

Geological-genetic peculiarities of Goshian gold-sulfide deposit formation (Azerbaijan area of the Lesser Caucasus)

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Abstract: This paper focuses on geological-genetic peculiarities of Goshian deposit formation. Considerable elements of corresponding conditions of gold-ore mineralization localization can be emphasized here, subvolcanic body and joined high-angle faults are the more typical among them.

Sequence and stages of mineral formation process are studied and also distribution of precious metals in ores and sulfide concentrations. Ore bodies refer to vein-disseminated type and are confined to inside part of metasomatic aureole which is represented by quartz-sericite facies of secondary quartzites. It is expected during ore-formation process physic-chemical conditions varied from midwater (quartz-pyritic stage, early-ore) to shallow (quartz-arsenic pyrite-polymetallic with “hidden” gold) up to near-surface (quartz-gold-telluride, quartz-gold goethite-hydrogoethite stage). Formation of Gosha deposit occurred in relatively narrow temperature interval from homogeneous fluids of mainly Na-chloride composition with moderate and low salinity.

It is established the temperature of ore-formation studied by homogenization method of gas-liquid inclusions in transparent minerals (quartz) of different mineral associations varies 140-390° C. Pressure of ore-forming medium calculated by isotherms cross in system H₂O-CO₂ and isochors CO₂ is 0,7-2,0 Kbar.

Keywords: gold-sulfide mineralization, ore bodies, mineralization zones, mineral associations, mineral formation, isotopic data, fluid inclusions.

1.Geological tectonic position of deposits. Metallogeny of Lok-Garabagh zone was studied in numerous works of such authors as R.Abdullayev, Sh.Azizbekov, et al., 1962; T.Hajiyev, 1976; Ramazanov, 1997; V.Baba-zade, 2005, et al. and noble methylation mining-magmatic systems (MMS) are discretely distributed within Lok-Garabagh zone; they are: Gedabek, Garadagh, Chovdar, Goshian, Dagkesaman, Gyzybulag and less considerable deposits, ore occurrence which formed according to activity of magmatic systems appeared in Middle-Late Mesozoic. This zone is of the same pattern of long polyformation development with Mesozoic Paleoisland-arc constructions and this zone is especially rich in deposits of non-ferrous and precious metals, however mineralization scales have yet to be defined. Epigenetic gold-bearing and proper gold-ore deposits are very typical for fragments of Paleoisland-arc (Lok-Garabagh and Kafan). These deposits differ by geological and structural position, quantitative ratio of mineral complexes and gold content [Baba-zade, Ramazanov, 2003] (fig.1).

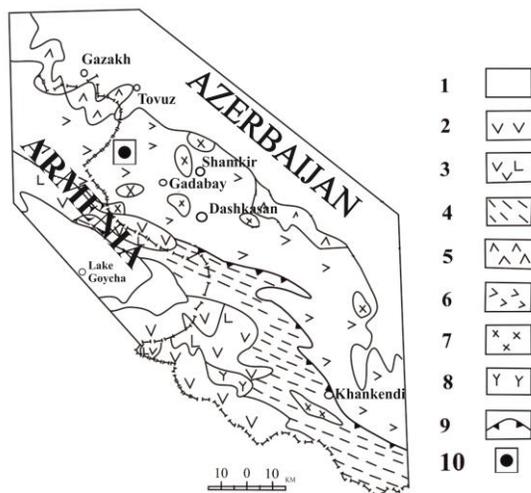


Fig.1. Scheme of work areas location. 1 – molasses, sandy-clayey deposits, in places (in section base) gypsum and ferruginous (Oligocene-Quaternary period); 2 – basaltic beds, dolerites, andesites, trachyandesites (Neogene – Quaternary period); 3 – andesitebasalts, trachy-andesites, terrigenous-carbonaceous flysch (Paleogene) of collision volcanogenic-depression structures on border between adjacent South-Caucasian and Daralagez continental blocks and subjected to late-collision and post-collision magmatic activation; 4 – dunites, peridotites, gabbroids, siliceous limestones, olistostrome (the Upper Jurassic-Cretaceous period);

oceanic formations, obducted on above-mentioned continental blocks and known as Geycha-Akerian suture zone); 5 – rhyolites, dacites, andesite-basalts, tuffaceous sandstones, in places (upper part of section) limestones (Upper Cretaceous period; volcanogenic-sedimentary complex of residual back-arc collision Paleodepressions); 6 – andesitebasalts, andesites, rhyolites, tuffaceous sandstones, clayey shales, in places (upper part of section| reefogenic limestones (Middle-Upper Jurassic-Lower Cretaceous period; fragments of Lessercaucasian Paleoinsular-arc known in literature as Paleoisland-arc Somkhito-Garabagh zone and its Kafan block shifted to south-east along submeridional fault); 7-diorites, tonalities, plagiogranites (Middle Jurassic-Early Cretaceous period); 8-monconites, sienites, granosienites (Upper Paleogene); 9-overthrust; 10-Goshian deposit.

Shamkir uplift where Goshian gold-sulfide deposit is located, is represented by large structure of sublatitudinal extension, mainly Middle Jurassic volcanogenic formations participate in its structure they are cut by the Upper Bajocian plagiogranite and granitoid intrusive complexes. Uplift structure is characterized by relatively simple construction and extends its general consistent strike (Abdullayev, Mustafayev, et al, 1988).

Goshian gold-sulfide deposit is a typical representer of volcanogenic deposits with progressive ore-formation and is connected with constant basalt-andesite-dacite-rhyolite formation localizing in upstructure portion of subvolcanic construction.

Goshian field is located in the most north-western area of Shamkir uplift. Goshian deposit is characterized by confinedness to local focal-dome structure of Jurassic period and volcanic and tectonic construction takes the central place in it which is fixed in crossing of large regional faults of north-western, submeridional and sublatitudinal extensions. The more typical elements of ore field which effect on mineralization distribution on deposit area, are subvolcanic body and steeply dipping faults – sublatitudinal and near-meridional faults. A close spatial connection is observed between ore-formation and Low-Upper Bajocian Middle-acid subvolcanic bodies – from andesites, andesitebasalts to rhyolites, rhyodacites and dacites. (Abdullayev, Mustafayev et al., 1988). Correlations of subvolcanic formations and endogenic mineralization of deposit in many cases are the following: their genetic connections can be supposed at relatively large depths. But chiefly (in rhyolites areal) the availability of relationship between hydrothermal and magmatic processes can be supported by geological research: endogenic ore mineralization and rhyolites are of close age; ore mineralization and metasomatites form aureolas around subvolcanic bodies or are localized in endocontacts of their apical parts; mineralization is epigenetical relatively to subvolcanic bodies and according to it we can conclude not large subvolcanic bodies of rhyolites irruptive earlier which are superimposed with ore bodies were outflow ways for solutions from depth. (Baba-zade, Ramazanov, 2003; Mansurov, 2004).

Mineralization of gold-sulfide type is concentrated in different oriented dilation veins and in zones of hydrothermal study of laval and pyroclastic series of andesites of Lower and rhyo-dacite porphyries of the Upper Bajocian as metasomatic bodies. Quartz veins according to morphology are usually different-scale. Along with relatively large simple veins the short ones are found which irregular along the strike and vein dip, with complex ramifications on the rise with transitions into zones of thin veinlet and brecciation. Generally veins form en echelon systems. Moreover, the ore bodies are represented by areas with more intensive hydrothermal alteration zone impregnated by gold-bearing sulfides of productive mineral associations-pyrite, chalcopyrite, etc. of typical vein – disseminated excretion pattern (Suleimanov, 1982; Baba-zade, Musayev, et al., 2003).

2.Metasomatic changes of host rocks. The typical feature of deposit is a widespread of pre-ore propylitization, silicification, kaolinization. Propylitic fields are characterized by zonal structure and it is supported by rise of temperature and solution acidity towards the centre of deposit. Secondary quartzites are along fractured zone and ruptured zone among propylites fields, these quartzites complete processes of pre-ore metamorphism. Due to strong hydrothermal study primary composition of rocks can be hardly recognized according to relicts of primary structures and quartz inclusions. It is assumed secondary quartzite metasomatites formed mainly on acid rocks and rarely tuffs. The main minerals of secondary quartzites alunite, diaspore, dickite, sericite and kaolin form various parageneses. Moreover the mentioned main minerals the other minerals such as pyrophyllite, zunyite, barite are found. Availability of sericite is more significant for zonation determination. Secondary quartzites as area with width of 100-150m stretch along fault zones. According to rocks outcrops they are of bedded, blanketlike form and steeply dip (70-85°) in West and East.

Such structural plan of secondary quartzite metasomatites is supported by drilling data and hypsometric position of facial borders. Despite mineral types of secondary quartzites they form the Upper supra-ore zone in hydrothermal-ore system being ore guides at depth and it needs reassessment to determine the contents of ore bodies under them. Formation of secondary quartzites was accompanied by supply of chlorine, noble and nonferrous metals, in this case content of ore components increases by 1-2 order in propylites and more by 1-2 order – in secondary quartzites.

The main pattern of matter deposition on ore stage – filling of fracture holes and pores. Metasomatism prevails on pre-ore stage, it considerably manifests at beginning of ore stage and accompanies deposit of ore matter as secondary phenomenon in nearly vein space (Baba-zade, Musayev et al., 2003; Mansurov, 2001).

3.Structure of ore bodies and zones of mineralization. Deposit has been revealed by five gallery levels. It is formed by system of quartz-sulfide veins and streaks of small extension (quartz-sulfide morphological type), by series of narrow steeply dipping mineralized and vein zones (morphological type – zones with stockwork veins) (fig.2). Ore bodies of vein type are localized in central part of deposit. Their dipping is steep, almost vertical. They have rather vivid geological borders and inconsiderable wallrock alteration of host rocks and it shows the prevalence of process execution in ore deposition. Typical peculiarity of mineralized and vein zones is highly irregular distribution of gold and availability of well-defined ore columns. Ore bodies №№5; 5 – in west and 3 in southern flanks, №№1 and 2 in northern flank of deposit. Ore zones are represented by silicified and kaolinized (with formation of quartz-kaoline association), by pyritized zone of hydrothermal alteration crooked quartz veined. Areas with intensive pyritization can be marked possessing small lens, veinlets, pockets and pyrite dissemination; here can be found pocketry of chalcopyrite, sphalerite

and magnetite. Quartz, often adular, rarely carbonates prevail in composition of vein filling. The rest minerals including ores, their types reach 30, are the admixtures. That's why in first approximation the composition of ore weight of Goshian ore field should be considered as essentially quartz. Quartz-kaoline mass with mentioned ore minerals and quartz fillings form ore zones having usually well-defined borders with host rocks though the latter are mineralized including gold. Due to this reason the outline of veinlike and lenticular gold ore bodies identified by sampling is beyond the scope of ore bearing zones. Vein quartz zones usually consists of one or more veins and areas of vein-disseminated mineralization correlated to them according to thickness. Veins can be characterized by steep dip (60-90°) and availability of numerous apophyses. Width of veins varies 0,2-0,3 up to 1-2,5m, extension 20-30 and up to 300-400m (Baba-zadeh, Musayev, et al, 2003; Mansurov, 2001).

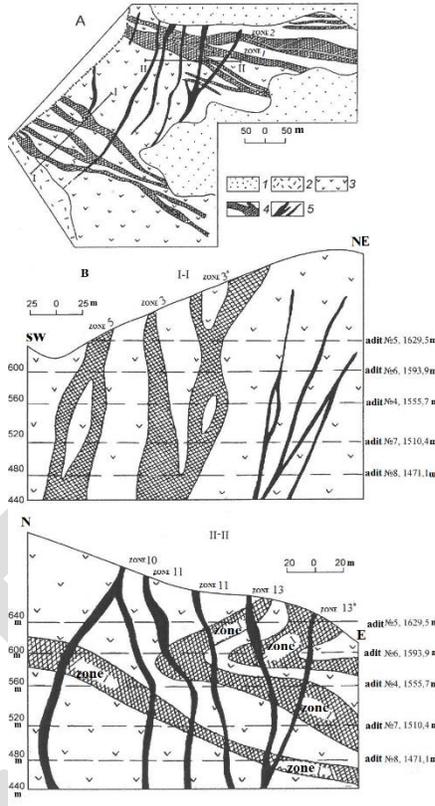


Fig.2. Structure (A) and sections (B) of the main ore bodies of Goshian gold-sulfide deposit

1 – quaternary deposits; 2 – subvolcanic body of rhyolite and rhyolite-dacite composition; 3 – altered andesites; 4 – mineralized and vein zones with gold; 5 – quartz-sulfide veins and veinlets with gold mineralization.

Mineralized zones and ore bodies are characterized by considerable extensions – 700-800m and more, thickness from several meters up to 15-20m reaching 30-50m and more in some zones. Gold content (from “tr” up to 60-90 g/t) varies within both ore bearing zones and quartz-pyrite (subordinate chalcopyrite) ore bodies of lenticular-vein form, in some intervals (and sections) which can be characterized by high gold content (fig.3).

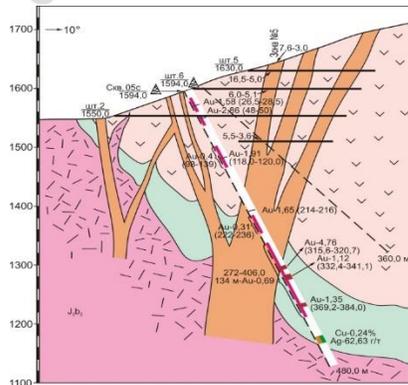


Fig.3. Profile on well №5 (Goshian deposit, zone №5)

Scale 1:2000

4. Mineral associations and stages of mineral formation. According to the results of mineralogical study of aggregates of ore and non-ore minerals, structural and textural peculiarities of ores in spite of simple mineral ore composition, majority of main minerals generations – quartz and pyrite one can conclude of long-term ore formation and multiple stages of hydrothermal-ore process (fig. 4, 5, 6).

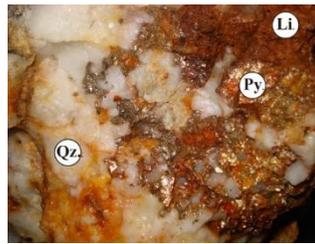


Fig. 4 Hand specimen shows quartz-pyrite-gold mineralization stage. (Qz.- quartz; Py.-pyrite; Li.-limonite)



Fig. 5 Hand specimen shows quartz- polymetallic mineralization stage. (Sph.- sphalerite; Gn.-galena; Py.-pyrite; Li.-limonite)

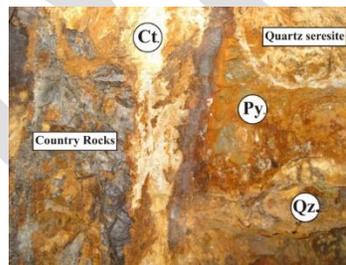


Fig. 6 Photo shows the inter-relationships between the different stages of mineralization. (Qz.- quartz; Py.-pyrite; Ct.- carbonates)

There are pre-ore and ore stages. Pre-ore stages includes all complex of metasomatic changes of host rock such as areal propylitic changes, silicification, sericitization, kaolinization and pyritization of fractures and crushed rhyolitic dacites. According to textural relationship of mineral aggregates indicating manifestations of tectonic movements in process of mineralization and it can be supported by availability of breccia-like textures and textures of inter-mineral intersection, ore stage can be divided into five successively formed stages of mineral formation (Baba-zade, Khasayev, et al., 2007; Mansurov, 2001;). Each stage is confined to some stages of deformation within the whole cycle of ore stage: quartz-pyrite (pyrite) early ore, quartz-arsenopyrite-polymetallic with “invisible” finely dispersed gold, quartz-gold-telluride (Productive), quartz-gold-hetite-hydrohetite (Productive) and final, post-ore, quartz-carbonate (Post-productive). As it is seen these three stages are gold-bearing: the first, quartz-pyrite stage, including minerals of metasomatites and pyrite, started by quartz formation – the main component of ore. Active migration of silica to water solutions during formation of hydrothermal deposits is possible only under alkaline conditions and this minimizes the ideas of joint migration of metals with silica. After quartz extraction which prevails in metasomatites composition mass densely disseminated and veinlet pyrite extractions (quartz-pyrite association). In this case microinclusions of pyrrhotine and chalcopyrite are found in large cuboctahedral habitus of crystals with size of two decimal places mm and in aggregates of isometric round forms of pyrite – I. At the same stage magnetite-hematite association was bedded. Quartz fine-grained is in intergrowth with small scales of sericite and fine-grained pyrite and it could partially form during recrystallization of diagenetic pyrite-markasite aggregates. As it is seen ore-genetic elements present at earliest portions of hydro-therms and further they gradually increase its concentration at late stages. At the second quartz-arsenopyrite-polymetallic stage redeposition and recrystallization occur. Minerals of this stage fill open joints and cement brecciated metasomatites with disseminated sulphur pyrite mineralization. This stage is represented by quartz-arsenopyrite-pyrite-chalcopyrite, quartz-pyrite-chalcopyrite, quartz-sphalerite-galena association; besides the mentioned minerals there are bornite, cinnabar in small and changeable quantities and alloy of “invisible” finely dispersed gold which is an important form of its concentration in Goshian deposit. Hidden gold is connected with chalcopyrite and pyrite, and silver – with fahl ores, sphalerite and chalcopyrite, sometimes with bornite (Baba-zade, Khasayev, et al., 2007) [fig. 7].

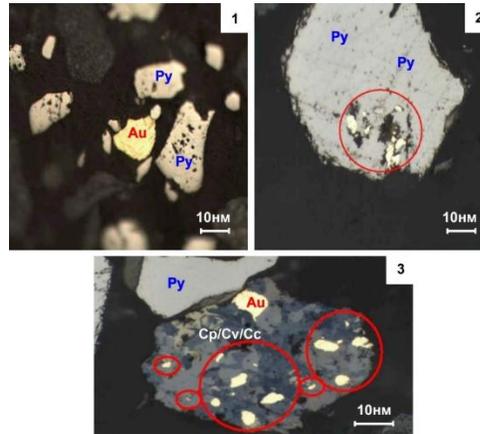


Fig. 7 Microphotographs of gold grains (yellow) in primary sulphide ores:

- 1) free gold; 2) inclusions in pyrite (Py); 3) inclusions in chalcopyrite (covelline, chalcosine) (Cp/Cv/Cc).

One of the main mineral form for gold presence in ores – is tellurium compounds among which hessite and petzite and in some cases minerals of Au-Ag-Te, Bi-Te-S systems represented by bismuth tellurate, altaite, tetradymite which are optically diagnosed and supported by X-ray. They characterize the third productive quartz-gold-telluride stage with paragenetic association of minerals quartz-gold-molybdenite, quartz-fahlore-gold, quartz-tetradymite-bismuth tellurate petzite-hessite-native gold. Tellurides are confined to those areas of ore bodies (sampling data) where high content of gold and silver is determined and develop jointly with chalcopyrite, sphalerite, halenite and tennantite.

Association of minerals of this stage are dimensionally combined with quartz-arsenopyrite-polymetallic stage, in veins of which veinlet quartz extraction develop with dissemination of molybdenite, tetradymite, hessite, sometimes – petzite. Molybdenite forms finely-squamosed crystals (up to 0,01mm) in non-ore mass. Hessite (up to 0,6 x 0,1mm) is deposited in intergranular openings of pyrite and jointly with tetradymite forms structure of mutual intergrowth.

Native gold closely associates with hessite and can be found in it as small veinlet formations or series of contiguous small (0,025-0,065mm), almost isometric inclusions. Small inclusions of petzite of irregular shape and also small amount and undefined number of silver telluride enriched by silver in comparison with hessite can be found in hessite. Results of microprobe analysis of hessite are in table 1.

Table 1

Chemical composition of tellurides and gold

Minerals	Au	Ag	Cu	Te	Se	Total
Hessite	0,91	60,50	0,22	37,10	not defined	98,73
	1,36	60,18	0,08	36,81	-	98,43
	1,98	60,48	not defined	36,26	-	98,72
Petzite	25,94	40,62	not defined	32,75	not defined	99,31
	23,66	43,00	0,20	34,06	0,19	100,92
	25,29	43,13	0,01	32,91	not defined	101,53
Gold	99,66	8,89	not defined	not defined	-	99,55
	87,34	10,90	not defined	-	-	98,24
	89,03	11,59	next	-	-	100,62
	86,91	12,51	0,03	-	-	99,79

Tetradymite and bismuth tellurate form bladed crystals (from 0,2 x 0,2 to 1,2 x 0,15mm and 0,082 x 0,042 mm correspondingly), creating structure of mutual intergrowth with hessite. Rarely tetradymite and bismuth tellurate develop in marginal parts of crystals of pyrite – III. Petzite is rarely found in quartz-telluride association and forms small extractions in mutual intergrowth with hessite. Bismuth tellurate as bladed crystals (0,042 x 0,082 mm) can be found in association with pyrite, tetradynamite, hessite. Rarely is found. Generally one can conclude for this productive stage the following: 1) the main part of native gold is closely connected with bismuth tellurates, silver and gold; 2) hessite Ag_2Te is probably mineral-concentrate of gold and silver and this defines its specific role in mineralization; 3) look of ore closely connected with tellurides has size of 0,002-0,2 mm and this points out dispersion form of its presence in ore mass.

Thus, such ore-genetic elements as gold, silver, molybden, tellurium, bismuth were in formation of quartz-gold-telluride stage in hydrothermal solutions.

The next time formation – quartz-gold-goethite-hydrogoethite stage is the second on scale and productivity (association quartz-goethite-hydrogoethite-native gold with pyrite alloy). The main mineral of the stage is goethite composing 80-90% of ore minerals volume. It is found in solid goethite-hydrogoethite aggregates with size of 1-3 to 2-5 mm with weather pits. According to relicts and also to goethite pseudomorphosis the latter displaces and develops on pyrite. In this case gold is found in those polished sections, where amount of substituted pyrite is 60-80% from primary one. Native gold forms thin inclusions in goethite – from 0,005 x 0,003 to 0,1 x 0,06 mm and more (fig. 8).

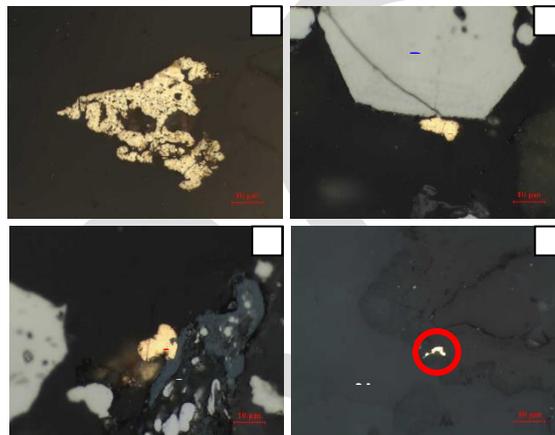


Fig. 8 Photos of gold grains (yellow) in sample of oxide ore (Comp. A)

- a)– large free and partially porous grain;
- b)– free grain around pyrite (Py);
- c)– is confined to covellite (CV) and to dark (indeterminate) minerals (NOP);
- d)– free grain (marked by red) is confined to dark (indeterminate) minerals.

Comparison of native gold of two generations connected with the third and fourth stage of hydrothermal process allows to conclude: 1) gold-I – low-grade is confined to massive pyrite; 2) gold-II – larger and high karat gold (by reason of redeposition) is confined to solid goethite-hydrogoethite aggregates (during oxidation of primary ore gold didn't migrate but deposited in place).

Thus, according to correlations between minerals of ore bodies, regular evolution of different generations composition including a native gold itself, one can state a successive change in time of quartz-arsenopyrite-polymetallic by quartz-gold-telluride and then by gold-goethite-hydrogoethite mineralization and it can be supported by spatial separate mineral associations in ore bodies. And in this case process of endogenic mineralization starts with formation of nearby joints metasomatic mineralized zones bearing quartz and ferrous sulphides (Proskuryakov, Khrenov, et al., 1979; Petrovskaya, et al., 1976).

5. Thermodynamic parameters of mineral formation. To solve this question necessarily to define temperature conditions of redivided concentrations formations by using thermobarometric analysis based on study of gas liquid inclusions in ore minerals. Methods of research includes the following. Microinclusions are found in transparent polished plates (mainly of vein quartz of different stages of ore process). Sizes, form, phase composition and quantity of inclusions are studied.

According to data of previous researchers such as A.A.Aliyev (1975), A.A.Magrabi and P.S.Garilyuk (1975), M.I.Mansurov (2001) succession of mineralization within each stage of mineralization occurred due to basicity entrainment of gashydro-therms and cyclicity, change of numerous ionization potentials of minerals.

Vein quartz is characterized by microinclusions of mineral-forming solutions of size 2-3 to 10-15µm. On relative age there are primary, primary-secondary and secondary inclusions (Yermakov, 1972; Yermakov, Dolgov, 1979). The same age generations inclusions were marked according to their morphology and temperatures of homogenization. In studied quartz the primary inclusions are usually represented by “negative microcrystals” of hexagonal syngony located on zones of growth. Vesicle is usually isometric in it and therefore it is opaque due to absolute refraction. Primary inclusions consist of water solution and gas. Primary-secondary and secondary inclusions can be characterized by irregular flattened form because they are, as a rule, confined to resistive fractures. Vesicle distinguishes by a big transparency in flattened inclusions. Mineralogical characteristics of plate material allows to correlate temperature of homogenization for primary and primary-secondary inclusions with formation conditions of this stage of mineral

formation. Secondary inclusions were used to characterize temperature parameters of next stages. So, each quartz plate was studied as source of information about several stages and phases of mineralization represented by different generations of inclusions (Yermakov, Dolgov, 1979).

About 40 quartz plates from Goshian deposit were studied. 35 measurements of temperature of homogenization were carried out.

The main results obtained are following.

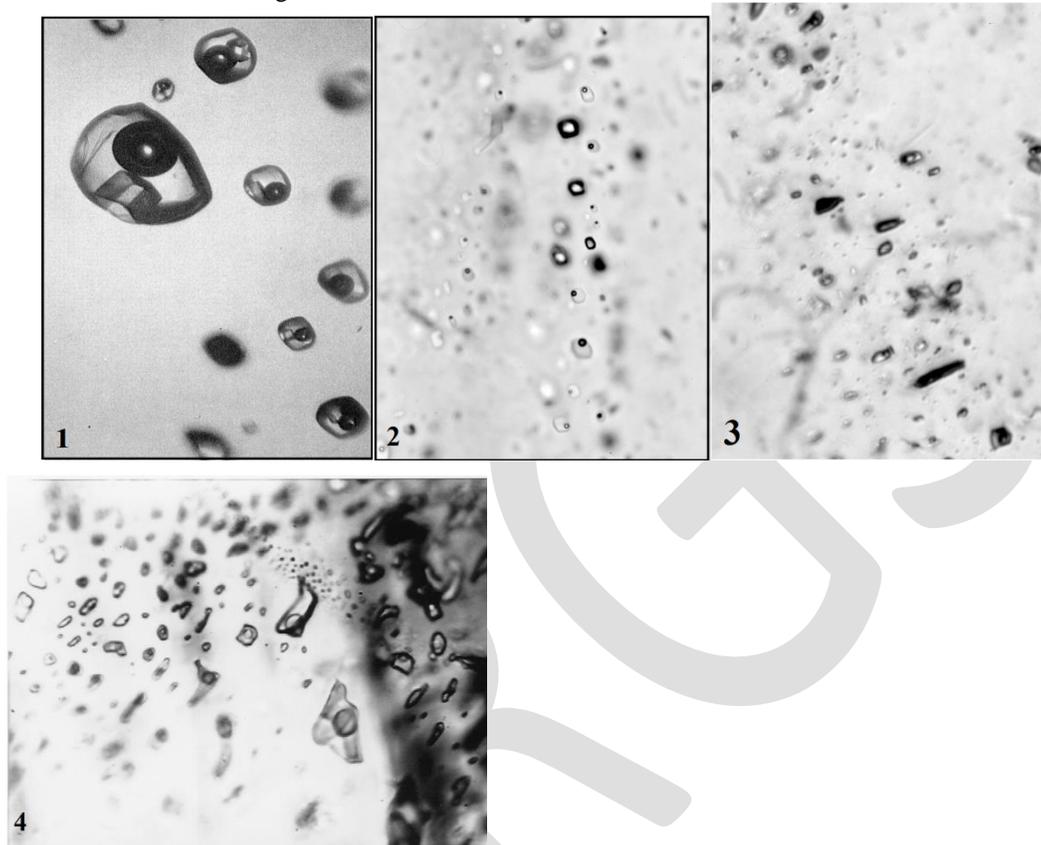


Fig.9 gas - liquid inclusions in goldbearing quartz of Goshia deposit. 1) Primary 2 phase: gas-liquid (two phase); 2) Substantially gasaceous: primary-secondary; 3) Substantially liquid: secondary three phase; 4) Liquid.

Fluid inclusions underwent thermometrical research in thermal chamber. According to it temperatures of homogenization were defined, these results are shown at fig. 10. Histograms of homogenization temperatures (Bowers, Helgeson, 1983) have polymodal nature in studied subjects and marked generations of inclusions fit abovementioned mineral associations. It is determined within Goshian ore field the same associations can be characterize by close temperature intervals of homogenization, despite of the fact they are subordinate or main productive in this subject. It is supposed the formation temperature of mineral associations are connected with level of erosion truncation of ore field. As it is established inclusions of first type almostly can homogenize into liquid phase by temperature 150-305°C with maxi interval 300-350°. Gas component of these inclusions, chiefly consists of dioxide carbon, homogenizes into liquid rarely into gas phase. It occurs by 12,0-22,8°C. The main mass of CO₂ homogenizes by temperature 4-13,5°C. In this case density of CO₂ estimates by interval 0,80 to 1,10 g/sm³. In gas phase of captured fluids besides CO₂ methane and dissolved chlorides are also present. It is defined methane presence in inclusions mainly occurs by temperature gas-hydrate melting above 10°C. Below this melting temperature they contain dissolved chlorides. Concentration of salts in fluid according to melting temperature of gas-hydrate (CO₂ 7,3 H₂O) is 1015,3 mas % - eq. NaCl, estimated according to melting temperature of ice (Roedder, Bodnar, 1980; Brown, Zamb, 1989).

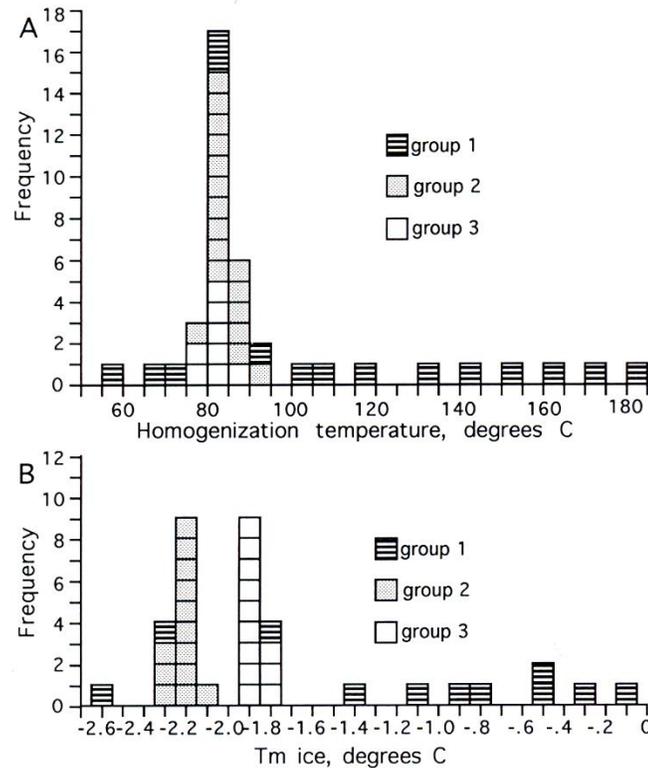


Fig. 10. Histogram of homogenization temperatures of fluid inclusions in quartz of Gosha deposit: 1. inclusions of I-II types; 2. inclusions of III type.

Fluid inclusions of second type represented essentially by gas components corresponding on CO₂ composition homogenize by temperature 21,5 to 23°C. In this temperature interval density of CO₂ is 0,59 to 0,95 g/sm³.

Homogenization of fluid inclusions of third type into liquid phase occurs by temperature 140-200°C. These solutions are characterized by higher concentrations of salts (from 7,5 to 10,2 mas. %-eq. NaCl). Besides natrium solution possesses magnesium as well.

Analysis of data obtained on thermometrical research shows during crystallization of minerals from Goshian deposit three types of fluids were captured, they differ due to composition: 1) water fluid with CO₂, CH₄ and Na and Mg chlorides; 2) gas fluid consisting of CO₂ and CH₄ alloy and 3) water fluid with moderate salinity possessing Na and Mg chlorides. The first two fluids are simultaneous and probably they are derivatives of the same fluid and formed during its foliation by pressure and temperature reduction or just only pressure. As temperatures of homogenization for both types of inclusions occurred the same in many cases one can suppose that separation of volatiles from fluid was caused by sudden drop in pressure but not by temperature reduction. Essential water fluid is typical for final stages of deposit formation. It could appear by fluid boiling as well consisting of H₂O + CO₂ alloy with chlorides. (Yermakov, 1972; Yermakov. Dolgov, 1979).

Isotopic composition of sulphur in sulphide minerals, and quartz oxygen of Goshian ore field was studied. Isotopic composition of sulphur is studied in main sulphide minerals-pyrite, chalcopryrite, sphalerite and galena represented by quartz-pyrite-gold-ore and quartz-polymetallic stages with gold. Correlation of sulphur isotopes in sulphides varies +3 to +6,8 ‰, partially for pyrite +3,2+4,1‰, galena +3,0+3,3‰. As a result of measurings values of sulphides δ³⁴S, bedded at different stages, change insignificantly (Gavrilyuk, Magribi, 1997; Baba-zadeh, 2003; Mansurov, 2001).

Table 2 Isotopic composition of sulphides sulphur of the Goshian ore field

Mineral	δ ³⁴ S‰	Mineral	δ ³⁴ S‰	Mineral	δ ³⁴ S‰
Pyrite	6,8	Chalcopryrite	4,1	Sphalerite	4,1
Pyrite	3,5	Chalcopryrite	4,4	Sphalerite	3,2
Pyrite	4,2	Chalcopryrite	4,8	Sphalerite	3,1
Pyrite	5,4	Sphalerite	3,3	Sphalerite	3,0

$\delta^{18}\text{O}$ quartz isotopes from different stages of mineralization of Goshian deposit vary +7,5 +16,9‰. In this case quartz of early quartz-sericite stage can be characterize by $\delta^{18}\text{O}$ values by interval +7,5 +8,7 ‰. Quartz of quartz-molybdenite stage is characterized by $\delta^{18}\text{O}$ values by interval +9,9 +11,0‰, and productive quartz-pyrite-oregold +12,6 + 15‰. Quartz of late quartz-polymetallic stage enriched in heavy oxygen isotope. For it $\delta^{18}\text{O}$ values are +14,9 +16,9‰.

Table 3

Isotopic composition of quartz oxygen of Goshian deposit

$\delta^{18}\text{O}\text{‰}$			
Stages of mineral formation			
I	II	III	IV
Quartz-sericite	Quartz-molybdenite	Quartz-pyrite-goldore	Quartz-polymetallic
+7,5	+9,9	+12,6	+14,9
+7,9	+10,2	+13,0	+16,2
+8,0	+10,4	+14,1	+16,9
+8,5	+11,0	+14,3	--
+8,7	--	+15,0	--

Correlation of obtained results with literature data (Berger, Drews, Goldfarb, Snee, 1994) shows $\delta^{34}\text{S}$ and $\delta^{18}\text{O}$ values of minerals from deposit of Goshian ore field are the same with data obtained according to numerous goldore deposits. A distinguishing feature of Goshian deposit is an essential change of $\delta^{34}\text{S}$ and $\delta^{18}\text{O}$ values while the values of many volcanogenic hydrothermal goldore deposits correspond to narrow intervals consisting on average 2-3%.

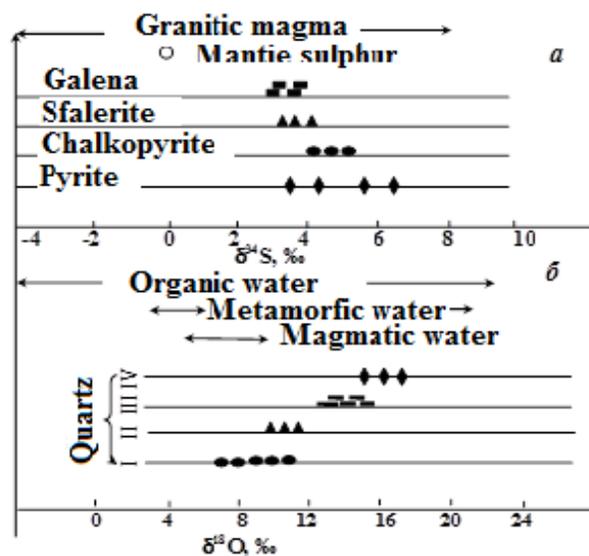


Fig.10. Isotope composition of the minerals from Goshia ore field: a - isotope content of sulphur of sulfide minerals; b - isotope content of oxygen of quartz from different stages of mineral formation on Goshia deposit.

According to results of obtained isotopic data one can judge of source of ore-forming fluid. Water-carbon dioxide fluids, with moderate saltness like fluid which provided ore deposition, are studied as products of magmatic activity (Ryabchikov, 1975), or reaction of dehydration and decarbonization occurring during metamorphism of terrigenous rocks (Kerrick, 1990). In case with dehydration usually fluid appears with low concentration of salts (usually less 6 mas.% eq. NaCl [Nesbitt, 1971]). Formation of highconcentrated brines is possible by fluid foliation, consisting of H₂O and CO₂ and NaCl, into essentially gas and aqueous saline phases. (Bowers, Helgeson, 1983). According to diagram of H₂O-CO₂-NaCl system (presented by these authors, fig. 11) with 6 mas.%

content of NaCl fluid foliation occurs into phase enriched in H₂O-CO₂ and liquid enriched in NaCl in temperature interval 600-1000°C under pressure 1-1,5kbar. Under higher pressures fluid remains homogenous (Bowers, Helgeson, 1983).

Foliation of mineral-forming fluid by formation of gold-ore veins of Goshian deposit occurred by other parameters P=0,7-2,5kbar and T=140-390°C, as it was mentioned above. Fluid balanced with these rocks must be characterized by the same parameters. So, low temperature fluid enriched in chloride salt could not form as a result of foliation of metamorphogenic fluid appearing by dehydration and decarbonization of rocks. According to above-mentioned chemical composition of mineral forming fluid shows its magmatic origin.

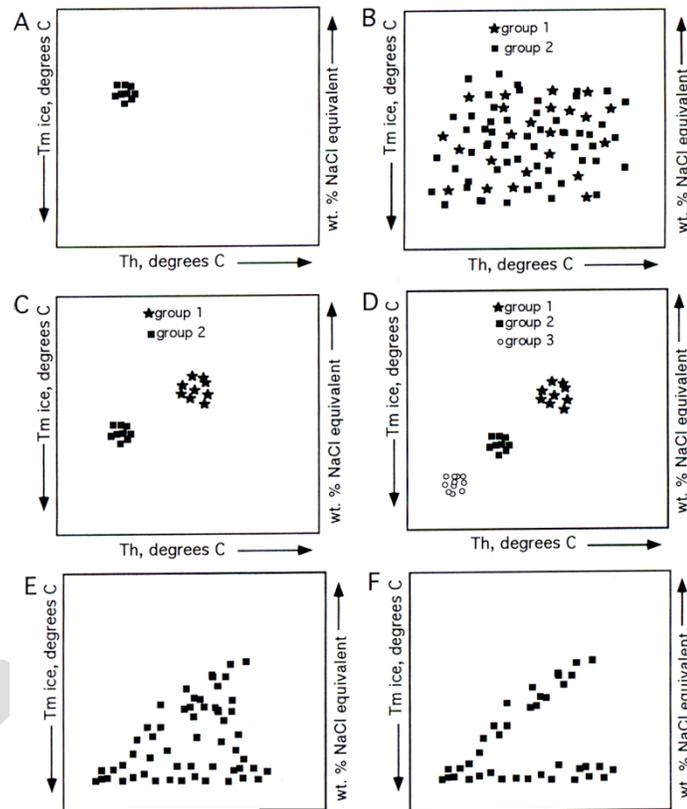


Fig.11 Phase ration in the system. Hatched area shows localization of ore formation on Goshian deposit. Phase boundaries correspond to different compositions .

Data of stable isotopes composition also demonstrates that components of various origin are included in ore deposition. The components supplied to the field of ore deposition and this can be supported by the same isotopic relationship of oxygen and sulphur in veins from different flanks and horizons of Goshian deposit and rock with different composition. To our opinion this points out that isotopic exchange reactions with host rocks didn't influence essentially on values $\delta^{34}\text{S}_{\text{H}_2\text{S}}$ and $\delta^{18}\text{O}_{\text{H}_2}$.

Data obtained from Goshian deposit shows values $\delta^{18}\text{O}$ of water are located in fluid in area of values typical for water, which appeared by transformation of sedimentary rocks with organic matter. These values are also close to isotopes correlation defined for metamorphogenic waters. They lightened by isotope in comparison with primary magmatic water, their values are correspondingly in following interval: -7 up to +20‰, +3 up to 20‰, from 5,5 up to +10‰.

Influence of exchange isotopic reactions of fluid with rock on correlation of oxygen isotopes in mesothermal mineral-forming systems is insignificantly (Kerrick, 1987). That's why initially magmatic fluid ($\delta^{18}\text{O}_{\text{H}_2\text{O}} = +7\%$, interacting with volcanogenic host rocks by 400 and 300°C, can enrich in light oxygen isotope up to 2‰. According to this there is a version of presence of magmatic origin water in ore-forming system (Kerrick, 1987). Estimated isotopic composition of oxygen in fluid is preferably interpreted as a result of shifting of two fluids differing by their values. One of them could have magmatic origin, and other was depleted by heavy isotope of oxygen and could appear as a result of water formation from organic matter decay. In this case variations of $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ value and its reduction up to -1‰ can quite be explained (Ohmoto, Rye, 1979).

Sulphur like oxygen could have a different origin in the process of ore deposition especially when its isotopic composition is located in area of values from +7‰. As a possible sources mantle and magmatic systems and also host sedimentary rocks are considered. Values $\delta^{34}\text{S}_{\text{H}_2\text{S}}$ equal to (+2) – (+7) ‰ are attributed to fluid derivative from granitoid melting where isotopic correlation of sulphur varies from -3 to +7‰ (Ohmoto, Rye, 1979). On this base one can suppose that sulphur participating in formation of Goshian deposit was extracted from magmatic sources. Does not exclude also the participation in the process of ore deposition of mantle sulphur and also sulphur borrowed from host rocks; their isotopic composition is located correspondingly in intervals from -3

to +3% and from less +10 to +20%. So, there is no a straight answer to this issue: did the sulphur supply to ore-forming system jointly with fluid which separated during crystallization of granitoid magma or maybe it was borrowed from host ore bodies rocks (Ohmoto, Rye, 1979).

So, one can suppose fluids had a different nature during deposit formation. They possess products of magmatic and metamorphogenic origin, their displacement occurred rather fast in area of ore deposition or nearby it. The crucial role probably performed by fluid of magmatic origin.

Results of research conducted on stages and length of mineralization formation allow to conclude:

- 1) Deposit formed by system of quartz-sulphide veins and veinlets of short length (quartz-sulphide-vein and morphological type), series of close dip steeply mineralized and vein zones (morphological type of mineralized and vein zones) and stockwork zones (morphological type – zones of stockwork veins).
- 2) According to relations between minerals of ore bodies, systematic evolution of different generations composition including native gold one can talk of successive change in time: quartz-arsenopyrite-polymetallic by quartz-gold-tellurid and then by gold-goethite-hydrogoethite mineralization and this is supported by spatial disconnection of mineral associations in ore bodies. In this case process of endogenic mineralization starts with formation nearby fracture metasomatic mineralized zones containing quartz and iron sulphides.
- 3) Temperature of ore formation, studied by methods of homogenization of gas-liquid inclusions in transparent minerals (quartz) of different mineral associations, varies in interval from 140 to 390°C. Pressure of ore-forming medium estimated by crossing of isotherm in system H₂O-CO₂ and isochors CO₂ is 0,7-2,0 kbar.
- 4) Taking into account that quartz veins possess the fragments of host rocks completely substituted by quartz-sericite aggregate, one can suppose they formed in balance with fluid pH from 5,45 to 6,1 at temperature 250-400°C and under 0,5-3,0 kbar pressure. Under conditions of quartz-sericite-potassium feldspar metasomatism fluids. Will be in balance with medium by pH from 5,2 to 6,1.
- 5) According to research data on isotopic composition of oxygen and sulphur in ore-forming fluids, one can suppose fluids could have a different nature, they possess products of magmatic and metamorphogenic origin, in this case prevailing role belonged to fluids of magmatic origin.

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