Cobalt-Bearing Structures of Tuva

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Abstract. The paper considers structures, which are spatially coincident with deep fault zones and limit fold-block structures of different age consolidation. They are characterized by high permeability of the Earth's upper mantle derivatives and distinctively fixed by gravity steps of the field; they control distribution of cobalt occurrences and manifestations of various formations. Each formational type has its specific set of ore-controlling factors, which are maximum developed in ore clusters and fields. An analysis of cluster and local ore-controlling factors influence on distribution and location of proper cobalt deposits along with established age levels of intensive manifestation of arsenide nickel-cobalt and sulfoarsenide mineralization has permitted revelation of lateral rows of ore formations with relatively close ages.

Keywords. cobalt-bearing structures, ore controlling faults, ore clusters, genetic types, mineral parageneses, hydrothermal solutions.

Introduction

Cobalt manifestations on the territory of Tuva (fig. 1) are related (Unksov, 1954; Krutov, 1978; Ore associations of Tuva, 1981; Lebedev, 1986; 2003) mainly to two genetic types: hydrothermal and less frequent contact-metasomatic. The first is represented by nickel-cobalt arsenide, copper-cobalt sulfoarsenide, cobalt-copper sulfoarsenide-fahlore veined ore association; the second — by cobalt sulfoarsenide skarn, sulfoarsenide-magnetite cobalt-bearing skarn and sulfoarsenide cobalt-bearing listwanite-beresite ore associations. As a rule, deposits of cobalt ores are confined to interblock zones which fix activated zones of deep faults, or to basement fractures of rigid blocks. And rich arsenide nickel-cobalt ores of commercial interest are concentrated in ore clusters and fields in intersections of deep and large regional faults with long history of geological development, differentiated intrusive magmatism and intensive hydrothermal-metasomatic transformations (Distanov and Obolenskii, 1986).

Uvs-Nuur – Khovu-Aksy cobalt-bearing zone

This ore-magmatic system, in the Late Paleozoic – Early Mesozoic resulted in formation of a deposit of complex silver-gold-bismuth-copper-nickel-cobalt arsenide and sulfoarsenide-sulfosalt ores, spatially coincides with junction area of the East-Tannuola anticlinorium and West-Tannuola synclinorium along the Uvs-Nuur–Bayankol deep fault zone. This metallogenic structure of the northeastern strike is nearly 20 km width and 180 km length. It controls distribution of the Khovu-Aksy (fig. 1–A) and Ulatai-Choza (fig. 1–B) ore clusters, which include Khovu-Aksy, Uzunoi, Boshtag, Kendei, Kara-Khem, Torgun, Teeli, Ulatai and other deposits and ore manifestations. The Uvs-Nuur – Khovu-Aksy deposit controls separate small intrusions presented by the two-phase Torgalyk intrusion complex (gabbro, gabbro-diabases, granophyres, granosyenite-porphyres) and dikes of basic, intermediate, and acidic composition and of relatively different ages (Lebedev, 1986, 2003). The zone is clearly noted in the gravitational fields in the 3–80 km depth interval. This zone is shared by two essentially different structural-facies zones — East-Tannu-Ola and West-Tannu-Ola. The East-Tannu-Ola part is characterized by occurrence of Early-Middle Cambrian formations of the basalt and rhyolite raw and terrigene-carbonate formations and by lesser completeness and thickness of Silurian deposits of the marine terrigene-carbonate formation and Devonian-Carboniferous continental variegated formation. The West-Tannu-Ola part is distinguished by the presence of deposits of the terrigene-carbonate and molassic rudaceous formations of the Ordovician, most completeness of stratigraphic section of Silurian, Devonian, Carboniferous, and Jurassic deposits. The cobalt-bearing zone can be treated as a peculiar kind of metallogenic structure with indicators typical of conjugated regions (Kuznetsov, 1975). Contact-metasomatic, hydrothermally-altered rocks and faults occupy a significant place in the history of formation of ore clusters and fields within the zone. The postmagmatic wall rock alterations, associated with intrusion of the granodiorite-plagiogranite magma in the Middle Cambrian, are manifested as wide fields of hornfels of the biotite-feldspar, quartz-feldspar, and amphibole-pyroxene-feldspar composition. Contact-metasomatic formations, originated from replacement of terrigenous-tuffaceous-carbonate rocks by magnetite-andradite-epidote skarns, are of significant occurrence. The hydrothermal alterations are generally placed locally along faults and are presented by fields of secondary quartzites, sericite- and chlorite-containing rocks in the southern part of the zone and by vein-like zones of silicification and carbonatization in the central and northern parts. The commercial cobalt concentrations, related with the Salairian tectono-magmatic cycle, have not been established and there are no prerequisites for their revealing. The Silurian and Devonian periods are characterized by alternating-sign movements of tectogenes of the Tannuola-Ondum island-arc system consolidated in the Late Cambrian–Ordovician. In the marginal part of the horst-anticlinorium East-Tannu-Ola rifting protrusion, in the zone of its conjugation with West-Tannu-Ola rifting trough structure, in the Early Devonian and Eifelian, intense volcanic eruptions of basalt, andesite-dacite, and trachyliparite lavas from volcanoes of the central type presumably occurred. In the endocontacts of subvolcanic piles of labradorite-bytownite porphyrites and gabbro-diabases hydrothermal alterations are locally noted. Chloritizatized and prehnitized extrusive rocks and tuffs of the basic-intermediate composition present the alterations. In the areas of development of quartz-ankerite stockworks and separated veins with the sulfide-sulfosalt mineralization, the amygdules in plagiophyres

and melanophyres intensely prehnitized contain an impregnation of native copper. At the end of the Upper Devonian epoch, the intense volcanic activity has been damped out. In the Eifelian, salt-bearing piles have been accumulated in the southwestern and central parts of the zone. Later on (up to the Frasnian), stable submergence was evident within the zone and terrigenous strata were formed in the conditions of intermountain trough. At the end of the Devonian and in the Early Carboniferous tectono-magmatic processes were activated, causing intruding basaltoid magma along zones of a deep fault. The formation of small differentiated gabbro-syenite intrusions of the Torgalyk complex in the Uvs-Nuur-Bayankol zone of faults leaded to activation of supersaturated chloride and sulfate solutions buried in the post-Eifelian. In Silurian and Lower Devonian terrigenous-carbonate rocks in the areas of intense jointing, fracture, and layer-by-layer movements, in the conditions of elevated temperatures, resulted from Hercynian intrusion of subalkaline granites-granophyres, contact-metasomatic chlorite-containing rocks (scapolite-containing garnet-pyroxene-amphibole skarns and pyroxene-prehnite-feldspar aposkarns) were formed by the action of these solutions (Shishkin, 1973; Lebedev, 2003). At this stage, the hydrothermal alterations of the host rocks were manifested as intense chloritization and carbonatization of basic rocks and as silicification and partial baritization of Lower Devonian volcanogenic rocks. Within the ore fields, in local areas along fault zones, the many times repeated hydrothermal alterations caused formation stages and in some cases zonation in localization of hydrothermal rocks and ore mineralization. The cobalt mineralization of the considered zone is clearly associated with this step. The arsenide nickel-cobalt mineralization is controlled by a system of faults in the area of intersection of the Uvs-Nuur–Bayankol –Ungesh and Uvs-Nuur–Bayankol–Ulatai-Choza deep fault zones. Besides the Khovu-Aksy and Ulatai ore fields, the cobalt-nickel mineralization is present in ores of the Uzun-Oi deposit, Boshtag, Yush-Karasug, Kara-Khem and Mednyi ore manifestations.

North-Tannuola cobalt-bearing zone

This metallogenic structure is of regional fragmentary type; it is confined to conjunction of Salairian-Caledonian Khemchik block with Chingekat uplift and Hercynian West-Tannuola trough. Geotectonic development of this zone is characterized by differently directed movement of separate blocks of the basement of its west, central and east parts with relative consolidation of the central block and high mobility of the east and west blocks. Mobility of marginal blocks seems to be conditioned by influence of tectonic movements along shear systems of Shapshal and Chazadyr-Karasug deep faults which control distribution of Vendian-Cambrian ophiolite association including massifs of chromite-bearing ultrabasites. Within the zone, stratified series are represented by metamorphic schists of the Late Proterozoic, ophiolite association of the Vendian, terrigene-carbonate deposits of the Silurian, andesite-dacites and their tuffs of the Low Devonian, tuffogenic-salt deposits of the Eifelian, and locally — by siltstone black-schist series of the Middle Devonian and coal molasse of the Jurassic. Pre-Cambrian and Low-Paleozoic formations underwent an intensive dynamometamorphism; they are folded, intruded by magmatites of different composition, broken by multiple shears and thrust faults. Hercynian step of tectono-magmatic activation are manifested all around the zone. It is manifested in formation of a belt of small separate intrusions of gabbro-syenite association, multiple dykes of basic composition, and imbricated thrust faults, zones of crumpling, layering and jointing. Spatially coincidental cobalt-bearing ore manifestations and occurrences are concentrated in clusters, outlining fragmental character of the zone. End-to-end fault systems, which traverse the North-Tannuola zone across the strike, had an important role in distribution of ore clusters. They are traced by chains of Late Paleozoic gabbroid intrusions. The Chergak, Akkhem and Ishtikhem ore clusters are confined to intersection areas. In general, the zone is characterized by the following peculiarities: many-acted interrupting manifestation of tectono-magmatic processes; distinct influence of deep-seated tectonic structures and end-to-end transverse faults of the basement, coincidental with the zone; close spatial connection of mineralization with Vendian – Low Cambrian ultrabasites and Late Paleozoic gabbro-monzonitoid intrusions of tectono-magmatic activation stage; fragmental character of manifestations mercury and copper-cobalt-antimony-arsenic mineralization.

Khemchik- Kurtushibinskaya cobalt-bearing zone

Rather extensive (more than 300 km) metallogenic structures comprises a band 10–25 km width and spatially coincides with the Sayan-Tuvinian deep fault zone which separates West-Sayan synclinorium and Kurtushibinskii uplift from Khemchik-Systyg-Khem trough. Within the zone, there are Akol, Baitaiga, Shugur, Ezim and Upper Saianyk occurrences and manifestations of arsenide and sulfoarsenide ores. The zone is a eugeosyncline trough with Vendian – Early Cambrian ophiolite association. It is characterized by a compound linear feathered structure which is clearly manifested in magnet field by a narrow line of intensive maxima and gravity steps. The peculiarity of the Khemchik-Kurtushibinskaya zone is expressed in its formation on the boundary of regions with different history of geotectonic development in Caledonian and Hercynian tectono-magmatic periods. The zone is a natural geotectonic boundary between Baikalian-Salairian-Caledonian West-Sayan trough and Tuvinian Episalairian massif of the early consolidation. It is characterized alternating-sign movements with relatively different ages. It resulted in formation of thick spilite-diabase series in the Low Cambrian, and amagmatic flyschoid-molassoid deposits – in the Upper Cambrian. The formation of Vendian – Low Cambrian ultrabasites with synchronous chromite and imposed chrysotile-asbestos mineralization was connected with initial stage of Salairides development , and the formation of Upper Cambrian gabbro-anaortozites, plagiogranites, granodiorites with synchronous iron ore mineralization, titano-magnetite and polymetallic mineralization — with its final stage. The coastal-continental Ordovician-Silurian molasse formed in the Caledonian. The Late stage of the Caledonian is characterized by accumulation of relatively thin series of Silurian terrigene-carbonate coastal-marine association. Low Devonian orogenic stage is expressed in formation of volcano-plutonic complexes of mainly acid composition and associated greisens and skarnoids with rare-earth mineralization. The sequential manifestations of subplatform fracture-type magmatism along deep fault zones were conditioned by Hercyninian and supposedly Mesozoic activation periods spatially and temporally coincidental with development stages of Gorny Altai palaeo-oceanic system. Hydrothermal and metasomatic transformations of host rocks and faults play an important role in history in formation of structures of ore clusters and fields of the Khemchik-Kurtushibinskaya cobalt-bearing zone. Autometasomatic transformations of ophiolite association rocks are connected with the Salairian stage. They have regional distribution and manifested by serpentinization of ultrabasites and spilites, chloritization, hematitization

and pyritization of effusives of basic-intermediate composition and their tuffs. The geochemical elements basis was formed in this stage; it could serve in the following as one of sources for ore components of cobalt deposits. The formation of wide fields of quartz veins in series of Cambrian-Ordovician flysch is connected with the period of West-Sayan anticlinorium zone forming. The significant intensity and wide range characterize post-magmatic transformations of host rocks under influence of intrusions of alkaline-granite magma of the Caledonian late stage. They are manifested as wide fields of hornfels of the biotite-feldspar and quartz-feldspar composition in Cambrian volcanogenic units and Cambrian-Ordovician terrigene deposits. Silurian sedimentary terrigene-carbonate rocks in exocontacts of these intrusions were transformed in epidote-garnet-pyroxene and garnet-epidote skarns of high-temperature facies. Local distribution of hydrothermalites along faults which traverse all complex of stratified and intrusive bodies including Eifelian rocks and Carboniferous gabbroids points to the connection of the most frequent hydrothermalites with the period of post-orogenic tectonomagmatic activation. Within the zone, hydrothermally altered rocks are represented by: aposerpentinite listwanites in Vendian – Low Cambrian ophiolites with gold, cobalt, nickel manifestations; listwanites-like quartz-dolomite-calcite lodes in Silurian and Eifelian terrigene deposits with mercury and polymetals manifestations; silicification, chalcedonization and argillization zones in volcanogene units of the Low Cambrian, Low Devonian and Eifelian; carbonatization, berestization and argillization zones in deposits of the Ordovician, Silurian and Low Devonian, in stocks of the Devonian, Carboniferous and Permian. Ore cluster with similar intensity and completeness of hydrothermal and metasomatic alteration are characterized by manifestation of ore objects with similar mineral composition. In general, the cobalt-bearing zone is characterized by the many-step directional tectono-magmatic development, similar metasomatic and hydrothermal alterations of host rocks in areas of conjunction with feathering fault zones, a repeating geochemical complex of ore components in separate clusters with leading gold-nickel-arsenic specialization. The directional character of tectono-magmatic development is fixed by sequence of three stages: Salairian which founded and formed an eugeosyncline trough with typical Vendian-Cambrian ophiolite complex that includes basic mass of cobalt as accessory sulfides, arsenides and admixture elements in rock-forming minerals; Caledonian which formed flyschoid complexes and sequential intrusion of granitoids accompanied by oxide, sulfide and sulfoarsenide mineralization in skarns and quartz veins; Late Paleozoic – Mesozoic which formed imposed basins during activation period of the deep fault zone with formation of a belt of basite intrusions of subalkaline row and fields of rocks of hydrothermal and metasomatic alteration with imposed arsenide nickel-cobalt veined and copper-cobalt sulfoarsenide-fahlore mineralization.

CONCLUSIONS

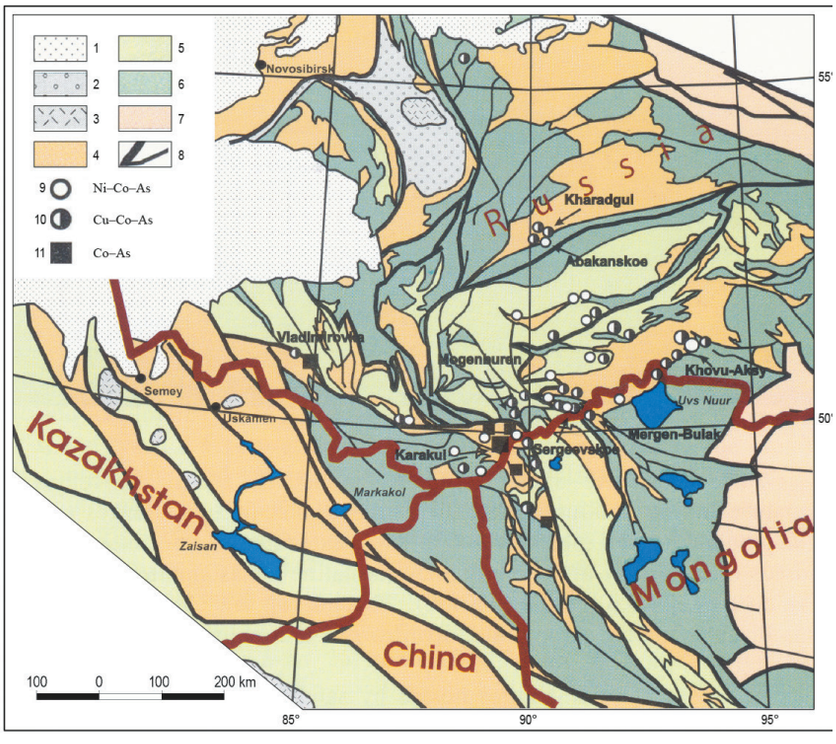
The considered cobalt-bearing zones enclose deposits with similar mineral composition and physicochemical conditions of hydrothermal ore formation.

1. Post-Devonian lowest age limit of mineralization has been established for the most of cobalt deposits; the upper age limit can be defined by early Mesozoic dykes of dolerites intersected by arsenide veins.

2. Within cobalt-bearing zones, ore fields are characterized by:

· distribution on areas of intersection of regional deep faults characterized by long pulsational development with distinct cobalt-arsenic geochemical mineralization;

LOCATION OF COBALT MINERALIZATION IN STRUCTURES OF THE ALTAI-SAYAN FOLDED REGION



THE AREA OF COBALT MINERALIZATION IN SE ALTAI AND NW MONGOLIA IS A PART OF THE ALTAI-SAYAN COBALT-BEARING REGION. THERE ARE DIFFERENT TYPES OF CO-MINERALIZATION: NI-CO-AS (KHOVU-AKSY, ASKHATIN-GOL, AND KYZYL-OYUK DEPOSITS), CU-CO-AS (UZUN-OY AND MOGENBUREN DEPOSITS), CO-AS SKARN (VLADIMIROVSKOYE), CU-CO-W (KARAKUL), ETC. THE CO-AS AND CU-CO-W MAJOR MINERALIZATION TYPES OF THE MIDDLE PALEOZOIC IN THAT AREA ARE SPATIALLY AND TEMPORALLY ASSOCIATED WITH GRANITOIDS OF THE YUSTID COMPLEX.

THERE ARE ALSO DEPOSITS OF THE PERMIAN-TRIASSIC NI-CO-AS MINERALIZATION: THE KARAKUL DEPOSIT IS A TYPICAL CU-CO-W MINERAL LOCALITY, AND THE ASKHATIN-GOL DEPOSIT REPRESENTS NI-CO-AS MINERALIZATION.

THE MESOZOIC AG-SB MINERALIZATION IS CONFINED TO SUBLATITUDINAL FAULTS AS WELL AS LAMPROPHYRE DIKES OF SIMILAR AGE. AG-SB MINERALIZATION OVERLIES SUBMERIDIONAL ZONES OF THE MIDDLE PALEOZOIC CO-AS AND MESOZOIC NI-CO-AS MINERALIZATION.

— Mz–Kz sedimentary rocks of West Siberia Plate; 2 — Late Paleozoic-Triassic molasses of Kuznetsk trough (pull-apart basin); 3 — Late carboniferous — Permian volcanic rocks; 4 — Devonian-Early carboniferous volcanosedimentary rocks; 5 — Late Cambrian-Ordovician-Silurian sea molasses and flyschoid; 6 — Vendian-Cambrian flyschoid strata; 7 — Archean-Proterozoic metamorphic strata; 8 — Faults and geologic boundaries; 9 — Ni-Co-As deposits; 10 — Cu-Co-As deposits; 11 — Co-As deposits.

- location near areas of accumulation of salt deposits and control of their distribution by intervals of deep fault zones which were activated in the Late Paleozoic and Mesozoic;

- the fact that they confined to relatively rigid structural blocks 15-20 km2 in area; within them, intensity of folded forms is conditioned by influence of fault tectonics;

- close spatial-structural connection of ore deposition zones with small separate intrusions of subalkaline granitoids of elevated basicity and fields of development of dykes of variegated composition: dolerites, lamprophyres, gabbro-diabases, plagioporphyries, andesites, trachysyenites, syenite-porphyries, and granophyres.

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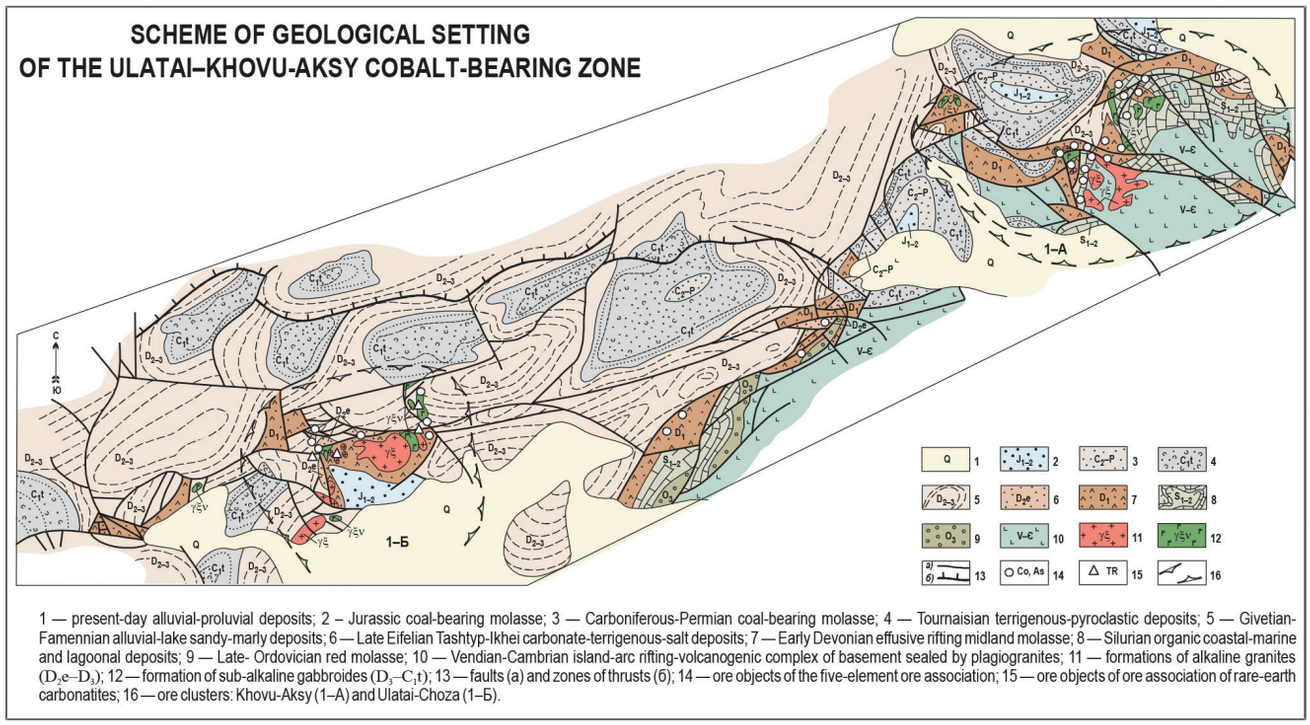
ULATAI–KHOVU-AKSY COBALT-BEARING ZONE IS CONFINED TO THE CONJUGATION OF HERCYNIDE OF THE WESTERN TANNU-OLA SYNCLINORIUM AND CALEDONIDES OF THE EASTERN TANNUOL ANTICLINORIUM ALONG UVS-NUUR-BAYANKOL SYSTEM OF DEEP FAULT



1 — present-day alluvial-proluvial deposits; 2 – Jurassic coal-bearing molasse; 3 — Carboniferous-Permian coal-bearing molasse; 4 — Tournaisian terrigenous-pyroclastic deposits; 5 — Givetian-Famennian alluvial-lake sandy-marly deposits; 6 — Late Eifelian Tashtyp-Ikhei carbonate-terrigenous-salt deposits; 7 — Early Devonian effusive rifting midland molasse; 8 — Silurian organic coastal-marine and lagoonal deposits; 9 — Late- Ordovician red molasse; 10 — Vendian-Cambrian island-arc rifting-volcanogenic complex of basement sealed by plagiogranites; 11 — formations of alkaline granites (D_2e–D_3); 12 — formation of sub-alkaline gabbroides (D_3–C_1t); 13 — faults (a) and zones of thrusts (б); 14 — ore objects of the five-element ore association; 15 — ore objects of ore association of rare-earth carbonatites; 16 — ore clusters: Khovu-Aksy (1–A) and Ulatai-Choza (1–Б).