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# MODE OF OCCURRENCE, MORPHOLOGY AND FORMATION MECHANISM OF PYRITE DEPOSITS OF THE FILIZCHAY FIELD

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**Abstract**

This article examines the occurrence conditions, morphology and formation mechanism of massive sulfide deposits at the Filizchay deposit. This paper draws on innovative data. It has been established that this deposit is characterized by a minor role of oxidation processes, likely due to intense erosion in the pronounced alpine relief. The proportion of oxidized ores developed in the upper part ("head") of the ore deposit is insignificant, amounting to 0.5% of the total ore mass. Of particular interest, although rare, are the compressed banding patterns, which take the form of microfolds caused by shearing and dragging in the layered host rocks. A characteristic component of these ores are fragments of completely chloritized host rocks, usually localized at the margins of the bodies. Fragments of quartz veinlets are less characteristic. The Filizchay deposit, like other deposits associated with basaltic volcanism, is a combination of formations and is formed by components transported by hydrothermal flows and associated with underwater alteration of basalts (palagonitization).

***Keywords**:* Morphology, formation mechanism, Filizchay pyrite-polymetallic deposit, Greater Caucasus

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**Introduction:**

The Filizchay pyrite-polymetallic deposit in the Greater Caucasus is a valuable resource for the extraction of zinc, lead, and silver, as well as associated components such as gold, cadmium, indium, copper, tin, bismuth, antimony, selenium, tellurium, and others. Many geologists have studied the geological structure, tectonics, stratigraphy, magmatism, and ore deposits. These issues are covered in sufficient detail in the works of R.N.Abdullaev, S.A.Agaev, V.B.Agaev, A.A.Aliev, G.I.Aliev, R.M.Aliev, D.M.Akhmedov, R.A.Akhundov, V.M.Baba-zade, S.F.Babaev, A.M.Babaev, A.A.Bayramov, N.A. Imamverdieva, M.A. Kashkay, G.I. Kerimov, N.K. Kurbanov, R.B. Kerimov, E.M. Ilyasov, N.A. Ismailov, T.M. Mamedov, D.D. Mazanov, A.I. Makhmudova, K.I. Museibov, B.V. Mustafa-zade, G.V. Mustafaev, V.N.Nagiyev, N.A.Novruzov, N.A.Sattar-zade, V.I.Smirnov, N.Sh.Yusifov, G.A.Tvalchrelidze, A.G.Tvalchrelidze, G.A.Chalabiev, Ch.M.Khalif-zade, A.B.Shiraliev, E.Sh.Shikhalibeyli and many others researchers. Although the deposits on the Southern Slope of the Greater Caucasus have been extensively studied, the morphology and formation mechanisms of the Filizchay deposit have not been examined in detail. This article addresses this issue.

**Features of the geological structure of the Filizchay deposit**

The geological structure of the deposit includes terrigenous deposits of the Upper Pliensbachian (Filizchay series ($J_1p_2$)) and Toarcian (Gubakh ($J_{1t1+2}$) and Murovdag ($J_{1t1}$) series) of the Lower Jurassic (Fig. 1) [7].

The main peculiarity of the morphology of the Filizchay pyrite-polymetallic field is that it is a single compact sheeted body, composed predominantly (90-95%) of sulfide ore aggregates.

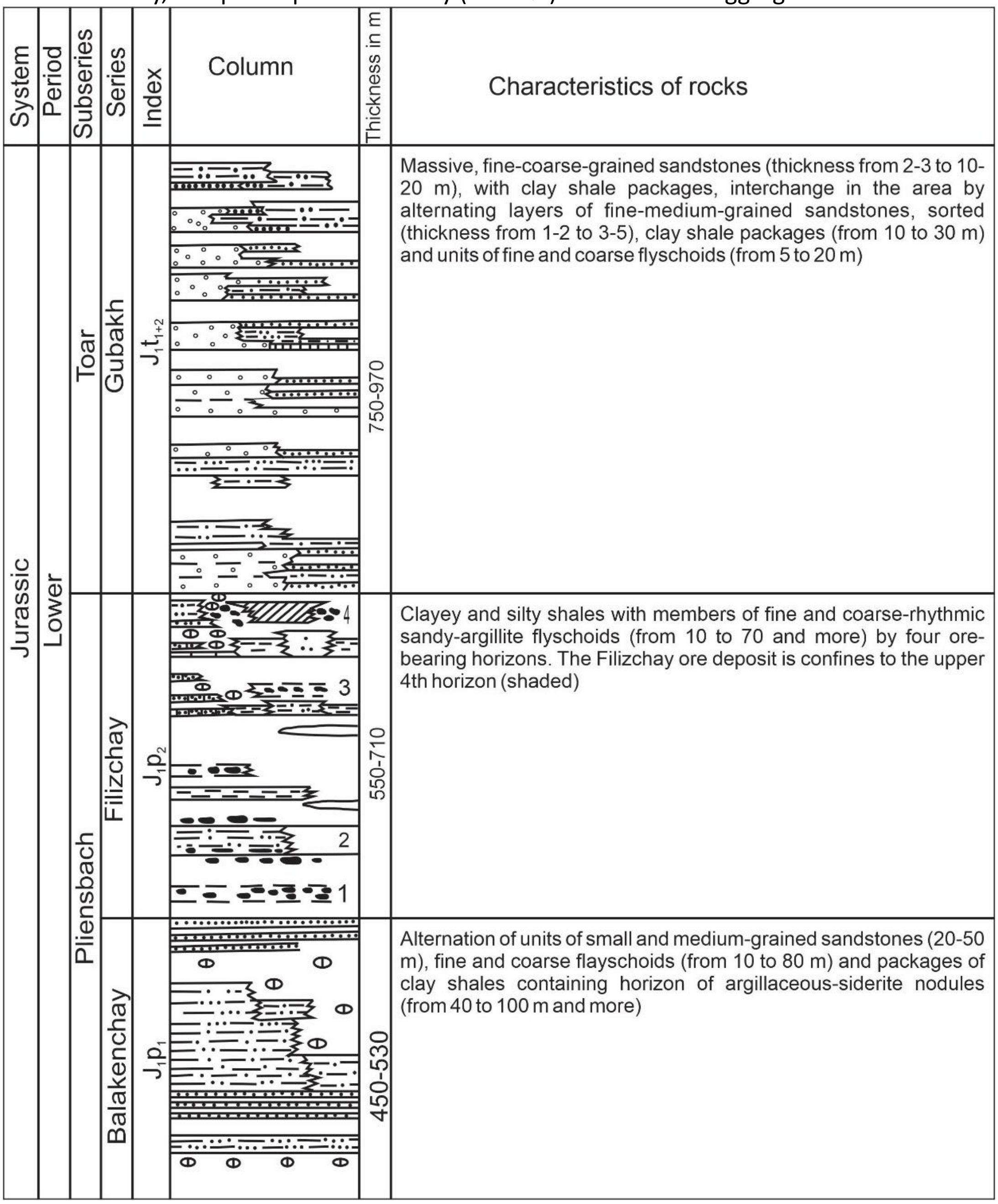


**Fig. 1. Stratigraphic column of the ore-bearing deposits of the Filizchay-Attagay facial subzone of the Sarybash structural-formational zone (the South part of the Katsdag-Filizchay ore cluster). Scale 1:10,000 (compiled by N.A. Sattar-zade)**

The main lithological and stratigraphic characteristics of the terrigenous complexes of the deposit are as follows:

a) all identified strata are characterized by facies stability and, to a lesser extent, thickness;

b) the rhythmic structure of the sections has a pronounced, thinned-out flyschoid character, most fully represented in the flyschoid packages of the Filizchay Series of the Upper Pliensbachian and least clearly in the Murovdag Series of the Lower Toarcian;

c) the number of sulfide inclusions, nodules, and concretions (primarily of pyrite composition) increases systematically from top to bottom from the Toarcian to the Pliensbachian, reaching a maximum in the third member of Pliensbachian clay shales (the Filizchay Series), which hosts the stratiform pyrite deposit of the deposit;

d) conversely, metamorphism increases in the opposite direction from the Pliensbachian to the Toarcian, which is explained by the envelopment of the Toarcian terrigenous strata by the Kehnamedan Shear Zone. The structural position of the Filizchay deposit is determined by its location at the junction of the northern limb of the Karabchay Chest Anticline and the Kehnamedan thrust fault, complicated by the Balakenchay local transverse inversion uplift [1]. The main structural elements of the deposit are the core of the Karabchay anticline, its northern limb, and part of the Kehnamedan shear zone, encompassed by the aforementioned transverse uplift. The characteristics of these main structural elements determine the fundamental structural features of the Filizchay deposit.

**Morphology of the Filizchay deposit's**

The main feature of the morphology of the Filizchay pyrite-polymetallic deposit is that it is a single compact layered body, composed predominantly (90-95%) of aggregates of sulfide ores (Fig. 2).

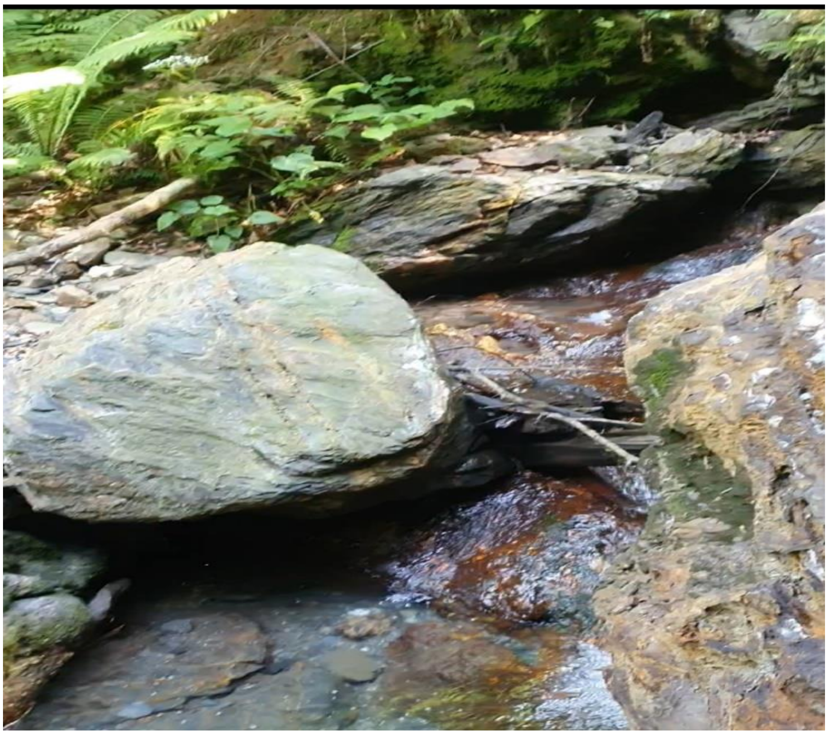

**Figure. 2. Outcrops of ore body in the Filizchay River basin**

Pyrite and to a much lesser extent sphalerite, galena and chalcopyrite (in descending order) form the basis of these ores. Carbonate minerals (calcite, ankerite, dolomite, siderite, etc.) and rarely encountered quartz, sericite and chlorite play a subordinate role in the composition of the deposit [11, 12]. The ores contain a variety of rare minerals. There are interlayers of weakly mineralized clay shales in various parts of the deposit. The field is characterized by a small role of oxidation processes, which is probably associated with intense erosion in the conditions of a strongly pronounced alpine relief. The share of oxidized ores developed in the upper part ("head") of the ore deposit is insignificant and amounts to 0.5% of the volume of the entire ore mass. These ores are altered into mixed polymetallic ores further down, in which oxidized minerals account for no more than 10-20% of all sulfide minerals [3].

The reserves of these ores amount to 2.2% of all reserves of commercial ores of category $B+C_1$. In this case, a significant role is played by minerals of the secondary sulfide enrichment zone: chalcosine, covellite, bornite, etc. in the zone of mixed ores. The main volume of the ore deposit (97.3%) consists of primary ores, within which the abovementioned main ore-forming minerals make up the following most common (main) mineral-textural natural ore types: 1) Laminated-banded pyrite-polymetallic; 2) Massive sulphur-pyrite; 3) Massive pyrite-polymetallic; 4) Spotted-impregnated pyrite-polymetallic; 5) Veinlet-impregnated pyrite-polymetallic; 6) Copper-pyrrhotite. The following of these are classified as commercial ore: banded, massive pyrite-polymetallic and sulphur pyrite ores. Spotted-impregnated and copper-pyrrhotite, as well as veinlet-impregnated ores are classified as non-commercial ores [13]. Laminated-banded ores are most widely developed in the stratiform part of the ore deposit. They make up about 67% of its volume. This texture in ores is caused by macroscopically well-distinguished alternation of thin parallel bands (or layers) of different mineral composition, the thickness of which varies from fractions of a millimeter to a few centimeters, averaging 1.5-3.0 mm (Fig. 3). The bands of the following composition are distinguished: - essentially pyrite with an admixture of carbonate, copper, lead and zinc sulfides and pyrrhotite in the intergranular spaces of pyrite; - carbonate; - pyrite-sphalerite and pyrite-galena-sphalerite with skeletal crystals of pyrite; - pyrite-chalcopyrite; pyrite-pyrrhotite. Besides this, active component of banded ores are interlayers of shales, less frequently sandstones, ranging from millimetres to several metres in thickness [2]. These layers are oriented according to the banding. The morphology of banding varies. The most common are ores with rectilinear banding. Ores with lenticular banding of carbonate bands are quite common. Banding patterns identical to crossbedded textures of host rocks, as well as resembling textures of plastic landslide deformations in unlithified sediments are much less common. Very interesting, although rare, are the curved banding patterns in the form of microfolding of shearing and dragging in laminated host rocks.

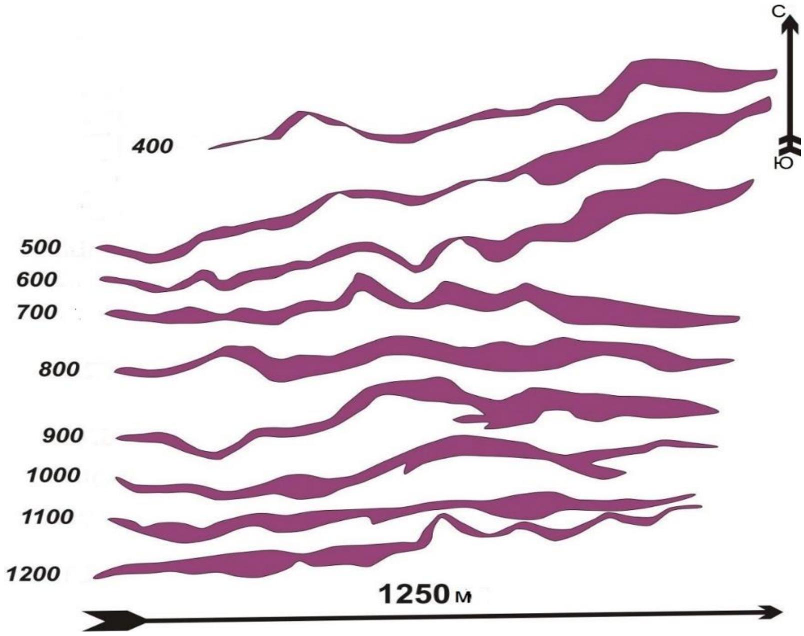


**Figure 3. Morphology of the ore body in different horizons**

A characteristic detail of the structure of banded ores are spot-like and fragment-like aggregates consisting of pinkish ankerite, white calcite and redeposited late generations of coarse-grained chalcopyrite, sphalerite, galena, pyrrhotite with sulfosalts. The sizes of such segregation do not exceed a few centimeters. The described banded ores are difficult to distinguish from the laminated structures created in the process of plastic flow of ore substance during dynamometamorphism at a number of fields that experienced folded deformations (fields of the Middle Urals, Khandiz in the Gissar Range, etc.). The same origin can be assumed for the Filizchay field, given that the orientation of the banding coincides with the direction of the fault separating the solid ores from the sidewall rocks. Massive sulphur pyrite and massive pyrite-polymetallic ores occur together with laminated-banded ores and form extended lenticular bodies in solid ore deposits. There is no regularity in the spatial arrangement of these ores. Their volume fraction is 8% and 4%, respectively. The textural peculiarities of these ores are not diverse. These are completely homogeneous, very fine-grained occurrences with small lenticular or irregular emissions of vein minerals. Occuring in all parts of the stratiform sheet deposit, their main mass is concentrated in the area of deep horizons of the north-eastern declination, where, besides the actual sulphur pyrite ores, there are also pyrite-polymetallic varieties in some intervals. Cryptogranular aggregates of aphanitic pyrite are saturated with spotted polymetallic emissions (galena of sphalerite or chalcopyrite-sphalerite composition) in the latter, which are connected by veinlets and veins (up to 5-6 cm thick) of the same composition of granular structure. Spotted-impregnated pyrite-polymetallic ores account for about 8% of the ore deposit volume and form wedge-shaped, tapering bodies in the upper parts of ore-supplying channels, concentrating in the modern structure, in the area of the bend of the steep part of the deposit to the flat-lying one [3]. The textural pattern of these ores is based on irregularly - spotted distributed impregnation of large, often spherical pyrite, in some places accompanied by sphalerite, galena and chalcopyrite against the background of carbonate mass. A characteristic component of these ores is fragments of completely chloritized host rocks, usually localized in the marginal parts of the bodies. Less characteristic are fragments of quartz veinlets. Veinlet-impregnated pyrite-polymetallic ores continue the bodies of spotted-impregnated ores down the dip of ore-bearing channels and are associated with them by gradual transitions. Depending on the density and orientation of the veinlets relative to the cleavage of the flow, parallel-veinlet, stockwork and stockwork-breccia varieties of veinlet ores can be distinguished. The veinlets are composed of carbonate, coarse recrystallized and crushed pyrite, often in association with sphalerite-galena and more often with sphalerite-chalcopyrite. Margin of big-scaled chlorite are quite frequent along the veinlets' casings. Most of the veinlets coincide in direction with the schistosity. A complication of their morphology is often observed in veinlets oriented obliquely to the schistosity. The latter is caused by the hauling of the crushed veinlet matter along the planes of schistosity. Laminated silicate-sulphide ores ("ore flysch") are developed in the footwall of a solid sulphide ore deposit. They replace the stratiform sheet deposit along the eastward strike and are essentially a gradual transition from solid ores to clayey rocks. These ores are characterized by alternating clay, sand and sulphide layers, ranging in thickness from fractions of a millimeter to 5-10 cm. As we approach solid ores, the number and thickness of sulphide layers increases. Sulfide layers are composed of carbonate, pyrite, less commonly chalcopyrite, sphalerite, galena and pyrrhotite. Pyrite is represented by framboids, small cubic crystals and nodules up to 0.5-1.0 cm in size, often exceeding the thickness of the host layer. Copper, lead, zinc sulfides, pyrrhotite and carbonates form often banded aggregates in the "pressure shadows" of pyrite nodules. Copper-pyrrhotite ores account for no more than 2% of volume of the ore deposit. They form a vein-like body in the footwall of the stratiform part of the deposit, intersecting wedge-shaped bodies of spotted-impregnated ores and sub-ore host rocks. The most typical of these ores are brecciated and porphyric textures. Brecciated textures are formed by fragments of coarse-grained impregnated carbonate-pyrite ores and fine-grained pyrrhotite cement with variable amounts of sphalerite and chalcopyrite. The quantitative ratios of fragments and cement vary widely from 5:1 to 1:1. The size of fragments reaches 10-15 cm and their shape is mostly angular. Porphyritic ores consist of a fine-grained pyrrhotite mass with chalcopyrite and sphalerite and rounded porphyritic residues of coarse-grained pyrite, up to 5 mm in size, often dissected by thin veinlets of pyrrhotite or chalcopyrite. Less characteristic are massive essentially pyrrhotite and veinlet chalcopyrite-pyrrhotite ores [9, 10].

**Mechanism of formation of pyrite deposits of the Filizchay field**

The correlation of natural ore types, composed of various mineral associations, with stages of folded and disjunctive dislocations allows to divide the process of deposit formation into the following three stages of ore formation: 1. Sediments of massive hydrothermal-sedimentary significant pyrite ores; 2. Formation of hydrothermal-metasomatic ores of pyrite-copper-polymetallic composition; 3. Sediments of hydrothermal-metamorphic ores of copper-pyrrhotite composition. The existing evidence suggests a favorable situation for the formation of sedimentary pyrite ores with a great significance of $C_{org}$ and sulfur reducing bacteria. At the same time, hydrothermal and sedimentary processes played the main role in the accumulation of the main volume of sulphide masses. The presence of these processes is evidenced by the widespread development of ore rhythmites ("ore flysch") in the clay shales and terrigenous flysch units of the bedding ore deposit, as well as veinlet ores of essentially pyritic composition that underwent intensive dynamometamorphism due to the development of flow cleavage fractures. The abovementioned veinlets form swarms that intersect the bedding of the sub-ore strata and close up with the massive laminated ores of the Filizchay deposit from the footwall updip. The occurrence of these swarms in deep horizons along the dip of the ore deposit, i.e. as it approaches the Kohnamedan fault, suggests the presence of a feeding source within the deep-sea trough that bounded the submarine basin from the north. The significant role of the hydrothermal sedimentary process is also supported by the sulfur isotope data of pyrite. Hydrothermal-sedimentary ore deposition is also evidenced by the fact that by the accumulation period of sediments of the ore-bearing horizon, spilites and basalts erupted in the neighbouring northern block (in a narrow trough-shaped depression). They can be associated with post-volcanic exhalations (as primary sources) by the introduction of iron sulphides into a more southern basin with stagnant waters. Taking this into account, it is likely that massive pyrite ores are a heterogeneous formation combining sedimentary and hydrothermal-sedimentary ores.

**Discussion of results:**

So, the Filizchay field, like other fields associated with basaltic volcanism, is combined in the way of formation and is formed due to components transported by hydrothermal flows and associated with underwater alteration of basalts (palagonitization). The temperatures of formation of primary pyrite-polymetallic ores are relatively low. The temperatures of formation of primary pyrite-polymetallic ores are relatively low. They are determined by the surprisingly constant difference $\delta S^{34}$ between pyrite and sphalerite coexisting in the same sample. The fluctuations of this difference are 1.0-3.0‰, on average 2.0‰ [4]. Such constancy indicates, on the one hand, the formation of sphalerite and pyrite from a single solution, and on the other hand, a relatively low temperature of their formation (from 200° to 100°C) according to different measurements [14, 16]. Copper-pyrrhotite ores were formed under different conditions. The close sulfur isotopic composition of their sulfides, the same spectrum and amount of impurities as in the sulfides of pyrite-polymetallic ores, as well as numerous remains of early pyrites of impregnated ores indicate that the substance of copper-pyrrhotite ores is not supplied from the outside, but occurs in the process of alteration of earlier impregnated ores. The occurrence of magnetite, biotite and actinolite in them indicates high formation temperature. According to the Fe content in pyrrhotite (mostly 47.2, less often 47.0%), the temperature of its formation is 350-400°C [15]. Apparently, the formation of metamorphogenic copper-pyrrhotite ores is caused by heat flows occurring during the intrusion of a complex of post-volcanic diabase dykes. This is indicated by the stronger alteration of ores at the Katsdag field, where the dikes are spatially associated with ore bodies, as well as the complete absence of late mineralization at the Katekh field, where intrusive magmatism is completely absent.

The sediment of these ores was preceded by a stage of intense tectonic deformation and the emplacement of subvolcanic small intrusions of a successively differentiated formation. By the time of the emplacement of pre-ore (in relation to the pyrite-polymetallic association) subvolcanic intrusions, a large box fold had been formed at the site of the Karabchay syndepositional uplift. A steep viscous fault occurred in place of the southernmost sublatitudinally oriented swarm of syngenetic pyrite veinlets. The northern wing of the Karabchay anticline experienced twisting north dip with the 45-50° angle. Transverse uplifts caused undulation of longitudinal folding and the occurrence of additional steep-bended folds. The whole complex process of folding movements was accompanied by the development of longitudinal reverse-thrust faults and thrusts, complicating the axial planes of the folds. The dip angles of faults increase as they approach the steep viscous fault from 30-45° to 60-70° to the north. The development of reversed and thrust faults was accompanied by intense S-shaped bends of the cleavage fractures of the flow from the footwall. The development of the abovementioned types of folded and faulted structures was permanent and affected the morphology of the complex pyrite ore deposit to varying degrees. The initial stage of deformations in the ore deposit was reflected in the form of low thrust faults conformable with the roof and the base. This caused the ore deposit to dip to the north at an angle apparently exceeding 30-35°. The subsequent development of steep-bended folds was accompanied in the roof and in the base of the ore deposit, by the occurrence of reversed-thrust faults and the recapture of vertical movements along the southern viscous fault. This process led to the boudinage of laminated pyrite ores [9]. The process of boudinage of the ore deposit and development of steep (in relation to the general low dip of the deposit) reversed-thrust faults culminated in 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 supported by the stable steep-bended overfolding to the north and the sharp twisting of the ore deposit near the southern viscous fault. The development of the abovementioned types of structures, which led to the boudinage of laminated pyrite ores, preceded the intrusion of subvolcanic dykes of continuously differentiated formation and the early formation of pyrite-polymetallic mineralization. The formation of minerals of the productive pyrite-polymetallic stage was preceded by weak tectonic movements. The mineralization of the productive stage was carried out metasomatically with the replacement of predominantly carbonate bands. Simultaneously with the formation of superimposed metamorphic-banded pyrite-polymetallic ores, spotted-impregnated pyrite-polymetallic ores were formed in pocket-shaped altered to intensively brecciated sub-ore rocks [5, 6, 8, 17].

Ores of copper-pyrrhotite stage are very poorly developed. The formation of copper-pyrrhotite ores was preceded by a stage of intensive tectonic deformations, expressed in the recapture of movements along early formed faults, the occurrence of new systems of ridge-like, angular and crenulated folds, steep-bended folds, expressed in the development of kink-bend structures and fans of steep secondary schistosity. The development of the abovementioned structures led to additional metamorphism of early deposited pyrite-polymetallic ores. The stage of tectonic deformations preceding copper-pyrrhotite mineralization ended with the intrusion of gabbro-diorite dykes. High-temperature hydrothermal solutions of the final stage of intrusive magmatism circulated along the largest zones of crushing and exocontacts of gabbro and gabbro-diorite dykes and metamorphosed pyrite and pyrite-polymetallic ores. Metamorphism was expressed not only in the crushing of these ores and recrystallization, but also in the skarnification of carbonates with the formation of hematite, magnetite, biotite and actinolite.

**Conclusion:**

So, assessing the mechanism of formation of the Filizchay field, the following can be stated: 1. The field developed over a long period, starting from the period of sedimentation until the formation of ores of copper-pyrrhotite stage [10]. The lower age limit of mineralization is determined by the occurrence of the Upper Pliensbachian hydrothermal-sedimentary ores. The upper age limit is established due to the occurrence of pebbles of hydrothermally altered rocks and their sulphide ores in conglomerates underlying the lower Upper Jurassic sediments. 2. The development of pyrite mineralization had an intermittent character and was accompanied by intensive tectonic deformations and the emplacement of various generations of subvolcanic, hypovolcanic and hypabyssal intrusions of two main stages: the earlier basalt-andesite-rhyolite-dacitic and the later gabbro-gabbro-diorite. In our opinion, this circumstance predetermined the polygenic genesis of the ores of the Filizchay field.

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