rite, which deposited from the new fluid portions closely to chalcopyrite and sphalerite, are enriched in Cu and Zn. The iron disulfides, which were formed on the seafloor, are strongly enriched in trace elements relative to the subseafloor crystalline pyrite that most likely is related to the effective accumulation of trace elements, when the high-temperature hydrothermal fluid meets the cold seawater. Gold is concentrated in the early generations of pyrite and marcasite.

The main carrier of the invisible gold in the Semenov-2 massive sulfides is covellite in contrast to traditional pyrite, chalcopyrite, bornite or isocubanite [e.g., Bortnikov et al., 2000]. Covellite from the Semenov-2 massive sulfides contains 22.51–226.64 ppm Au that is much higher than Au content in sphalerite (0.00–0.01 ppm), chalcopyrite (0.11–0.22 ppm), and isocubanite (0.03–0.06 ppm). Covellite, which replaces sphalerite, is characterized by the higher Au contents. We suggest that gold in covellite is chemically bound because each of 11 analyses has stable gold content and Au and Cu contents in covellite directly depend on each other.

Similarly to Au, all identified elements have more or less stable contents in all analyses that does not favor microinclusions of minerals. However, direct correlation between Bi and Te may probably indicate presence of microinclusions of Bi-telluride. The source of most trace elements in covellite, which replace sphalerite, is problematic and the mechanism of their incorporation is still unclear. Some of trace elements (Mn, Co, Ga, Cd) were inherited from the replaced sphalerite and were removed during the replacement. In case of covellite, which is developed after chalcopyrite, most trace elements (Mn, Co, Ni, Ga, As, Se, Mo, In, Sn, Te, Tl, and Bi) derive from the host chalcopyrite.

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THE ALDAN-MAADYR ZONE, WESTERN TUVA, RUSSIA: FORMATION CONDITIONS OF GOLD-QUARTZ VEINS IN LISTVENITES, CONGLOMERATES, AND BERESITES

Установлено три стадии образования золото-кварцевых жил на месторождениях Алдан-Маадырской зоны в Западной Туве: высоко-, средне- и низкотемпературная (>350 °С, 270–180 °С и <180 °С). Отмечается понижение пробности золота от высоко- к низкотемпературной стадии. На основании близкого изотопного состава кислорода в кварце исследованных месторождений и валового состава флюидных включений сделан вывод о единой гидротермальной системе, образовавшей месторождения в лиственитах, конгломератах и березитах.

The gold-quartz deposits of the Aldan-Maadyr zone in the Western Tuva are worthy of interest because they are located in the common geological structure but are hosted in different kinds of rocks (listvenites, conglomerates, and beresites). Their formation is considered to be related to the Devonian granitic magmatism [Zaykov et al., 1981]. The aim of the present work was an identification of

Table 1

Homogenization temperatures, salinity, salt composition of fluid inclusions and composition of gold for the studied deposits

Deposit	Homogenization temperature, °C	Salinity, wt % NaCl-eq	Major salts	Statistical groups of values of Th and salinity	Statistical groups of composition of gold	Gold fineness
Khaak-Sair, vein 7	248–211 (n 42) 231 (10)	7.5–14.2 (n 42) 11.0 (2.0)	$NaCl–KCl–H_2O$	1) 248–233, 14.2–12.9 2) 248–214, 12.6–7.5 3) 230–211, 13.1–11.7 4) 229–214, 11.3–8.9	1) Au 96.84–99.87, Ag 0.00–2.74, Cu 0.00–0.57 2) Au 91.98–95.08, Ag 4.46–7.81, Cu 0.00–1.30 3) Au 87.59–90.24, Ag 8.73–11.88, Cu 0.32–2.51 4) Au 85.30–87.00, Ag 12.59–13.94, Cu 0.00–1.38	853–999 941 (39)
Khaak-Sair, vein 2	188–124 (n 83) 152 (17)	4.0–8.2 (n 83) 5.9 (1.1)	$NaCl–H_2O$ ± $NaCl–KCl–H_2O$	1) 188–167, 7.5–4.9 2) 168–147, 5.5–4.0 3) 161–150, 7.8–7.3 4) 151–129, 8.0–4.4 5) 137–124, 8.2–6.0	1) Au 91.92–94.09, Ag 4.63–9.37, Cu 0.00–0.47 2) Au 90.03–91.94, Ag 5.61–9.64, Cu 0.00–0.61 3) Au 99.30–99.80, Ag 0.00–0.57	867–998 925 (31)
Khaak-Sair, vein 1	233–188 (n 31) 213 (12)	3.2–5.2 (n 31) 4.0 (0.6)	$NaCl–KCl–H_2O$	1) 233–200, 3.2–4.9 2) 231–210, 4.0–4.6 3) 232–188, 3.5–5.2	1) Au 86.04–90.58, Ag 8.97–13.15, Cu 0–0.65 2) Au 68.67–74.64, Ag 24.83–30.97	687–906 832 (76)
Ulug-Sair, vein 18	357–295 (n 37) 323 (15)	6.0–9.6 (n 37) 7.9 (1.1)	$MgCl_2–H_2O$ + $NaCl–KCl–H_2O$	1) 357–299, 7.3–8.8 2) 344–314, 6.0–6.6 3) 351–295, 7.3–9.6	1) Au 93.82–96.44, Ag 3.31–5.33 2) Au 90.94–92.83, Ag 7.08–8.68	909–964 936(21)
Ulug-Sair, vein 4	237–200 (n 23) 220 (9)	4.5–6.8 (n 23) 5.4 (0.7)	$NaCl–KCl–H_2O$ + $MgCl_2–H_2O$	1) 237–200, 4.5–5.1 2) 231–226, 6.4–6.8 3) 223–201, 5.4–6.0	1) Au 89.89–94.94, Ag 6.37–8.27 2) Au 86.96–91.27, 9.32–12.2, Cu 0.00–0.69, Fe 0.00–0.34 3) Au 64.2–78.45, Ag 21.87–35.35, Cu 0.00–0.52, Fe 0.00–0.61, Te 0.00–0.86	642–949 841(104)
Ulug-Sair, vein 33	168–114 (n 51) 135 (13)	3.5–9.3 (n 51) 5.9 (1.4)	$NaCl–KCl–H_2O$ + $MgCl_2–H_2O$ ± $NaCl–Na_2B_5O_8–H_2O$	1) 168–148, 3.5–5.4 2) 152–114, 7.8–9.3 3) 141–120, 6.5–7.4 4) 140–115, 4.3–6.3	1) Au 93.49–91.71, Ag 7.70–5.99, Cu 0.37–0.19 2) Au 85.76–82.83, Ag 16.96–14.13, Cu 0.30–0.08 3) Au 88.11–85.45, Ag 14.38–11.6, Cu 0.33–0.16 4) Au 94.5–94.01, Ag 5.76–5.3, Cu 0.26–0.19	828–945 893 (39)
Aryskan	272–201 (n 44) 237 (18)	3.8–8.2 (n 44) 5.8 (1.0)	$NaCl–KCl–H_2O$	1) 264–201, 5.4–6.8 2) 272–205, 3.8–4.8 3) 257–210, 6.5–8.2	1) Au 90.16–93.12, Ag 6.59–9.43, Cu 0.16–0.35 2) Au 88.63–92.44, Ag 7.21–10.89, Cu 0.26–0.40 3) Au 84.05–87.22, Ag 12.59–15.66, Cu 0.15–0.31	841–931 907(21)
Duushkunnug	158–116 (n 56) 139 (10)	4.1–7.5 (n 56) 5.5 (0.8)	$NaCl–KCl–H_2O$ + $FeCl_2–H_2O$	1) 158–146, 5.7–6.5 2) 158–138, 4.1–5.4 3) 142–128, 4.8–6.0 4) 145–116, 6.3–7.5	1) Au 90.32–93.15, Ag 6.92–9.12, Cu 0.00–0.08, Hg 0.00–0.08, Te 0.00–0.04 2) Au 89.44–91.95, Ag 7.59–10.28, Cu 0.16–0.30 3) Au 88.16–89.95, Ag 9.79–10.79, Cu 0.00–0.04, Hg 0.00–0.11, Te 0.00–0.04 4) Au 86.64–88.67, Ag 11.09–12.90, Cu 0.18–0.28	866–932 904 (16)

The maximum and minimum values are given in the numerator and the average value and standard deviation are given in the denominator. Major salt composition based on eutectic tempertaures is estimated after the method of Borisenko [1977].

similar and distinct formation conditions of these deposits based on study of chemical composition of gold, fluid inclusions and O isotopic analysis of gold-bearing quartz.

The Aldan-Maadyr zone 5–6 km wide extends up to 20 km in the east-northeastern direction and is situated in a junction of the Western Sayan with Tuvinian trough [Zaykov et al., 1981]. The area is hosted in Silurian and Ordovician sediments rumpled into the linear isoclinal folds, the cores of which contain the wedges of Cambrian basalts and ultramafic rocks. The major gold-quartz deposits are hosted in listvenites (Khaak-Sair), conglomerates (Ulug-Sair), beresites (Aryskan), and beresitized rhyolites (Duushkunnug).

The composition and fineness of gold, homogenization temperatures, salinity, and major salt composition of the primary fluid inclusions in gold-bearing quartz from the studied deposits are shown in Table 1. The results of the gas chromatography and bulk (ICP MS) analysis of fluid inclusions are given in Table 2. The oxygen isotopic composition was analyzed for the gold-bearing quartz from the Khaak-Sair, Ulug-Sair, and Aryskan deposits. The δO^{18} values range from +17.0 to +17.7 ‰ (up to 18.5 ‰ in a single analysis).

Based on the correlation of homogenization temperatures and salinity, we may conclude that gold-quartz veins were formed in several stages. Their formation began from the crystallization of the Ulug-Sair vein 18 from most high-temperature (> 350 °C) moderately saline (6.0–9.0 wt % NaCl-eq) fluids and deposition of gold with the least dispersion of fineness. The following stage is characterized by medium-temperature (272–188 °C) and moderately saline (3.2–8.2 wt % NaCl-eq) fluids, which form gold-quartz veins at the Aryskan deposit, Ulug-Sair vein 4, and the Khaak-Sair vein 1. The homogenization temperatures of the fluid inclusions in quartz from the Khaak-Sair vein 7 may also belong to this stage but the fluid inclusions demonstrate the highest salinity among the studied veins (Table 1). The gold fineness from the medium-temperature veins is similar for the Khaak-Sair vein 7 and Aryskan deposits and for the Khaak-Sair vein 1 and Ulug-Sair vein 4. The low-temperature (188–114 °C) moderately saline (3.5–9.3 wt % NaCl-eq) stage of formation of gold-quartz veins was manifested at the Ulug-Sair vein 33, Khaak-Sair vein 2, and Duushkunnug deposit. The gold fineness of the low-temperature veins is similar (Table 1). As is seen from Table 1, in most cases, the number of statistical groups of gold composition and fluid inclusion data coincide that reflects the pulsating gold-quartz deposition while temperature decrease, which is also supported by gold grains zonal by Ag and Cu.

The higher (up to 14 wt % NaCl-eq) salinity of the fluids identified in the Khaak-Sair quartz and a wide development of tourmaline and auxinite both in the deposits and at the contacts with the nearest intrusive bodies may indicate magmatic contribution to the mineral formation. This is comparable to the Berezovskoe and Kochkar gold-quartz in the Urals associated with porphyry granites [Baksheev et al., 1998; Prokof’ev and Spiridonov, 2005]. These deposits also show higher saline (up 17 and 15.7 wt % NaCl-eq, respectively) fluids with dominant NaCl composition and admixture of $MgCl_2$ similar to the Tuvinian deposits.

The bulk composition of fluid inclusions has revealed the broad elements related to the ore-forming fluid (Table 2). Only Zn, Bi, Sn, Hg и Tl shows minor contents. Three groups of elements may be distinguished on the basis of the correlation analysis. The first group includes Cl and Na, which have strong positive correlation with H_2O content in quartz. The second group consists of B, As, and Sb, which are negatively correlated with Cl and Na, that may probably reflect the mixing of fluids of different composition. It is important all correlations are characteristic both of each deposit and the entire Aldan-Maadyr zone that supports an idea on the same type of the hydrothermal system for the reviewed deposits.

The third group includes K, Mg, Ca, and carbon-bearing gases. The contents of precious metals (Au and Ag) correlate precisely with elements of this group that may indicate their certain relation to the ore formation. The correlation between Au and CO_2/CH_4 ratio (a degree of the fluid oxidation) may testify to the fluid oxidation as one of the reasons of gold deposition.

The CO_2/H_2O ratio (relative content of the gaseous phase), which indirectly reflects the pressure and erosion level of the ore-forming system, respectively, increases towards the west and is maximum at the westward Khaak-Sair deposit, which geological structure is mostly eroded. This deposit is also distinct by elevated contents of As, B, Sb, Pb, Cd, W, Mo and presence of minor amounts of Bi, Zn, Hg. This is in accordance with occurrence of different kinds of fahlores, tourmaline, auxinite, galena, arsenopyrite, gersdorffite, bismuthinite, cinnabar, and sheelite in veins and listvenites. The high Cu contents in the fluid at the Ulug-Sair deposit may be correlated to the wide development

Table 2

Average contents of fluid components in quartz from the studied deposits

Component	KS (4)	US (4)	A (1)		Component	KS (4)	US (4)	A (1)
Major components, mg/kg quartz					Trace elements, mkg/kg quartz			
H_2O	871	1955	1544		Li	4.0	3.8	5.4
CO_2	127.0	114.3	37.0		Rb	1.2	1.0	1.2
CH_4	0.21	0.11	0.30		Cs	0.3	0.4	0.7
Cl	0.91	6.48	6.59		Sr	56.0	57.0	97.2
HCO_3^-	14.0	25.0	56.0		Sb	9352.7	18.2	0.0
Na	4.08	13.51	21.34		Ge	0.1	0.1	0.2
K	0.78	0.69	0.81		Cu	1.3	178.6	73.3
Ca	2.29	0.45	2.68		Cd	2.8	0.2	0.3
Mg	0.35	0.14	0.69		Pb	43.6	0.3	0.3
B	0.92	0.48	0.32		Au	0.08	0.07	0.16
Ba	1.13	0.37	0.54		Ag	2.8	0.1	4.8
As	0.69	0.16	0.16		Mo	8.2	3.1	4.5
Molar ratios					W	19.4	1.9	0.0
CO_2/H_2O	0.06	0.02	0.01		Co	0.2	0.1	0.7
CO_2/CH_4	223	370	44		Ni	2.9	7.6	2.2
Cl/HCO_3^-	0.11	0.45	0.21		Cr	0.5	0.0	1.4
B/Cl	3.22	0.24	0.15		Mn	9.5	16.9	54.2
Na/Cl	6.9	3.2	4.9		Fe	35.9	4.3	28.7

Gas chromatography and bulk analysis are carried out in TsNIGRI, Moscow, analyst Yu. V. Vasyuta. Deposits: KS (Khaak-Sair), US (Ulug-Sair), A (Aryskan). The number of analyses is given in brackets.

of chalcopyrite in the quartz veins. The higher concentrations of HCO_3^-, K, Ca, Mg, Mn, and Sr in quartz from the Aryskan deposit probably reflect beresite-type of alteration.

The narrow range of the oxygen isotopic composition in quartz from the studied deposit, which is similar to that from many world gold deposits, indicates (i) the common sources of the fluids, (ii) no isotopic exchange with host rocks, (iii) homogeneous isotopic system, and (iv) similar formation temperatures [Kerrich, 1987; Goldfarb et al., 1991; Jia and Kerrich, 2001]. The latter conclusion is well demonstrated by the overlapped homogenization temperatures at the studied deposits. The oxygen isotopic composition of quartz from the Tuvinian deposit is close to that from the metamorphic or sedimentary source [Taylor, 1974; Faure, 1989; Hoefs, 2009]. The $\delta^{18}O_{H2O}$ values of 10.02–11.51 ‰ calculated from the equation $1000 \ln \alpha = 3.38 (10^6\ T^{-2}) - 3.40$ at 300 °C [Clayton et al., 1972] correspond to the metamorphic water. Similar $\delta^{18}O_{H2O}$ values of the fluids and their narrow variations are typical of many gold deposits in sedimentary sequences [Goldfarb et al., 1991]. The origin of the fluids at these deposits is considered to be related with progressive metamorphic dehydration and degassing of the host rocks. In case of Tuvinian deposit, we may suggest that the source of Si-O compounds in the fluids were the Precambrian metamorphic rocks presently occurred in the northern wall of the Sayan-Tuva fault.

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GOLD MINERALISATION IN PIILOLA AREA (EAST FINLAND)

Рассмотрена геологическая позиция и минералогия рудопроявлений золота площади Пиилола (Восточная Финляндия). Площадь находится в пределах зеленокаменного пояса Кухмо в архейском домене Фенноскандинавского щита. Минералогия руд характеризуется преобладанием пирротина и арсенопирита; золото выявлено в самородной форме и в форме мальдонита. В ассоциации с золотом часто наблюдается самородный висмут.

Komatiite-hosted Ni, VMS, and orogenic gold are the most common metallogenic components in Archaean greenstone belts. Canadian shield, Western Australia and other Archaean areas have well-known examples of orogenic gold deposits.

The main Au provinces in Finland are the Archaean greenstones in the east of Finland, Palaeoproterozoic greenstone belts in Lapland, and the Palaeoproterozoic Svecofennian schist belts in central and southern Finland. About 200 hard-rock gold occurrences are presently known.

These are short results of investigations of the Piilola area which is located in the Kuhmo greenstone belt in Eastern Finland. Works are carried out by Mineral Exploration Network (Finland) Ltd. Geophysical, geochemical methods, and drilling have been used.

The Finnish part of the Fennoscandian shield comprises three major domains. There are the Archaean cratonic nucleus (Karelian domain) and the Paleoproterozoic mobile belts of Kola-Lapland and Svecofennia.

The Archaean bedrock can be subdivided into TTG-type complexes, and a few major supracrustal belts: Oijarvi, Kuhmo-Suomussalmi and Ilomantsi. The Kuhmo-Suomussalmi volcano-sedimentary complex (Kuhmo, Suomussalmi and Tipasjarvi greenstone belts combined) was probably formed in an intra-plate, oceanic environment [Lahtinen et al., 2011]. Its central part (the Kuhmo greenstone belt) has a symmetrical syncline structure with a submeridional trend. The most voluminous rocks are mafic volcanic rocks [Papunen et al., 2009]. Several phases of the Archaean TTG granitoids have intruded the greenstone belt.