Nat. Volatiles & Essent. Oils, 2021; 8(4): 11020-11036

Modelling Of Magmatogene Ore Systems: Case Study Of Kazakhstan Stockwork And Quartz Vein Deposits

Gulizat Orazbekova[1]* , Arkady Mizerniy[1] , Anastassia Miroshnikova[1] , Mizernaya Marina[1] , Boris Dyachkov[1], Tatiana Oitseva[2]

[1]Department Geoscience, East Kazakhstan State Technical University, Ust-Kamenogorsk, Republic of Kazakhstan

[2]LLP «Geos»

*Email orazbekova_g@rambler.ru

Abstract

The article describes the results of using the consistent geological simulation while predicting gold ore fields in the territory of the oldest gold mining areas in the Republic of Kazakhstan - the West Kalba gold ore belt (Eastern Kazakhstan). The article studies the matters of formation of magmatogenic ore systems within quartz-vein and stockwork gold-sulphide deposits (Northern and Eastern Kazakhstan). The studies are aimed at the development of criteria for forecasting and searching the new ore objects in favorable geological structures. The main attention during the research was paid to the system analysis of geological factors whose interaction provides the synergetic effect and identification of patterns of formation of gold ore objects. For solving this problem, the authors carried out a quantitive assessment of the development stability of ore parent system elements according to S. V. Vasilyev. Using the geological materials, the results of geophysical works, cosmic-geological data, the localization of prospective areas within the West Kalba structural-formation zone and the Zhumbinsk ore-magmatic system (RMS) in East Kazakhstan was carried out.

Keywords: Ore-magmatic system, gold, deposit, assessment of the geological factors stability

1. Introduction

Studied deposits are located in Northern and Eastern Kazakhstan, within the Kazakhstan Middle Massif and the Kazakh part of the Greater Altai (GA), which are a part of the Central Asian Mobile Belt system. Within the territory under consideration, many deposits of non-ferrous metals, gold, rare metals, rare earths and other minerals of various geological and industrial types are concentrated, on the basis of which operating mining and metallurgical enterprises have been created. Currently, due to the reserve depletion of developed deposits, there is a problem of reserve replacement of all these types of raw materials.

In recent years, on the basis of modern geotectonic concepts, regularities of the formation and allocation of gold ore belts and metallogenic zones of the GA (Ore-Altai, West Kalba, Zharma-Saur), as well as in Northern Kazakhstan have been clarified. Metallogenic zoning of territories distinguishing the most important ore areas and ore nodes was performed. Classification of ore formational-based geological formations was carried out, the most important geological and industrial types of deposits were identified determining their practical significance (gold-pyrite-polymetallic, gold-quartz, gold-sulfide-quartz stockwork, gold-listvenite, gold-sulfide in carbonaceous carbonate terrigenous and gold-sulfide objects in black shale strata and others).

Crucial significance for practice of geological exploration is identification of the mineragenic specialization of various geodynamic situations and regimes associated with certain types of ore deposits. It was found that the studied gold ore objects – Bakyrchik, Zhumba, Vasilkovskoye and others were formed in Eastern and Northern Kazakhstan at the final stage of the collision process in the gabbro - granodiorite - plagiogranite gold-bearing ore - magmatic system ($C_{2\text{-}3}$-C_3).

The high-priority problem of the follow-up studies lies in geological and genetic modeling the ore-magmatic systems of specific gold deposits, the development of geological and structural, petrological and mineral-geochemical criteria for forecasting and searching the hidden ore objects.

2. Descriptions of materials, areas, and methods of study

During the research, the main attention was paid to the systematic analysis of geological factors identified based on the results of previous years [1], [2],[3],[4],[5], [6], [7], [8], [9], [10], [11], [12], [13], [14]. The interaction of these factors provides the synergistic effect and reveals the regularities of gold ore object formations. To solve this problem, the authors carried out the quantitative assessment of the development stability of ore parent system elements [2] and[4]. The assessment of individual factors stability and their interaction made it possible to assess the qualitative state of individual sections and determine the natural boundaries of the corresponding hierarchical level areas that are prospective in searching the certain mineral deposits[5] and[6].

Predictive metallogenic research of the region was conducted several times in different periods [13],[14], [15], [16], [17]and[18]. Geotectonic, lithologic-stratigraphic, igneous, metamorphic, structural-tectonic, mineralogical-geochemical and geophysical criteria were deemed the principal factors of localization of gold mineralization. By summarizing geological and geophysical data, researchers defined the main types of models [14], [15],[16],[17],[19].

Structural-metallogenic models of volumetric structure of structural-formational zones specify the distribution of mineralization in the section of ore belts and metallogenic zones.

Structural-ore-bearing multifactor models of ore clusters and ore fields characterize their tectonic positions within structure-formation zones, particularities of localization of ore deposits and ore bodies in connection with plicated and fault tectonics, give geophysical and geochemical characteristics, assess the depth of erosion section.

Geological-genetic models of typical deposits with their principal taxa: ore-bearing structures; parameters and shape of ore bodies; their being explored to a certain degree in depth and on the flanks; geophysical characteristics of ore bodies and wall rocks; mineral composition of ores, mineralization stages; ore processing technology; the remaining reserves and resources in the bowels (balance, off-balance, oxidated, man-made and other); prospects of stock growth.

Obviously, the practical informational “filling” of the models at all levels is scarcely possible, because the study levels of the parameters constituting these models are unequal. This will result in lowering of the reliability of a prognosis [16]. However, the use of microarrays for faster and more precise qualitative and quantitative analysis of object similitude under changing conditions [20] and applying of image segmentation which latest development shows promising results [18]for future automatized analysis of the collected data can positively affect the geological-genetic models' development.

The study purpose is to carry out simulation of ore-magmatic systems on the basis of a systematic analysis of geological studies on the example of studying quartz-vein and stockwork gold deposits whose development makes the significant contribution to the economy of Kazakhstan.

3. The structural setting and geology

The urgency of extending the resource base for gold mining industry is not to have doubts about. Though gold can be recycled via mineral extraction and refining from electronic waste as a part of the recycle program developed after the Life Circle Assessment (LCA) of the devices [1], the demand for it in technological and other industries is still high.

According to their industrial importance, natural Kazakhstan gold reserves are located in the four most thoroughly explored geological-and-industrial areas, which include large and medium-sized deposits: gold-silver-pyrite-polymetallic (Ridder-Sokolnoe), gold-sulphide-quartz stockwork (Vasilkovskoe, Sekisovskoe), gold-sulphide-quartz veined (Akbakai, Bestobe, Zholymbet), gold-sulphide streak-impregnated (Bakyrchik, Suzdalskoe). Currently, the share of these industrial types is estimated at about 65-70% of the gold mining industry of Kazakhstan[7].

The area under investigation makes a part of the Central Asian orogenic belt. There are different estimations of structure details and tectonic zoning of Central Asia[1], [2], [3], [4]. A Kazakh-Baikal composite continent is singled out; its basement was formed in the Vendian-Cambrian as a result of subduction. It combines microcontinents and Gondwana group terrains: Issyk-Kul, Karatau, Ulutau, Kokchetau, Aktau-Mointin, Tarbagatai, Central Tien Shan, Altai-Mongolian, Tuva-Mongolian, and other. The subduction and subsequent Hercynian collision of microcontinents was accompanied by metamorphism manifestations and mineralization processes.

Rudny Altai and West Kalbametallogenic zones (Sekisovskoe deposit and Bakyrchik and Zhumba deposits correspondingly), which constitute the immediate object of our study, make part of the north-western sector of Central Asian mobile belt; its tectonic structure and evolution have been already studied in detail [15].

Vasilkovskoe ore field has been formed within Kokshektau terrain in the structures of Lower Paleozoic floor of Central Kazakhstan. It is located west and north-west of Torgai-Medial-Tien-Shan microcontinent and makes part of Kokshetau-North-Tien-Shan Early Paleozoic orogenic belt, which consists of a series of suture zones [15]and[16].

The West Kalba metallogenic zone, which is most thoroughly studied in the article, belongs to the North-Western section of the Central Asian folded belt. Its final formation as a geological structure occurred in the late Paleozoic in the form of a belt of the north-western extension as a result of a collision of Kazakhstan and Altai-Mongolia paleo-continents. The structure of this territory is represented by the aleurolitic schist formation deposits (D3fm1-2), basalt limestone-terrigenously-Famennian formation, and early Visean formations are represented by limestone-sand-aleurolitic formation covered with flushoid carbonate-terrigenous formation of Vise (From$_1$v2-3), with a capacity of 500 m and a gray-colored strata silt-Sandstone formation of Serpukhov(C_1s). Among intrusive formations, the most ancient outcrops (PR_3) are confined to the zone of the Charsko-Gornostaevsky snap. In the Paleozoic, the main sub-volcanic bodies and dikes, associated with Devonian volcanism, appeared. During the Carboniferous period, small intrusions and dikes were introduced in collisional geodynamic conditions (gabbronorite-diabase formation, Karabiryuk complex C_{2-3}), as well as plagiogranite-granodiorite formation (Kunush complex C_3), which is associated with the occurrence of gold-quartz and gold-sulfide-quartz mineralization. Ore-controlling systems are north-western and latitudinal deep faults (Charsk-Gornostaevsky, West-Kalbinsky, Kyzylovsky, etc.), as well as north-eastern and meridional faults recorded from geological and geophysical data and decryption of satellite images) [16].

4. Results and data

4.1Characteristicsofore-magmaticsystemsofgold-sulfidestockworkdeposits

Vasilkovskoe deposit in Northern Kazakhstan is a model deposit of gold ore objects of stockwork type. It is located on the territory of Kokshetau median massif (terrain) – a large block of Precambrian metamorphic rocks, exposed to intensive granitization and accretion in the Phanerozoic. The main structural elements of the ore district are: the north-eastern periphery of Kokshetau terrain, the crossing node of regional faults of northwest (Dongulagash, Alekseevsky), northeast (Vasilkovsko-Berezovsky) and latitude (Shyrotny) orientations, and North-Kokshetau elliptical dome-ring structure.

Vasilkovskoe deposit is formed by the metamorphic basement of Proterozoic, intruded by granitoids of the Ordovician and overlapped by later Paleozoic sediment. Here, a dome-shaped intrusion of Zerenda complex of compound composition stands apart. Intrusive rocks are characterized by phase-facial transitions, banding, schlich insulations, magmatic rocks and branching apophyses. Scientists distinguish “gabbro” (gabbroes, gabbrodiorites, diorites, quartz diorites) and “granodiorite” (plagiogranites, granodiorites and granites) series. The granodiorites are characterized by a well-developed areal califeldsparization with red, pinkish-gray and gray porphyroblasts of microcline, which make from 5 to 70% of the rock volume. Among the dyke formations predominating are fine-grained granite, aplite-like and pegmatite granite.

The southwestern flank of the district is rich in red bed and terrigenous carbonate deposits (North Kokshetau deflection). The north-eastern flank is composed by upper Riphean-Vendian carbonaceous-terrigenous-carbonate rocks with a heightened content of gold (sharyk suite) [13].

The leading type of ore is gold-sulphide-quartz stockwork in intrusive rocks (Vasilkovskoe, Turan, Dalnee, etc.). A gold-pyrite-barite-polymetallic Berezovskoe deposit is located within the sharyk suite. A schematic structural tectonic model of the deposit is shown in Figure 1.

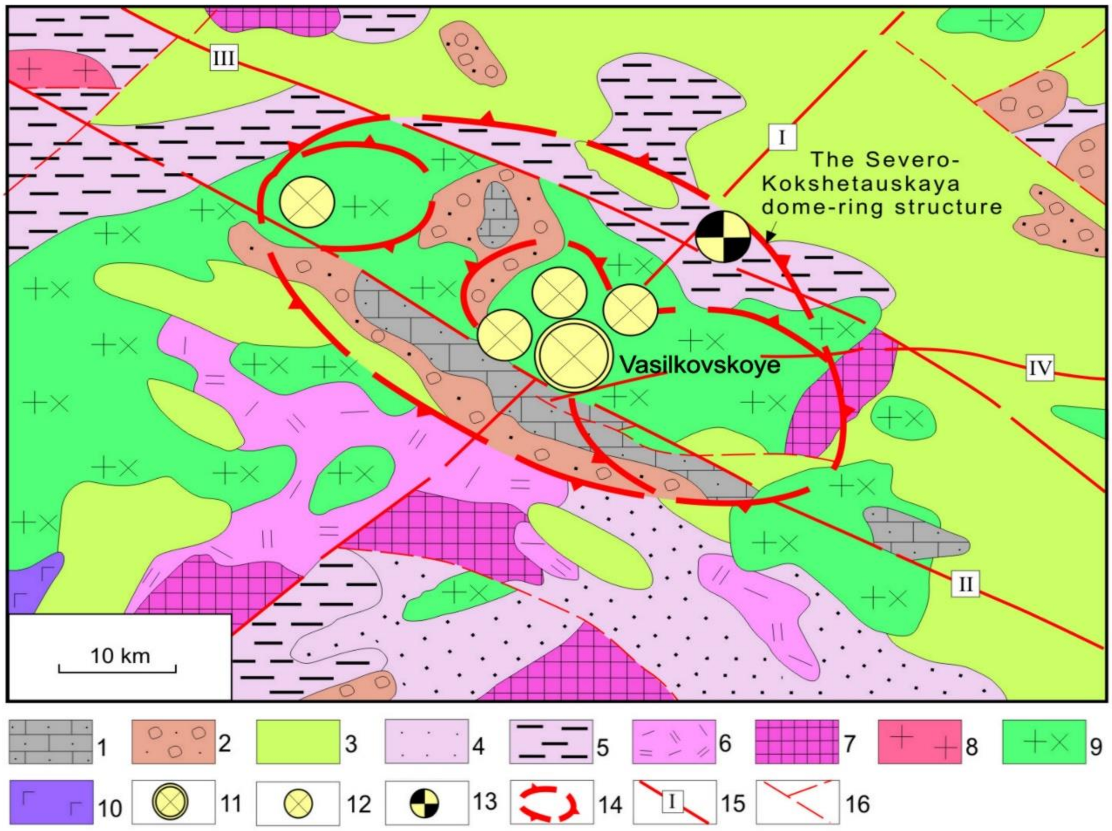

Figure - 1 1-10 – geological formations: 1 – terrigenous-carbonate C1, 2 – molasse conglomerate-sandstone D2-3, 3 – terrigenous, volcanogenic-terrigenous O1-2, O2, O2-3, 4 – terrigenous quartzite-sandstone R3-V (Kokshetau suite), 5 – carbonic terrigenous-carbonate R3-V (Sharyk suite), 6 – porphyroid-porphyritic R1-2 (Kuuspek suite), 7 – amphibolite-gneissic PR1-2 (Zerenda depositional sequence), 8 – leucogranite D2 (Zolotonoshensky intrusive complex), 9 – batholithic mottled consistence O3-S1 (Zerenda intrusive complex), 10 – gabbro gabbro-dioritic, 11-12 – gold-sulfide-quartz objects of the stockwork type: 11 – very large Vasilkovskoye deposit, 12 – small deposits and ore occurrences, 13 – Berezovskoye gold-pyrite-barite-polymetallic deposit; 14 – dome-ring structures, 15 – regional snaps: I – Vasilkovsko-Berezovsky snap, II – Dongulagash, III – Alekseevsky, IV – Shirotny, 16 – snaps of the second and third order

Vasilkovsky gold ore district clearly manifests itself through geophysical fields, deep tectonic structures, regional and local geochemical anomalies. Concentrated gold mineralization is located in the area of Dongulagash fault in hybridized intrusive rocks of heightened magnetization. Gold ore objects are located at the transitions from positive gravity anomalies to negative anomalies. The first indicate poorly granitized rocks of the basement, the second – an intensively granitized substrate. The ore district is associated with the mobile tectonic zone constituted by the contact areas of the granite-gneiss dome and femic (greenstone) block of basement rocks. This zone, located above the area of the local lifting of Conrad surface and the local deflection of Mokh surface, has deep roots connecting it to the lens of granulite-basalt layer of heightened thickness (24-26 km).

The gold ore field, localized at the intersection of Dongulagash and Vasilkovsky -Berezovsky faults, is characterized by a frame-bloc tectonic structure and contrasting hydrothermal rock alterations. Formation of the ore field and localization of the gold mineralization area have been greatly influenced by systems of faults. Fissures and fracture zones acted as frames for metasomatism processes. The deposit was formed in the area of contacting gabbro-diorites, diorites and corniferous-biotite granodiorites, and plagiogranites of Zerenda complex. The cross-section of the stockwork on the surface is first few hundred meters, the vertical extent is up to 1.0-1.5 km. The average gold content is 3.5 grammes per ton. The stockwork consists of a series of gold-bearing streams, trending at angles of 35-40° in the south-west.

Major importance in control over the mineralization is attached to the frame of faults and fracture zones of northwest (Dongulagash) and northeast-course (Berezovsko-Vasilkovska) (Figure 1).

Sekisovsky gold ore district is located within the Aleisk subzone of Rudny Altai structure-formation zone within the area of the south-east embedding of Aleisk anticlinorium. Of primary importance are intrusive formations of Zmeinogorsk complex, well-developed are volcanogenic sediments of Frankish and Famennian stages, Tournasian and Visean stages [2].

Structurally, Sekisovskoe ore field is related to Shemonaikhin-Sekisovska horst anticline, which complicates the northeast wing of Aleisk anticline, which in its turn is a hard lump of pre-hercinian base, significantly raised and complicated with shallow mid-Palaeozoic deflections. The northeast wing of the horst anticline is complicated with an eponymous major fault of northwest course, which is the main magma-efferent structure at the time of realization of the first phase of Zmeinogorsk complex. In general, the ore field is characterized by concentration of mineralization in the junctions of faults of different orders.

The structure of ore fields features intrusive rocks of Sekisovsky massif formed by magmatites of all four phases of Zmeinogorsk complex. Post-granite dykes of mid-basic and acid composition are widely spread.

The ore field is characterized by intensive development of faults of different orders and courses, which determine its frame-block structure. The basic northwest faults controlled the location of explosive-hydrothermal breccias, ore bodies and dykes [2], [9].

All of the known ore bodies are localized within modified explosive-hydrothermal breccias with tubular, elongated shapes, their size ranging from 40x100 meters to 120x500 meters. The gold is distributed very unevenly, forming a kind of cluster-striated type of mineralization with a heightened concentration (of sprays) of gold in places of contacts of various breccias types. Mineralization is represented by two types: ingrained hydrothermal-metasomatic and cluster-vein hydrothermal, manifested mainly in the cement of breccias[19]. The deposit is being currently excavated.

4.2. Characteristics of ore-magmatic systems of gold-quartz deposits on the example of Western Kalba (Eastern Kazakhstan)

West Kalbametallogenic zone is an essential element of the architecture of the Big Altai, a leader by the potential of gold among the folded belts of Kazakhstan. The zone was formed in the Late Palaeozoic in the form of a strip taking a northwestern course as a result of a conflict of Kazakhstan and Altai-Mongolian palaeocontinents. In the lower part of the section, there are deposits of aleurolitic-slate formation at least 300 meters thick, which is overlapped by a basalt limestone-terrigenous-siliceous formation of the late tourne capacity of 1500 meters thick.

Early Visean formations are represented by limestone-sandstone-aleurolitic formation 300 meters thick. They are overlapped by carbonaceous-calcareous-terrigenous formation 500 meters thick. These deposits are overlapped with a break by a cover grey wacke aleurolitic-sandstone formation up to 1400 meters thick [20].

Among the intrusive formations, the oldest are the serpentinite protrusions associated with the area of Charsko-Gornostaevsky deep fault. Basic and subvolcanic bodies and dykes are related to the Devonian volcanism. Small intrusions and dykes originated in a collision geodynamic environment (gabbronorite-diabase formation, Karabiryuk complex and plagiogranite-granodiorite formation, Kunush complex), which is associated with gold-quartz and gold-sulphide-quartz mineralization [1]. Ore-controlling are the systems of north-western and latitudinal deep faults (Charsko-Gornostaevsky, West Kalba, Kyzyl, etc.), as well as north-eastern and meridian faults, detected by geological and geophysical data and decoding of satellite monitoring [12]and[14]and[15].

On example of the Zhumbinskaya ore-magmatic system (MOS) of East Kazakhstan, work was carried out to identify promising areas for identification of gold ore objects. The work performed was carried out on the basis of a quantitative assessment of the stability of individual factors using geological materials on a scale of 1: 50,000, results of geophysical work, and cosmogeological data.

5. Interpretation and discussion

The performed research helped to substantiate the choice of typical models of ore-forming systems for various geological-industrial types of gold mineralization. In case of West Kalba, the ore-forming formation system of gold-sulphide-quartz deposits is indicated by faults that caused the rise of magma melts, introduction of small intrusions and dykes (C_3), penetration of ore-bearing fluid flows into the upper part of the crust and formation of a zonal ore column (Figure 2). A partial borrowing of sediment gold from the wallrocks of Arkalyk suite by ore-bearing solutions is suggested (S_1V_{2-3}). Mineralization mainly in the form of gold-bearing quartz veins took place in the fracture structures of grey wacke formation (C_1s) (deposits of Zhumba, Kuludzhun, Sentash, Laiby, etc.) (Figure 3).

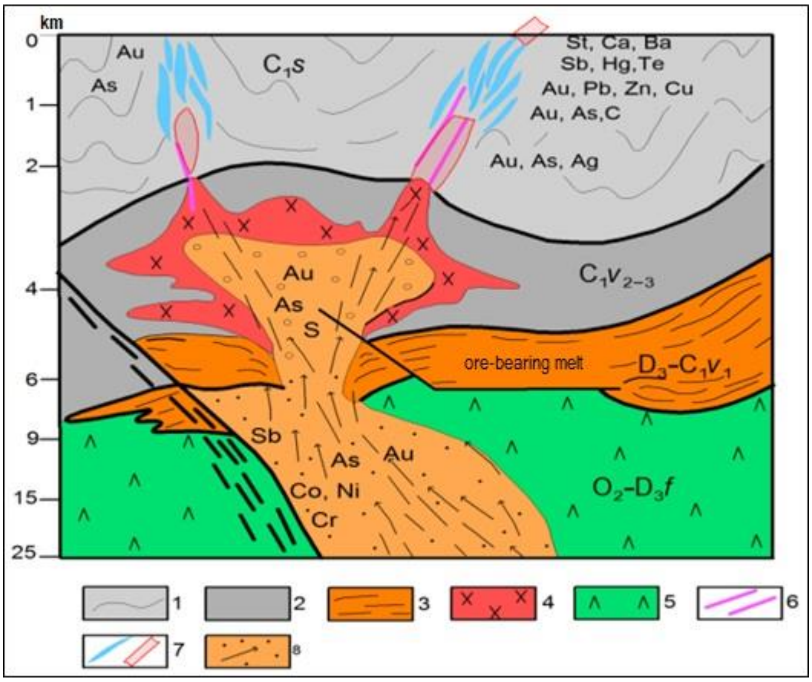

Figure - 2 Modelling of the formation process of the column of gold-bearing hydrothermal ore-forming system. West Kalba, East Kazakhstan: 1 – ore-bearing terrigenous complex C1s; 2 – area of magmatic replacement of the original matrix gold formation C1v2-3; 3 – granodiorites and plagiogranites C3; 4 – metapelitolites and metaofiolites O2 - D3; 5 – beresitizedgranitoid dykes; 6 – gold-bearing veins and zones of mineralization.

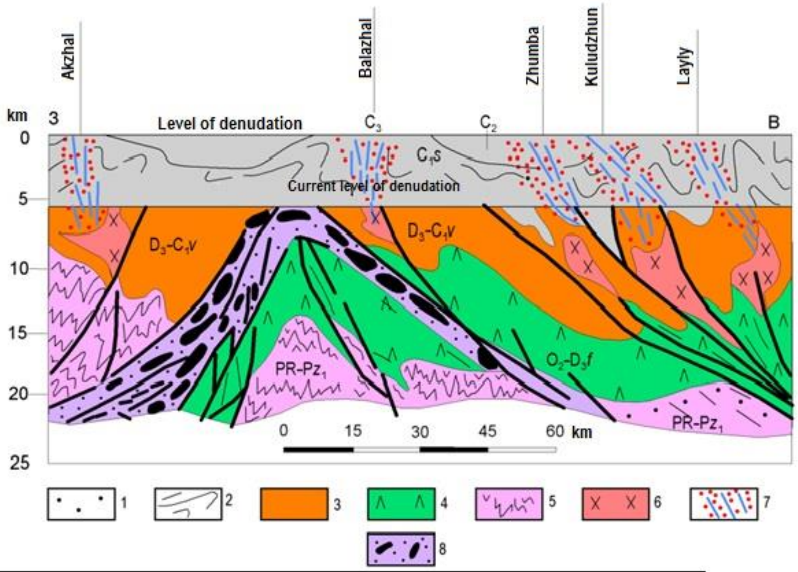

Figure -3 Modelling of ore-forming system of gold-quartz vein and beresite mineralization: 1 – sea molasses C2; 2 – melassoids C3; 3 – volcanogenic-siliceous-terrigenous formations D3 – C1v; 4 – metaofiolites O2 - D3f; 5 – plagiogranites, granodiorites, quartz diorites C3; 6 – gold-bearing quartz vein system; 7 – serpentinitelito-melange.

This model of mineralization is typical of all gold-quartz deposits in West Kalba (Figure 3).

The ideas of uniformity of ore-controlling structures are consistent with the data on the fundamental similarity of geological factors that determine the location of gold ore fields of various regions of the world. Local areas of development of endogenous mineralization are controlled by nature overlapping tectonic-magmatic structures of focal character of the same type[18]. These include the areas of development of small intrusions and juvenile diamagmatic fluids [16]. These factors are invariant for different stages in the development of gold ore provinces: doming (North Kazakhstan, Vasilkovskoe deposit); conflict (Bakyrchik, Sekisovka); late orogenous (Southern Tien Shan); of tectonomagmatic activation (Daur zone); of formation of greenstone troughs (Canada, Zimbabwe) [5]and[6].

Research is primarily focused at a systemic analysis of geological factors, the interaction of which provides a synergistic effect and enables identification of regularities in the formation of gold ore objects. To perform this task, a quantitative assessment of the sustainability of system ore-generating elements was made according to a certain procedure [2]. Quantitative assessment of the stability of individual factors and their interaction made it possible to assess the quality of the state of individual sections and to define the natural boundaries of the areas of a certain hierarchical level, which is promising for the search of certain mineral deposits.

As ore-generating factors, the structures of location of small intrusions of various compositions and gold ore objects were explored; as ore lead-in elements – deep fault system, structure zones and crumple zones, identified according to the results of space and ground-based monitoring. Reconstruction of magmatogene ore system (MOS) made it possible to identify promising local area of ore clusters.

The purpose of a detailed study of Zhumba MOS case was the localization of promising areas to the ore field and deposit sizes. These studies were carried out on the basis of geological materials of scale 1:50 000.

Zhumba ore zone is situated on the eastern flank of West Kalba area (Zhumba, Variag, Fedor-Ivanovskoe deposits) (Figure 4). The area is composed of tuff-sandstones of middle strata of serpukhovsky stage with aleurolite interlayers. The peculiarity of the structure is its “cryptmagmatic" type. On the surface there are no magmatic formations; results of the interpretation of geophysical fields indicate the presence of unopened intrusions of granitoid composition. Within the ore zone metasomatic formations are detected (areas of sulfidized rock oxidation and pyritization). Quartz vein bodies are compactly grouped in five clusters, four of which involve well-known gold deposits (Zhumba, Variag, Fedor-Ivanovskoe, Svistun).

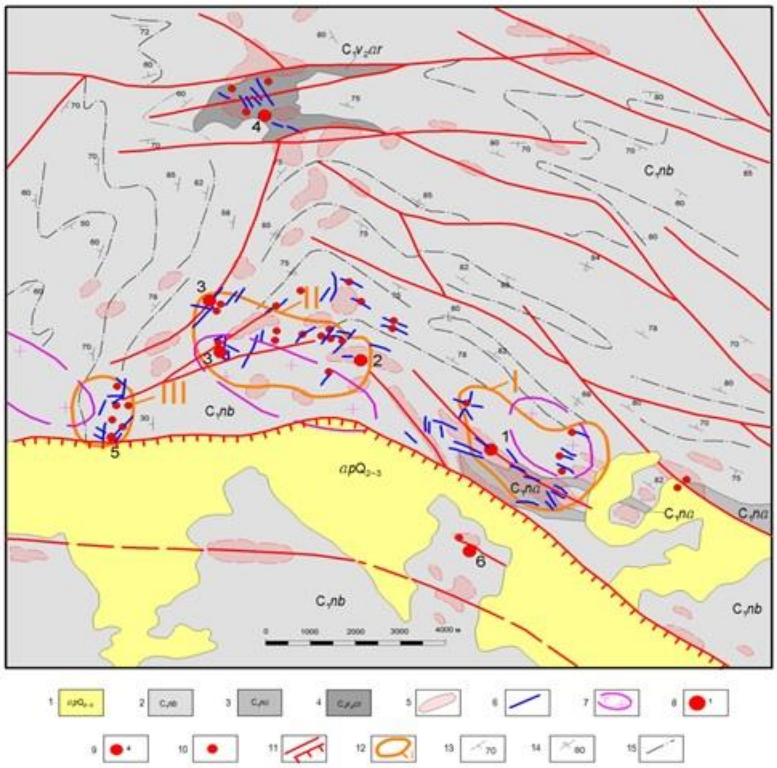

Figure -4 Schematic map of Zhumba ore field (Drawn up jointly with PGO "Vostkazgeologiia"): 1 – alluvial-proluvial deposits; 2 – Serpukhov stage, the middle strata (tuff-sandstones, infrequent tuffites and tuffs interbedded with aleurolites, lenses of limestone and gravelites); 3 – namur stage, the lower strata (coarse interbedding of siltstones with aleurolites with tuff-sandstones and polymictic sandstones); 4 – Visean stage, Arkalyk suite (aleurolites, polymictic and grey wacke sandstones); 5 – areas of ferrugination and pyritization; 6 – quartz veins; 7 – unopened granitoid intrusions according to geophysical data; 8 – gold deposits (1 – Zhumba, 2 – Variag, 3 – Fedor-Ivanovskoe); 9 – gold mineralization (4 – Svistun, 5 – RP №15, 6 – Belyi); 10 – spots of gold mineralization; 11 – faults, including those activated (strokes are directed towards the lowered block); 12 – promising areas; 13 – sloping bedding of layers; 14 – overturned bedding of layers; 15 – structural lines.

The researchers performed a structuring of metasomatic altered rocks and quartz vein bodies. Assessment of the extent of stability helped to localize the outer boundary of the zone of influence of the hidden intrusions. At the same time, localization of hydrothermal-metasomatic formations and gold deposits within it is distributed to three radially oriented zones, which makes graphic its underlying focal character (Figure 5).

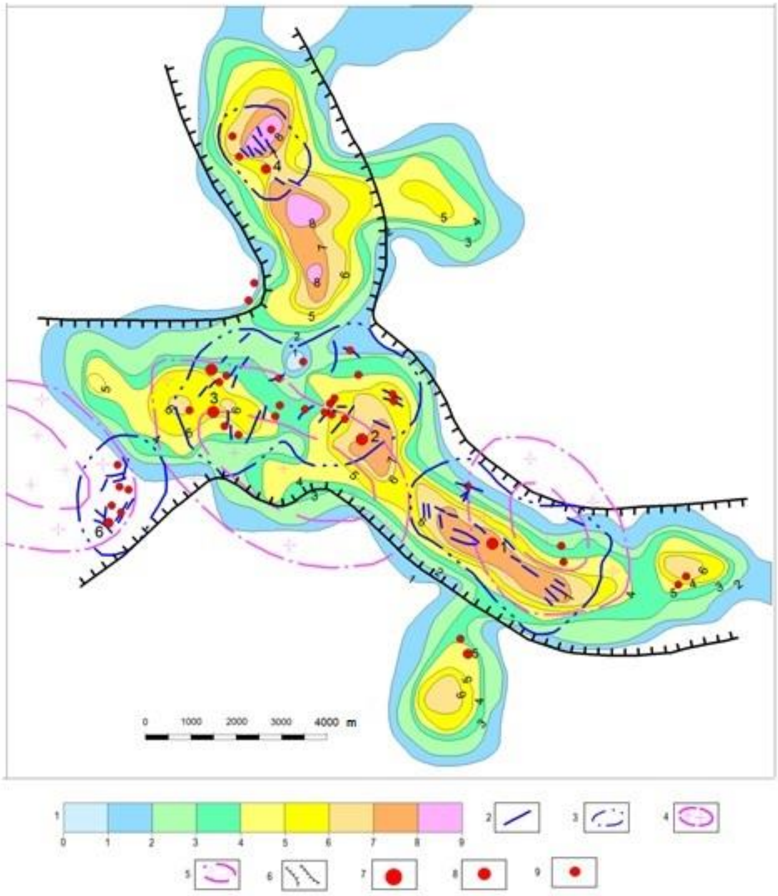

Figure -5 The structure of localization of metasomatic formations, quartz vein bodies of Zhumba territory and position of unopened intrusions and gold ore objects: 1 – ranges of values of stability extent of metasomatic formations; 2 – quartz veins; 3 – areas of sustainable development of quartz veins; 4 – unopened granitoid intrusions according to geophysical data; 5 – exocontact area of influence of granitoid intrusions; 6 – borders of hydrothermal ore systems; 7 – deposits; 8 – gold mineralization; 9 – spots of gold mineralization.

The most extensive area of metasomatically altered rocks is found in the area of hydrothermal ore system (ore cluster). The inner parts of the "rays" feature dissipative structures with the maximum values of sustainability measures, which indicates the "centres" of most explicit manifestations of metasomatic processes. The largest field of quartz vein formation is situated in the nuclear part of the structure[15] and [17].

The deposits known to the science and promising mineralization areas in the structure of metasomatic formations are localized in the areas of measure values of 4-7 (Figure 5), covering the territory of 33 km^2, or 40.5% of the total area of metasomatites.

Quartz vein bodies are less significant (Figure 5). Their area makes 50.5 km^2, and they are localized mainly in the inner parts of metasomatites. Analysis of the distribution of gold ore objects shows that they are concentrated in the areas of the intervals of 5, 6 and 7 measure values on the territory of 13.75 km^2 (27.23% of the area of quartz vein bodies and 16.8% of the area of metasomatic formations).

Both analysis of geological material and the statistical data show that all the deposits are located in the areas of joint sustainable development of metasomatic formations and quartz vein bodies, which is considered a multiplicative indicator of location (Figure 6).

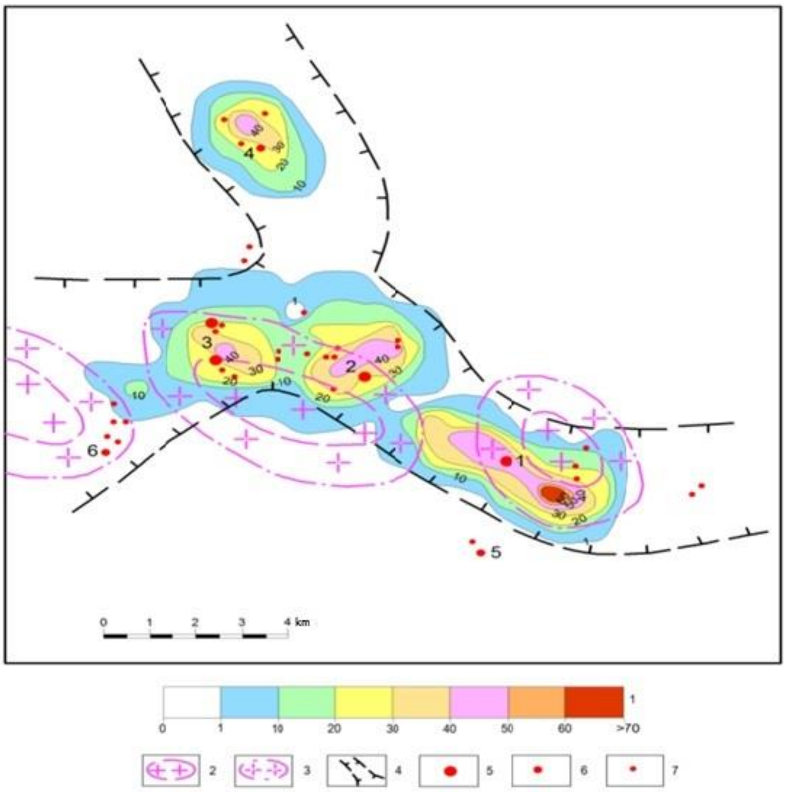

Figure -6 The structure of the joint development of quartz vein bodies and metasomatic formations of Zhumba zone: 1 – intervals of values of sustainability measure; 2 – exocontact area of influence of unopened granitoid intrusions; 3 – unopened granitoid intrusions according to geophysical data; 4 – borders of the hydrothermal ore systems. The remaining symbols are defined in Figure 5.

The area of sustainable joint development of these formations is 43.7 km^2, or 14.7% of the ore cluster area. Analysis of the distribution of gold ore objects of different scales shows that they are localized in the areas of intervals of measure values of over 20, which makes 13.5 km^2, or 30.9% of the area of the joint development of these formations and bodies and, respectively, 4.5% of the ore cluster area.

As intrusive formations constitute a key element of the model, in order to evaluate the regularities of distribution of ore bodies and granitoids, a measure of their stable combination was calculated (Figure 7).

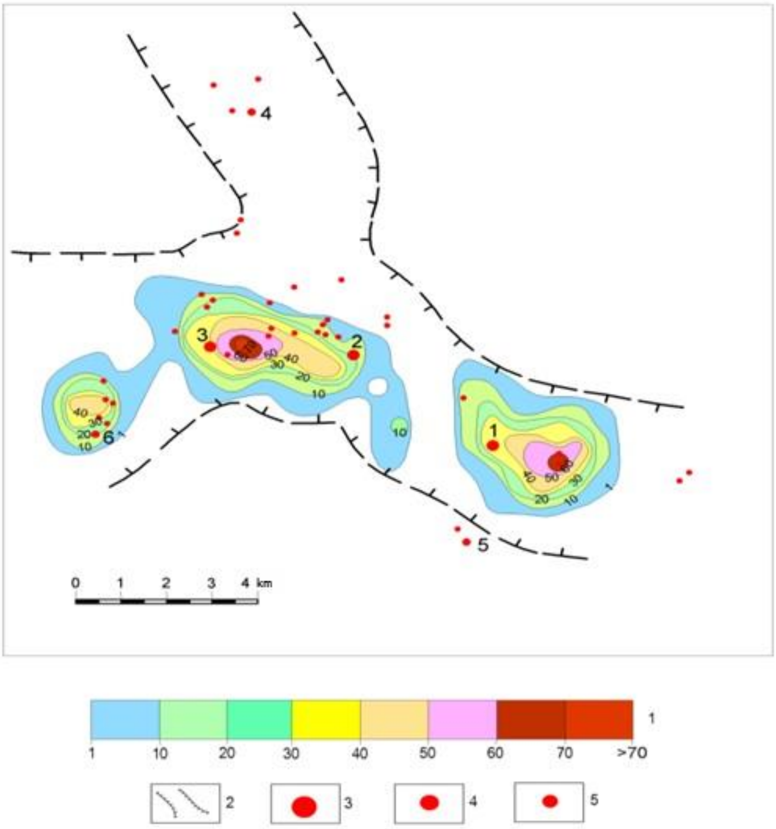

Figure -7 The structure of the joint development of quartz vein bodies and intrusive formations on the area of Zhumba zones: 1 – intervals of values of sustainability measure, according to geophysical data; 2 – borders of the magmatogene-ore system. The remaining symbols are defined in Figure 5.

As it is shown, the largest gold ore sites are localized within the areas of intervals of measure values of over 20 (on the area of 10.8 km^2) and are singled out as most promising predicted areas (Figure 4).

Thus, predicting gold ore objects of Zhumba ore zone is associated with the three areas, each of them being seen as a potential ore field (Zhumba, Variag-Fedor-Ivanovskoe and Novaia in the area of mineralization No15), where a new gold deposit is most likely to be discovered.

6. **Conclusions**

Thus, based on the results of studies at the regional level, general patterns and principles of the formation of the gold ore-magmatic system have been identified.Particular importance is attached to the duration of functioning of the system of ore-controlling deep-lying faults of different orders, which furthered the introduction of intrusive-dyke series of gabbro-diorite-granodiorite-plagiogranite composition, the powerful development of metasomatism and ore formation processes.

For a Zhumba ore zone, the ore-metasomatic system in the intrusive zone of a hidden granitoid massif was reconstructed by methods of system analysis. During the initial stages of its development, vast fields of hornfelsing were detected with zones of pyritization and ferrugination of the enclosing strata.

It was found out that the intensity of manifestation of metasomatic processes and quartz vein bodies is uneven and is accompanied by formation of local clusters, called forth by isolation of the centers of ore-bearing silicate melts on the final stages of mineralization. Localization of gold mineralization takes place at all stages of the ore system formation. This is evidenced by the presence of free gold associated with sulfides in the ores.

On the basis of the aforementioned findings, the promising areas in grades of ore cluster rank for future search of new gold ore deposits were identified.

Funding

This work was supported by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan, grant BR10264558, AP08856325.

References

[1] P. Yermolov, Y. Ponomareva and V. Portnov, «Age and geodynamics of the Irtysh shear zone,» Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, vol. 6, pp. 13-19, 2018.

[2] Y. Antonov, «About some structural and lithological factors of control of gold mineralization of the Bolshevik deposit in East Kazakhstan,» Geology and protection of mineral resources, vol.2, pp. 15-26, 2010.

[3] S. Srinivas, H. Ganesh, K. Singh, J. Sagar and H. Anitha, «Survey on Electronic Devices and its Impact on Environment during Each Phase of Their Life Cycle,» International Journal of Emerging Technologies in Engineering Research, vol. 8(6), 2020.

[4] S. Vasiliev, «Forecasting based on the system-information approach,» вComputer forecast of mineral deposits, M. , Nedra, 1990, pp. 208-225.

[5] F. Letnikov, Synergetics of geological systems, Novosibirsk: Nauka, 1992.

[6] A. Marakushev, «X All-Union Metallogenic Meeting,» вThe nature and metallogenic significance of deep fluids. Metallogenis of the Ural-Mongolian folded belt, Alma-Ata, 1983.

[7] M. Buslov, D. Kokh and I.De Grave, «Mesozoic-Cenozoic tectonics and geodynamics of Altai, Tien Shan, and Northern Kazakhstan, from apatite fission-track data,» Russian Geology and Geophysics, vol.49(9), pp. 648-654, 2008.

[8] M. Rafailovich, The underground gold of Kazakhstan: geology, metallogeny, forecasting, and predictive-search patterns, Almaty: Кompleks, 2009.

[9] M. Buslov, «Tectonics and geodynamics of the Central Asian Foldbelt: The role of the Late Paleozoic large-amplitude strike-slip faults,» Russian Geology and Geophysics, vol.52(1), pp. 52-71 , 2011.

[10] M. Buslov, H. Geng, A. Travin, D. Otgonbaatar, A. Kulikova, M. Chen, S. Glorie, N. Semakov, E. Rubanova, M. Abildaeva, E. Voltishek и D. and Trofimova, «Tectonics and geodynamics of Gorny Altai and adjacent structures of the Altai–Sayan folded area,» Russian Geology and Geophysics, vol.54(10), pp. 1250-1271, 2013.

[11] A. Didenko, A. Efimov, P. Nelyubov, A. Sal'nikov, V. Starosel'tsev, B. Shevchenko, M. Goroshko, V. Gur'yanov and N.Zamozhnyaya, «Structure and evolution of the Earth's crust in the region of junction of the Central Asian Fold Belt and the Siberian Platform: Skovorodino–Tommot profile,» Russian Geology and Geophysics, vol. 54(10), pp. 1236-1249, 2013.

[12] M. Rafailovich, Gold geology of Central Asia: mineralization evolution, metasomatic formations, explosive breccias, Almaty: KazGeo Publishing, 2013.

[13] V. Lyubetskiy, Deep criteria of localization of gold mineralization in Kazakhstan based on geophysical data. In: Experience of forecasting and evaluation of gold deposits in Kazakhstan,

Alma-Ata: KazIMS Publishing, 1985.

[14] K. Bespaev, V. Lyubetskiy, L. Lyubetskaya and B.Uzhkenov, «Gold ore belts of Kazakhstan (deep structure, geodynamics of development, underlying factors of localization of mineralization),» Herald of NAS RK, Geology Series, vol.6, pp. 39-48, 2008.

[15] M. Mizernaya, S. S. Aitbayeva, A. Mizerny, B. Dyachkov и A. & Miroshnikova, «Geochemical characteristics and metalogeny of Herzin granitoid complexes (Eastern Kazakhstan),» Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, vol. 1, pp. 5-10, 2020.

[16] M. Mizernaya, B. Dyachkov, O. Kusmina, A. Mizerny and T.Oitseva, «International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management (SGEM),» вMain types of gold deposits of the eastern Kazakhstan, Albena, 2017.

[17] V. Globa, «Gold ore formations of the regions of mobile-belt activation of Kazakhstan,» Herald of NAS RK, Geology Series, vol.3-4, pp. 110-114, 2004.

[18] S. Ravichandran, «An Inventive Technique of Reciprocated Report and Fuzzy Constructed Huddling in Microarray Genetic Statement Facts.,» International Journal of Emerging Technologies in Engineering Research, т. 8(8), 2020.

[19] S. Chourasia и A. and Bhalla, «Review of Segmentation and DT-DWT Techniques» International Journal of Emerging Technologies in Engineering Research, vol. 7(4), 2019.

[20] A. Mizerny, A. Miroshnikova, M. Mizernaya и B. Diachkov, «Geological and structural features, magmatism and mineralization of Sekysivske and Vasylkivske Stockwork gold deposits (Kazakhstan),» Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, vol. 2, pp. 5-13, 2017 .