source of the ore elements varied, perhaps, in response to variations in the physicochemical conditions of mobilization of ore-forming components.

The genesis and composition of the fluids responsible for the development of the gumbeites and beresites–listwanites were generally similar, whereas their pressures were different, 3390–1660 and 3470–1470 bar, respectively, and are consistent with experimental data [28]. Nevertheless, the ranges of the genetic parameters of both types of metasomatics overlap, and, hence, the activity of K⁺ and pH should have played a significant role during the origin of the gumbeites and beresites [28].

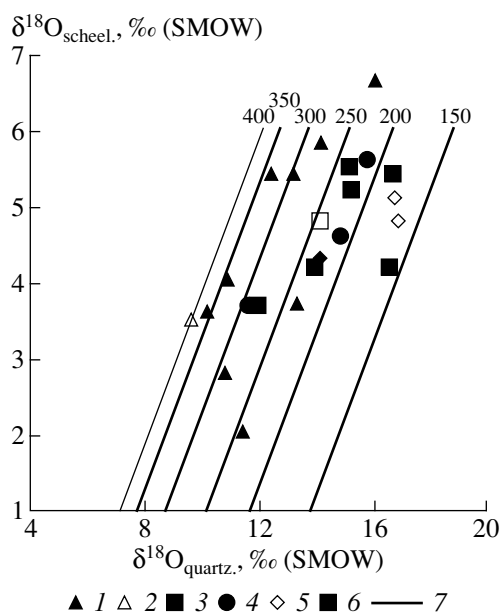


Fig. 6. Oxygen isotopic composition of coexisting quartz and scheelite from a variety of gold deposits affiliating with the beresite–listwanite association. (1) Berezovskoe deposit, Central Urals; (2) Shershnevskoe deposit, Southern Urals; (3) Bestybe deposit, northern Kazakhstan; (4) Dzhelambet deposit, northern Kazakhstan; (5) Glenorchy deposit, New Zealand; (6) Hollinger deposit, Canada; and (7) isotherm, °C.

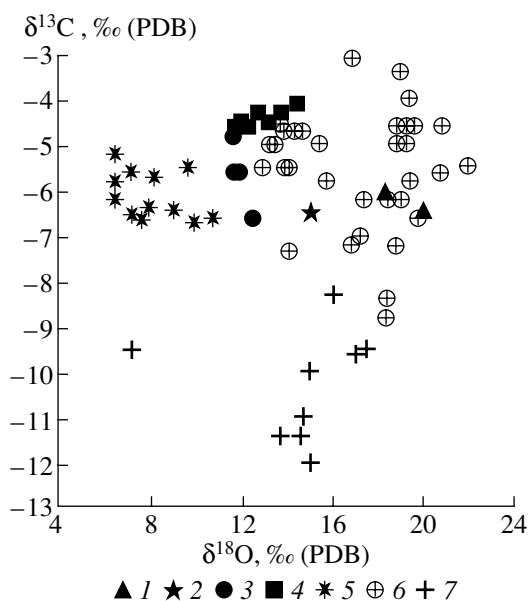


Fig. 7. Correlation between $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ in carbonates from a variety of gold deposits affiliating with the beresite–listwanite association. (1–2) Berezovskoe deposit, Central Urals: (1) beresite–listwanite association, (2) gumbelite association; (3) Bestybe deposit, northern Kazakhstan [33]; (4) Dzhelambet deposit, northern Kazakhstan [34]; (5) various deposits in eastern Siberia [34]; (6) Mother Lode, United States [24]; and (7) Bralorne Pioneer deposit, Canada [25].

The observed positive linear correlation between $\delta^{18}\text{O}$ for quartz and scheelite from the Berezovskoe deposit (Fig. 6) testify to equilibrium crystallization of these minerals. The oxygen isotopic composition of quartz and scheelite from some other plutogenic gold deposits of the former USSR, Canada, and New Zealand (Table 5) also display positive linear correlations and suggest identical crystallization temperatures but different oxygen isotopic compositions of the aqueous phases of the mineralizing fluids (Fig. 6).

It follows that the scheelite–quartz association at deposits of the plutogenic gold–quartz association throughout the world crystallized at identical temperatures.

The homogenization temperatures of fluid inclusions in quartz–scheelite pairs varied from 300 to 360°C and significantly differed from some values yielded by isotopic thermometry (Table 5, Fig. 6). It can be hypothesized that the early quartz of these samples was partly recrystallized under the effect of later solutions, which could be gold-bearing.

The oxygen isotopic composition of the aqueous phase of the fluid that produced gold mineralization at the Berezovskoe deposit was calculated based on isotopic analyses of quartz I and the homogenization temperatures of fluid inclusions (with the use of data from [29]; Table 5). The calculated $\delta^{18}\text{O}$ values of the aqueous phase are $5.5 \pm 2.5\%$. They correspond to the analogous values for deposits in New Zealand [30], Canada [31], and northern Kazakhstan [33] (Table 5) and provide evidence that the fluids came from a magmatic and/or metamorphic source.

The carbon isotopic composition of carbonates from the Berezovskoe deposit is analogous to those from other plutogenic gold deposits (Fig. 7) and points to a deep-seated source of carbon.

CONCLUSIONS

(1) The development of the propylites, gumbelites, and beresites was controlled, first of all, by the chemistry of the hydrothermal fluids (concentrations of Mg for propylites and K for beresites, as well as pH). Variation in the concentrations of elements were detected in the fluids responsible for the origin of the metasomatic rocks (from propylites to later beresites–listwanites) and related veins.

(2) Data obtained from individual fluid inclusions suggest that the wall-rock metasomatic alterations and gold-bearing veins at the Berezovskoe deposit developed at temperatures of 365–255°C and pressures of 3460–810 bar under the effect of predominantly chloride solutions with salt concentrations of 14.9–2.0 wt % equiv. NaCl and high concentrations of CO_2 (6.3–2.4 mol/kg of the solution) simultaneously with the boiling and devolatilization of the fluid. The gold-bearing mineralized veins were produced at weak vertical variations in the physicochemical parameters, and this was favorable

for the significant depth interval suitable to ore deposition and the notable ore potential of the lower levels of this deposit.

(3) The calculated oxygen isotopic composition of the aqueous phase of the fluids that produced the association of quartz I ($\delta^{18}\text{O}_{\text{H}_2\text{O}}$ from +3.6 to +6.5‰) with scheelite ($\delta^{18}\text{O}_{\text{H}_2\text{O}}$ from +2.8 to +5.4‰) points to a magmatic and/or metamorphic provenance of the fluid. It was determined that the scheelite-quartz assemblage at deposits of the plutogenic gold-quartz association at different deposits around the world crystallized at identical temperatures and somewhat different oxygen isotopic compositions of the fluids.

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SAMPLE DESCRIPTIONS

TZh-2—Uspenskaya Gorka, quartz from a tourmaline–quartz vein related to propylite.

Shartash-1—Shartash quarry, quartz from a vein related to gumbeite.

SHV-1—Shartash quarry, quartz from a vein related to gumbeite.

1d—Mine Yuzhnaya, dike Soimanovskaya, level –314 m, quartz from a ladder vein, quartz II + fahlore assemblage.

2d—Mine Yuzhnaya, dike II'inskaya, level –314 m, quartz from a ladder vein, quartz II + fahlore assemblage.

3d—Mine Tsentral'naya, dike Petropavlovskaya, level –712 m, quartz from a ladder vein, quartz II + fahlore assemblage.

4d—Mine Yuzhnaya, level –284 m, quartz from a vein, quartz II + fahlore assemblage.

8d—Mine Tsentral'naya, level –512 m, quartz from a ladder vein, quartz I + scheelite assemblage. Quartz and scheelite display surfaces of concurrent growth.

32a—Mine Severnaya, dike Petropavlovskaya, level –462 m, quartz from a ladder vein, quartz II + scheelite assemblage.

36—Mine Severnaya, dike Sevastopol'skaya, level –512 m, quartz from a ladder vein, quartz I + scheelite assemblage.

37—Mine Severnaya, level –412 m, quartz from a vein, quartz II + fahlore assemblage.

38—Mine Severnaya, dike Petropavlovskaya, level –462 m, quartz from a ladder vein, quartz II + fahlore assemblage.

42—Mine Tsentral'naya, dike Petropavlovskaya, level –712 m, quartz from a ladder vein, quartz I + scheelite assemblage.

43—Mine Severnaya, dike Petropavlovskaya, level –512 m, quartz from a ladder vein, quartz II + fahlore assemblage.

Level 262—Mine Yuzhnaya, level –262 m, quartz from a vein, quartz II + fahlore assemblage.

3G-1—Northern flank of the Berezovskoe deposit, Zolotaya Gorka quarry, quartz from a ladder vein, quartz + fahlore assemblage.

Ber-2—Mine Yuzhnaya, scheelite.

Ber-35—Mine Severnaya, dump, quartz from a ladder vein, quartz II + scheelite assemblage.