Origin of the Filizchay ore field (the southern slope of the Greater Caucasus)

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Abstract. The article deals with the origin of the Filizchay ore field, which is a valuable object for the extraction of zinc, lead, copper, silver as well as for the extraction of the associated components. The data and types (VMS, SEDEX, VMT) of the pyrite deposits in the world have been briefly presented. Their comparative analysis has been carried out and it has been revealed that the Filizchay ore field is very different from the VMS-type pyrite deposits and it belongs to the SEDEX type. A direct relationship with volcanism has not been observed in this deposit. Unlike the containing rocks related to volcanism in the Filizchay field, there are fine-rhythmic flyschoids with packages of sandstones, clay shales and silt-clay shales. The ratio of the natural ore types composed of the different mineral associations, with stages of the folded and disjunctive dislocations, allows us to divide the process of the deposit formation into the following three stages of the ore formation: 1) deposits of the massive hydrothermal-sedimentary essentially pyrite ores; 2) formation of the hydrothermal-metasomatic ores of the pyrite-copper-polymetallic composition; 3) deposition of the hydrothermal-metasomorphogenic ores of the copper-pyrrhotite composition. The available data indicate a favorable environment for sedimentary pyrite ore formation subject to a significant role of $C_{org.}$ and sulfate-reducing bacteria. Moreover, the hydrothermal-sedimentary processes played the main role in the accumulation of the main volume of the sulfide masses. On the basis of the sulfur isotopic composition (according to Zaïri, 1992) of the main minerals (pyrite, galena, sphalerite, pyrrhotite, chalcopyrite) from various types of the Filizchay ore field ores it was concluded that the deposit formation occurred from several portions of the entered hydrothermal solutions. It was found that by the period of accumulation of sediments of the ore-bearing horizon in the northern block – there occurred outpouring of the spilites and basalts in the narrow trough-like depression. The iron sulfides supplying the more southern basin with stagnant waters can be associated with their post-volcanic exhalations (as primary sources). The Filizchay ore field being connected with basaltic volcanism is combined according to formation method. It has been formed due to components which have been carried out by hydrothermal flows and due to basalts, which are associated with underwater alteration. The temperatures of the primary pyrite-polymetallic ores formation are relatively low (200-100 °C).

Keywords: Filizchay fields, the southern slope of the Greater Caucasus, isotope composition of the sulfur, SEDEX type, hydrothermal solutions, post-volcanic exhalation.

До походження Філізчайського родовища поліметалів (Південний схил Великого Кавказу)

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Анотація. У статті розглядається питання про походження родовища Філізчай, яке є цінним об’єктом для видобутку цинку, свинцю, міді, срібла, а також для вилучення попутних компонентів. Коротко викладено відомості про колчеданні родовища світу та їх типи (VMS, SEDEX, VMT). Зроблено їх порівняльний аналіз та з’ясовано, що Філізчайськое родовище сильно відрізняється від колчеданних родовищ типу VMS та відносяться до типу SEDEX. У цього родовища немає прямих зв’язку з вулканаїзмом. На відміну від пов’язаних із вулканаїзмом у Філізчайському родовищі вміщуючими породами є тонкоритмічні флішоїди з пачками пісковиків, глинистих сланців, алевро-глинистих сланців. Співвідношення природних типів руд, складених різними мінеральними асоціаціями, з етапами складчастих та розривних дислокацій, дозволяє розподілити процес формування покладу на наступні три етапи рудоутворення: 1) відкладення масивних гідротермально-осадових істотно піритових руд; 2) формування гідротермально-метасоматичних руд піріт-мідно-поліметалічного складу; 3) відкладення гідротермально-метаморфогенних руд мідно-пірротинового складу. Наявні дані свідчать про сприятливі умови утворення осадових піритових руд за значної ролі $C_{org.}$ та сульфатредукуючих бактерій. Разом з тим, головну роль у накопиченні основного обсягу сульфідних мас грали гідротермально-осадові процеси. На основі ізотопного складу сірки (по Заїрі, 1992) головних мінералів (піриту, галеніту, сфалериту, пірротину, халькопіриту) з різних типів руд Філізчайського родовища зроблено висновок, що формування...
Introduction

The pyrite-polymetallic Filizchay ore field is a valuable object for the extraction of zinc, lead, copper, silver as well as for the extraction of the associated components – such as gold, cadmium, indium, tin, bismuth, antimony, selenium, tellurium and etc. Many geologists have investigated the geological structure, tectonics, stratigraphy, magmatism, ore fields of the area. Many problems remain unresolved despite the fact that the fields of the southern slope of the Greater Caucasus have been studied sufficiently. There is no consensus on the pyrite deposit origin of this type up till now.

Brief geological structure of the Filizchay field

The Filizchay ore field is located within the Kasdag-Filizchay ore cluster (Fig. 1). The geological position of the Kasdag-Filizchay ore cluster is determined by its location on the western flank of the Balakyan-Zagatala ore region, where it is confined to the junction area of the Tufan and Mazym-Sarybash subzones along the Kekhnamedan zone of deep faults. The terrigenous deposits (Fig. 1) of the Upper Pliensbach (Filizchay series (J1p2)) and Toarcian (Gu-bakh (J1t1+2) and Murovdag (J1t1) series) of the Lower Jurassic take part in the geological structure of the field. The structural position of the field is determined by its confinement to the junction area of the northern flank of Karabchay coffer-shaped anticline with the Kekhnamedan reverse-thrust, which is complicated by the Balakyanchay local transverse inversion uplift. The main elements of the field structure are: the Karabchay anticline core, its northern flank and part of the Kekhnamedan shear zone, which are covered by the indicated transverse uplift. The peculiarities of these main elements of the structure determine the main features of the Filizchay ore field structure.

The longitudinal fault structures also play an important role in the field structure. The reverse-thrust faults oriented subparallel to the longitudinal folded structures along the strike are the dominant ones. The Kekhnamedan reverse-thrust and the Filizchay thrust relate to the main longitudinal fault structures of the field (Geologiya Azerbaydzhan, 2005).

The main peculiarity of the pyrite-polymetallic deposit morphology of the Filizchay ore field is that it is a single, compact sheet-like body being mainly composed (at 90-95%) of sulfide ores aggregates which are based on pyrite, sphalerite, galena, chalcopyrite and pyrrhotite. The carbonates and even less – quartz, sericite, and chlorite play a subordinate role in the deposit composition (Baba-zade and Agayev, 1999, Novruzov, 2016).

The ore body occurs among the monotonous clay shales of the upper – third member of the Filizchay
series. Here the deposit has been confined to the thick ore-bearing horizon, the boundary of which is laterally determined by the boundaries of the Balakyan-chay transverse uplift where ore-bearing clay shales are facially replaced by sandy flyschoid. Pyrite represented by several generations is the dominant sulfide mineral of the primary ores of the field. Sphalerite, galena, chalcopyrite and pyrrhotite are also related to the main ore minerals of the studied ores.

**General data on pyrite fields**

According to V.I. Smirnov (Smirnov, 1968) the ores being mainly composed of iron sulfides refer to pyrite fields. Pyrite, pyrrhotite and marcasite in the form of massive or disseminated ore predominate sharply in all pyrite fields. Sphalerite, chalcopyrite, galena, fahl ores, bornite and other ore minerals are associated with them.

Pyrite-polymetallic deposits are concentrated either among igneous rocks (mainly Ural, Altai, Lesser Caucasus types) or they are localized both among effusives and sedimentary strata («Kuroko» types) or among sedimentary shale strata (the fields localized in the Jurassic shale strata of the Greater Caucasus). The Filizchay ore field belongs to last type.

Presently the family of the pyrite fields is usually divided into 3 groups (Goodfellow, Lydon, 2007, Emsbo, Poul, Seal et al., 2010, Lobanova et al., 2017):

*The first of them* being closely associated with volcanic rocks is accepted as a typical classical pyrite field. These fields are named as VMS (Volcanogenic Massive Sulfide) in the western countries. They are called as pyrite-polymetallic fields. Their formation is connected with underwater hydrothermal activity of a volcanogenic nature.

*The second group* is closely connected with terrigenous and terrigenous-carbonate strata at insignificant development of the volcanites. Volcanogenic formations are poorly developed in them. This group of deposits was often called as stratiform Pb-Zn deposits. The western analogue of this field is SEDEX (Sedimentary Exhalative) (Imamverdiyev, Sattar-zade, 2022). Presently the SEDEX type deposits (Candel, 2003, Goodfellow, Lydon, 2007, Emsbo, Poul, Seal et al., 2010, Sedimentary_exhalative_deposits) are the main source of zinc, lead and silver.

The new data on the geological structure of both deposit groups (SEDEX and VMS) and on the modern hydrothermal systems which have been obtained over the last 20-30 years show their significant differences. The most important of them are the composition of the ore-bearing rock strata and the absence of the direct connection with volcanism for the SEDEX type deposits in contrast to the VMS type deposits. Their formation is associated with underwater hydrothermal activity of volcanogenic nature. Besides, stratiform lead-zinc fields in the terrigenous and terrigenous-carbonate strata (SEDEX) with rare exceptions don’t contain commercial accumulations of copper in their composition but then they have high silver content in ores in contrast to the pyrite-polymetallic fields of the volcanic association (VMS).

*The third group* – it is stratiform fields in the carbonate formations. They are analogous to MVT (Mississippi Valley-Type).

Their common peculiarity is that they are all stratified. There are predominantly sheet- and lenticular forms of the ore bodies. The geochemical composition of ores is of similar importance.

The pyrite-polymetallic fields of the VMS type are divided into Ural (Gaiksky, Uchalinsky, Podolsky and etc. fields) and Rudno-Altai (Rubtsovskiy, Korbalkhinkhskiy and etc. fields) in Russia (Tvarche-lidze, 1978).

*The Kuroko-Altai type* is connected with complete differentiated calc-alkalic basalt-andesite-dacite-rhyolite association. It is represented by rich lead-zinc-copper ores. The fields are confined to mature ensialic island arcs that occur within mobile belts [Kuroko, Shakanai (Japan); Korbalkhinkhskiy, Zyranoovsky (Russia, Rudny Altai)].

The belonging of the Rudno-Altai pyrite-polymetallic fields to the pyrite series is confirmed by their confinement to volcanogenic strata of the certain composition, the halo structure of the wall-rock alterations and mineralogical-geochemical features, etc.

Among the pyrite formation fields of the Rudny Altai, pyrite, pyrite-polymetallic and polymetallic are defined (Smirnov, 1960). Therefore, the first of them are subdivided into sulfur pyrite (Starkovskiy and others) and copper pyrite (Nikolaevskiy, Novo-Berezovskiy, etc.) fields. Pyrite, chalcopyrite and sphalerite are the main ore-forming minerals in copper pyrite ores. *These sulfur- and copper-zinc pyrite ores are associated with basaltoid volcanism. Pyrite, chalcopyrite, sphalerite and galena are the main minerals in ores of the pyrite-polymetallic fields (Ridder-Sokolnıy, Nikolaevskiy and etc.). The copper-pyrite polymetallic fields (Sugatovskiy, Nikolaevskiy and etc.) gravitate towards near-vent and vent zones of the basaltoid volcanism. Polymetallic fields are confined to the facies of the intermediate and remote zones, barite-polymetallic fields – to the same zones’ deposits but which contain an increased amount of the carbonate-siliceous facies (Zmeinogorskiy, Zarechenskiy and etc.).*
Fig. 2. Geological and structural map of the Filizchay ore field (Scale 1:2000). (it is compiled by N.A. Sattar-zade according to the materials of the Main Caucasian geological exploration expedition)

Legend
- $J_1$ $T_1$: strata of alternating packages of sandstones, siltstones and clay shales
- $J_1$ $T_2$: strata of monotonous silt-clay shales
- $J_1$ $T_2$ $K_2$: strata of clay shales
- $J_1$ $T_2$ $K_3$: strata of sandy-shale (alternating packages of clay shale and sandstone layers)
- $J_3$ $P_1$: clay shale sequence with sandy flyschoid packages
- the rhythm of a fine sandy flyschoid
- clay and silt-clay shales
- packages of alternating layers of sandstones, silty-sandstones and clay shales
- sandstone layers
- bags of sandy flyschoid
- projection of the output of the ore deposit
- thin-layered alternation of sulfides of essentially pyrite composition and clay shales (ree flysch)
- vein-disseminated ores (linear-stockwork) of essentially pyrite composition
- concretions of pyrite, pyrite-siderite and pyrrhotite composition
- lenticular-stratified accumulations of fine dissemination of pyrite
- veins and veins of chlorite-quartz-carbonate composition
- halos of carbonatization and chloritization
- Keynesomer reverse-thrust zone (long-lived deep fault)
- fault
- thrust, reverse-thrust
- zone of intense shearing
- diabasic and gabbrodiabasic dikes
- elements of occurrence
- adit
- wellhead
- exploration profile line
The forms of ore bodies of the pyrite fields and the nature of the wall-rock alternations in the volcanogenic strata of the Rudny Altai are generally close to their equivalents in the Southern Urals and the Lesser Caucasus. The sheet-like and lenticular ore bodies are especially often observed in Rudny Altai. The quartz-sericite, quartz-sericite-chlorite facies of the secondary quartzites, mon quartzites and sericitites are their host rocks. They are developed against the background of the medium-temperature propylitization (the associations of the epidote and chlorite with albite and pyrite).

**Cyprian type** is connected with an undifferentiated basalt association that is represented by sulfur-and copper-pyrite and copper-zinc-pyrite ores. It is characteristic of the oceanic type crust [for example the fields of the Skouriotsissa (Cyprus), Broken-Hill (Australia), Outokumpu (Finland), Lokken (Norway), Ergani-Maden (Turkey), Newfoundland (Canada)].

**Bessie type** is connected with an undifferentiated basalt association and it is formed within the outer (nonvolcanic) island arcs at a distance from the centers of spreading volcanism. It is represented by the copper-zinc-pyrite composition ores (Lobanov, 1978).

The fields localized in the terrigenous flyshoid strata of the folded belts are widely distributed on the southern slope of the Greater Caucasus (Filizchay, Katekh and etc. – in Azerbaijan, Kyzyl-Dere – in Dagestan) (Kurbanov, 1986).

It should be noted that the Bessi region fields are located within the metamorphic belt of Sambagava. They together with the ore-bearing rocks of the Upper Paleozoic (Permian) have been crushed in isoclinal folds being metamorphosed to the facies of the glauconophae shales or the epidote-amphibolite facies, which led to obscuration of the primary peculiarities of the ores and rocks (Smirnov, 1960, 1968). These peculiarities, as rightly noted by N.I. Eremin and others (Eremin, et al., 2000), have led to the mistaken opinion of attributing Bessie-type fields to the Filizchay-type group of fields. A close association is certainly noted of the basic lavas and pyroclastic rocks with massifs of the ultrabasites and basites (the Makimine and Shimokawa fields in the Hidaka ore zone on Hokkaido island) in the metamorphic belt of Sambagava in contrast to the Filizchay field. The main rocks of the Bessie-type fields are represented by pillow lavas and basalts tuffs, which petrochemically correspond to the rocks of the mid-ocean ridges or calc-alkaline rocks. Therefore, the pyrite ores’ formation occurred in the settings of the back-arc basins above subduction zones or in mid-ocean ridges near the continental margin.

**The Ural type** is connected with a contrastively differentiated association that is characteristic of the early evolution stages of the ensimatic island arcs forming over subduction zones on the basaltic crust. It contains either copper-pyrite (Blyavinsky field in the Southern Urals) or copper-zinc-pyrite ores (Gaisky field in the Southern Urals; Urupsky – in the North Caucasus). The fields are localized within volcanic troughs (Vikentyev, 2017, Kontar, 2003, 2013).

Pyrite fields of the Southern Urals showing identity with manifestations of the pyrite mineralization in Rudny Altai and the Lesser Caucasus at the same time differ from them by a number of the specific peculiarities of the mineralogical and geochemical order and geological position.

The regional ore-bearing structures of the Southern Urals are confined to linear volcanic structures specifically to volcanic-tectonic uplifts on the slopes of which strato-volcanoes and caldera-like depressions are located. In the Southern Urals the pyrite fields are mostly distributed in the Tagil-Magnitogorsk trough. The geological position of the pyrite fields is determined by their confinement to volcananites of the differentiated sodic rhyolite-basalt association, which has mainly accumulated as a result of the central-type volcanic eruptions and protruded in the form of the submeridional volcanic belt in the Tagil-Magnitogorsk trough. Pyrite mineralization both in the Lesser Caucasus and Rudny Altai is mainly located in the upper part of the section, in the rhyodacitic volcanites’ strata or at their contacts with adjacent basalt and andesite-basalt strata, limestones (in the hanging wall) confined to the horizons of the volcanogenic-sedimentary strata. The volcanogenic and volcanogenic-sedimentary strata of the trough are accompanied by subvolcanic structures, being synchronous with them in age and similar in composition. Plagiogranite intrusives can be found, which have practically formed simultaneously with late subvolcanic rocks. They form a volcanic-plutonic association with them and the host effusives, tuffogen formations.

The comparison of the processes of the volcanism and the endogenous pyrite ore formation in the Lesser Caucasus, Rudny Altai and in the Southern Urals shows that the time lag between the processes of the active volcanism and the deposit of ores from hydrothermal solutions in the Southern Urals was much less than in the two mentioned pyrite-bearing provinces. Injection took place, not only subvolcanic formations but also formation of the plagiogranite intrusives and complexly differentiated vein series in the interval between the accumulation of ore-bearing strata and the deposition of pyrite ores in the latter two.
Thereby the pyrite fields of the Rudny Altai, the Southern Urals and the Lesser Caucasus have many common features in the folded zones of the Hercynian and Alpine age. Their ore formation was multi-stage. It occurred according to the single scheme in two stages. The second stage played a leading role in the commercially valuable ores formation. It occurred at one and other fields in several stages, more often sulphur-pyrite, copper-zinc, polymetallic or barite-polymetallic. The ores were formed under the conditions of the active volcanic process. The ore-bearing volcanic formations, pyrite ores, explosive breccias and post-ore dikes were its derivatives.

So as can be seen from the above-mentioned, the Filizchay ore field is very different from the pyrite fields of the above-stated types. There is no direct relationship with volcanism in this field. In contrast to them, the fine-rhythmic flyschoids with component sandstones, clay shales and silt-clay shales are the host rocks in this field.

As noted by A.A. Marakushev (Marakushev, 2011), «an association of the pyrite-polymetallic ores with copper-pyrrhotite ores has been described for the Caucasian fields using the example of the Filizchay ore field, which has been represented by a rhythmically laminated layer of the solid copper-lead-zinc ores with barite and with copper-pyrrhotite ores' overlaying. The latter are also formed independent fields (Kasdag, Kizil-Dere, Adange). They belong to the pyrite ores association, being fundamentally different from the Ural copper-pyrrhotite ores.

Based on the above-mentioned, we refer the Filizchay ore field to the SEDEX type (Imaverdiyev, Sattar-zade, 2022).

The origin and mechanism of the formation of the ore deposits of the Filizchay ore field

The origin of the pyrite fields has attracted the attention of geologists for a long time. Since the beginning of the XX\textsuperscript{th} century and up to this date this problem has been of importance.

Many geologists have dealt with the problems of the genesis of the pyrite-polymetallic fields on the southern slope of the Greater Caucasus. Thereby two opposing hypotheses were created.

Summarizing the views on the origin of the pyrite-polymetallic fields of the southern slope of the Greater Caucasus, we note that most researchers support their exhalative-sedimentary genesis. Then the fields are subjected to the hydrothermal-metasomatic and metamorphogenic process. This situation is typical for the SEDEX type fields.

The ratio of the natural ore types composed of the different mineral associations, with stages of the folded and disjunctive dislocations allows us to divide the process of the deposit formation into the following three stages of ore formation: 1. deposits of the massive hydrothermal-sedimentary essentially pyrite ores; 2. formation of the hydrothermal-metasomatic ores of the pyrite-copper-polymetallic composition; 3. deposition of the hydrothermal-metamorphogenic ores of the copper-pyrrhotite composition. The available data indicate a favorable environment for the sedimentary pyrite ores formation under the significant role of \( C_{\text{org}} \) and sulfate-reducing bacteria. Moreover, the hydrothermal-sedimentary processes played the main role in the accumulation of the main volume of the sulfide masses. The widespread development of the clay shales and the components of the terrigenous flysch of the ore rhythmites («ore flysch») underlying ore deposit (Fig. 3) as well as veinlet ores of essentially pyrite composition which have been subjected to the intense dynamic metamorphism in connection with the development of the flow cleavage crack show the presence of these processes. Evidently pyrite ores of the consedimentary depressions were accumulated in the clay sediments deposited in the environment of the stagnant regime. The content of the organic carbon reached 5-6% in them, against a background – 0.1-0.2%. The massive ores (pyrite, chalcopyrite, galena, sphalerite) then alternation of sulfide and clay layers («ore flysch») and, even closer to the periphery of the depressions, pyrite-siderite and siderite concretions formed in the central parts, near the ore conduits. Later inversion uplifts formed in the place of the depressions. Then the swarms cross-cutting layering of the sub-ore strata were formed. They are joined up dip from the side of the lying-wall with the massive laminated ores of the Filizchay deposit. These appearances of the swarms in the deep horizons along the ore deposit dipping i.e. as approaching the Kekhnamedan fault allow us to suggest the presence of the feeding chamber within the deep-water trough that is limited to the underground basin from the north. The data of the pyrites sulfur isotope also testify to the significant role of the hydrothermal-sedimentary process.

According to N.M. Zairi (Zairi, 1972, 1992), syn-genetic pyrites from host rocks are characterized by wide dispersion of the isotope composition \( \delta^{34}S \) – 60% sulfur that indicates the biogenic nature. In all textual ores varieties \( \delta^{34}S \) varies in narrow range (from +1.0% up to 6.0%) relating to isotopically normal, homogeneous, high-temperature. They are associated with a deep magmatic source.
Sulfides of the pyrite-polymetallic stage of mineralization are characterized by the presence of several sets of prevalence of δS$^{34}$ values: the following values have obtained for pyrites: Pyrite I – +3‰ (±0.5‰) and for pyrite II – +4‰ (±0.5‰). Similar data have been obtained for coexisting galena +1.5‰ (±0.5‰) and sphalerite +3‰ (±0.5‰) (Fig. 2). Based on these isotope data it is assumed that sulfides of the pyrite-polymetallic stage have been deposited from two solutions that differ in sulfur isotopic composition. Galena and sphalerite have simultaneously crystallized with pyrites at both stages.

![Diagram](image)

**Fig. 3.** The isotopic composition of sulfur in the minerals of the Filizchay ore field: 1-pyrite sulfur; 2- sphalerite + galena sulfur; 3- galena sulfur; 4- chalcopyrite sulfur; 5- pyrrhotite sulfur accordingly (Zairi, 1992).

Pyrrhotite and chalcopyrite were analyzed for ores of the copper-pyrrhotite stage. δS$^{34}$ varies from +4‰ to +6‰ (±0.5‰) with a maximum prevalence of +5‰ (±0.5‰) for pyrrhotite. This solution portion, from which pyrrhotite has crystallized, is the next separate (pyrrhotite) stage of mineralization.

The isotope composition of chalcopyrite sulfur from the pyrrhotite association has homogeneous ratios of sulfur isotopes with clearly defined maximum δS$^{34}$ in the region of +6‰ (±0.5‰). Therefore, it can be concluded that isotopically heavy chalcopyrite is non-equilibrium with pyrrhotite coexisting with it.

Therefore, the isotope composition of the sulfur of the main minerals (pyrite, galena, sphalerite, pyrrhotite, chalcopyrite) selected from various ores types of the Filizchay ore field allowed N.M. Zairi (Zairi, 1972, 1992) to conclude that the deposit was formed from several portions of entering hydrothermal solutions. Moreover, each of the solutions’ portions was different in the isotope composition of sulfur with the general tendency of isotope content increasing S$^{34}$ from the earliest pyrite stage (δS$^{34}$ = +3‰) to the chalcopyrite stage closing ore genesis process (δS$^{34}$ = +6‰).

Further evidence of hydrothermal-sedimentary ore deposition is the fact that outpouring of spilites and basalts took place to the period of sediment accumulation of the ore-bearing horizon in the adjacent northern block (in narrow trough-like depression). Supplying iron sulfides into the more southern basin with stagnant water can be connected with their post-volcanic exhalations (as primary sources). Taking this into consideration, it can be assumed that massive essentially pyrite ores are heterogeneous formations that combine both sedimentary and hydrothermal-sedimentary accumulations of the indicated iron disulfide.

**Conclusions**

Therefore, the Filizchay ore field connected with basalt volcanism is combined according to the formation method. It has formed due to components which were carried out by hydrothermal flows and associated with underwater alteration of basalts (palagonitization). The temperatures of the primary pyrite-polymetallic ores’ formation were relatively low. They have been determined by the surprisingly constant difference of δS$^{34}$ between pyrite and sphalerite t, which coexisted in the same sample. The fluctuations of this difference are 1.0-3.0%, averaging 2.0% (Grinenko et al., 1974). Such constancy indicates on the one hand the formation of sphalerite and pyrite from a single solution and on the other hand – relatively low temperature of their formation (from 200° up to 100°C) according to different measurements (Vikent’ev, 2004, 2017, Trufanov, 1983, Ohimoto, Rye, 1979).

Under other conditions copper-pyrrhotite ores were formed. The similar isotopic sulfur composition of their
sulfides, the same spectrum and amount of impurities as in the sulfides of the pyrite-polymetallic ores as well as numerous remains of the early pyrites of the disseminated ores indicate that the substance of copper-pyrrhotite ores was not introduced from outside. It occurs in the transformation process of the earlier disseminated ores. The presence in them of magnetite, biotite, and actinolite indicates the high temperature of formation. According to Fe content in pyrrhotites (mostly 47.2, more rarely – 47.0%), its formation temperature is 350-400°C (Ingerson, 1958; Vikent’ev, 2017). Evidently the formation of the metamorphogenic copper-pyrrhotite ores is due to heat flows that occur during the injection of the postvolcanic diabasic dikes complex. The stronger ore transformation of the Kasdag fields demonstrates this where dikes are spatially associated with ore bodies as well as the complete absence of the late mineralization in the Katekh field where intrusive magmatism isn’t manifested at all.

The deposition of these ores was preceded by the intense tectonic deformation stage and the injection of the subvolcanic small intrusives of the successively differentiated formation. By the time of the injection of pre-ore (in relation to the pyrite-polymetallic association) subvolcanic intrusive, the large coffer fold of the Karabchay consedimentary uplift had been formed in situ. The steep viscous fault arose at the site of the extreme southern sublatitudinally oriented swarm of the syngenetic pyrite veinlets. The northern flank of the Karabchay anticline experienced wrenching with dipping to the north at an angle of 45-50°. The transverse uplifts caused the undulation of the longitudinal folding and appearance of the additional steep hinge folds. The entire complex process of folding movements was accompanied by the development of the longitudinal reverse-thrusts and thrusts that complicate the axial folds planes. The dip angles of the faults are naturally increased as they approach the steep viscous fault from 30-45° up to 60-70° to the northward. The development of the reverse faults and thrusts was accompanied by intense S-shaped bends of the flow cleavage fractures from the lying-wall. The development of the mentioned types of the folded and discontinuous structures had a permanent nature. It had an effect on the deposit morphology of the complex pyrite ores in a different degree. The stage of initial deformations in the ore deposit was reflected as flat thrust disturbances being relevant to the roof and foot. In this regard the ore deposit began to dip to the north at an angle that apparently exceeded 30-35°. The following development of the steep hinge folds was accompanied by the origin of the reverse-thrust disturbances both at the roof and at the foot of the ore deposit and by the renewal of the vertical movements along the southern viscous fault. This process led to the boudinage of the layered pyrite ores. The boudination process of the ore deposit and the development of steep (in regards to the general flat deposit dipping) reverse-thrusts was completed by intense displacements along the roof of the ore deposit, which led to the final formation of the so-called Filizchay «ore-limiting» thrust. This is evidenced by the steady overturning of the steep hinge folds to the north and the sharp wrench of the ore deposit near the southern viscous fault. The development of the types of mentioned structures which led to the boudinage of the layered pyrite ores was a preliminary to the injection of the subvolcanic dikes of the continuously differentiated basalt-andesite-dacite-rhyolite association and to the beginning of the pyrite-polymetallic mineralization formation. The mineral formation of the productive pyrite-polymetallic stage was preceded by weak tectonic movements.

The deposition of minerals of the productive stage was carried out by the metasomatic way with the replacement of the predominantly carbonate bands. The spotted-disseminated pyrite-polymetallic ores were formed simultaneously with the formation of the superimposed metamorphogenic-banded pyrite-polymetallic ores in pocket-changed intensively brecciated sub-ore rocks.

The copper-pyrrhotite stage ores have very insignificant development. The formation of copper-pyrrhotite ores was a preliminary to the intense tectonic deformation stage, which was expressed in the renewal of the movements along previously filled faults and the appearance of the new systems of the ridge-like, angular and puckered folds, steep hinge folds, which expressed in the development of kink-bend structures and fans of the steep secondary schistosity. The development of the mentioned structures led to the additional metamorphism of the previously deposited pyrite-polymetallic ores. The tectonic deformation stage preceding copper-pyrrhotite mineralization was completed of the injection of the dikes of the gabbro-diorite association. The high-temperature hydrothermal solutions of the final stage of the intrusive magmatism circulated along the largest crushing zones and exocontacts of gabbro and gabbro-diorite dikes and metamorphosed the pyrite and pyrite-polymetallic ores. The metamorphism was expressed not only in crushing and recrystallization of these ores but also in the skarnification of the carbonates with the formation of hematite, magnetite, biotite, and actin-
olite. The uplifts and folding took place only at the end of the Bathonian and the pyrrhotite ores formation occurred later than the formation of the poly-
metallic sulfide accumulations of the Filizchay ore field in the Azerbaijani part of the southern slope of the Main Caucasian Range.

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