

Fluid inclusion evidence for barbotage and its role in gold deposition at the Darasun goldfield (eastern Transbaikalia, Russia)

Research Article

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Received 16 September 2013; accepted 23 January 2014

Abstract: “Barbotage” is a process of gas penetration through a layer of liquid as a flow of dispersed small gas bubbles. Barbotage is widely used in technology particularly due to its high coefficients of interphase energy and material transfer. It promotes the heat- and mass-exchange processes as well as the chemical interactions in gas-liquid systems. Upon investigation of the fluid regime at the magmatic-hydrothermal system of Darasun goldfield (Eastern Transbaikalia, Russia) we have found evidences of barbotage as an effective mechanism resulting in the formation of vein gold deposits. In spite of the fact that early associations of gold ores in the Darasun goldfield deposits were formed from a heterogeneous fluid, their histograms of fluid salinity distributions are quite different. These differences can be explained by including into the ore-forming process the stage at which the vapour phase generated by boiling rose up as a stream of small bubbles. The corresponding scheme of the formation of the Darasun goldfield hydrothermal ore-bearing system is proposed and discussed. The possibility to use gallium fractionation and the fluid salinity distribution in hydrothermal systems as the indicators of barbotage participation in hydrothermal ore-forming processes is evaluated.

Keywords: fluid inclusions • Darasun gold deposits • magmatic-hydrothermal system • heterogeneous fluid • barbotage.

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1. Introduction

Many scientists regard fluid heterogenization as an important factor of hydrothermal ore deposition [1–3], et al.. Numerous fluid physicochemical parameters change upon heterogeneous state appearance. These changes can cause the deposition of dissolved compounds. During the study of hydrothermal ore deposition, the heterogenic state of the fluid is usually identified by the investigation

of fluid inclusion data. The heterogeneous fluid is commonly considered as the result of homogeneous fluid separation into two phases. The boiling of aqueous fluid can be regarded as the simplest case of such phase separation. An alternative way of heterogeneous fluid formation has to be considered here, that is, fluid heterogenization upon gas flow penetration through a water solution. In technology such a process is named “barbotage”. A “barbotage” is a process of gas flow penetration through a layer of liquid. This process is accompanied by the appearance of a lot of small gas bubbles.

Barbotage is widely used in technology particularly due to its high coefficients of interphase energy and mate-

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rial transfer and also due to large specific interface areas which can be reached in the barbotage layer.

It promotes the heat- and mass-exchange processes, as well as the chemical interactions in gas-liquid systems. Barbotage also promotes the flotation (e.g. transfer) of fine-dispersed hard particles, whose amount can exceed their solubility in natural fluids. It is necessary to emphasize that all mentioned phenomena can take place during the hydrothermal activity.

There are some facts which cannot be explained by simple phase separation of a homogeneous fluid. However, it is very difficult to find a direct proof of the occurrence of barbotage in the natural ore-forming processes. Upon the investigation of the fluid regime during formation of the Darasun goldfield deposits (Eastern Transbaikalia, Russia) we have derived a series of observations providing circumstantial evidence of barbotage participation in this process.

2. Geological setting

There are three main gold deposits of Darasun goldfield: Darasun, Teremkinskoye and Talatuy [4]. These deposits comprise quartz-tourmaline ores of Mesozoic age, which are hosted in Paleozoic magmatic rocks (Fig. 1).

The Talatuy deposit includes mineralized zones, which are in turn crosscut by dikes and stock-like intrusions of porphyritic diorite, granite porphyry, granodiorite porphyry, quartz porphyry, and lamprophyres of the Amudzhikansky Complex (J_2-K_1). Lenslike ore bodies consist of veinlets and disseminated gold-sulphide ore mineralization. Pyrite, chalcopyrite, magnetite, hematite, ilmenite, native gold and sheelite are the major ore minerals. The gangue minerals are tourmaline, epidote, clinocllore, quartz, carbonate, biotite and K-feldspar. The host rocks are hydrothermally altered gabbros of the Kruchininsky complex (Pz1).

The Teremkinskoye deposit occurs at the intersection between a system of faults and dikes of K-rich granodiorite porphyries of Mesozoic age. Dikes and Au mineralized veins occur together in three levels of the deposit, forming a distinctive field association. Pyrite, chalcopyrite, galena, sphalerite, sulphosalts of Cu, Ag, Bi, Pb, and native gold are the major ore minerals. The gangue minerals are represented by quartz, tourmaline and carbonates. The host rocks of the Teremkinskoye deposit are also the hydrothermally altered gabbros of the Kruchininsky complex (Pz1).

The Darasun deposit includes more than 200 steeply dipping gold-mineralized quartz veins spatially related to the subvolcanic, K-rich Amudzhikansky granodiorite-porphyry

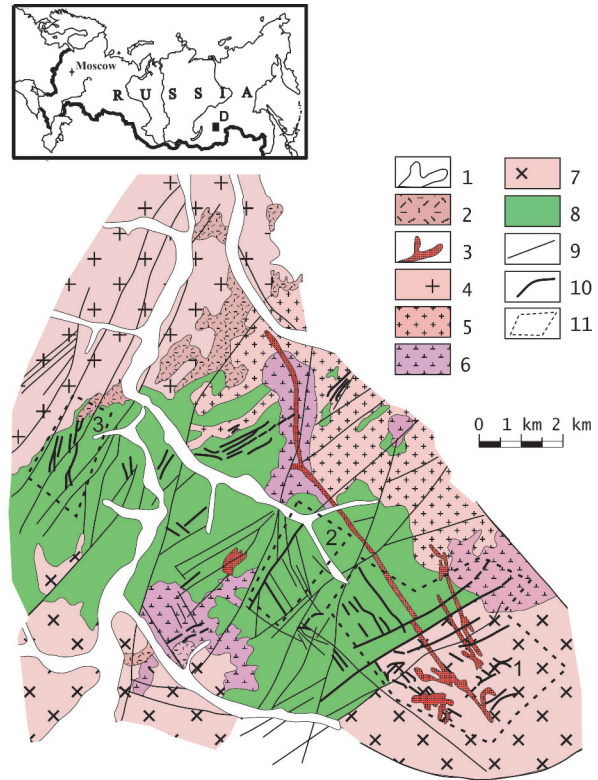


Figure 1. Location of the Darasun goldfield (D) and geological sketch map (adopted from the Darasun exploration expedition).

1 – alluvium; 2–3 – Middle-Upper Jurassic Amudzhikan-Sretensky complex: 2 – volcanics, 3 – porphyry subvolcanics and dykes: diorite porphyry, granodiorite-porphyry, granite porphyry and others; 4 – biotite-hornblende granite and granodiorite of the Triassic Amanansky complex; 5–6 – Upper Paleozoic – Lower Mesozoic Olyokminsky complex: 5 – biotite granite and leucogranite, 6 – syenite, granosyenite, quartz syenite; 7 – diorite, quartz diorite, granodiorite of the Middle Paleozoic Krestovskiy complex; 8 – metamorphosed gabbroids (gabbro, amphibolite, gabbro-diorite, troctolite) of the Lower Paleozoic Kruchininsky complex; 9 – faults; 10 – ore bodies; 11 – deposits: 1 – Darasun, 2 – Teremkinskoye, 3 – Talatuy.

intrusion (J_2-K_1). Ore minerals are pyrite, arsenopyrite, chalcopyrite, pyrrothite, tennantite, tetrahedrite, sphalerite, galena, sulphosalts of Cu, Ag, As, Bi, Pb, tellurides and native gold. Quartz, tourmaline, carbonates, gypsum, anhydrite are the gangue minerals. The host rocks are Lower Paleozoic gabbroids and granitoids of Middle to Lower Paleozoic age.

3. Methods

Fluid inclusion data were obtained from doubly-polished wafers of quartz, calcite, sphalerite and anhydrite, using a LINKAM THMSG-600 heating-freezing stage, coupled

to an Olympus microscope at IGEM RAS, Moscow. The stage allows one to measure temperatures of phase transition from -196 to 600°C , to monitor this process at high magnification, and to take digital photomicrographs. The estimated accuracy of the heating and freezing measurements is $\pm 2^{\circ}\text{C}$ and $\pm 0.5^{\circ}\text{C}$, respectively. The salt concentration was calculated from either the temperature of ice melting or halite crystal dissolution, according to [5]. The salt composition of solutions was determined from the eutectic temperature [6]. The pressure of the heterogeneous fluid was estimated from substantially gas and gas-liquid syngenetic inclusions as the sum of the partial pressures of water vapor and carbon dioxide. The estimation of salt concentration was carried out using the FLINCOR program [7].

Aqueous extracts from inclusions were analyzed by several methods, including gas and ion chromatography and ICP MS, in 0.5g charges of the 0.50- to 0.25-mm fraction at the Central Institute of Geological Exploration for Base and Precious Metals (analyst Yu.V. Vasyuta); the technique described by [8] was used. The amount of water in inclusions of the same charge was determined in order to calculate concentrations of elements in the hydrothermal solution. Carbon dioxide and methane were analyzed as well. After preparation of the extract, the concentrations of Cl, K, Na, Ca, Mg, and all elements (including Ga) that could be detected with ICP MS were determined.

4. Fluid inclusions study

There are three types of primary fluid inclusions in quartz (and sphalerite, anhydrite) accompanying gold ores at Darasun goldfield: three-phase or multiphase fluid inclusions of chloride brines (Type-1); two-phase fluid inclusions of dilute solutions (Type-2); and gas-dominated inclusions (Type-3) (Fig. 2). As a rule, Type-3 inclusions are syngenetic to the 1st and 2nd type inclusions and also indicate the immiscibility of the ore-forming fluids during ore deposition. Fluid composition and the conditions of ore deposition at the Darasun, Teremkinskoye and Talatuy deposits are similar to those of porphyry-style deposits. The data of thermo- and cryometric measurements of fluid inclusions are presented in Table 1 and Figure 3. The chemical composition of the fluid extracted from inclusions in quartz is shown in Table 2.

According to these data the ores of Talatuy deposit were crystallized at temperatures in the range 611 – 133°C and the fluid salinity changes from 55.8 to 0.4 wt. % equiv. NaCl. Heterogeneous fluid containing CO_2 -bearing gas phase was observed in the temperature range of 611 – 310°C . The fluids (covering the whole spectrum of tem-

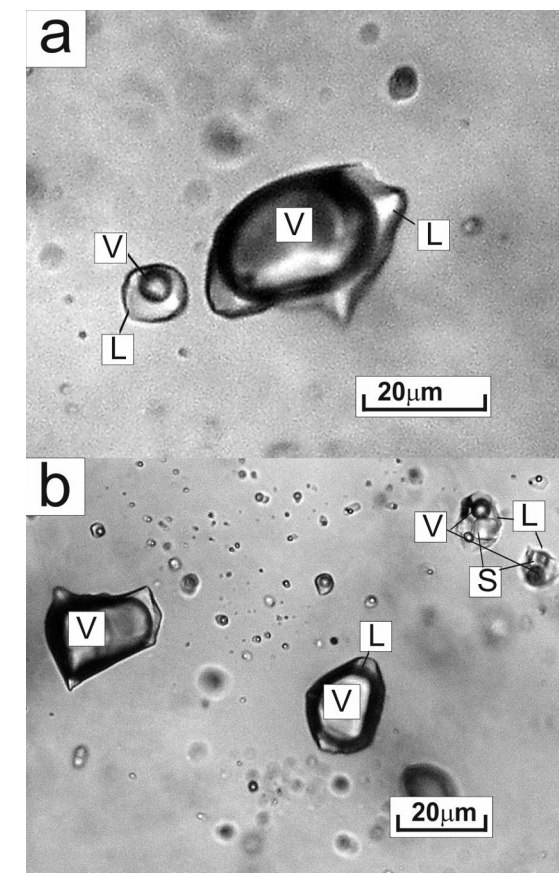


Figure 2. Fluid inclusion assemblages in quartz from the Darasun goldfield deposits. (a) coexisting V-rich and two-phase L-V inclusions (Darasun); (b) coexisting V-rich and three-phase inclusions (Talatuy).

peratures and salinities) composed of the following components (g/kg of solution): CO_2 49.8–5.9, CH_4 0.35–0.02, Na 54.5–8.2, K 31.0–4.7, Ca 40.3–4.3 and Mg 2.7–0.1, and also contained elevated concentrations of Sr, Ba, Mn and Tl.

The early stage quartz of the Teremkinskoye deposit was deposited from a heterogeneous fluid containing a CO_2 -bearing gas phase at salt concentration of 41.0–1.2 wt. % equiv. NaCl and temperatures of 466 – 295°C . At temperatures below 290°C the fluid state changed into a homogeneous one. The gold-bearing quartz was formed from the homogeneous fluid with salt concentration of 26.3–4.2 wt. % equiv. NaCl at temperatures between 298 and 216°C . The post-ore quartz was deposited at temperatures 195 – 118°C from solutions with a salt concentration of 27.8–2.6 wt. % equiv. NaCl. The fluids (covering the whole spectrum of temperatures and salinities) contained (g/kg of solution) CO_2 35.9–6.5, CH_4 3.5–0.05, Na 28.9–4.5, K 15.3–0.9, Ca 72.6–0.5 and Mg 9.6–0.08. There are

Table 1. Summary of microthermometric fluid inclusion data of vein quartz of the Darasun goldfield deposits.

Mineral	Incl.	n*	$T_h \text{ } ^\circ\text{C}$	Hom.	$T_e \text{ } ^\circ\text{C}$	$T_m \text{ CO}_2$	$T_h \text{ CO}_2 \text{ } ^\circ\text{C}$	Hom.	T_m	Eq. wt%	ρ
Type				mode				mode CO ₂	Clatrate \text{ } ^\circ\text{C}	NaCl	(g/cm) ³
Darasun deposit											
Early stage											
Qtz	3	155	429-290	Vapor	-27 to -31	-56.6 to -59.0	24.7 to -40.0	Liquid to Vapor	9.1 to 5.1	21.3-0.7	0.77-0.20
Qtz	2	376	399-280	Liquid	-22 to -52					24.1-1.4	1.04-0.88
Qtz	1	32	412-230	Liquid	-52 to -62					44.8-29.3	1.08-0.89
Main stage											
Sph	2	117	383-160	Liquid	-27 to -54					16.8-0.7	0.98-0.70
Qtz	2	207	340-210	Liquid	-25 to -63					22.0-2.2	0.97-0.66
Anh	2	18	247-214	Liquid	-38 to -40					15.5-14.8	0.97-0.94
Late stage											
Qtz	2	52	223-124	Liquid	-25 to -53					17.0-2.2	1.04-0.90
Calc	2	5	209	Liquid	-38					10.9	0.94
Teremkinskoye deposit											
Early stage											
Qtz	3	333	443-320	Vapor	-20 to -29	-56.8 to -58.2	11.5 to -53.0	Vapor	8.6 to 8.0	8.1-1.2	0.48-0.02
Qtz	2	507	438-300	Liquid	-22 to -58					26.3-4.0	0.99-0.47
Qtz	1	23	466-295	Liquid	-55 to -68					41.0-28.0	1.10-0.88
Main stage											
Qtz	2	120	298-216	Liquid	-28 to -58					26.3-4.2	0.99-0.82
Late stage											
Qtz	2	61	195-118	Liquid	-27 to -58					27.8-2.6	1.10-0.89
Talatuy deposit											
Early stage											
Qtz	3	17	589-431	Vapor	-35 to -55	-56.7 to -58.9	31.0 to -49.3	Vapor	-	17.6-0.9	0.57-0.02
Qtz	2	6	495-469	Liquid	-35 to -42					23.2-0.7	0.54-0.49
Qtz	1	41	611-402	Liquid	-35 to -62					56.3-29.9	1.25-0.78
Main stage											
Qtz	3	40	377-292	Vapor	-26 to -55	-56.6 to -59.0	24.7 to -40.0	Vapor	8.6 to 7.9	8.0-1.4	0.42-0.03
Qtz	2	105	438-273	Liquid	-22 to -61					24.1-1.4	0.91-0.47
Qtz	1	97	397-269	Liquid	-36 to -61					48.4-29.3	1.21-0.97
Late stage											
Qtz	2	18	251-133	Liquid	-21 to -30					5.4-0.4	1.03-0.88
Calc	2	19	231-146	Liquid	-28 to -35					2.1-0.7	0.94-0.83

Note: * - number of inclusions

also elevated concentrations of Br, B, Cs, Ag, Cd, Bi, Co, Ni and Au in the fluid from the Teremkinskoye deposit.

At the Darasun deposit ore deposition took place at temperatures between 430–120°C. The ore-forming fluid contained chlorides of sodium, potassium and magnesium, and its salinity varied from 44.8 up to 0.7 % wt. equiv. NaCl. The early mineral association was deposited from a heterogeneous fluid containing CO₂-bearing gas phase. At temperatures below 300°C the ore-forming fluid became homogeneous and native gold was deposited. At temper-

atures below 200°C a post-ore quartz-calcite association was formed.

It was established that the fluids from the Darasun gold deposit contain (g/kg of solution): CO₂ 147–2.4, CH₂ 10.4–0.12, Na 75–4.3, K 123–0.8, Ca 30.5–1.1 and Mg 8.9–0.2. There are also elevated concentrations of As, Cu, Zn, Pb, Fe, Li, Sb, Te and REE in the solutions.

The highest and widest range of homogenization temperature (611–120°C) and salinity (56.3–0.4 wt. % equiv. NaCl) are observed in gangue minerals of the Talatuy deposit. Lower temperature (430–120°C) and salinity (44.8–

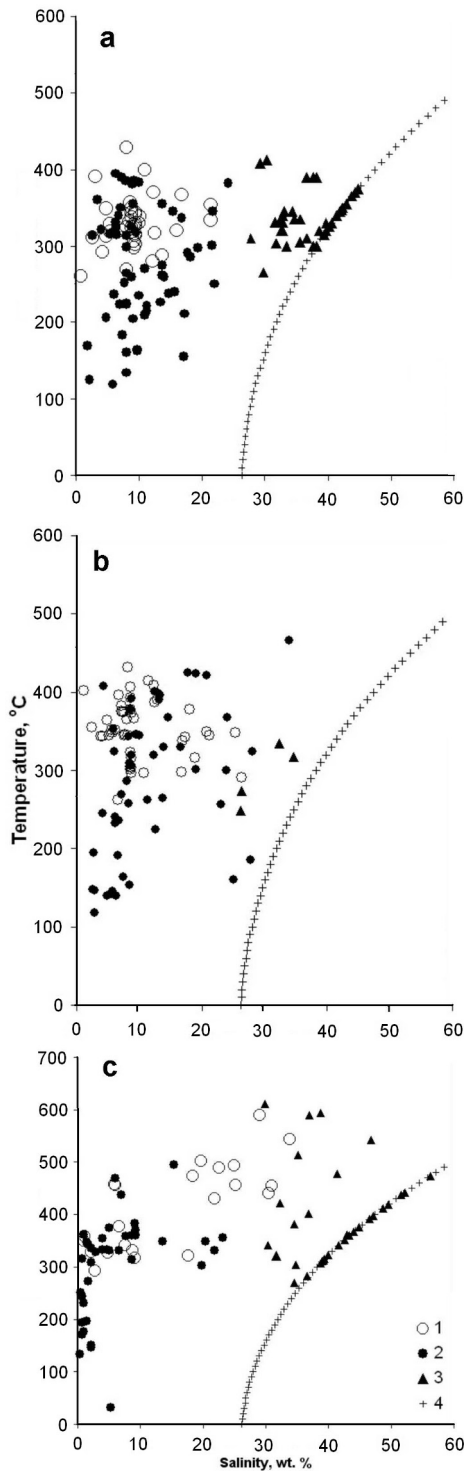


Figure 3. The plot of salinity (wt.% equiv. NaCl) vs. temperature (°C) for fluids from quartz in the ores of Darasun (a), Teremkinskoye (b) and Talatuy (c) deposits. 1 – gas inclusions, 2 – liquid rich inclusions, 3 – brine inclusions, 4 – saturation curve of the H₂O–NaCl system.

0.7 wt. % equiv NaCl) are characteristics of the Darasun and Teremkinskoye ores.

5. Discussion

The geological and mineralogical data allowed us to compare Darasun, Teremkinskoye and Talatuy deposits under the assumption of a single ore-forming system with varying physicochemical conditions in time and space. The results of the fluid inclusion study have shown that early associations of gold ores in all three deposits were formed from a heterogeneous (potentially carbonic) fluid.

The changes in chemical composition of the ore-bearing fluids in the Darasun goldfield can be explained by the processes of fluid fractionation in the ore-forming system [4]. The differences of these three deposits can be accounted for their location in temperature field with respect to magmatic intrusions of granodiorite porphyries (Fig. 4). The high (colder) horizon inclusions are enriched in relatively volatile components (CO₂, CH₄, HCO₃⁻, As, Li, etc.). At the same time less volatile components (Cl, SO₄²⁻, Ca, Br, Sr etc.) are accumulated into the bottom, higher temperature zones.

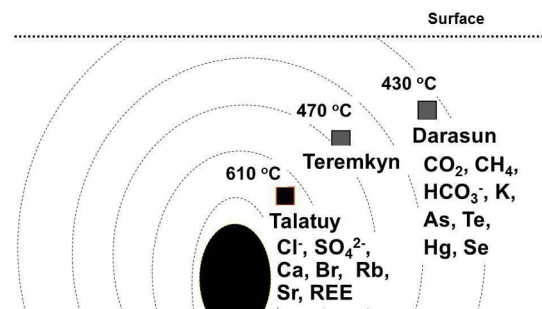


Figure 4. The schematic location of the Darasun goldfield deposits in the temperature field relatively the granitoid source.

In spite of the fact that early associations of gold ores in the deposits under consideration were formed from a heterogeneous fluid, their histograms of fluid salinity distributions are quite different (Fig. 5).

There is clearly a bimodal salt concentration distribution for the Talatuy deposit (Fig. 5). Such a distribution can be explained by phase separation of the water–salt fluid which divided into the water vapour and the brine.

However for the Darasun and Teremkinskoye deposits, which lay more distal from the magmatic heat source, there is one-modal salinity distribution (Fig. 5). This suggests

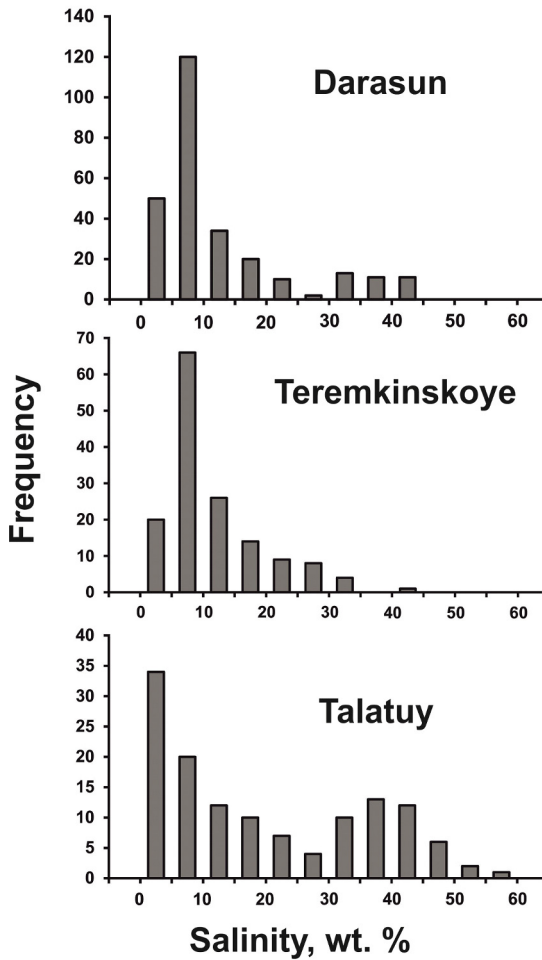


Figure 5. Histograms of fluid inclusion salinities in minerals of ore veins of the Darusun goldfield deposits.

that probably there is an alternative way of heterogeneous fluid formation.

It is quite possible that in these cases the heterogeneous fluid was formed by barbotage participation. Water vapour generated near the heat source passes through water fluid up to the more cold (more remote from heat source) top levels (Fig. 6). This process can affect the fluid composition and its spatial location.

In order to prove or to refute this assumption we have examined the gallium distribution into these three gold deposits. Experimental studies show that in heterogenic hydrothermal systems gallium accumulates into the gas phase [9]. Therefore the concentration of gallium in the ore-forming fluid can be used as an indicator of gas phase transport. On the other hand barbotage should cause gallium fractionation into the system. The same can be suggested for two other elements, e.g. Hg and Te that also

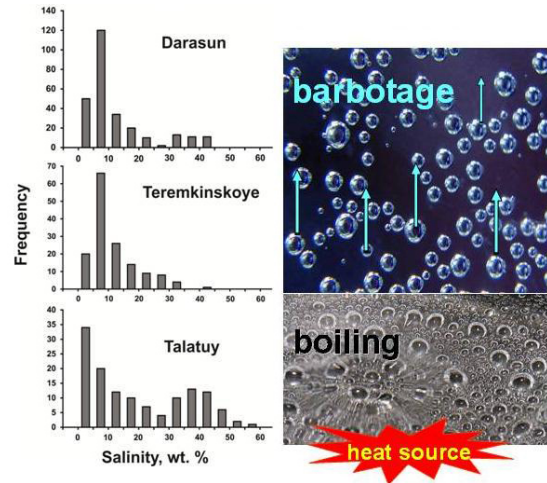


Figure 6. Schematic model of heterogeneous fluid distribution in the Darusun ore forming system: area of boiling (bottom) and area of “barbotage” (top).

are transported in the vapour phase. Te and Hg are most likely carried in the vapor phase under ore-forming conditions [10–13].

The investigation of fluid composition by crush-leach method has shown the presence of high content of gallium in fluids from Darusun goldfield deposits (average concentrations, ppm: 10.8 from Talatuy, 20.7 from Teremkinskoye and 59.5 from Darusun gold deposit, Fig. 7, Table 2). The revealed fractionation of gallium into the ore-forming system can serve as the independent proof of gas transfer through the Darusun goldfield hydrothermal system. The similar regularities exist in distribution of Te and Hg (Fig. 7, Table 2).

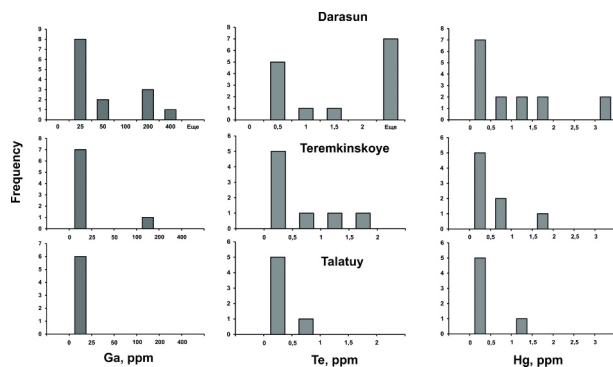


Figure 7. Histogram demonstrating Ga, Te and Hg contents in fluid inclusions in quartz of ore veins from the deposits of the Darusun goldfield.

The scheme of the formation of the Darusun goldfield hydrothermal ore system is shown in Fig. 6. The phase separation (boiling) took place near the magma source and

Table 2. Chemical composition of ore-forming fluids of the Darasun goldfield deposits.

Parameter	Darasun (15)		Teremkyn (8)		Talatui (6)	
	Max-min	Mean	Max-min	Mean	Max-min	Mean
CO ₂ , g/kg of H ₂ O	147-2.4	50.1	35.9-6.5	23.1	49.8-5.9	18.0
CH ₄ , "	10.4-0.12	2.4	3.5-0.05	0.65	0.35-0.02	0.14
Cl, "	23.5-1.5	11.6	30.9-2.5	12.5	166.7-21.9	81.3
HCO ₃ ⁻ , "	620-18.5	170.8	287.4-2.5	88.0	83.5-0.5	32.8
SO ₄ ²⁻ , "	16.8-0	2.2	10.1-0	1.3	66.2-0	11.0
Na, "	75-4.3	19.4	28.9-4.5	11.6	54.5-8.2	36.1
K, "	123-0.8	21.1	15.3-0.9	4.5	31.0-4.7	19.3
Ca, "	30.5-1.1	10.9	72.6-0.5	18.7	40.3-4.3	18.8
Mg, "	8.9-0.2	2.8	9.6-0.08	3.7	2.7-0.1	1.3
Br, "	1.30-0.002	0.26	0.48-0.01	0.39	1.73-0.04	0.44
As, "	3.55-0.06	0.76	0.80-0.02	0.28	0.62-0.07	0.25
B, "	1.89-0.13	0.53	5.12-0.08	1.11	1.48-0.11	0.39
Sr, "	0.80-0.01	0.23	0.75-0.01	0.20	1.39-0.05	0.56
Ba, "	0.59-0.002	0.77	0.39-0.002	0.12	1.31-0.03	0.38
Cu, "	6.48-0.01	1.11	1.51-0.02	0.24	0.18-0.02	0.11
Zn, "	10.81-0.02	1.55	3.57-0.04	0.62	2.28-0.07	1.10
Mn, "	0.94-0.02	0.19	1.44-0.01	0.41	5.75-0.49	2.54
Fe, "	7.94-0.04	1.73	7.24-0.04	1.08	1.05-0.01	0.52
Rb, ppm	1185.2-17.5	340.5	328.7-18.4	126.5	1955.3-334.1	917.7
Li, "	2138.1-48.2	648.5	906.7-61.2	445.5	627.9-6.8	393.1
Cs, "	155.1-0.9	36.6	303.8-12.6	100.7	930.6-105.4	303.3
Mo, "	1767.3-2.6	222.7	643.2-2.2	154.6	115.5-7.0	38.4
Ag, "	79.6-1.1	22.1	491.4-1.7	124.7	26.2-1.4	5.1
Sb, "	75059.1-32.1	6681.8	2084.7-6.1	364.8	1068.8-7.4	252.1
Cd, "	219.8-0.02	37.0	297.4-6.1	91.3	158.2-6.7	63.7
Pb, "	1924.7-19.9	400.2	1208.1-6.8	342.1	623.6-72.0	230.4
Bi, "	81.5-0.2	18.8	162.3-0.3	53.6	3.4-0.1	1.3
U, "	479.9-0.2	34.6	17.8-0.1	2.9	10.3-0.1	2.2
Th, "	8.3-0.3	7.2	13.7-0.1	2.7	2.5-0.1	1.0
Ga, "	250.6-1.2	59.5	144.5-0.6	20.7	22.8-1.0	10.8
Ge, "	396.9-19.0	100.8	103.0-5.2	24.8	26.4-1.9	11.6
Sc, "	7650.7-324.3	2317.5	7887-265	1556	709.9-7.2	262.4
Ti, "	5649.7-6.3	1482.3	11699-26.7	1601.4	378.1-11.4	178.3
Co, "	146.3-1.3	19.3	122.8-1.7	19.8	36.0-5.6	15.6
Ni, "	1692.4-4.1	239.5	2670.8-36.1	409.8	173.5-51.5	119.4
V, "	364.4-4.1	199.2	22.8-0.9	4.7	17.2-0.4	5.2
Cr, "	2016.5-2.9	208.5	1940.2-10.2	249.7	72.4-3.8	27.6
Y, "	1175.9-0.2	88.6	17.8-0.3	3.7	3.3-0.1	0.9
Zr, "	114.8-0.2	26.1	194.0-1.4	28.6	14.0-0.1	4.7
Nb, "	33.8-0.2	5.6	41.6-0.02	5.6	2.1-0.1	0.5
Sn, "	1477.9-0.3	156.0	251.4-0.4	33.6	27.2-1.3	5.6
W, "	1735.5-19.3	171.4	247.6-1.6	57.1	123.4-0.7	33.9
Te, "	185.1-6.2	32.1	17.0-2.9	5.8	6.6-0.1	1.1
Au, "	17.1-0.2	3.8	30.0-0.2	5.6	5.5-1.0	2.3
Hg, "	32.8-1.7	8.1	19.5-0.3	4.7	12.6-0.4	3.7
Se, "	182.5-15.8	32.9	49.4-3.7	8.3	61.0-7.3	17.0
Tl, "	24.1-0.7	6.8	10.5-1.8	5.0	66.2-5.6	30.0
ΣREE, "	946.3-2.1	120.3	225.7-1.2	32.0	19.3-0.4	5.3

Note: Values in brackets are numbers of analyzed samples. The data from Darasun and Teremkinskoye refer to the main-stage, high-T ore fluid, while that of Talatuy represent a early quartz with all types fluid inclusions. For each analysis, data include maximum and minimum concentration, and calculated mean in bracket

led to the separation of the initial fluid into a brine and a low density vapour phase. This process continued for a long time and as a result of boiling the chloride brines were accumulated in the low (bottom) part of the system. The vapour phase generated by boiling ascended in the form of abundant small bubbles increasing the efficiency of the heat transfer and the process of the ore-forming fluid chemical differentiation (notably a barbotage occurred!). This process was long enough to cause fluid fractionation and to result into strong differences in the chemical composition of the fluid, depending on the distance from the heat source. The crystallization of the hydrothermal minerals was induced by the temperature (and pressure) drop and started after a long time when the fluid was already greatly fractionated. Thereby the solutions in fluid inclusions from different zones differ strongly in composition, thus resulting in the crystallization of various gold-bearing assemblages.

6. Conclusions

1. Some aspects of the influence of barbotage on the physicochemical processes in hydrothermal ore-forming systems are described.
2. Using the example of gold deposits of Darasun goldfield the possibility of the vapour phase barbotage in natural hydrothermal ore-forming systems is demonstrated and the influence of this phenomenon on ore-forming process is revealed.
3. The possibility of using gallium fractionation and the fluid salinity distribution in hydrothermal systems as the indicators of barbotage participation in hydrothermal ore-forming processes is evaluated.

Acknowledgments

This work was carried out within the framework of the Russian Foundation for Basic Research (project 12-05-01083-a) and Russian Scientific Fund.

References

- [1] White, D. E., Muffler, L. J. P., Truesdell, A. H. Vapor-dominated hydrothermal systems compared with hot-water systems. *Econ. Geol.*, 1971, 66, 75–97.
- [2] Kigai, I. N. A Model of Multistage Ore Formation Consistent with Variations of Main Hydrothermal Process Parameters. In: *Main Parameters of Natural Processes of Endogenic Ore Formation* (Nauka, Novosibirsk), 1979, 2, 7–34 (in Russian).
- [3] Bodnar, R. J., Reynolds, T. J., and Kuehn, C. A. Fluid-inclusion systematic in epithermal systems. *Rev. in Econ. Geol.*, 1985, 2, 73–97.
- [4] Prokofiev, V.Yu., Garofalo, P.S., Bortnikov N.S., Kovalenker, V.A., Zorina L.D., Grichuk, D.V., Selektor, S.L. Fluid Inclusion Constraints on the Genesis of Gold in the Darasun District (Eastern Transbaikalia), Russia. *Econ. Geol.*, 2010, 105, 395–416.
- [5] Bodnar, R. J., and Vityk, M. O. Interpretation of microthermometric data for H₂O–NaCl fluid inclusions. In: Benedetto de Vivo (Ed.) *Fluid inclusions in minerals: methods and applications*, Siena, Italy, 1994, 117–130.
- [6] Borisenko, A. S. Cryometric analysis of salt composition in vapor-fluid inclusions in minerals. *Geologia i Geofizika.*, 1977, 8, 16–27. (in Russian).
- [7] Brown, P., 1989, FLINCOR: a computer program for the reduction and investigation of fluid inclusion data. *Amer. Mineral.*, 74, 1390–1393.
- [8] Kryazhev, S. G., Prokofiev, V. Y., and Vasyuta, Y. V. Application of ICPMS method by analyze of ore-forming fluids composition. *Vestnik MGU*, 2006, 30–36 (in Russian).
- [9] Nekrasov, S. Yu., Bychkov, A. Yu. Experimental Study of Ga and Al Oxide Solubility in Gas–Vapor Mixture at 200°C. *Geochem. Internat.*, 2011, 49, 90–94.
- [10] Cooke, D. R., McPhail, D. C. Epithermal Au–Ag–Te mineralization, Acupan, Baguio District, Philippines: numerical simulations of mineral deposition. *Econ Geol.*, 2001, 96, 109–131.
- [11] Heinrich, C. A., Driesner T., Stefansson A., Seward T. M. Magmatic vapor contraction and the transport of gold from the porphyry environment to epithermal ore deposits. *Geology*, 2004, 32, 761–764.
- [12] Williams-Jones, A.E., Heinrich, C.A. Vapor transport of metals and the formation of magmatic-hydrothermal ore deposits. *Econ. Geol.*, 2005, 100, 1287–1312.
- [13] Grundler, P.V., Brugger, J., Etschmann, B., Helm, L., Liu, W., Spry, P.G., Tian, Y., Testemale, D., and Pring, A., Speciation of aqueous tellurium (IV) in hydrothermal solutions and vapors and the role of oxidized tellurium species in gold metallogenesis. *Geochimica et Cosmochimica Acta*, 2013, 120, 298–325.