Chapter 5

Tectonics and Metallogeny of East Kazakhstan

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Additional information is available at the end of the chapter

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Abstract

General regularities in the formation of tectonic and metallogenic structures are considered as a scientific basis for forecasting new deposits of nonferrous, precious and rare metals in the territory of East Kazakhstan and are considered on the basis of modern geotectonic concepts of the Earth self-development. Regular connections between the main ore-bearing structures and the leading geological-industrial types of deposits are determined with features of the deep crustal structure and certain geodynamic settings of various geotectonic cycles and eras (from the Precambrian to the Quaternary). The belt placement of ore deposits is emphasized with the identification of four ore belts: Rudny Altai (Cu, Pb, Zn, Au), West Kalba (Au, Ag), Kalba-Narym (Ta, Nb, Be, Li, Sn, W) and Zharma-Saurs (Cr, Ni, Co, Au, TR). In the location of gold ore deposits, the Zaisan suture zone, formed in the collision zone of the Kazakhstan and Siberian lithospheric plates, is the ore-controlling value. Spatial-genetic connections of rare metal and rare-earth deposits with granitoid belts formed in post-collision (orogenic) geodynamic conditions of Permian time are determined. The research is aimed at strengthening the mineral and raw material base for the operating enterprises of the East Kazakhstan region.

Keywords: Central-Asia, Zaisan zone, suture, ore-bearing structures, deposits

1. Introduction

The beginning of the twenty-first century was marked by a sharp increase in fundamental geological research in the world to create a modern scientific basis for further development of mineral and raw materials sector of the world economy. Mineral resources are still the backbone of the economies of many countries, but there is a general tendency for their depletion as a result of mining the deposits discovered in previous years. The most important task is to open new mineral deposits on the basis of modern geotectonic concepts of geological structure development and processes of ore formation with the aim to develop new technologies of deep earth prognosis and prospect for ore deposits [1].

The territory of East Kazakhstan is a unique geological area, in which many deposits of copper, lead, zinc, gold, silver, rare metals and rare earths, titanium, hydrocarbon raw materials and other minerals are concentrated. A powerful industrial infrastructure of mining and metallurgical works and plants has been built in the region on their basis.

The novelty of the study is further development of scientific idea of the Greater Altai (GA) geostructure formation during the Hercynian collision (C_1-C_3) of Kazakhstan and Siberian paleomicrocontinents, horizontal displacement and coalescence of large tectonic blocks of the earth's crust (terranes) during the Irtysh-Zaisan paleobasin (a part of the Paleo-Asiatic ocean) degradation. A significant ore-controlling importance is attached to justification of belt placement of ore-bearing structures and deposits which were formed in various geodynamic settings and regimes.

The tendency of ore deposit's belt distribution is manifested in the North American, Mexican, South China, Urals metallogenic provinces and other regions of Kazakhstan [4, 6]. Revealed ore belts within the territory of the Greater Altai regional ranks offer new opportunities for deposit forecasting and prospecting especially on poorly studied and closed territories.

2. Geotectonic position of the Greater Altai geological structures

The Hercynian geostructure of the Greater Altai is located in the Central Asian mobile belt, in the northwest of the Altai-Alashan Modal Zone, and is bounded by deep faults in the northwestern direction (Loktevsko-Karairtyshsky and Chingiz-Saursky) which separate it from the Caledonides of the Gorny Altai (in the northeast) and Chingiz-Tarbagatai (in the southwest). The territory under consideration unites the geological structures of the Rudny Altai, Kalba-Narym, Western Kalba, Zharma-Saur and adjacent areas of Russia and China, the total length of which is more than 100 km with an average width of 3000 km in modern coordinates (**Figure 1**).

According to geotectonic zoning, they are separate blocks of the earth's crust or terranes that were welded together during the Hercynian collision and separated by a system of deep faults or structural zones (the Northeast, Irtysh, Zaisan, and so on). The latter are also considered as zones of upwelling and the entry of mantle material, and ore-bearing fluid flows into the earth's crust [2].

The deep structure of the region in terms of geological and geophysical data is sharply heterogeneous and is characterized by a multilayered earth crust (up to 50–55 km thick) with heterogeneous linear-mosaic blocks complicated by folded and discontinuous deformations.

The model of the GA deep structure is presented at the geological and geophysical section of the Altai geotraverse compiled by Lyubetskiy et al. (**Figure 2**) [2, 3]. The upper mantle (UM) is characterized by an inhomogeneous structure, and it lies at a depth of 38–55 km and has a dissected relief. Mohorovichich's (M) raising of the surface is also recorded in the northwestern flank of the suture zone (Gornostaevsk) and its southeastern continuation (Zaisan), and in the Rudny Altai (Rubtsovsk) [2].

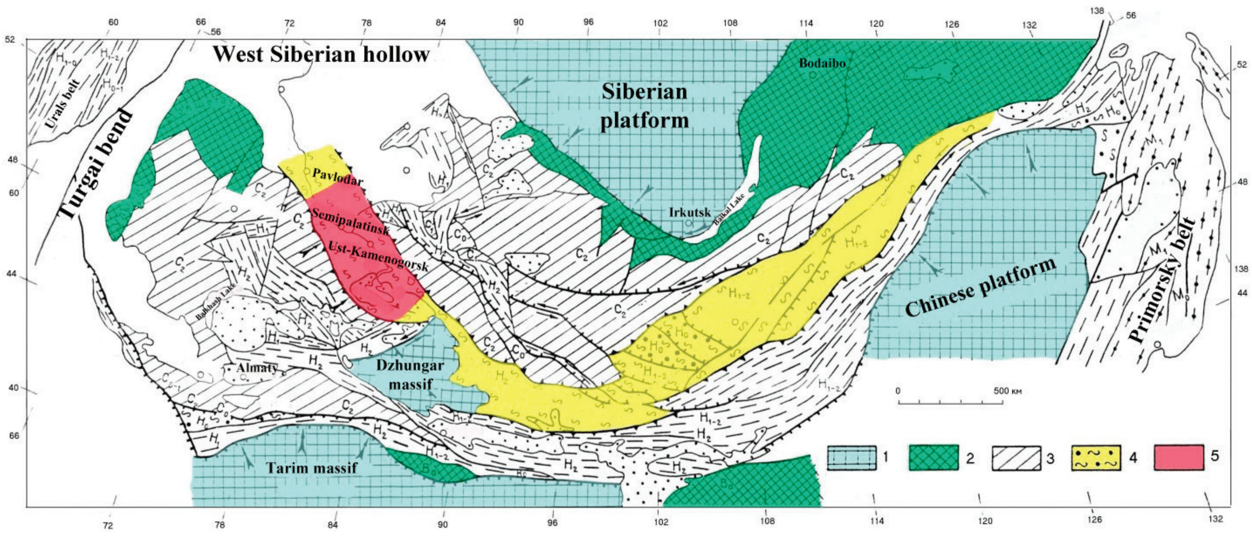

Figure 1. The Greater Altai geotectonic position in the structures of the Central Asian belt. 1—Ancient platforms and massifs; 2—Baikal; 3—Caledonian orogeny region; 4—Altai-Alashan area; and 5—position of the Greater Altai.

Deep mobile zones (DMZs) and associated systems of longitudinal-transverse faults which caused intensive transformations of the entire section of the EC and the upper mantle played a decisive role in magmatism origin and evolution, the spatial arrangement of volcanic and intrusive belts. The real differentiation of the upper mantle and the level of foci nucleation in the EC reformation column determined the composition and geochemical specialization of magmatism. The influence of the mantle plume evidently played a decisive role in the metallogenic specialization of Charskaya, West Kalbinsk and Zharma-Saur tectonic zones (Cr, Ni, Fe, Cu, Pb, Zn, Au, and so on).

These data are consistent with the views of a number of researchers on the relationship between plume magmatism and metallogeny in Tarim, Siberian, Emeishan, Central European and other large magmatic provinces (R.D. Dzhenchuraeva, 2015).

In fact, small deposits of magmatic Cu-Ni formation $C_{2–3}$ (Maksut et al.) are known in the territory of East Kazakhstan, and the earlier action of the asthenolite plume was recorded in the Rudniy Altai (in the Devonian) and Chara zone during the stage of the Hercynian collision of C_1-C_3 [3]. Later, in the lower Triassic, the Semeytauska volcano-tectonic construction of the trachybasalt-trachyriolite composition was formed under the influence of a local mantle plume. Therefore, the manifestation of mantle plumes in East Kazakhstan occurred, probably, repeatedly, and the mantle source of ore matter (Cr, Ni, Pt, Ir, Hg) is fixed in deposits of different types (copper-polymetallic, gold ore, rare metals and others). Consequently, it is also necessary to take into account the mantle plume models of the formation of ore-magmatic systems for metallogenic constructions in the territory of the Greater Altai.

The metabasalt layer (K surface) is fixed by amphibolites and hyperbasites fragments in the deep melange of Charskii, Irtysh-Markakol and other faults. In the axial part of the Rudny Altai, according to G.P. Nakhtigal's materials, the crust surface is elevated (at a depth of 22–24 km) bounded by Kalba-Narymsky (26–28 km) and Belousinsk-Sarymsaktin (28–30 km) edge deflections [2, 4, 5]. Metabasaltic layer elevations are also noted in the core zones of

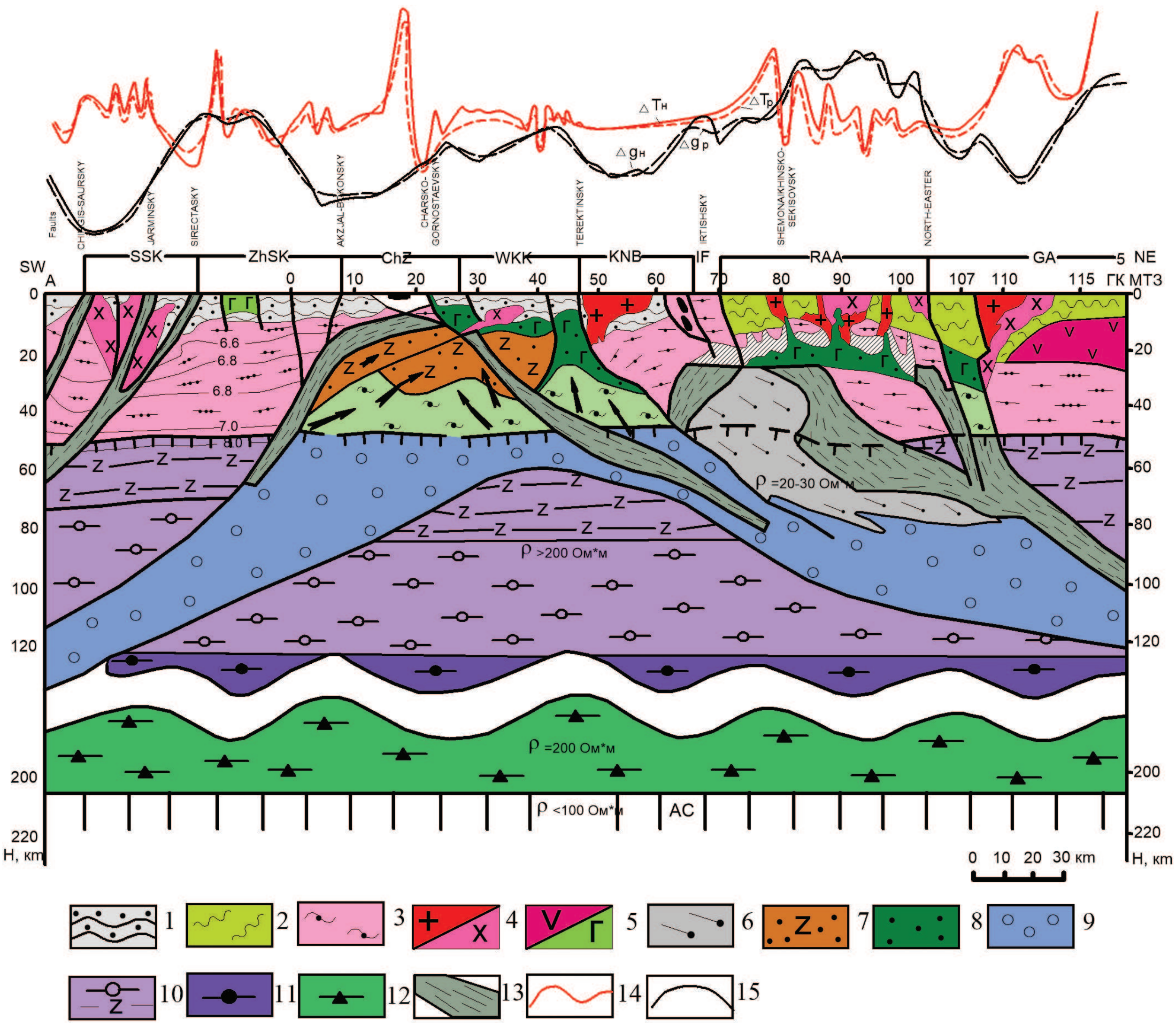

Figure 2. Geological and geophysical section of the lithosphere at the Greater Altai according to Aleisk geotraverse. Granite-metamorphic layer: 1—Hercynides; 2—Caledonian; 3—Proterozoic. Intrusive bodies: 4—granites and granodiorites, plagiogranites; 5—diorite and gabbro; 6—metamorphic carbonaceous rocks. Meta basalt layer: 7—amphibolites; 8—granulites. The upper mantle: 9—primary; 10—ultrabasites; 11—eclogite garnet; 12—diamondiferous eclogite; 13—upwelling zones; 14—gravity field curves (Δg); (15) curves of the anomalous magnetic field (ΔT). Metallogenic zones: SSK, Syrektas-Sarsazan-Kobukskaya; ZhSK, Zharma-Saur-Kharatungskaya; ChZ, Charco-Zimunayskaya; WKK, West-Kalbinsk-Koksentauskaya; KNB, Kalba-Narym-Burchumskaya; IF, Irtysh-Fuyunskaya; RAA, Rudnoaltaisko-Ashalinskaya; GA, Gornyi Altai.

Zharma-Saursky and Chingiz-Tarbagatai belts. Evidently, this is a general pattern for the entire East Kazakhstan region.

The analysis of represented geological and geophysical data emphasizes the transverse heterogeneity of the deep structure of East Kazakhstan territory and different maturity of the EC in its different parts. Typical models of EC tectonic zone structure are reconstructed accordingly: (1) femic with increased capacity of metabasalt to 24–28 km (Chingiz-Tarbagatai, Rudnoaltayskaya and Zharma-Saurskaya zones); (2) sialic with a high thickness of metagranite layer up to 12 km and the EC up to 50–55 km (Kalba-Narymskaya, Syrektas-Sarzanskaya zone, Gorny Altai) and (3) interbedded femichesical—saliches on a heterogeneous (Precambrian-Caledonian) base

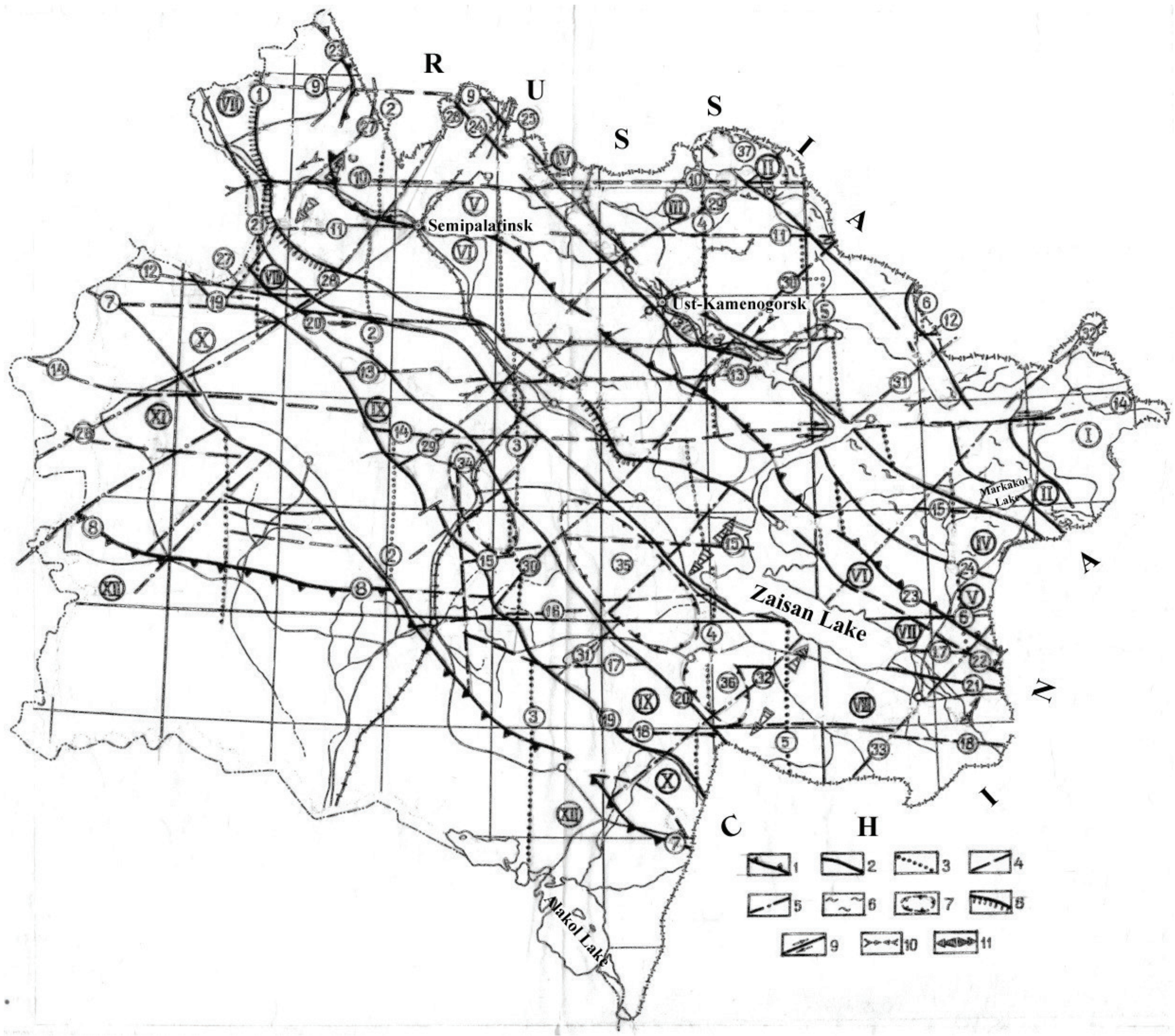

Figure 3. The layout of the faults of the Eastern Kazakhstan (by B.A. Dyachkov, G.P. Nakhtigal). 1—Deep longitudinal faults restricting tectonic structures and 2—their structure-formation zone; 3 and 4—regmatic system longitude-latitude prehercinian structural fault occurrence; 5—transverse deep faults of the Hercynian activation; 6—crushing zones; 7—ring structures; 8—thrusts; 9—fault-shifts; 10—direction of prevailing tectonic compression and 11—tension. Structural area (roman number in circles): I—Mountain Altai (Charyshskaya, Holzunsko-Chuiskaya), II—Beloubinsko-Sarymsaktinskaya (northeastern zone crumpling), III—Rudnoaltayskaya, IV—Irtyshskaya (Irtysh zone crumpling), (V) Kalba-Narymskaya, VI—Western Kalbinskaya, VII—Charskaya, VIII—Zharma-Saurskaya, IX—Sirektasskaya, X, XI—Chengis Tarbagataiskaya, XII—Pribalhashkaya.

with a suboceanic EK type of section (Charskaya, West Kalbinsk, the Irtysh zones). These tectonic zones, which have unequal tectonic magmatic activity, were saturated with basaltoid and granitoid matter in different ways with different geochemical specialization.

Thus, the geodynamic model of the GA mobile belt development reflects a long and complex history of geological structure formation and emphasizes the intensity of ore-magmatic processes and metallogeny. As a result of polycyclic development of tectonic magmatic processes, the main epochs of ore formation have been outlined, reflecting vertical and lateral zonation within the ore belts and in general for East Kazakhstan. During the stepwise EC transformation and the migration of magmatic foci from the upper mantle, a homodromic evolution of the magmatic formations and associated mineralization occurred. The change of sidero-chalcophile mineralization (Fe, Mn, Cu, Pb, Zn, Au, Ag) by chalcophile (Pb, Zn, Au, Ag, Bi, Sb, etc.) and lithophilic (Ta, Nb, Sn, W, Mo, TR, etc.) occurred from early to late epochs [6]. System analysis of the materials shows that in each metallogenic zone the maximum outburst of mineralization (with the formation of industrial deposits) occurred only in a certain geodynamic regime and in the age interval.

The role of deep faults in the development of geological structures and metallogeny was considered in the works of many researchers (G.D. Azhgirey, A.V. Peive, N.P. Nekhoroshev, G.N. Shcherba, P.F. Ivankin, et al.). Deep faults had a long history of development, among which the Proterozoic, Caledonian and Hercynian fault systems as well as Cimmerian and Alpine (new and refurbished) are distinguished by age (location or intensive activation). The following systems also differ in direction: (1) longitudinally transverse (northwestern and northeastern), (2) longitude-latitudinal (regmatical), (3) diagonal, and (4) annular (according to space images interpretation) (**Figure 3**).

3. Peculiarities of metallogeny

3.1. The geological history of development of structures

In recent years, some common patterns of geological structure formation of Central Asian belt have been addressed in a number of publications from the theoretical standpoint of mobilism [6–10]. Particular attention has been given to determining the role of the mantle in tectogenesis, magmatism and ore formation processes, sources of magmatic melts and ore matter, clarifying geotectonic positions, age and ore content of granitoid batholiths and their connection with large Siberian and Tarim mantle plumes. General orientation of evolution of geology and metallogeny of the Greater Altai and skirting structures (Gorny Altai and Chingiz-Tarbagatai) occurred over a long geological history (from Precambrian to Quaternary time) in various geodynamic regimes and conditions.

In the Precambrian, near-fault intrusions of hyperbasites were accompanied by mineralization of magmatic formation under oceanic rifting conditions—Cr, Ni, Co, Cu (Charco-Gornostaevsky belt). In the early stages of caledonides and hercinides, stratiform iron-manganese, polymetallic, and copper-pyrite volcanogenic sedimentary deposits of the Ural and Rudno-Altai types (Fe, Mn, Pb, Zn, Cu, Au, Ag, etc.) were formed under rift-arc island geodynamic conditions (Chingiz-Tarbagatai, Rudny Altai).

Predominantly small intrusions and dikes of the gabbro-diorite-granodiorite-plagiogranite series are localized under collision geodynamic conditions, productive for copper-nickel sulfide, copper-porphyry and gold mineralization—Ni, Co, Mo, Au, Ag, etc. (Chingiz-Tarbagatai, Zharma-Saur, Western Kalba, the Rudny Altai). Southeastern zones formed in the process of lithospheric plate collision with oceanic and continental earth crust types are fixed by a system of deep crust–mantle faults, ophiolite belts, blocks of metamorphic rocks and thrust-melange structures which have ore-controlling importance. They are accompanied by many minerals (Cr, Ni, Co, Cu, Hg, Au, etc.), including large gold deposits (Bakyrchik, Vasilkovskoe, Suzdalskoe, etc.) [11, 12].

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The post-collisional (orogenic) situation in the Permian was characterized by the activation of intra-plate tectonics and powerful development of granitoid magmatism, which is associated with deposits of rare metals and rare earths (Ta, Nb, Be, Li, Sn, W, Mo, TR, and so on). Deposits of rare metals are concentrated in the Kalba-Narym zone, Zharma-Saur, the Gorny Altai and other regions of Central Asia (China, Mongolia, the Urals, and so on) [13–15].

In the Cimmerian cycle, residual weathering crusts of nontronite profile (Ni, Co) accumulated in the Chara zone, kaolinite-hydromica (Au) in Western Kalba and Zharma-Saur, kaolinite (Ti, Zr) in northern Prizaisan (Karaotkel deposit) under continental rifting conditions. Deposits of coal and oil shale were formed in intermontane depressions (Karazhyra, Kenderlyk). Deposits of various minerals including placer gold, ilmenite, monazite, cassiterite and other minerals were formed in a Mesozoic-Cenozoic platform cover.

3.2. Metallogenic zoning

As a result of study, it has been determined that geotectonic and metallogenic zoning is fully consistent and the following ore-bearing structures have been identified: a metallogenic province, ore belt, metallogenic zone (subzone), ore region, ore zone, ore site and ore field. The Hercynian geostructure of the Greater Altai which covers the territory of the Rudny Altai, Kalba-Narym, Western Kalba, Zharma-Saur and adjacent regions of Russia and China is the largest.

Four ore belts have been determined within the Greater Altai by metallogenic zoning (**Figure 4**):

1. Rudnoaltai copper-polymetallic (Fe, Mn, Cu, Pb, Zn, Au, Ag, and so on)
2. Kalba-Narym rare metal (Ta, Nb, Be, Li, Cs, Sn, W).
3. West Kalbinsky gold ore (Au, Ag, As, Sb).
4. Zharma-Saursky multimetal (Cs, Ni, Co, Cu, Au, Hg, Mo, W, TR).

Chingiz-Tarbagatai belt in the southwest of the GA unites two metallogenic zones (West-Chingiz and East-Chingiz), and in the northeast there are Charyshskaya, Kholzun-Chuysko-Sicikhe and Tsunghu-Chihuye zones adjacent to the Gorny Altai [8].

The Rudny Altai belt was formed on the destructured continental crust of the Gorny Altai during the Hercynian cycle, and the change of geodynamic regimes from the initial rifting (D1e) to the island-arc (D_3-C_1) was accompanied by a collision (C_2-C_3), orogenic activation (P_1-T_1) and stabilization (Mesozoic-Cenozoic). The ore-control importance is given to a system of echeloned deep faults in the northwestern direction penetrating the activated upper mantle, which contributed to the entry of mantle-crustal magma and ore-bearing fluxes into the upper parts of the EC [3, 16]. Industrial copper-pyrite and pyrite-polymetallic deposits are concentrated in the core Rudny Altai zone of increased femininity of the EC section, the magmatic saturation and the density of mineralization and are clearly correlated with the elevation of the upper mantle, the metabasaltic layer, and the blocks of the Proterozoic and Caledonian basement.

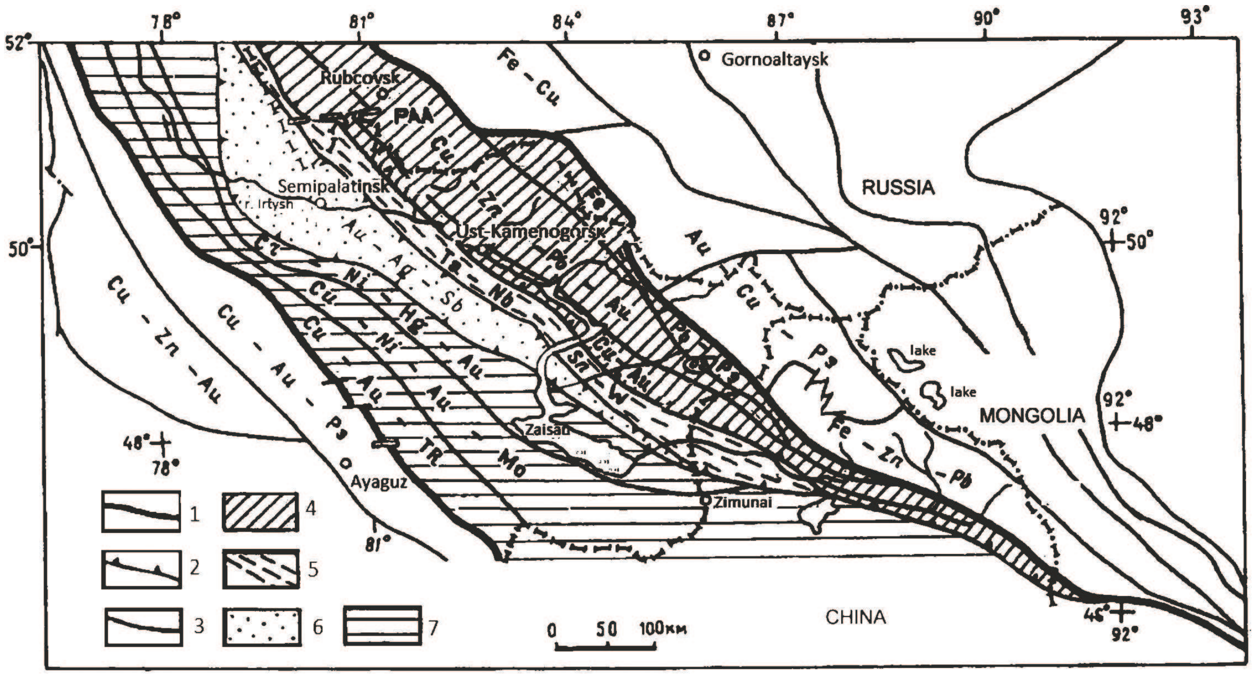

Figure 4. Greater Altai metallogeny division into areas. 1—Border of Greater Altai; 2—of ore belts and 3—of metallogenic zones; 4—Rudnoaltaisk gold-copper-polymetal; 5—Qalba-Narym rare metal; 6—West Qalba gold bearing and (7) Zharma-Saur multimetal.

Pyrite-copper-polymetallic mineralization is genetically associated with a group of basalt-andesite-rhyolite formations (D_{1-3}), differentiated and contrasting antidirectional series, forming several productive geochronological levels from D_1e to D_3fr$_1$ (**Figure 5**). Accordingly, multi-rhythmic zoning and high-level distribution of mineralization in ore zones, ore sites and, in general, the ore belt (with a vertical span of ores up to 1000–1500 m) are manifested. There is a concentration of deposits in the Devonian volcanic arcs of ring structure framing the Caledonian paleo-elevations (Sinyushinsky, Revnushinsky, Alei and Rubtsovskoye), characterized by volcanic processes and ore formation duration.

The linear cluster distribution of volcanic-tectonic structures with pyrite-polymetallic deposits in longitudinal ore zones (Leninogorsk, Zyryanovskaya, Orlovsky-Belousovskaya, etc.) with a step of ore nodes at the intersection of faults of 20–40 km is also characteristic. Sublatitudinal ore-control faults played an important role (Leninogorskii and others), especially at the junctions of their intersection with breaks in other directions, where volcanogenic ore centers were created (according to G.F. Yakovlev, 1976).

Ore formation took place under submarine conditions, evidently with an ascending water-and-hydrothermal system of solutions with a juvenile source of metals (Fe, Cu, Pb, Zn, S, Au, Ag, etc.) and dissolved gases (CO_2, N_2, H_2S, S, Cl and others) (Dyachkov, Titov, 2005).

Two types of ores differ in origin:

1. stratiform hydrothermal sedimentary, characterized by the accumulation of ore matter at the bottom of the basin among sedimentary-pyroclastic rocks with the formation of stratified rhythmically layered ores (Ridder-Sokolnoye, Verkh-Ubinskoe, Nikitinsky deposits, and so on);

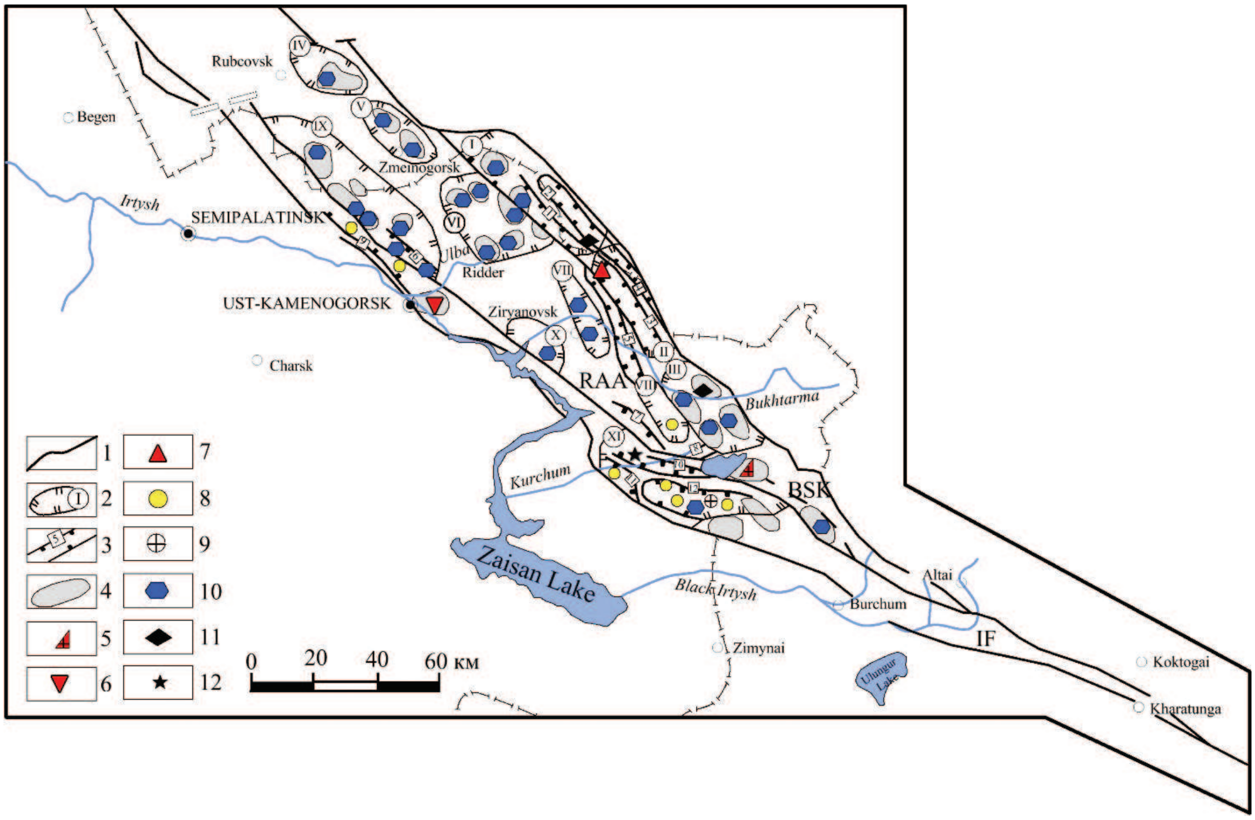

Figure 5. Rudny Altai copper-polymetallic belt. 1—Boundary of metallogenic zones; 2—ore district; 3—ore zone; 4—ore node; 5 to 12—ore formations: 5—epimagmatic; 6—skarn; 7—greisen-quartz-vein; 8—quartz vein golden; 9—gold-quartz berezitic; 10—pyrite-polymetallic; 11—volcanogenic-sedimentary iron-manganese; 12—metamorphogenic (golden). Metallogenic zones: IF—Irtysh-Fuyun; RAA—Rudny Altai-Ashalinsk; BSK—Belousinsk-Sarymsaktin-Kurstinskaya. Ore regions (roman numerals in circles): I—Beloubinsky; II—Khamirsky; III—South Altai; IV—Rubtsovsky; V—Zmeinogorsky; VI—Leninogorsk; VII—Zyryanovsky; VIII—Maymyr; IX—Priirtyshsky; X—Bukhtarminsky; XI—Kurchum-Caldzhirsky.

2. hydrothermal metasomatic, associated with changes in volcanic-sedimentary rocks and fluid-porphyry complexes on the path of ore-bearing flows. The latter type includes the majority of commercial pyrite-polymetallic deposits (Zyryanovskoye, Maleevskoe, Belousovskoye, and so on).

The Rudny Altai is the main raw material base of nonferrous metallurgy in Kazakhstan. As a result of studies, the overall large scale of the Rudny Altai gold-copper-polymetallic belt is renewed, the belt continues in Russia on the northwestern flank (Rubtsovskoye, Zmeinogorskoye, Talovskoye, etc.), and in the southeast, with a sharp narrowing, it is traced to the territory of China Aschaly, Koktal, Timurty, and so on [8, 17]. This regional position of high productivity ore zone shows that the Rudny Altai prospects are not yet exhausted.

The West Kalbia belt is the main gold-bearing structure in East Kazakhstan, in which more than 450 deposits and gold ore occurrences of various geological and industrial types are concentrated [18].The general regularity of the spatial confinedness of gold ore deposits to Zaisan southeast zone formed during the Hercynian collision of Kazakhstan and Siberian lithospheric plates has been established (**Figure 6**). The Charsko-Gornostaevsky ophiolitic belt, which fixes the zone of deep mantle fault, was localized as a result of complex geodynamic development in the southeast zone; fold-melange, overlying thrust and ruptural structures were formed.

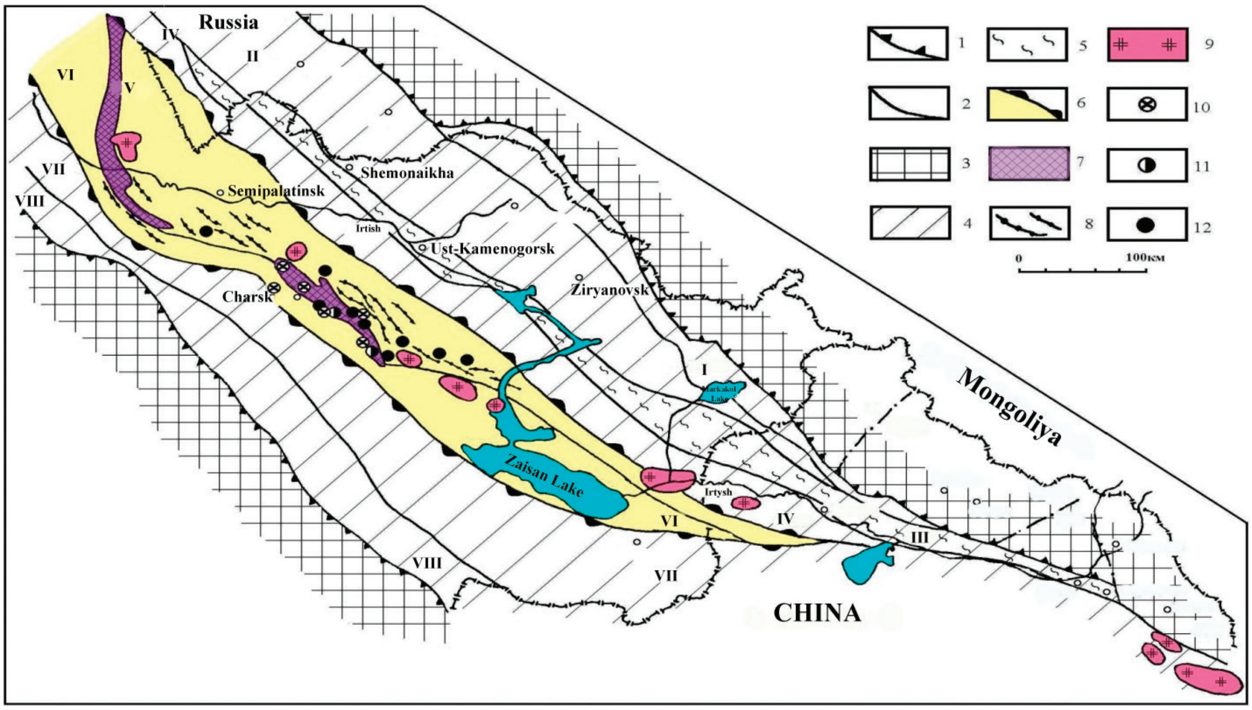

Figure 6. Location of Zaisan suture zone. 1—Borders of Greater Altai and 2—borders of metallogeny zones; 3—Caledonian, and 4 and 5—Hercynian structures; 6—Azaisansky suture; 7—protrusion of hyperbasites; 8—dikes and 9—dubalkalic granitoids; 10 to 12—Cr, Au, Hg deposits. Metallogenic zones (I—Beloubinsko-Sarymsaktinskaya, II—Rudno-Altaiskaya, III—Irtysh-Fyunskaya, IV—Kalba-Narym, V—West-Kalba, VI—Charsko-Zimunaiskaya, VII—Zharma-Saurs, VIII—Syrektas-Sarsazan).

The system of diagonal deep faults in the west-north-west direction (West Kalbinsky, Charskiy, Terektinsky and Baiguzin-Bulaksky) had ore-controlling importance along which the belts of the near-fault small intrusions and dikes of the gabbro-diorite-granodiorite-plagiogranite series (C_{2-3}-C_3) in association with ore-bearing fluid flows were formed.

It was here that, at the junction of continental margins in a collision geodynamic situation, favorable conditions were created for the formation of gold-bearing structures and deposits (Zapadno-Kalkinskaya, Zhanan-Boko-Zaisanskaya, Yuzhnoaltaiskaya and other ore zones), which, according to geological and geophysical data, frame the Charko-Gornostaevsky uplift from the northeast and southwest).The patterns of formation and the criteria for predicting gold ore deposits in the region under study (geotectonic, geological-structural, magmatic, mineralogical-geochemical and others) have been considered in a number of publications [11, 12]. One of the main regularities is belt placement of ore zones and gold ore objects which we unite into a large East Kazakhstan gold belt of regional ranks [1]. The arc belt has a considerable length (length of about 800 km with a width of 40–60 km), and in the north-western flank, it has a gateway in the meridional direction and is covered with loose sediments in Kulunda depression; in the southeast, it is intersected by rare-metal granites of the Kalba-Narym pluton and it further penetrates into the territory of the Southern Altai and is traced to China (**Figure 7**).

Such a regional position of the gold belt allows us to reevaluate the prospects of Semipalatinsk Priirtyshye to identify gold deposits under the cover of loose sediments of the Kulunda depression (**Figure 8**).

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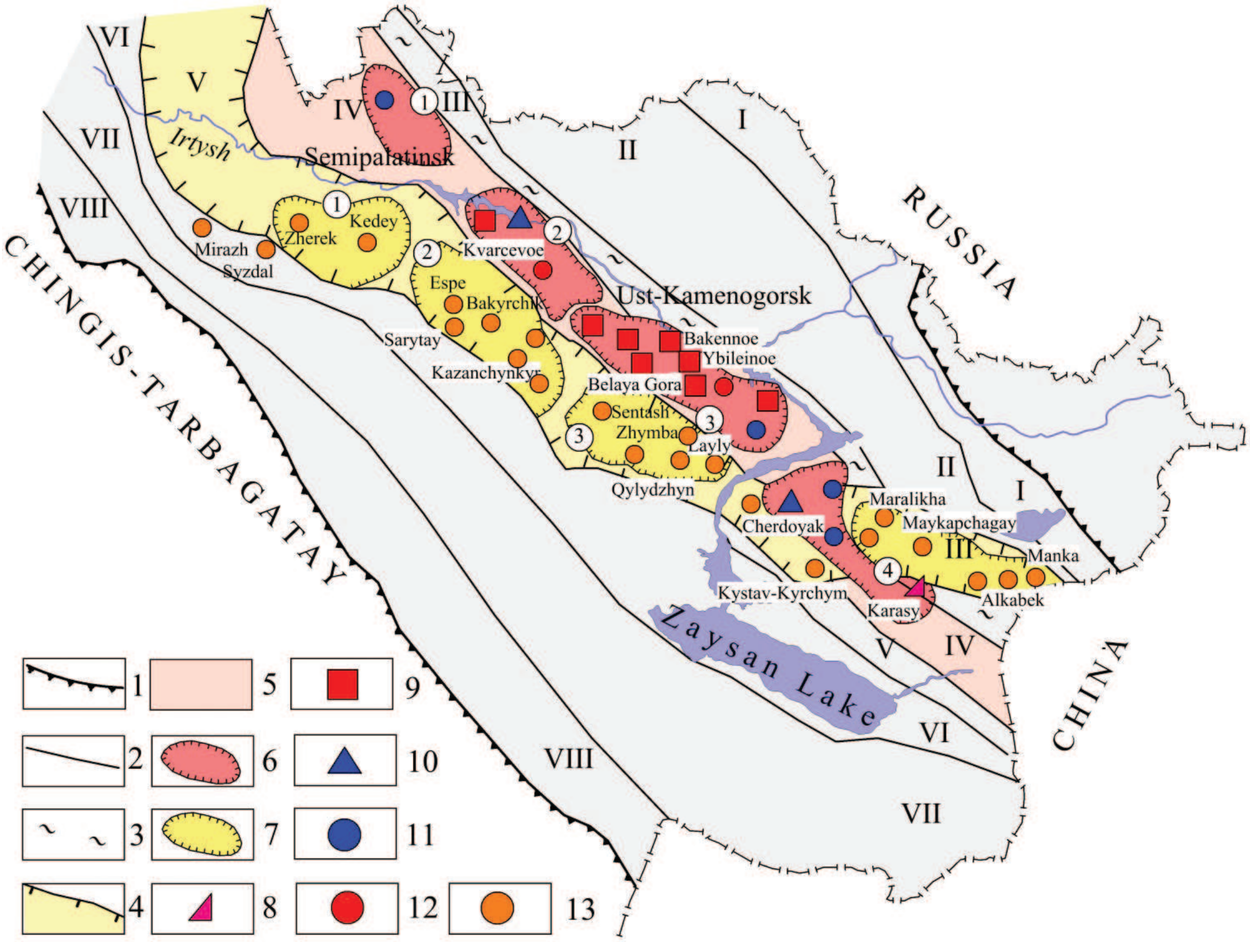

Figure 7. Scheme of placement of rare metal and gold-ore belts. 1—The boundaries of the Greater Altai and 2—metallogenic zones; 3—Irtysh crush zone; 4—East Kazakhstan gold ore, and 5—Kalba-Narym rare metal belt; 6—rare metal ore regions (1—Shulbinsk; 2—North-West-Kalba; 3—Central-Kalba; 4—Narym); (7) gold ore regions (1—Mukursky; 2—Bakyrchik; 3—Kuludjun; 4, South Altai); (8–13) types of deposits: 8—albitite-greisen (Sn, Ta); 9—rare metal pegmatites (Ta, Nb, Be, Li, etc.); 10—greisen-quartz-vein (Sn, W); 11—quartz vein tin (Sn, W); 12—tungsten; 13—gold ore deposits. Metallogenic zones (I—Beloubinsko-Sarymsaktinskaya; II—Rudy Altai; III—Irtysh; IV—Kalba-Narym; V—West-Kalba; VI—Charsk; VII—Zharma-Saurs; VIII—Syrektas-Sarsazan). Deposits of the Kalba-Narym zone: 1—quartz; 2—Bakennoye; 3—Jubilee; 4—Belaya Gora; 5—Cherdoyak; 6—Karasu. Deposits of the West Kalba zone: 1—Kazanchunchur; 2—Kuludjun; 3—Layla; 4—Kystav-Kurchum; 5—Maralikha; 6—Maykapchagay; 7—Alkabek; 8—Manka.

An important ore-petrological criterion is determined in establishing paragenetic connection of gold with small intrusions and dikes of Kunushsky complex C3 and its analogues (Saldyrminsky and Katoy complexes). The leading geological and industrial types of gold deposits are: (1) gold-listenitic (Maralakha deposit); (2) gold-sulfide (Suzdalskoe, Mirage, etc.); (3) gold-quartz (Kuludzhun, Sentash, Kystav-Kurchum); (4) gold-quartz beresit (Baladzhal, Manka); (5) gold-arsenic-carbonaceous (Bakyrchik, Bolshevik); (6) crust weathering (Zhanan, Mukur) and (7) gold-placer (West Kalba, the South Altai).

The Bakyrchik deposit is the largest world-level object of the "black shale type" represented by zones of gold-arsenic-carbon mineralization and vein silicification [3, 11, 12]. Depositions of molasses, limnic formations (Buconian suite $C_{2–3}$) which are subject to intense dynamometamorphic and hydrothermal-metasomatic changes in the zone of latitudinal Kyzylovskiy deep fault (overthrust) are ore-bearing (**Figure 9**).

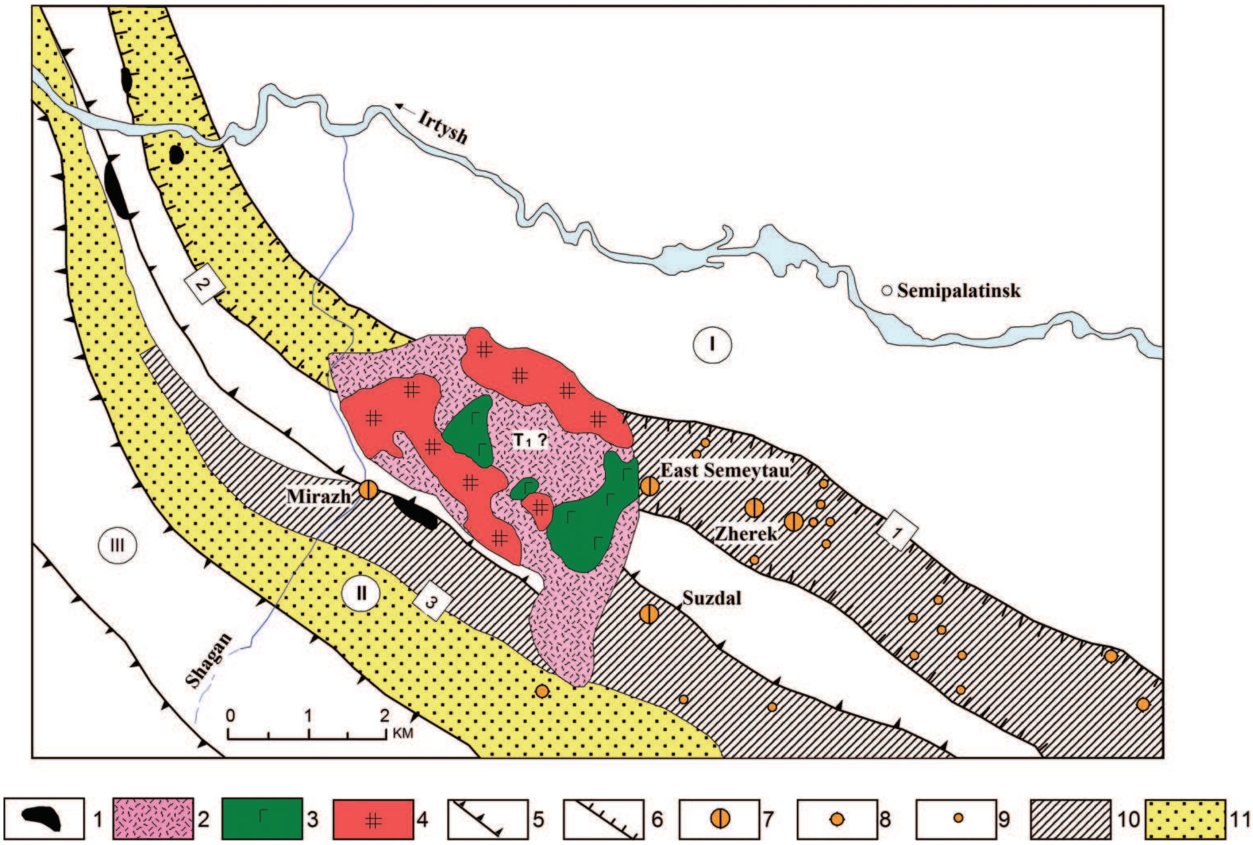

Figure 8. Forecast-metallogenic scheme of Semipalatinsk Priirtysh. 1—Precambrian hyperbasite formation; 2 to 4—volcano-plutonic trachybasal-trachyriolithic formation T1? (2—trachybasalt-trachyriolithic; 3—gabbro-monzonite; 4—granosyenite-granite-porphyry subformation; semeitauskaya series); 5—boundary of metallogenic zones (I—West Kalba; II—Charsk; III—Zharma-Saur); 6—boundary of ore zones (1—Mukur; 2—Shagan; 3—Mirage-Suzdal); 7 to 9—gold ore objects (7—deposits; 8—ore occurrences; and 9—mineralization points); 10 to 11—prospective areas (10—high degree of prospects; 11—predictive).

Ore bodies are represented by lenticular and ribbon-like deposits, stockworks of hydrothermally altered sedimentary rocks with veins and nests of metasomatic quartz and abundant dissemination of gold-bearing pyrite and arsenopyrite. Their thickness varies from 0.6 to 20 m, and gently sloping deposits are traced by a drop of 1700 m. The average gold content is 8–9 g/t. The Bakyrchik ore region retains high prospects for the increasing of forecast gold resources, which makes it possible to bring them to a number of world super-large objects.

The Kalba-Narym belt is the main rare-metal structure in East Kazakhstan. According to new geodynamic schemes, it is regarded as a foreign block of EC (terrain) which has become connected to the Greater Altai during the Hercynian collision (C_1 and later). Based on analysis and generalization of deep geophysical studies, it is assumed that the Kalba-Narym granitoid belt is located in the head part of a giant tectonic magmatic zone, steeply falling to the northeast under the Rudny Altai (to a depth of more than 100 km). The centers of magma formation originated, judging by the composition of the granite smelting, in a metagranite layer or on its boundary with metadiorite. The zones of transit heat-mass flows penetrated from the lower parts of the EC and the upper mantle through the system of deep faults.

The Kalba-Narym granitoid belt unites many deposits and ore occurrences of pegmatite, albit-greisen, greisen-quartz, and other ore-forming types. Well-known industrial deposits

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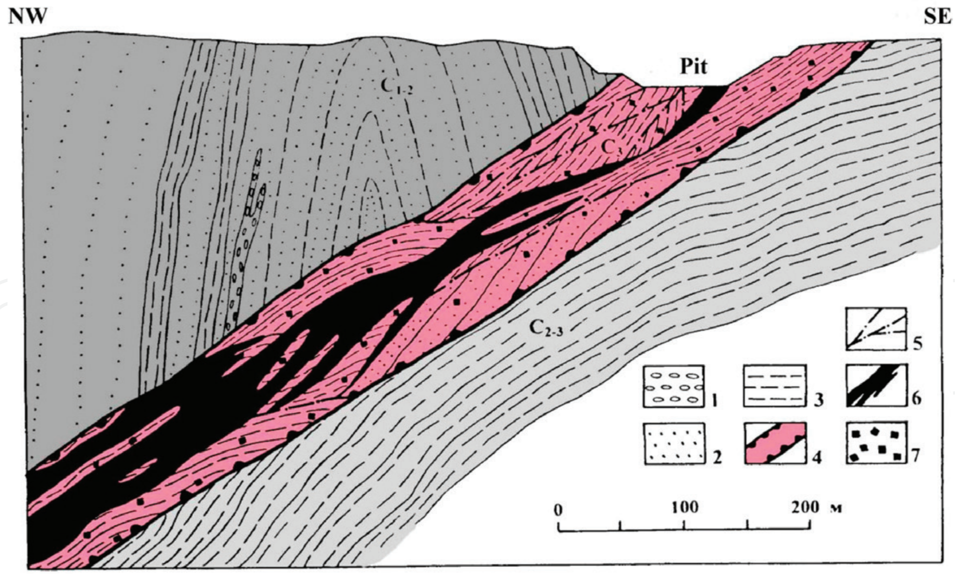

Figure 9. Geological section of gold-sulfide deposit Bakyrchik through the central ore body (based on the materials of V. M. Yanovsky, Y.V. Chudikova). 1–3 carboniferous sediments: 1—conglomerates, gravelites; 2—sandstones; 3—carbonaceous siltstones and shales; 4—Kyzylovskaya zone of deep fault; 5—faults, tectonic cracks; 6—ore body; 7—diffuse sulfide mineralization.

(Bakennoye, Yubileynoye, Belaya Gora, etc.) were developed by Belogorsk mining and dressing plant in previous years, but at present they are mothballed. The main source of rare metals is deposits of rare metal pegmatite (Ta, Nb, Be, Li, Cs, Sn) genetically associated with the granites of the Kalbinsk complex (P_1) [13].

Deep faults and feathering faults that functioned for a long period of time were of decisive importance in the location of the Kalba-Nyrym granitoid belt. The most magmatically submissive role of the northwestern deep faults is manifested in the late Herzinian post-collision (orogenic) stage of development. The Kalba-Narymsky and Terektinsky deep faults served as the largest magma guides. Granite intrusions which formed in a mobile geodynamic environment turned out to be the most ore-bearing; it contributed to more intensive ore formation processes in nonequilibrium PT—conditions and, ultimately, the formation of industrial deposits (Bakennoe, Ybileinoe, and so on). On the contrary, quieter tectonic conditions of crystallization of relatively inactive and viscous granite melts lead to dispersion of RE and poor ore content of granites (the massifs of Dubygaly, Sibinsky, and so on). On this basis, ore-magmatic systems with different degrees of productivity were identified, ore-petrochemical typification of granitoids was performed and geological-genetic models of ore formation were constructed as the leading factors for forecasting new rare metal deposits [19].

Importance is attached to ore-controlling role of latitudinal deep faults of ancient deposits and long-term activation, especially at clusters at their intersection with northwestern, northeastern or meridional disjunctives (Gremyachinsko-Kiinsky, Asubulaksky, Belogorsky, Mirolyubovsky, and so on).

Thus, Asubulak latitudinal fault controls pegmatite field location in which two ore-bearing strips of sublatitudinal strike separated by a fault are distinguished: (1) Ungur (northern), including ore objects in Carmen-Kuus, Akkesen, Ungursai and Plachgor, and (2)

Krasnokordonskaya (southern), uniting the Yubileynoye industrial deposit and ore occurrences in Red Cordon, Rock and Budo in 1.5 km increments.

Mirolyubovsky latitudinal long-term activation fault had a decisive role in distribution of tungsten-greisens and hydrothermalites of the same granite massif, in which the main ore bodies were localized in meridional discontinuities that cut across Kalbin granites and leucogranites of the monastirskiy complex. At the final stage of the Hercynian tectonic magmatic cycle, the Mirolyubovsky fault was transformed into a fault-shift with displacement of all intrusive formations and ore bodies with an amplitude of 3 km.

Favorable factors of ore formation include the multistage structure of the Kalba-Narym pluton in the form of alternating cross sections of granite plates and enclosing sedimentary rocks, which caused formation of structural traps and screens for pegmatite fields. Apical parts and above intrusive zones of granite massifs, their apophyses, hidden domes and tectonically weakened zones saturated with vein formations are the most promising for the concentration of rare metal mineralization. According to geological and geophysical data, the main ore sites and ore fields are spatially located in a thickened part of granite massifs, above the magmatic-leading roots or along their periphery [4, 20].

The Zharma-Saursky belt was formed on the northeastern outskirts of the Kazakhstani massif, and it is characterized by complex geodynamic development and polycyclic metallogeny. It unites three metallogenic zones: Charskaya, Zharma-Saurskaya and Sariktas-Sarsazanskaya.

Charskaya zone is a structure of regional or planetary rank, and it has a long and complex history of development. Within its limits, the Charsko-Gornostaevsky ophiolite belt is distinguished which is fixed by separate fragmentary outcrops of Precambrian metamorphic rocks, protrusions of hyperbasites, thrust zones and serpentinite melange [2, 18, 21]. In the Precambrian cycle, the primary ores (Cr, Ni, Co, Cu) formed in the oceanic geodynamic environment are associated with the hyperbasite formation (Charsky complex, PR?). The ores belong to the hysteromagmatic chromium, magmatically liquation and hydrothermal copper-cobalt-nickel formations.

Zharma-Saurskaya zone, located in the central part of the ore belt, developed under the influence of a deep mobile zone (DMZ), was characterized by an elevation of the upper mantle and a high-power metabasalt layer (24 km). The focal part of the DMZ was characterized by high magmatic saturation with a strong development of syncollision intrusions of gabbro-diorite-granodiorite-plagiogranite series (C_1 and C_{2-3}) productive for copper-porphyry, sulfide copper-nickel and gold mineralization. Copper-porphyry type of mineralization is manifested in a volcano-plutonic belt of intrusions of Saursky complex C_1 (the Kyzylkain deposit in Saursky ore district) [3]. Maksut deposit is genetically associated with stratified intrusions and dike-like bodies of the late-collision activation stage, controlled by deep faults. Gold ore objects are associated with small intrusions and collision-type dikes (C_3) and are fixed by quartz-vein and stockwork zones (Ashaly, Daubai, Chang, and so on).

Syrektas-Sarsazan zone is a margin southwestern structure in Zharma-Saur, and it is bounded by Syrektas (East Tarbagatay) and Chingiz-Saur deep faults. It is characterized by a section of the EC of increased syality and copper-rare metal-rare earth specialization (Cu, Mo, W, Nb, Zr, TR) [3, 19].

4. Discussion of results

Cardinal changes in views on the Earth development and world geological science have occurred in recent years on the basis of provisions of modern geotectonic hypotheses (new global tectonics, tectonics of lithospheric plates, terranean tectonics, plumectonics, and so on). Identification of regular relationships between cyclically directed self-development of geological structures and ore formation processes in certain geotectonic cycles and epochs is of fundamental importance [11]. Mineral and raw materials sector continues to be the basis of economies in many countries, but experts point to the depletion of the world's mineral resources. The most important task is to open new mineral deposits taking into account current trends in world geological science. This is of particular importance for East Kazakhstan region territory—a unique geological test site, where there is an urgent need to replenish ore reserves of deposits exploited by mining and metallurgical enterprises.

The considered territory of East Kazakhstan, located in the Central Asian mobile belt, is a unique geological providing ground that unites many deposits of ferrous, nonferrous, precious, rare metals and other minerals. For decades, accumulated large factual material on geology, tectonics and metallogeny has been traditionally tied up from the positions of classical geosynclinal hypothesis [22]. The Irtysh-Zaisan and Chingiz-Tarbagatai fold systems were distinguished here, including structural-formational zones, ore-bearing structures with their own set of geological and ore formations. In recent years, from the new theoretical positions, the main problematic issues of geodynamic and metallogenic development of geological structures have been considered in a trilogy "Big Altai" (BA) and a number of other publications [2, 3, 6, 20, 21, 23, 24]. Based on these studies results, the emergence and formation of large geological structures in Kazakhstan, Siberia, the Urals and other regions are associated with Eurasian continent disruption into individual slabs, geoblocks, massifs and detachments in the late Proterozoic that migrated and experienced complex development in the evolution of the Paleo-Asian ocean (Buslov, 2011; Geodynamics, 2007). According to paleomagnetic and geodynamic reconstructions, it is assumed that modern geological structures (the Rudnyi Altai, Kalba-Narymskaya, West-Kalbinsky Zones and others) are erratic masses of paleocontinents (Eastern Gondwana, etc.), possibly terranes, that drifted in the Paleo-Asiatic ocean and interlocked in the collision stage (C_1-C_3) when Kazakhstan and Siberian lithospheric plates collided. Paleogeodynamic analysis of the BA structure formation was carried out from the Precambrian to the Cimmerian and Alpine cycles inclusive. As a result of a complex polycyclic development of tectonic magmatic processes and metallogeny in the region, a system of ore belts and metallogenic zones that unite many types of mineral deposits was formed.

5. Conclusion

On the basis of theoretical positions of mobilism, the BA represents a single system of parallel ore belts of regional ranks in the northwestern direction (Rudnoaltayskiy, Kalba-Narymsky, Zapadno-Kalkinsky and Zharma-Saursky) formed as a result of the Hercynian collision of Kazakhstan and Siberian lithospheric plates and the degradation of the Irtysh-Zaisan paleobasin (parts of the Paleo-Asiatic ocean). According to geological and geophysical data, the ore belts are characterized by a large-scale development along their length and depth, which reflects their high material and energy potential and opens new prospects for forecasting and prospecting works within their boundaries.

In each ore belt, the maximum mineralization productivity was manifested in certain geodynamic settings and regimes. In the Rudnyi Altai, the main pyrite-polymetallic deposits were formed in a riftogenic geodynamic environment, genetically related to the Devonian basalt-andesite-rhyolite volcanism (D_1e-D_3fr) and were controlled by a system of echeloned deep faults in the northwestern direction.

Gold-bearing deposits of Western Kalba, the Southern Altai and Zharma-Saur were formed in the Middle Gerzinian stage (C_1-C_3) in a collision geodynamic situation under conditions of horizontal displacement, jointing and turning of Kazakhstan and Siberian lithospheric plates, manifestations of main folding phases, thrust and melange structures and introduction of gold-bearing small intrusions and dikes ($C_{2–3}$-C_3). The ore-controlling role of diagonal deep faults system of mantle-crustal location and the regmatic system of renewed sublatitudinal deep faults in location of gold ore objects has been determined. The main gold deposits (Bakyrchik, Bolshevik, Suzdal, Kuludgun, Maralikha, etc.) were located in the Zaisan suture zone forming East Kazakhstan gold belt of regional ranks.

Rare-metal deposits are formed mainly in the Hercynian cycle in post-collision (orogenic) geodynamic situation as a result of vertical arched motions and a powerful development of Permian granitoid magmatism. They are spatially placed in granitoid belts of the northwestern direction formed in tectonically weakened blocks of EC of increased syality. The main importance is given to rare-metal and rare-earth deposits (pegmatite, albitite-riebeckite, etc.) formed in certain nonstandard geological settings and nonequilibrium PT conditions for granite massif formation.

As a result of study, regular relationships of tectonic and metallogenic development of geological structures in East Kazakhstan have been determined. The revealed mineralogical specialization of geodynamic environments is one of the main methods for forecasting and searching for new deposits along with detailed structural and physical studies of geological formations. The setting of detailed prognostic-metallogenic works in selected perspective structures at modern scientific and technical level is recommended for forecast implementation.

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