Journal of Geology, Geography and Geoecology

Journal home page: geology-dnu.dp.ua

ISSN 2617-2909 (print)
ISSN 2617-2119 (online)

Journ. Geol. Geograph. Geology, 31(4), 643-652.

doi:10.15421/112260

Filizchay pyrite-polymetallic deposit (the southern slope of the Greater Caucasus) – as a typical representative of the SEDEX type pyrite deposits

Nazim A. Imamverdiyev, Nigar A. Sattar-zade

Baku State University, Republic of Azerbaijan, Baku, inazim17@yahoo.com

Received 31.07.2022;
Received in revised form 13.09.2022;
Accepted 24.09.2022

Abstract. The article has been devoted to one of the largest deposits of the southern slope of the Greater Caucasus – the Filizchay pyrite-polymetallic deposit. It has been found that the main morphology peculiarity of the pyrite-polymetallic deposit of the Filizchay deposit is that it is a single, compact sheet-like body composed mainly (at 90-95%) by the aggregates of the sulfide ores which are based on pyrite, sphalerite, galena and to a far lesser extent chalcopyrite and pyrrhotite. The carbonate minerals played a subordinate role in the deposit composition and quartz, sericite and chlorite – even less. The pyrite –polymetalic ores of the deposit are characterized by the following main mineralogical-textural varieties of ores: layered-bedded pyrite-polymetallic, massive sulfur-pyrite, massive pyrite-polymetallic, spotted-disseminated pyrite-polymetallic and vein-disseminated pyrite-polymetallic. The vein-disseminated ores are adjacent to the deposit on the footwall and are considered as independent bodies. Two industrial-technological types of ores, oxidized and pyrite-polymetallic, have been distinguished at the deposit. The latter is in turn divided into two grades: mixed and primary ores. These three varieties of ores differ in the content of the oxidized lead forms. The ores with a content of the oxidized lead speciation above 60% have been classed as oxidized ores, those from 20% to 60% as mixed and those below 20% as primary. The Filizchay deposit consists of thin-bedded massive sulfides with shales, siltstones or sandstones interbeds («ore flysch») which have been formed exclusively or mainly as a result of the exhalative processes on the seabed and differ from massive sulfide deposits in volcanic rocks. On the basis of this and also according to the geological structure, the reserves of the valuable Zn + Pb components of the deposit belong to the SEDEX type that is the most important source of lead, zinc and silver. The deposit had been developing for a long time starting from the period of sedimentation and up to the ore's formation of the copper-pyrrhotite stage. The lower age limit of the mineralization is determined by the presence of the hydrothermal-sedimentary ores of the Upper Pliensbachian. The upper age limit is established by the presence of the pebbles of the hydrothermally altered rocks and by their sulfide ores in the conglomerates underlying the deposits of the lower parts of the Upper Jurassic.

Key words: Filizchay pyrite-polymetallic deposit, Southern slope of the Greater Caucasus, mineralogical-textural types of ores, exhalative processes, «ore flysch», SEDEX type, Zn, Pb, Ag – valuable components.

Філізчайське колчеданно-поліметалеве родовище (Південний схил Великого Кавказу) – як типовий представник колчеданних родовищ типу SEDEX

Н.А.Імамвердієв, Н.А.Саттар-заде

Бакинський Державний Університет, Азербайджанська республіка, Баку, inazim17@yahoo.com

Анотація. Стаття присвячена одному із найбільших родовищ південного схилу Великого Кавказу – Філізчайського колчеданно-поліметалевого родовища. З'ясовано, що основною особливістю морфології колчеданно-поліметалевого покладу Філізчайського родовища є те, що це єдине, компактне пластоподібне тіло, складене переважно (на 90-95%) агрегатами сульфідних руд, основу яких складає пірит, сфалерит, галеніт та значно меншою мірою халькопірит та піротин. Підлеглу роль у складі покладу відіграють карбонатні мінерали та ще менше – кварц, серицит та хлорит. Для колчеданно-поліметалевих руд родовища характерні наступні основні мінералого-текстурні різновиди руд: шарувато-смужкові колчеданно-поліметалеві, масивні сірчано-колчеданні, масивні колчеданно-поліметалеві, плямисто-вкраплені колчеданно-поліметалеві. Прожилково-вкраплені руди притуляються до покладу з боку лежачого боку і розглядаються як самостійні тіла. На родовищі виділено два промислово-технологічні типи руд: оксидний і колчеданно-поліметалевий. Останній поділяється на два гатунки: змішані та первинні руди. Ці три різновиди руд різняться за змістом оксидних форм свинцю. До оксидних відносяться руди із вмістом оксидних форм знаходження свинцю більше 60%, змішаним – від 60% до 20% та первинним – менше 20%. Філізчайське родовище складається з тонкошаруватих масивних сульфідів з прошарками сланців, алевролітів або пісковиків («рудний фліш»), що утворилися виключно або в основному в результаті ексгаляційних процесів на морському дні і відрізняються від родовищ масивних сульфідів у вулканічних породах. Виходячи з цього, а також судячи з геологічної будови, запасів цінних компонентів Zn+Pb родовища відноситься до типу SEDEX, що є найважливішим джерелом свинцю, цинку та срібла. Родовище розвивалося довго, починаючи з періоду осадонакопичення і аж до становлення руд мідно-піротинового етапу. Нижня вікова межа зруденіння визначається наявністю гідротермально-осадових руд верхнього плінсбаху. Верхня вікова межа встановлюється завдяки наявності гальок гідротермально змінених порід та їх сульфідних руд у конгломератах, що підстилають відклади низів верхньої юри.

Ключові слова: Філізчайське колчеданно-поліметалеве родовище, Південний схил Великого Кавказу, мінерало-текстурні типи руд, ексгаляційні процеси, рудний фліш, тип SEDEX, Zn, Pb, Ag – цінні компоненти.

Introduction

Pyrite-polymetallic deposits are either concentrated among magmatic rocks (mainly Ural, Altai, Lesser Caucasian types) or are localized both among effusive and sedimentary strata («Kuroko» types) or among sedimentary shale strata (the deposit localized in the Jurassic shale strata of the Greater Caucasus).

At present these pyrite deposits families are combined in two groups:

The first of them is closely related to the volcanic rocks and accepted as a typical classical pyrite. It is called as VMS (Volcanogenic Massive Sulfide).

The second group is connected with terrigenous-carbonate and terrigenous strata. It is referred to as stratiform Pb-Zn deposits or SEDEX (Sedimentary Exhalative). At present the SEDEX type deposits are the main source of zinc, lead and silver.

If the origin of the first group of deposits has been sufficiently substantiated and the models have been developed in the literature, then there is no general consensus for origin of the second group of deposits. Most geologists support the concept of academician V.I. Smirnov – about the polygenic genesis of the pyrite-polymetallic deposits in the Greater Caucasus.

Due to the above-mentioned factors, the development and the construction of the geological and genetic 3D models of the ore-forming systems on the basis of the geochemical data on the boreholes are a new stage in the study of pyrite deposits. Based on the detailed mineralogical-geochemical data, the determination of the ore formation stages, their referral to a particular pyrite deposit type (VMS or SEDEX) and the clarification of the source of the ore-forming systems are highly relevant to modern geology.

Geological structure of the Filizchay deposit. According to the data of T.N.Kengerli, the Alpine mountain-fold structure of the Greater Caucasus occupies the northern part of the Caucasian isthmus and it extends from the Taman up to the Absheron Peninsula for a distance of 1300 km at the maximum width of 150 km (Geologiya Azerbaydzhana, 2005; Kengerli, 2009). According to the data obtained by this author, in the modern structure, the Greater Caucasus is represented as a complex folded-cover structure which formed as a result of the late Alpine tectonic movements from three main Mesozoic structures – the North Caucasian and South Caucasian (Transcaucasian) continental microplates and the vast marginal-marine basin Tethys which separated them.

The deep faults or structural seams, the Main Caucasian in the north and the Krasnopolyan-Zanginskiy in the south correspond to the boundaries between these macrostructures. They are mapped as southward deep overthrusts with a great amplitude in the modern structure of the consolidated crust and the Alpine cover.

The analysis of the facies and thicknesses of the geosynclinal sedimentary and magmatic complexes across the strike of the main structures of the mega-antclinorium of the Greater Caucasus formed the basis for the definition of the following longitudinal structural-formational zones (from north to south) within the Belokan-Zakatala ore region and generally the southeastern segment of the Greater Caucasus (Shikhalibeyli, 1956; Shikhalibeyli and Karabanov, 1979).

1. Metlyuta-Akhtachay; 2. Tufan; 3. Sarybash; 4. Durudzhin.

The geological position of the Katsdag-Filizchay ore cluster is determined by its location on the western flank of the Belakan-Zagatala ore region, where it is confined to the junction region of the Tufan and Sarybash structural-formation zones along the Kekhnamedan deep zone of the faults. The terrigenous deposits of the Upper Pliensbachian (Filizchay series), Lower (Murovdag series), and Upper (Djikhikh series) Toarcian are exposed within the ore cluster in the Tufan zone, (Fig. 1). They form the Katsdag linear anticline of the first order enclosing the similarly-named deposit.

The lithological-stratigraphic characteristics of the terrigenous complexes of the deposit are characterized by the following peculiarities:

a) all defined strata are distinguished by facies stability and to a lesser degree by thicknesses;
b) the rhythmicity of the sections' structure has a clearly marked flyschoid character, most fully represented in the flyschoid packets of the Filizchay series of the Upper Pliensbachian and the least clearly defined in the Murovdag series of the Lower Toarcian;
c) the amount of the sulfide disseminations, concretions and septarian nodules (mainly pyrite composition) increases naturally from top to bottom from the Toarcian up to the Pliensbachian, reaching a maximum in the third band of the clay shales of the Pliensbachian (the Filizchay series) enclosing the stratiform pyrite deposit of the field;
d) contrarily, metamorphism grows in the opposite direction from the Pliensbachian to the Toarcian which is explained by the covering of the Toarcian terrigenous strata by the Kekhnamedan shear zone.

The structural position of the Filizchay deposit is defined by its confinement to the junction region of the northern flank of the Karabchay coffer-shaped anticline with the Kekhnamedan upthrow-thrust, complicated by the Belakanchay local transverse inversion uplift. The main elements of the deposit structure are: the core of the Karabchay anticline, 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 deposit structure.

The deposit area covers a small part of the vast core of the Karabchay anticline – its northern band of the transition to the wing is complicated by the Belakanchay transverse uplift. According to the axial plane of the Karabchay anticline, its core extends transversally for about 2 km and it is composed of the Filizchay series deposits. The peculiarities of the internal core structure are established well enough due to the presence of two packets of the sandy flyschoid in its composition. The Filizchay series deposits in the considered part of the Karabchay anticline core have intensively folded into the single sufficiently extended (up to 1.5 km in the sublatitudinal direction) linear subsidiary anticline of the east-west trending which is termed Filizchay. This anticline limbs have been composed of the third ore-bearing band of the clay shales and the upper packet of the sandy flyschoid but the core is composed of the second band of the clay shales. The axial plane of this anticline is subvertical and it is observed subparallel to the main box-shaped anticline (Baba-zade and Agayev, 1999).

Morphology and internal structure of the ore deposit. The main peculiarity of the pyrite-polymetallic deposit morphology of the Filizchay deposit is that it is a single, compact sheet-like body which is mainly composed (at 90-95%) of sulfide ores aggregates which are based on pyrite, sphalerite, galena and, to a much lesser extent chalcopyrite and pyrrhotite. The carbonate minerals are of a subordinate importance in the deposit composition and quartz, sericite, chlorite – much less.

The ore body occurs among the monotonous clayey shales of the upper – third band of the Filizchay series. Here the deposit is confined to the thick ore-bearing horizon, the boundary of which is laterally determined by the boundaries of the Belakanchay transverse uplift, where ore-bearing clay shales are facially replaced by sandy flyschoid (Fig. 2).

The structural position of the layer-like pyrite deposit is determined by its confinement to the central part of the north flank of the Karabchay east-west trending anticline. According to the occurrence with the northern flank of the Karabchay anticline, the deposit extends with 80-85^o azimuth and decreases in accordance with the general dip of the northern flank to the north-north-west of 350-355^o at an average angle of 35-45^o. The most extended transverse flexure bends which complicate the north flank of the anticline in the west and east, respectively are the western and eastern limits of the deposit.

The main mineralogical-textural varieties (natural types) of pyrite-polymetallic ores characteristic of the deposit are as follows: layered-banded pyrite-polymetallic, massive sulfur-pyrite, massive pyrite-polymetallic, spotted-disseminated pyrite-polymetallic and vein-disseminated pyrite-polymetallic. The vein-disseminated ores are adjacent to the deposit on the footwall and they are considered as independent bodies (Akberov et al., 1982).

Two industrial and technological types of ores: oxidized and pyrite-polymetallic ones have been identified at the Filizchay deposit. The latter is divided into two grades: mixed and primary ores. These three varieties of ores differ in the content of the oxidized lead forms. The ores with a content of oxidized lead speciation above 60% have been classified as oxidized, from 20% to 60% as mixed and less than 20% as primary.

*The oxidized ores s*preading to a depth of up to 100 m from the boundary of Quaternary deposits have an insignificant development in the field and they occupy 0.5% of the volume of the balance ores. The thickness of these ores is of uneven nature and varies from 2 up to 45 m (visible).

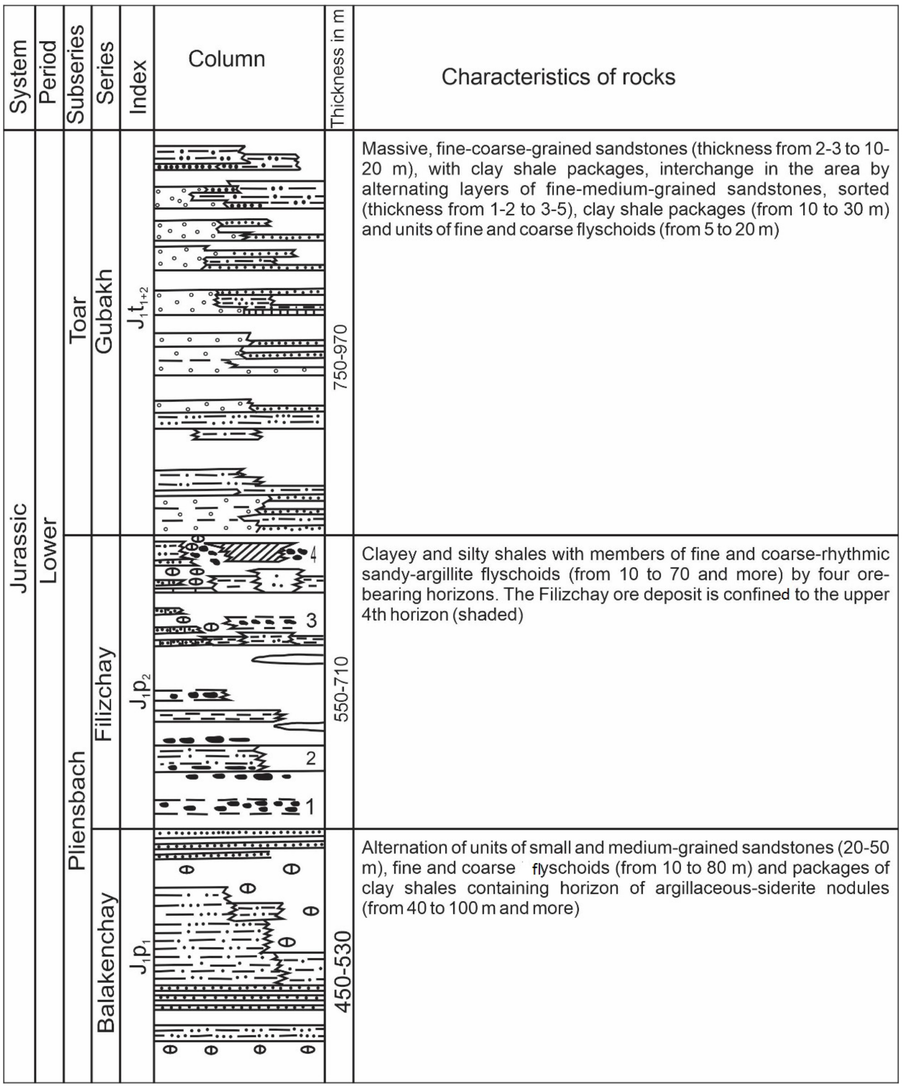

Fig. 1. Stratigraphic column of the ore-bearing deposits of the Filizchay-Attagay facial subzone of the Sarybash structural-formational zone (the South part of the Katsdag-Filizchay ore cluster). Scale 1:10,000 (compiled by N.A. Sattar-zade).

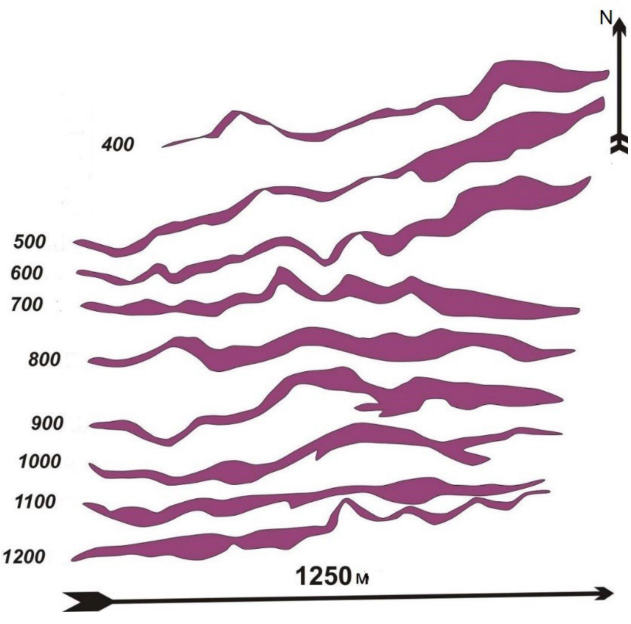

Fig. 2. Ore body morphology in the different horizons

Taking into consideration that pyrite is of the main importance in the composition of the ore deposit, the reactions in the oxidation zone occur with a greater proportion of sulfuric acid. Depending on the different migration abilities of compounds of the individual elements, the concentrations of some components (lead, gold, silver) are increased in the oxidation zone while others (copper, zinc) are removed from this zone. In this regard, oxides and hydroxides of the iron (limonite, goethite, hydrogoethite, jarosites) formed due to pyrite as well as numerous oxidized forms of lead and accompanying silver and gold play the main role in the composition of the considered ores. A significant proportion of the opper and zinc minerals was removed from this zone due to the transformation of their sulfide forms into easily soluble sulfates. The maximum amounts of the mentioned elements in the individual samples taken from the oxidation zone of the Filizchay deposit are: copper – 0.27%, zinc –

0.45%, lead – 55.5%, silver – 772.9 ppm, gold – 14.2 ppm. Among these elements, the concentrations of lead, silver, gold are worth attention. Their average-weighted contents are: 3.45%, – 160.1 ppm and 6.1 ppm, respectively in the considered zone of the deposit. The oxidized lead minerals have been mainly represented by anglesite, cerrusite, plumbojarosite, beudantite and etc. The limited amount of the copper and zinc minerals is represented by a wide range of the oxidized compounds. The malachite, azurite, chalcanthite, chalcosine, covelline, native-copper and etc. are found among the coppers but goslarite, calamine, smithsonite and etc. are found among the zincs.

The mixed ores zone is located below the oxidized ores. These ores occupy 2.2 % volume of the balance reserves of the deposit. They develop even more locally and change the oxidized ores along the fall of the deposit. They are mainly developed in zones of intense fracturing and crushing. The transition from mixed to primary pyrite-polymetallic ores is not clear and it has flexuous character.

They cover the zone of the secondary sulfide enrichment of the deposit. These ores are characterized by partial touching of the primary ore minerals with oxidation products. The presence of so-called friable ores is characterized for zone of the mixed ores of the deposit. The last ones in the form of small «pockets» are developed along tectonically crushed ores. These «pockets» have been composed by loose and fine grains aggregates that usually correspond to the grain sizes of this mineral in the primary ores. The transition of pyrite to melnicovite and marcasite is often observed (under a microscope) in the loose ores. This is especially clearly observed in adit of №6 where melnicovite has been widely developed. Here it forms separate lenticular accumulations with a thickness reaching up to 0.5 m. The pyrite is the most developed in the mineral composition of the mixed ores as well as in primary pyrite-polymetallic ones. The sulfides of zinc, lead and copper are commonly found but the role of the secondary minerals of lead and especially copper is increasing. The supergene copper minerals (chalcosine, covelline, bornite) developed in this zone. They were formed as a result of the chalcopyrite replacement. The amount of the secondary lead minerals (anglesite and cerussite), the characteristic companions of the oxidized ores, varies in the mixed ores over a rather wide range. However, it isn't greater than 60%, mainly 20-40% of the total lead content.

The primary pyrite-polymetallic ores that composed of the individual texture-mineralogical varieties occupy the main volume of the ore deposit (97.3%) and they are located below the mixed ores. The ores of the Filizchay deposit being localized in the Lower Jurassic clay-sand deposits are similar to pyrite ores occurring in the sedimentary exhalative deposits according to the general peculiarities of the mineral composition and the structures of the ore masses. Firstly, this similarity consists in the significantly sulfide composition of the ores and in the sharp predominance among sulfides – pyrite, sphalerite, galena in the primary metacolloidal composition of the ore mass.

Pyrite is the most common ore mineral. Chalcopyrite, galena and sphalerite are present in industrial concentrations. The minor and rare minerals are characterized by the pyrrhotite, arsenopyrite, gudmundite, sulphosalts of antimony, arsenic and bismuth (wolfsbergite, fahl ore, geocronite, jamsonite, boulangerite, etc.), tellurides of gold and silver (tetradymite, altaite, petzite, etc.). The iron oxides – magnetite and goethite can be found. The nonmetallic minerals are characterized by carbonate, quartz, biotite, actinolite, and residual minerals of host rocks – hydromica, ilmenite and organic matter.

It can be expected that according to the mineralogical and geochemical peculiarities the Filizchay deposit ores combine the features of the Cyprian and Kuroko type deposits. The high iron content (average 36.0 %) connected mainly with pyrite as well as other siderophile components (Co, Ti, Mn) characterize the first mentioned features while high concentrations of lead and zinc at a relatively low content of copper characterize the latter mentioned features. However, unlike these deposits, the direct relationship between mineralization and magmatism is not observed in the Filizchay deposit and they are close to sedimentary-exhalative deposits according to the mineral composition and the content of zinc, lead and silver.

The research into the textural and structural peculiarities and the sequence of mineral separation in the ores of the Filizchay pyrite-polymetallic deposit will allow us to give an overall picture of the deposit's formation. The ore deposit's formation occurred in two stages. The first stage begins with the deposition of pyrite masses from solutions followed by the superimposition of lead, zinc and copper sulfides and ends with the formation of pyrite-polymetallic ores. The copper-pyrrhotite ores' formation corresponds to the second stage. Generally, the ore deposition of the second stage occurred at high temperatures as evidenced by the association with pyrrhotite and chalcopyrite of such high-temperature minerals as biotite, actinolite, and magnetite.

The detailed mineralogical mapping of the separate types of ore and the microscopic examination of the minerals composing them showed that the ore deposit formation occurred in the several pulsation stages of the mineral formation

The main pyrite mass of the deposit was formed with nonmetallic minerals represented by quartz, carbonate and in a subordinate amount by chlorite and sericite in the first stage.

The second stage being more productive is characterized by the injection of hydrothermal solutions from which Cu, Pb, Zn sulfides were formed at the beginning. The decrease in the amount of the mentioned metals and an increase in As, Sb, and B in the hydrothermal contents are established towards the end of the process. The circulation of solutions enriched in lead and zinc occurs after crystallization and recrystallization of pyrite gels and slight crushing of the transformed aggregates. They are accompanied by partial dissolution and redeposition of pyrite with the formation of characteristic skeletal metacrystals.

The third stage of the mineral formation corresponds to the formation of rare-metal ore formations of the vein type. The cracks, where ore veins have localized, indicate that the fragmentation of the previously formed ore body at certain time intervals was preceded by the formation of these veins.

Finally, the formation of the minerals complex of the copper-pyrrhotite ores being secant in regard to pyrite ores can be referred to the fourth final stage in the general mineral formation plan.

The several generations of the same mineral occur in each stage. The tectonic movements were accompanied by crushing the previously formed mineral complexes, the host rocks were preliminary to the mineral's deposition of each stage. The cavities which originated in them were filled with minerals of the next mineralization stage.

The impact of the post-ore tectonic phenomena on mineral complexes is insignificant and it has resulted only in the crushing of some minerals along intense tectonic faults and even then not everywhere. The first, third and fourth stage complexes of ore formation are represented by associations of paragenetic minerals connected with a common character of formation conditions from a single solution at approximately the same time.

In the second stage of the mineral formation two paragenetic associations are conditionally distinguished on the basis of the well-marked difference in their mineral composition. The nature of the mineral groups formed at the beginning and at the end of the hydrothermal process of this stage indicates that each group corresponds to separate «mineral equilibrium stages» and that they can be considered as independent mineral associations.

The paragenetic associations of the pyrite-polymetallic formations of the Filizchay demonstrate a significant similarity with the mineral associations of the classical pyrite deposits formed in the sedimentary basins. The differences are only that the high-temperature chalcopyrite is absent in the pyrites of the early Filizchay generation and there is a complex of composite sulphosalts separating into independent paragenetic mineral associations.

The pyrite-polymetallic deposits were formed in three stages according to N.K. Kurbanov et al. (Kurbanov et al., 1976, 1983; Kurbanov, 1982, 1986). Firstly, the exhalative-sedimentary process occurred according to the «Krasnomorskiy» model in the Lower-Middle Jurassic period. At the second stage, the pyrite-polymetallic association was formed in the Filizchay deposit. This happened after the formation of folding, cleavage and faults. According to the opinion of these authors, this stage is connected with the formation of the island-arc magmatic formation and the island arcs formation. Minor gabbro-diorite intrusions developed and late copper-pyrrhotite-polymetallic deposits were formed after folding. According to the opinion of this scientist this stage represents industrial interest. The quartz-chlorite-carbonate-pyrrhotite-copper polymetallic vein mineralization was developed at the third stage. Therefore, the combined deposit was formed at Filizchay. The results of the conducted investigations of the Central Research Institute of Geological Prospecting staff in our opinion are of interest according to the lithofacies and paleogeographic environment of the deposits' formation on the Southern slope of the Greater Caucasus. According to their opinion, this situation predetermined the exhalative-sedimentary formation of the ores of the first type which occurred in the consedimentary troughs. Moreover, the ores were deposited in the deep-water troughs in the Kizil-Dere deposit but they were deposited in the isolated basins of the trenches on the continental slope in Filizchay. As noted below, at present such setting of the pyrite-polymetallic ores formation is called SEDEX.

Filichay pyrite-polymetallic deposit is a typical representative of the pyrite deposits of the SEDEX type. According to V.I. Smirnov (Smirnov, 1968), the ores composed mainly of the iron sulfides refer to the pyrite deposits. Pyrite, pyrrhotite and marcasite as the massive or disseminated ore predominate sharply in all pyrite deposits. They are associated with sphalerite, chalcopyrite, galena, fahl ores, bornite and other ore minerals.

As mentioned above at present the pyrite deposits' family is divided into two distinct groups according to the composition of the ore-bearing formations (Smirnov, 1968; Tvalchrelidze, 1978). One of them is closely associated with volcanogenic formations and one might say it is classical pyrite. It is just an analogue of VMS (*Volcanogenic Massive Sulfide*) deposits in the western terminology. They are called as the pyrite-polymetallic deposits. Their formation is connected with underwater hydrothermal activity of the volcanic nature.

The other group is closely connected with terrigenous and terrigenous-carbonate sequences with insignificant development of the vulcanite and it is as an analog of SEDEX (*Sedimentary Exhalative*) deposits. The volcanogenic formations are poorly developed in them. Often this group of deposit has been called stratiform Pb-Zn deposits. At present time SEDEX-type deposits are the main source of zinc, lead and silver (Goodfellow and Lydon, 2007; Large and Walcher, 1999; Lobanova and Nekosb, 2017).

The mineralized waters and brines of the internal strata, leaching the metals from terrigenous sedimentary rocks and the underlying basement, are the source of the metals and the mineralizing solutions for SEDEX deposits. The fluids obtained their salinity as the result of the marine water evaporation and perhaps they were mixed with meteoric and pore water that had been squeezed out of the deposits. Such metals as lead, copper and zinc are found in trace amounts in the fragmental and magmatic rocks (Candela, 2003).

New data on the geological structure of both groups of deposits (SEDEX and VMS) and modern hydrothermal systems obtained during last 20-30 years show their significant differences. The most important of them are the composition of the ore-bearing rocks mass and the absence of the direct connection with volcanism for SEDEX-type deposits in contrast to VMS-type deposits, the formation of which is associated with underwater hydrothermal activity of the volcanogenic nature. Moreover, in contrast to the pyrite-polymetallic deposits of the volcanic association (VMS), the stratiform lead-zinc deposits with rare exceptions do not contain commercial copper accumulations in the terrigenous and terrigenous-carbonate sequences (SEDEX) but then they have the high silver contents in the ores.

According to the geological structure and geodynamic conditions of formation, the Besshi-type pyrite deposits can be an intermediate link between these two groups (VMS and SEDEX) (Lobanov, Yakubchuk, 2014). They can be found in the areas of SEDEX deposits' development (for example the Sullivan basin) but they differ from them in the ores' composition (Dergachev, Yeremin, 2008). Based on the mineralization scale and formation conditions, the deposits of the metal-bearing sediments are the close modern analogue of SEDEX-type deposits in the rift zone depression at the bottom of the Red Sea. The depression dimensions reach 5x14 km with a maximum depth of 2,170 m. Under the conditions of the oxygen-free basin the metals are deposited as the thin layers of the ferruginous sediments and sulfides forming layered deposits of the pyrite ores within its limits. The average content of Zn within such deposits is 2.8-5.05%, iron – 23.5-35.5%; gold concentration is about 1 ppm, silver – 80 ppm. The total zinc and silver reserves are estimated at about 2.5 million tons and 9 thousand tons respectively in the depression.

Besides SEDEX, VMS- and MVT (Mississippi Valley-Type) type deposits (stratiform deposits in the carbonate formations) are of great importance in the world balance of Pb and Zn. These deposit types (SEDEX, VMS and MVT) contain about 70-80 % of the total world reserves of Pb and Zn (Lobanova, Nekosb, 2017).

The latest obtained geological and geochemical data show that the first two types of deposits (SEDEX, VMS) are significantly different. Firstly, these deposits are different in the composition of the enclosing strata and there isn't a direct connection with volcanism. They present as lead-zinc deposits, being rich and poor in copper, which have formed at lower temperatures (less than 260°C). SEDEX deposits are thin-bedded massive sulfides with shales, siltstones or sandstone interlayers that are typical of the deep-sea turbidites (Fig. 3). These deposits do not contain high-commercial copper content but high silver content is usually observed.

The VMS type deposit – the pyrite-polymetallic deposit of the volcanic association is connected with underwater hydrothermal activity of the volcanogenic rocks. VMS deposits present usually the massive lenticular bodies that are underlain by the discordant vein-type mineralization and by the altered volcanic rocks.

Table 1 shows the content of the ore components formed in the different geodynamic settings.

As can be seen from this table, the ore metal deposits of the SEDEX type differ from other deposits formed in other geodynamic conditions.

In Russia the pyrite-polymetallic deposits of the VMS type are divided into Ural (deposits of Gayskiy, Uchalinskiy, Podolskiy, etc.) and Rudno-Altai (deposits of Rubtsovskiy, Korbalikhinskiy, etc.).

As noted by A.A. Marakushev (Marakushev et al., 2011), «an association of the pyrite-polymetallic ores with copper-pyrrhotite ores has been described in Caucasian deposits for example in the Filizchay

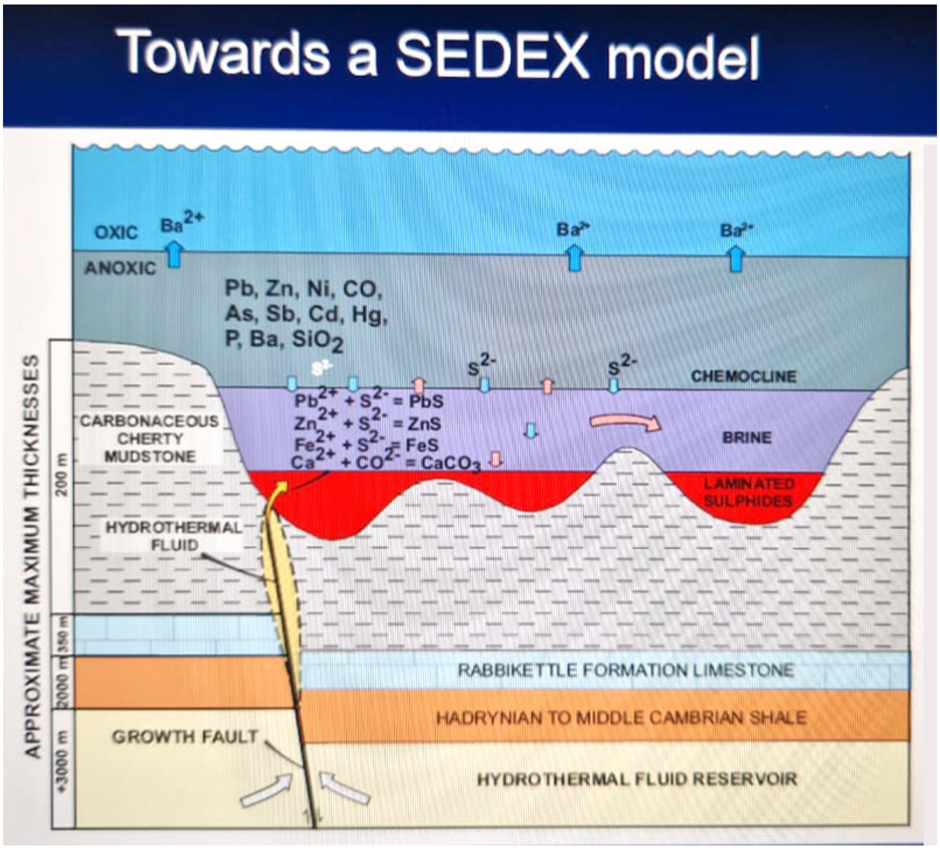

Fig.3. Typical model of the SEDEX deposit. According to (Sedimentary_exhalative_deposits).

Table 1. The content of the ore components formed in the different geodynamic settings. According to (Candela, 2003).

Deposit types	Primary ore metals	Other metals
SEDEX	Zn, Pb, Ag	Cu, Ba, Sn, Au
VMS Cyprus	Cu	S, Fe, Cu, Au, Ag, Zn, Co, Cd, Pb
VMS Kuroko	Cu, Pb, Zn, Ag, Au	S, Fe, Ba, As, Se, Cd, Sn, Bi, B
Besshi	Cu, Zn, Ag, Co	S, Fe, Pb, Ni, Mn, As, Sb, Sn, Mo, B
Island-arc porphyry deposits	Cu, Mo, Au	Re, S, Fe, As, Se, Bi, W, B, Sr, Zn, Pb, Co, V, PGE, Sn
Continental rifts – magmatic Ni-S deposits	Cu, Ni, PGE, Co	S, Fe
Island arc epithermal	Cu, Au, Ag	As, Sb, Hg, Pb, Zn, Cu, Ba, F, Mn, Mo, Se

deposit. It has been represented by the rhythmically laminated layer of the solid copper-lead-zinc ores with barite and with the superposition of the copper-pyrrhotite ores. The latter also form independent deposits (Katsdag, Kizil-Dere, Adange) referring to the pyrite ores formation. They differ fundamentally from the Ural copper-pyrrhotite ores».

Considering the above-mentioned we may conclude that the Filizchay deposit belongs to the SEDEX type.

Below we present some peculiarities of the SEDEX type pyrite deposits according to the literature data.

The sedimentary exhalative deposits (SEDEX deposit) are zinc-lead deposits which have been initially interpreted as formed by the release of the metal-bearing basin fluids on the seabed resulting in the deposition of the mostly sheet-like ores, often with thin interlayers of the sulfide minerals (140).

The term of SEDEX or «sedimentary exhalative» is a common name that shows the modern understanding of the genesis of these deposits as being formed by the sulfides' precipitation from the hydrothermal fluids released or «exhaled» onto the seabed.

SEDEX deposits consist mainly of the fragmental rocks deposited in the intracontinental rifts or in the collapsed rift basins and the passive continental margins. Because these ore deposits often form massive sulfide lenses they are also called massive sulfide deposits in sedimentary rocks (SHMS) in comparison with the massive sulfide deposits in volcanic rocks

(VMS) (Large, Walcher, 1999). The sedimentary view of the thin layers led to the early interpretations that the deposits were formed exclusively or mainly by the action of the exhalative processes on the seafloor .From here followed the SEDEX term. However recent research of numerous fields shows that shallow subsurface displacement is also an important process being predominant in some fields and having only local release to the seabed.

Therefore, in today's usage, the term SEDEX should not be understood to mean that the hydrothermal fluids have actually seeped into the overlying water column although in some cases this may have occurred (Emsbo, Poul, et al, 2010; Wilkinson, 2014).

The main ore minerals of SEDEX deposits are fine-grained *sphalerite* and *galena.* Chalcopyrite occupies a significant place in some deposits. Pyrite is always present and may be minor component or dominant sulfide, as is the case of the massive sulfide bodies. The barite content is from total to absent. The SEDEX deposits are the most important source of lead and zinc as well as the main source of silver and copper.

SEDEX deposits are distributed in various ore provinces of the world and they have sufficiently large reserves. Thus, one can note firstly «Zinc Belt of Australia». In this belt there is a large deposit of lead and zinc «Broken Hill», where the Zn + Pb reserves are about 52 million tons. The Canadian Cordillera deposits (Zn + Pb reserves – 67 million tons) for example the Sullivian deposits are in North America. Besides the above-mentioned, large deposits of this type are noted in India, China, Germany, Russia and Kazakhstan. In Russia in contrast to the Ural and Rudno-Altai types, SEDEX deposits include Siberian deposits – Kholodninskiy, Gorevskiy, Ozerniy. According to the preliminary data the Zn+Pb reserves of the Filizchay deposit are estimated at 4.751 million tons (total ore reserve – 60 million tons).

Therefore, judging by the geological structure, the reserves of the valuable Zn + Pb components of the Filizchay deposit can be referred to deposits of these types.

Conclusions:

1. The Filizchay deposit consists of thin-bedded massive sulfides with shales, siltstones or sandstones interbeds («ore flysch») which have been formed exclusively or mainly as a result of exhalative processes on the seabed and differ from massive sulfide deposits in the volcanic rocks. On the basis of this, the deposit belongs to the SEDEX type, being the most important source of lead, zinc and silver.
2. The deposit had been developing for a long time starting from the period of sedimentation and up to the ore formation of the copper-pyrrhotite stage. The lower age limit of mineralization is determined by the presence of the hydrothermal-sedimentary ores of the Upper Pliensbachian. The upper age limit is established by the presence of the pebbles of the hydrothermally altered rocks and by their sulfide ores in the conglomerates underlying the deposits of the Upper Jurassic lower parts.
3. The Filizchay field is combined according to the formation process and it has formed due to the components carried out by the hydrothermal flows. The deposits of the field have formed from several portions of the incoming hydrothermal solutions.

References

Akberov, M.A. Samedov, A.M. Mamedov, G.SH. et al. (1982). Ob osobennostyakh morfologii i prirodnykh tipakh rud Filizchayskogo mestorozhdeniya [On the peculiarities of morphology and natural types of ores of the Filizchay deposit]. Trudy TSNIGRI, M.: 168, 44-49 (In Russian).

Baba-zade, V.M., Agayev S.A. (1999). Osobennosti strukturnykh usloviy lokalizatsii i morfologii rudnoy zalezhi Filizchayskogo mestorozhdeniya [Features of the structural conditions of localization and morphology of the ore deposit of the Filizchay deposit]. Vestnik Bakinskogo Universiteta, Seriya yestestvennykh nauk, – Baku: –1, 91-108 (In Russian).

Candela P.A. (2003) Sedimentary exhalative deposits in: https://en.wikipedia.org/wiki/ Sedimentary_exhalative_deposits

Dergachev, A.L., Yeremin, N.I. (2008). Sootnosheniye vulkanogennogo kolchedannogo i stratiformnogo svintsovo-tsinkovogo orudeneniya v istorii Zemli [Correlation between volcanogenic pyrite and stratiform lead-zinc mineralization in the history of the Earth]. Vestnik Moskovskogo Universiteta. Seriya 4. Geologiya, 4, 26-34 (In Russian).

Emsbo, Poul, Seal, R.R., Breit, G.N. Diehl, S.F. (and &) (2010). Sedimentary exhalative (sedex) zinc-lead-silver deposit model. U.S. Geological Survey Scientific Investigations Report, 5070, 57. http://dx.doi.org/10.3133/sir20105070N.

Geologiya Azerbaydzhana: (v 10 tomakh). (2005). [Geology of Azerbaijan: (in 10 volumes)] Pod red. akademika A.A.Alizade. Baku: Nafta-Press, – vol.4, Tektonika, 505 (In Russian).

Goodfellow, W.D., Lydon, J.W. (2007). Sedimentary exhalative (SEDEX) deposits. In: Goodfellow, W.D. (Ed.)

Mineral deposits of Canada: a synthesis of major deposit types, district metallogeny, the evolution of geological provinces, and exploration methods. Ottawa: Geological Association of Canada Special Publication 5, 163–183.

Kengerli, T.N. (2009). Tektonicheskaya rassloyennost′ al′piyskogo chekhla Bol′shogo Kavkaza Bol′shogo Kavkaza v predelakh Azerbaydzhana (Tectonic layering of the Alpine cover of the Greater Caucasus of the Greater Caucasus within Azerbaijan). Avtoreferat diss. dokt. geol.-min. nauk. Baku, 61 (In Russian).

Kurbanov, N.K. Zaytseva, L.V., Gadzhiyev, T.G. (1976). Svinets i tsink [Lead and zinc]. Geologiya SSSR, Azerbaydzhanskaya SSR, chast′ II. Poleznyye iskopayemyye – M: Nedra, ILVII, 249-283 (In Russian).

Kurbanov, N.K. (1982). Kriterii poiskov i printsipy prognoziravaniya kombinirovannykh kolchedanno-medno-polimetallicheskikh mestorozhdeniy v Al′piyskoy terrigennoy geosinklinaley Bol′shogo Kavkaza [Search criteria and principles for predicting combined pyrite-copper-polymetallic deposits in the Alpine terrigenous geosynclines of the Greater Caucasus]. Trudy TSNIGRI. M.: 168, 87-97 (In Russian).

Kurbanov, N.K. (1982). Osnovnyye etapy formirovaniya kombinirovannykh medno-polimetallicheskikh mestorozhdeniy i ikh sootnosheniye so stadiyami evolyutsii al′piyskoy terrigennoy geosinklinali Bol′shogo Kavkaza [The main stages in the formation of combined copper-polymetallic deposits and their relationship with the stages of evolution of the Alpine terrigenous geosyncline of the Greater Caucasus]. Trudy TSNIGRI, M.: 168, 3-18 (In Russian).

Kurbanov, N.K. (1986). Usloviya formirovaniya i zakonomernosti razmeshcheniya stratiformnykh kolchedanno-polimetallicheskikh mestorozhdeniy terrigennykh evgeosinklinaley (na primere al′piyskoy provintsii Bol′shogo Kavkaza) [Formation conditions and distribution patterns of stratiform pyrite-polymetallic deposits of terrigenous eugeosynclines (on the example of the Alpine province of the Greater Caucasus)]. Avtoref. diss. … dokt.geol.-min.nauk. M.49 (In Russian).

Kurbanov, N.K., Buadze, V.I., Tvalchrelidze, A.G. (1983). Zona yurskikh slantsev Bol′shogo Kavkaza [Jurassic Shale Zone of the Greater Caucasus]. Kolchedannyye mestorozhdeniya SSSR, M: Nauka, 38-58 (In Russian).

Large, D, Walcher, E. (1999). The Rammelsberg massive sulphide Cu-Zn-Pb-Ba- Deposit, Germany: an example of sediment-hosted, massive sulphide mineralisation. Koln: Mineralium Deposita, 34 (5–6), 522–538.

Lobanov, K.V., Yakubchuk, R.A. (2014). Besshi-Type VMS Deposits of the Rudny Altai (Central Asia). Creaser Economic Geology, 109, 1403-1430.

Lobanova, K.V., Nekosb, V.V. (2017). Mestorozhdeniya tipa SEDEX – vazhneyshiy istochnik Zn, Pb i Ag v mire. Kratkiy mirovoy obzor. Perspektivy Rossii i Krasnoyarskogo kraya [SEDEX type deposits are the most important source of Zn, Pb and Ag in the world. Brief world survey]. Engineering & Technologies, – Siberian: Journal of Siberian Federal University, 10 (7), 881-907 (In Russian).

Marakushev, A.A., Paneyakh, N.A., Zotov, I.A. (2011). Petrogeneticheskiye tipy kolchedannykh i polimetallicheskikh mestorozhdeniy [Petrogenetic types of sulfide and polymetallic deposits]. Litosfera. 3, 84-103 (In Russian).

Sedimentary_exhalative_deposits in: https://www.sciencedirect.com/topics/earth-and-planetary-sciences/ exhalative-deposit

Shikhalibeyli, E.SH. (1956). Geologicheskoye stroyeniye i razvitiye Azerbaydzhanskoy chasti Bol′shogo Kavkaza [Geological structure and development of the Azerbaijan part of the Greater Caucasus]. Baku: izd. AN Azerb. SSR, 224 (In Russian).

Shikhalibeyli, E.SH., Karabanov, V.V. (1979). Geologicheskoye stroyeniye Durudzhinskoy shovnoy zony v vostochnoy chasti yuzhnogo sklona Bol′shogo Kavkaza (mezhdurech′ye Vandamchaya i Akhokhchaya) [Geological structure of the Durudzha suture zone in the eastern part of the southern slope of the Greater Caucasus (the interfluve of Vandamchay and Akhokhchay)]. Baku: Izvestiya AN Azerb. SSR, seriya nauk o Zemle, 2, 24-28 (In Russian).

Smirnov, V.I. (1968). Kolchedannyye mestorozhdeniya [Pyrite deposits]. V kn.: «Genezis endogennykh rudnykh mestorozhdeniy». M: Nedra, 586-649 (In Russian).

Tvalchrelidze, A.G. (1978). O tipakh kolchedannykh mestorozhdeniy i provintsiy [On the types of pyrite deposits and provinces]. Izvestiya AN SSSR, ser. geologicheskaya,10, 5-16 (In Russian).

Wilkinson, J.J. (2014). Sediment-Hosted Zinc-Lead Mineralization: Processes and Perspectives. Geochemistry of Mineral Deposits, Elsevier, 13, 219-249.