METALLOGENIC EVOLUTION AND MODEL OF MANZHOULI-XINBAERHU METALLOGENIC PROVINCE①

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ABSTRACT

This area is a superlarge potentiality metallogenic province of multimetal resource, belonging to Ergun accretionary fold system of early Caledonian. The regional basement (Neoproterozoic-Lower Cambrian Series) is the outer extent of the Siberian craton margin, and the metallization in this area was affected intensely by Pacific plate tectonics. The NE trending Ergun-Hulun deep-seated fracture controls the giant volcano-magmatic activty and mineralization in this area. NW cross trending tenso-shear fractures control the formation of ore cluster in this area. The major types of ore deposits in this area are porphyry type, subvolcanic hydrothermal vein type and skarn type. They are the products of different depths and environments as genetically-related, which can be collectively regarded as porphyry copper-multimetal metallogenic series.

Key words: Manzhouli metallogenic province metallogenic evolution metallogenic model porphyry

1 INTRODUCTION

The Manzhouli-Xinbaerhu region in Inner Mongolia tectonically belongs to the early Caledonian Ergun accreting fold system. Its southwestern and northeastern parts extend into Mongolia and Russia respectively and its southeastern part is separated from the Hercynian Greater Khingan accreting fold system by the Ergun-Hulun deep fault. Its total area exceeds 20, 000 km^2 . This region is a metallogenic province with exceedingly considerable potential polymetal resources[1]. During the period from 1985 to 1990, the Beijing Institute of Geology for Mineral Resources and the Nonferrous Metals Geological Exploration Bureau of Heilongjiang Province cooperated closely to establish the metallogenic evolution, metallogenic model and exploration model of the region. On that basis, 16 rock bodies and geophysical and geochemical anomalies in the region were compared and identified one by one and some target areas were delineated, thus providing scientific grounds for further ore prospecting and evaluation in the region. The work has yielded outstanding economic effects.

2 REGIONAL GEOLOGICAL SETTINGS FOR ORE FORMATION

The upper Proterozoic-Lower Cambrian constitutes the old basement of the region.

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After the early Caledonian orogeny, the region was set along the margins of the Siberian platform[2], thus leading to the initiation of an oldland. By the early Paleozoic, this region had become a part of the Mongolian-Ochotsk Sea. In the late Hercynian, the Ergun-Hulun deep fault was mainly subjected to plate compression and assembling; as a result, the ancient sea closed up, continental crust formed and there appeared the intermediate-acid volcano-magmatic complexes in the region. The Hercynian Greater Khingan fold system on the eastern side of the deep fault was assembled with the region, forming a unified continent (Fig. 1).

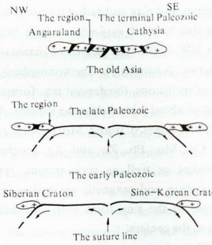

Fig. 1 Schematic diagram showing tectonic evolution of the paleozoic oceanic slabs between the Sino-Korean craton and the Siberian Craton

The two cratons grew up associated with the disappearance of the oceanic crusts. The old Asian ultraland was formed due to the percussion of the two cratons in the terminal paleozoic. The coarse black lines stand for the oceanic crusts

In the early Yanshanian period, the Kola-Pacific mid-ocean ridge expanded dramatically and affected the region. There occurred NW-directed compression, and the Ergun-Hulun deep fault operated intensely, with compressive thrusting predominating. Thus the western side of the fault (i. e. this region) was faulted and uplifted, where there occurred a NE-trending, widespread, polycyclic calc-alkaline, intermediate-acid volcano-magmatic complex belt and related mineral deposits; while the southeastern side was downfaulted , where continental basin (Hailar basin) sediments were deposited. In the terminal Mesozoic and Cenozoic, the Ergun-Hulun deep fault was mainly subjected to extension, resulting in the deposition of the sediments of the Ergun River-Hulun Lake and eruption of voluminous basalt along the deep fault (Fig.2).

The Ergun-Hulun deep fault controls the distribution of the polymetallic metallogenic belt in the region. To the south-west in the territory of Mongolia, it is connected with the Middle Mongolian fault, and within the territory of China it is over 800km long and shows the feature of long-continued inherited activity. The development of regional strata and volcano-magmatic activity were both controlled by this particular tectonic setting.

Under the regional tectonic stresses, the NW-trending tenso-shear or tensile faults intersecting the main structure, i. e. the transverse structure, such as the Hanigou fault in the north and the Muhar fault in the south (both of which are over 60 km in length and enter the territory of Mongolia), control the formation of two main ore fields in the region respectively. The Hanigou ore field contains the large Wushan porphyry copper (molybdenum) deposit, the Halasheng subvolcanic hydrothermal lead-zinc occurrence and so on; the Muhar ore field in the south comprises the large Jiawula subvolcanic hydrothermal lead-zinc-silver-copper-gold deposit, large chagan subvolcanic hydrothermal lead-zinc-gold deposit, large Eren Taolegai subvolcanic hydrothermal silver deposit, etc. The compounding site of the NW and NE-trending fault is usually the center of the volcano-magmatic activity.

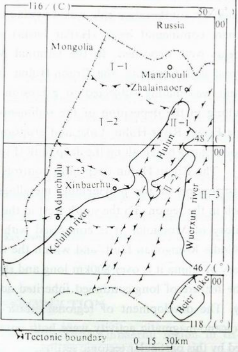

Fig. 2 Sketch map of tectonic division for Manzhouli-Xinbaerhu region

Ⅰ—ManZhouli-Xinbaerhu Volcanic uplifted zone; 2—Hailar basin; Ⅱ-1—Hanigou fault upwarp; Ⅱ-1—Hulun lake graben; Ⅱ-2—Daba-Huanghuali Volcanic fault depression; Ⅱ-2—Cuogang uplift; Ⅰ-3—Muhar fault upwarp; Ⅱ-3—WurXun (river)-Beir (lake) fault depression

3 MINERALIZATION FEATURES OF MAJOR DEPOSIT TYPES

The ore deposits and occurrences discovered in the region may be classified into porphyry type, subvolcanic hydrothermal vein type and skarn type. The first two types contribute the majority of the ore reserves and their metallogenic epochs are mainly late Yanshanian. The last one is of no economic value and its metallogenic epoch is early Yanshanian. In terms of space, they are mainly distributed along the Hanigou fault and the Muhar fault.

3.1 *Porphyry Type*

The porphyry type is represented by the Wushan copper (molybdenum) deposit. Located on the northern side of the NW-trending Hanigou structural belt and on the anticlinal uplift zone composed of Middle Devonian strata, this deposit is controlled by paleo volcanic edifices made up of subvolcanic composite pipes and ring and radial fractures and fissures due to their explosion, which migrated from NW to SE. The degree of denudation is moderate. According to the atmospheric pressure of inclusions, the deposit was formed at a depth of about 2 km below the surface. All the alteration zones, Cu and Mo mineralizations and Cu, Mo, Pb, Zn and Ag geochemical anomalies as well as spontaneous, induced polarization and magnetic anomalies are distributed in the ring form with volcanic conduits as the centers.

The volcano-magmatic activity in the Wushan deposit shows the features of polyphase activity. In the early Yanshanian, extensive eruption of andesite-rhyolite took place first, and then biotite granite intruded. In the late Yanshanian, the subvolcanic pipes whose centers migrated were filled with rhyolitic crystal tuffaceous lava of the early mineralization stage, monzonitic granite porphyry of the mineralization stage and dacitic breccia tuffaceous lava of the late mineralization stage, accompanied by intrusion of still later diorite porphyrite, dacite and granite porphyry dikes. The magmas largely show the feature of evolution of intermediateacid subalkaline compositions.

The near-ore country rocks consist mainly of biotite granite (187 Ma), derived from anatexis of the materials of the lower part of the upper crust[3]. The mineralized parent rocks are monzonitic granite porphyry (138 Ma) with an exposed area of about 0. 5 km^2. They have high acidity, differentiation degree and rock-forming temperatures as compared with main copper (molybdenum) porphyry in China, and were derived from partial melting of the lower crustal materialsl[3].

After the alteration of porphyry, the AN% of the plagioclase decreases, the ordering degree of K-feldspar rises, magnetite and apatite are reduced and rutile appears in large amount, so they are important indicator minerals of Cu and Mo mineralizations of porphyry. In addition to Cu and Mo metals, associated Ag, Re, Au, Pb, Zn, Pt and Pd are also of great value in comprehensive uses.

There occurs symmetrical alteration with the monzonitic granite porphyry body as the center, covering an area up to over 10 km^2. From the center outward there are the quartz-K-feldspar (Q-Kf), quartz-sericite (Q-S) and illite-hydromuscovite (I-H) alteration zones. The termperature, pressure, salinity and density of the fluid inclusions of the three alteration zones decrease successively. The temperatures of Mo and Cu ore formation are 410~340 ℃ and 340~240 ℃ respectively. The ore textures, metallic mineral association, ore-forming elements and volatile components exhibit distinct zoning. Petrological, mineralogical, hydrogen and oxygen isotope, REE and inclusion studies indicate the superimposition of two stages of alteration: the early stage witnessed the Q-Kf (magmatic water predominated) and I-H (meteoric water was introduced) alteration; the late stage witnessed the Q-S (meteoric water increased) and I-H (meteoric water predominated) alteration. Superimposed by the Q-S zone to a certain extent, the inner borders of the Q-Kf zone are the main position where Mo ore-bodies are localized. The Q-S zone is superimposed on the I-H zone of the early stage and the super-imposed place is the main position where Cu ore-bodies are localized. The I-H zone of the late stage expands outward and there appear Pb and Zn mineralizations. Cu and Mo orebodies are hosted in the endo-and exocontact zones of the porphyry body. The superimposition of alteration, leaching of REE, extraction of ore substances from the country rocks accompanied by precipitation and reworking of protores are of major importance for the formation of deposits of this type. Eu depletion is intimately associated with mineralization. The more notable the Eu depletion is, the better the mineralization will be[4]. The REE variations in host rocks and country rocks during the alteration show the feature of supplementing each other[5], proving the existence of hydrothermal convection.

The ore substances were not all provided by parent rocks. There exists a decrease field of the ore-forming element Mo. Mo was derived from the country rocks-biotite granite during the hydrothermal convection and super-imposition of alteration. The host rocks-monzonitic granite porphyry mainly provided Cu, Ag, Pb and Zn as well as heat.

3. 2 *Subvolcanic Hydrothermal Vein Type*

From deep to shallow levels there occur

the Jiawula, Chagan, Halasheng and Erentaolegai ore deposits or occurrences. They are represented by the Jiawula deposit.

This Jiawula lead-zinc-silver-copper-gold deposit: deposit is located on the southern side of the NW-trending Muhar fault zone, in a setting of distribution of Upper Permian clastic rocks, intermediate to intermediate-acid volcanic rocks and late Hercynian biotite-plagioclase granite. The Muhar fault zone in the early part of the late Yanshanian movement: led to the intrusion and localization of a series of polyphase subvolcanic rocks and mineralization The depth of denudation is moderate to shallow. According to the atmospheric pressure of the inclusions, the orebodies were formed at about 350 m below the surface.

The order of intrusion of the subvolcanic complexes is uralite porphyrite (182.8 Ma; the early mineralization stage)→feldspar porphyry (122 Ma; main mineralization stage)→qu- artz porphyry (117 Ma; mineralizationstage)→ quartz monzoporphyry (109 Ma; late mineralization stage), showing the sequence of evolution intermediate→ intermediate-acid→ acid→ subalkaline compositions. In these respects the deposit bears some resemblance to the Wushan deposit.

The main ore-bodies show certain relation to the porphyry bodies in terms of spatial distribution. The main ore-bearing faults all have the anomalies of geochemical secondary halo groups occurring as zones and positive points of the intersection of composite resistivity profiling. According to the temperature measurements of inclusions and analysis of their composition, two centers of heat sources expanded upward and laterally respectively, which might be related to the intrusion of feldspar porphyry and quartz porphyry from deep levels. The ore formation temperature ranges from 200～300 ℃. The formation temperature, pressure and salinity are lower than those of the Wushan deposit. The tempera- ture difference is 150～200 ℃ and the pressure difference is $1\times10^7\sim2.5\times10^7$ Pa. This indicates that the Jiawula deposit was localized at a shallower depth than the Wushan deposit. The hydrothermal ore solutions were derived from magmatic water and meteoric water, but the meteoric water had played the dominant role in the main mineralization stage. Sulfur and lead isotope studies indicate that the ore metals and sulfur were derived from the same source as the porphyry body, i. e. from the deep levels of the crust. Both altered feldspar porphyry and quartz porphyry show notable Eu depletion and their REE values are the highest in the whole region. It is inferred that there might exist relatively large copper ore-bodies in their corresponding alteration zones at depth.

The principal ore minerals are galena, sphalerite, chalcopyrite, pyrite and pyrihotite. The gold and silver minerals include native silver, freibergite, skinnerite and silver-bearing galenobismutite. Native gold has been observed. The carrier minerals of silver are galena, chalcopyrite and pyrite.

Wall-rock alteration adjacent to ore occurs along the fracture zones, with quartzification, silicification, chloritization and carbonatization predominating and fluoritization, kaolinization and pyrophyllitization occurring locally.

3.3 *Skarn Type*

This type is represented by the Toudaogou iron-copper occurrence and the Longling copper-zinc-tin occurrence. Located on the northern side of the NW-trending Hanigou fault zone, they both occur in the contact zones of early Yanshanian mesozone-plutonic granite and Paleozoic carbonate rocks. The ore-bearing skarn is composed of diopside, actinote, tremolite and serpentine. They are characterized by lenticular shape, high variation in ore grade and small size and are of no economic value.

4 REGIONAL METALLOGENIC EVOLUTION & METALLOGENIC MODEL

(1) This region is situated on the southeastern margin of the early Caledonian Ergun accreting fold system along the outer margin of the Siberian platform. The basement (upper Proterozoic-Lower Cambrian) of the region is the extension of the margin of the Siberian platform, while the mineralization was affected by the Pacific plate from the southeast.

(2) The NE-trending Ergun-Hulun deep fault controls the distribution of the gigantic metallogenic belt of porphyry series in the region. The development of this fault zone progressed through three stages with different modes of movement: late Hercynian (late Paleozoic) compression and assembling, Yanshanian (Mesozoic) compression and thrusting and terminal Mesozoic to Cenozoic extension. During the Yanshanian orogeny, this fault operated intensely and the fault block dipped and was subducted north-westward, thus controlling the development of the NE and NW structures in the region and leading to intrusion or eruption or deepseated magmas to form large-scale NE-trending volcano-magmatic complex zone related to polymetallic mineralizaion in the region.

(3) The NW-trending transverse fault zones control the formation of the ore fields. The NW-trending tensoshear or tensile transverse structural zones intersectimg the NE-trending principal structural line are the main structures as passageways for ore fluids or for ore housing. The NW-trending Hanigou and Muhar fault zones gave rise to the Mo, Cu, Pb and Zn ore field in the north and the Pb, Zn, Ag, Cu and Au ore field of the south in the region respectively.

(4) The volcanic edifices or subvolcanic structures formed by the intersection of the NE and NW structures as well as the subsidiary structures of the NW-trending transvers structure control large-sized deposits in the region.

(5) The late Yanshanian, polyphase, intermediate-acid and acid, calc-alkaline subvolcanic porphyry bodies are associated with mineralization. Those that show close relation are monzonitic granite porphyry, feldspar porphyry and quartz porphyry . The isotopic age values are 138~ 117 Ma and, in a few cases, 98 Ma. The host rocks for ore formation were derived from the lower crust.

(6) There should be a shallow magma chamber at depths of 4~5 km. Magmas in the magma chamber originated from the anatexis of the materials in the lower part of the upper crust and from partial melting of the materials of the lower crust. The magmas underwent differentiation and evolution and ascended and erupted in a pulsatory way along the connecting openings under the structural action, thus forming polyphase subvolcanic composite porphyry bodies of different lithologies. High-salinity hydrotheramal ore solutions were also derived from the magma chamber. They ascended and migrated along volcanic conduits and structural fissures, and meanwhile meteoric water infiltrating from the surface

participated in the circulation system.

(7) The main ore deposit types in the region are porphyry type, subvolcanic hydrothermal vein type and skarn type. The minerals include those of Cu, Mo, Pb, Zn, Ag, Au, Fe and Sn. They are genetically related but were formed at different depths and in different environments (Fig. 3).

The porphyry type or skarn type deposits were formed at 1. 5～2 km from the surface and at temperatures of about 370～450 ℃. The subvolcanic hydrothermal vein type deposits occurred at relatively shallow depths from the surface and at temperatures ranging between 180 ℃ and 320 ℃. The resulting deposits generally contain an association of multiple elements. Apart from major oreforming elements, there are usually other associated elements, which show zoning owing to different temperatures and other physico-chemical conditions. Mo mostly lies in a relatively deep position in the center and Cu occurs in its

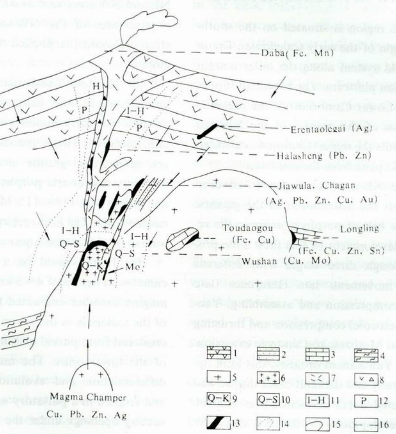

Fig. 3 Schematic diagram showing the metallogenic model of Manzhouli-Xinbaerhu region

1—Jurassic Volcanic rocks; 2—Permian psephonite and andesite; 3—Devonian Carbonate rocks with sand rocks; 4—Upper Proterozoic-Lawer Cambrian cystalline Schist; 5—Early Yanshanian granite; 6—Late Yanshanian intermediate porphyry; 7—Acid porphyry; 8—brecciated andesite; 9—quartz-K feldspar zone; 10—quartz-Sericite zone; 11—illite-hydromuscorite zone; 12—propylitization zone; 13—ore-body; 14—alteration boundary; 15—geologic bounday; 16—denudation boundary outer shells; upward and out-ward there occur Pb, Zn, Ag, Fe and Mo successively. In the light of the metallogenic series, the subvolcanic hydro- thermal polymetal veins along the structural fracture zones belong to the upper part of the series, and the Pb and Zn mineralizations in the ring fissure zones belong to the uppermost part of the series. The example is given by the Halasheng occurrence. Located on the distal side are manganous Ag-bearing quartz veins in the fracture-fissure zones, as examplified by the large Erentaolegai deposit. Downward the Pb, Zn, Ag, Cu and Au veins in the radial fracture system belong to the middle-shallow part of the series, as examplified by the large Jiawula deposit. On its adjacent side are the Ag, Pb, Zn and Au veins in the structural zones, as examplified by the large Chagan deposit. Granitic subvolcanic porphyry veinlet- disseminated Cu (Mo) deposits generally belong to the middle part of the series, as examplified by the large Wushan deposit. The disseminated Mo deposits in porphyroid granitic rocks belong to the lower part of the metallogenic series. The skarn type Cu-Fe deposits and Cu-Zn-Sn deposits on the contact zone between early Yanshanian meso-zone-plutonic granite and carbonate rocks belong to the outer side of the middle part of the metallogenic series. Daba is situated in the downfaulted position between the Muhar and Hanigou transverse faults, where volcanic cones are well preserved; its position corresponds with the top of metallogenic series.

According to the aforesaid metallogenic evolution and metallogenic model, attention should be paid to looking for porphyry type copper deposits at deep levels of Jiawula and Halasheng. At present, Cu mineralization in Jiawula is intensified with increasing stripping depth. In the present stage, this regional metallogenic model and the established regional exploration model[5] may serve as the guide to ore prospecting and evaluation in the region.

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