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Reviews

Phanerozoic felsic magmatism and related mineralization in Mongolia

Ochir GEREL*

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Abstract: Mongolia situated between the Siberian craton in north and the Northern Chinese and Tarim platforms in south was the arena for multiple orogenies which resulted in the complicated geological structures of Precambrian to Cenozoic systems. Granite magmatism occurs in Early, Middle and Late Paleozoic and Mesozoic Periods. Granites were generated at Phanerozoic convergent plate margins, including island arc, plate margin and continental collision zone. Majority of economically important mineral deposits and occurrences are related to Late Paleozoic and Mesozoic granites, generated in mature continental crust. Porphyry-copper-molybdenum, skarn, pegmatite, rare metal, rare earth, and Pb-Zn-Ag mineralization are associated with such granites. This paper will list some representative deposits of granitic affinity in Mongolia.

1. Introduction

Many of the Mongolian economically important mineral deposits and occurrences, including porphyry copper-molybdenum, rare metal stockwork/vein, and REE deposits are related to Phanerozoic granites. Phanerozoic granite magmatism widely occurred in Mongolia has features common for Central Asian fold belt which formed during the closure of the Paleoasian Ocean. The most intensive granitic activity appeared in Paleozoic time, and also during the Caledonian and Hercynian orogeny. Mesozoic granite magmatism was caused by continental collision and occur within the Mongol-Okhotsk belt. This paper summarises granite magmatism of different tectonic positions and describes the major deposit-types of granitic affinity in Mongolia. However mineral deposits of subsequent importance, e.g., Au-copper porphyry, disseminated replacemnet Au deposits in carbonate and terrigenous rocks in South Govi Hercynian belt (Dandar *et al.*, 1995) will not be discussed here.

2. Geological setting

Mongolia is divided into two large blocks: northern Caledonian and southern Hercynian blocks, with different development history (Yanshin ed., 1974; Tseden *et al.*, 1992). After these two orogenies all territory was developed in the continental tectonics. Mesozoic processes are related to intracontinental collision and post-collisional setting. Major mineralization in Mongolia is associated with granite magmatism, as follows: porphyry copper-molybdenum, porphyry molybdenum, Fe and W-Sn skarns, rare metal, Pb-Zn-U vein/stockworks, Ta, Nb, REE, rare metal-and REE-bearing pegmatites.

Caledonian magmatic activity started with calc-alkaline tonalite-plagiogranite which were followed by granodiorite and granite. These series mainly occur in northern Mongolia, and are considered to have developed on the continental crust being related to subduction. Hercynian rocks are chracterized by calc-alkaline and alkaline chemistry, widespread in Mongolian Altai, South and Northern blocks of Mongolia, and are distributed to form zoned provinces. In Mongolian Altai (Gavrilova, 1975) occurs spatial distribution from southwest to northeast from tholeiite through calc-alkaline to alkaline series. In northern Mongolia alkaline series occur (Yashina and Pavlov, 1975) being divided by amagmatic "Lake zone". This zoning shows alkalinity increasing from continental margin to continent, which is characterisitc for active continental margin areas.

In northern Mongolia alkaline rocks are developed on the Caledonian framework of the Siberian craton. Distribution of alkaline rocks such as alkaline gabbro, ijolite-urtite, foyaite and syenite, is controlled by deep faults of northwestern direction. Syenite-nepheline syenite series are younger (C_1) and occur as small bodies surrounding Devonian granites. Shallow alaskite and granite bodies of A-type

*Mongolian Technical University, Ulaanbaatar 46, Mongolia

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emplaced along the activated regional fault zones. In Middle Paleozoic by subduction of the South Block to the North Block, most of the Mongolian terraine was dominated by continental regime, but the southernmost part ,Suliinkheer zone, remained as oceanic basin. By the end of Middle Paleozoic, the continental crust has been formed and most part of Mongolia was developed as one continental megablock (Kovalenko *et al.*, 1984), leaving north-eastern edge of the nation as oceanic regime still continued.

South-Mongolian zone was a southern part of Late Paleozoic continent bordered by thrust zone of the Main Mongolian lineament. Magmatic rocks of calc-alkaline, subalkaline and alkaline series occur. Two stages are distinguished: early (late Early Carboniferous-Middle Carboniferous) with andesite-dacite-rhyolite and andesite-basaltic andesite series. Late stage is characterized by intrusive magmatism: leucogranite, granodiorite-granite series of I-type of normal or higher alkalinity with quartz syenites and monzonites. Rifts forming along the large latitudinal fault zones have followed this process. Rift depressions are filled by bimodal trachybasalt-trachyrhyolite-comendite series (Yarmolyuk, 1983). These form together with alkaline volcano-plutonic associations.

The North Mongolian zone includes the Khangai batholith as a result of intracontinental collision which started from Late Paleozoic time (Fig. 1). The Khangai batholith is composed of granodiorites (Tarbagatai complex), granites and granodiorites (Khangai complex) of I-type and leucogranites with granosyenites (Sharusgol complex) forming from the Late Carboniferous to Late Permian Period. The Khangai batholith is surrounded by volcanic rocks forming the North-Mongolian and Central-Mongolian volcanic belts. On the early stage volcanic series of normal alkalinity (basalt-andesite, andesite-dacite-rhyolite series) and higher alkalinity (trachybasalt-trachyandesite, trachyrhyolite series) have been formed. Late stage is characterized by rift formation with bimodal trachybaslt-trachyrhyolite-comendite series and alakline granites.

Mesozoic magmatism was developed on the mature continental crust and is concentrated mainly in the eastern part of Mongolia, locally in western and

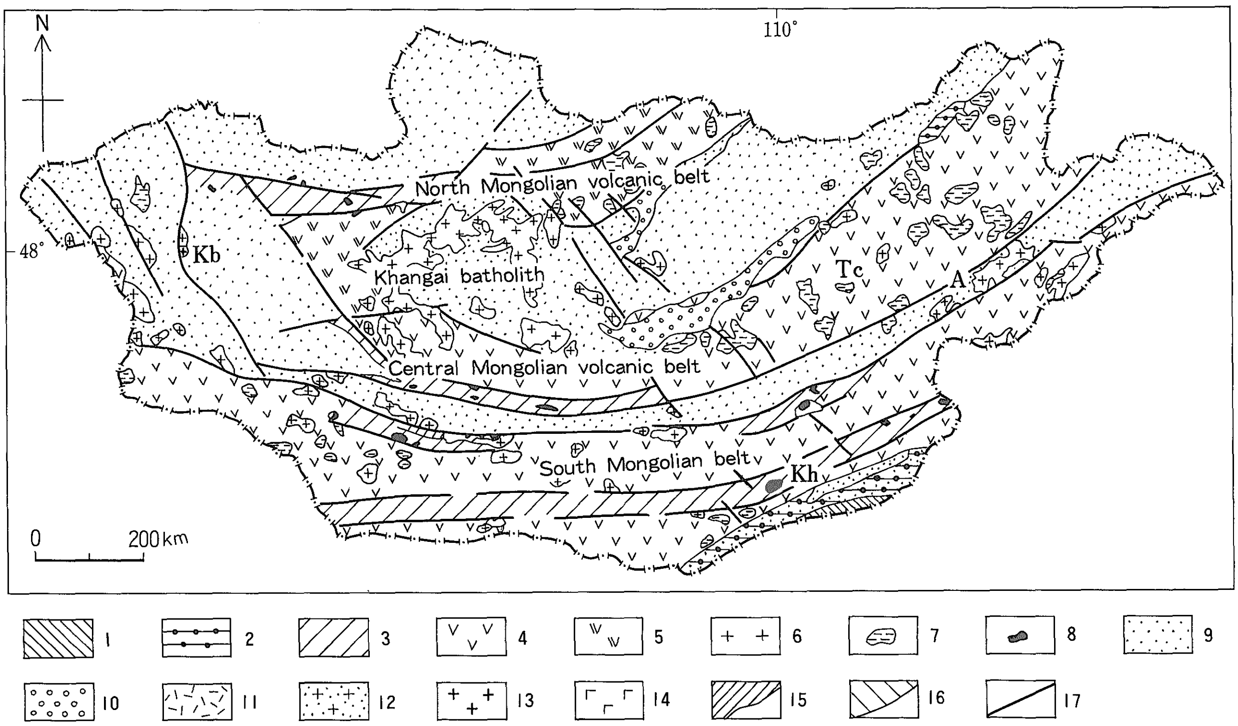

Fig. 1 Granitoid distribution in Late Paleozoic (compiled from Kovalenko *et al.*, 1984).
1: ophiolites of ocean stage, 2: terrigenous rocks of transitional stage, 3: continental rift zone, 4: calc-alkaline volcanics, 5: calc-alkaline volcanics of elevated alkalinity, 6: granitoids of calc-alkaline series, 7: calc-alkaline granitoids of elevated alkalinity, 8: alkaline granites, 9: regions developed in continental regime, 10: terrigenous rocks of continental stage, 11: felsic volcanics, 12: granodiorites and granites, 13: leucogranites, 14: basic volcanics, 15: area of calc-alkaline series of normal alkalinity, 16: area of calc-alkaline series of elevated alkalinity, 17: faults. Examples of deposits and occurrences, kh: Khan Bogd, Kb: Khalzgn, A: Arynnuur, Tc: Tsagaan chuluut.

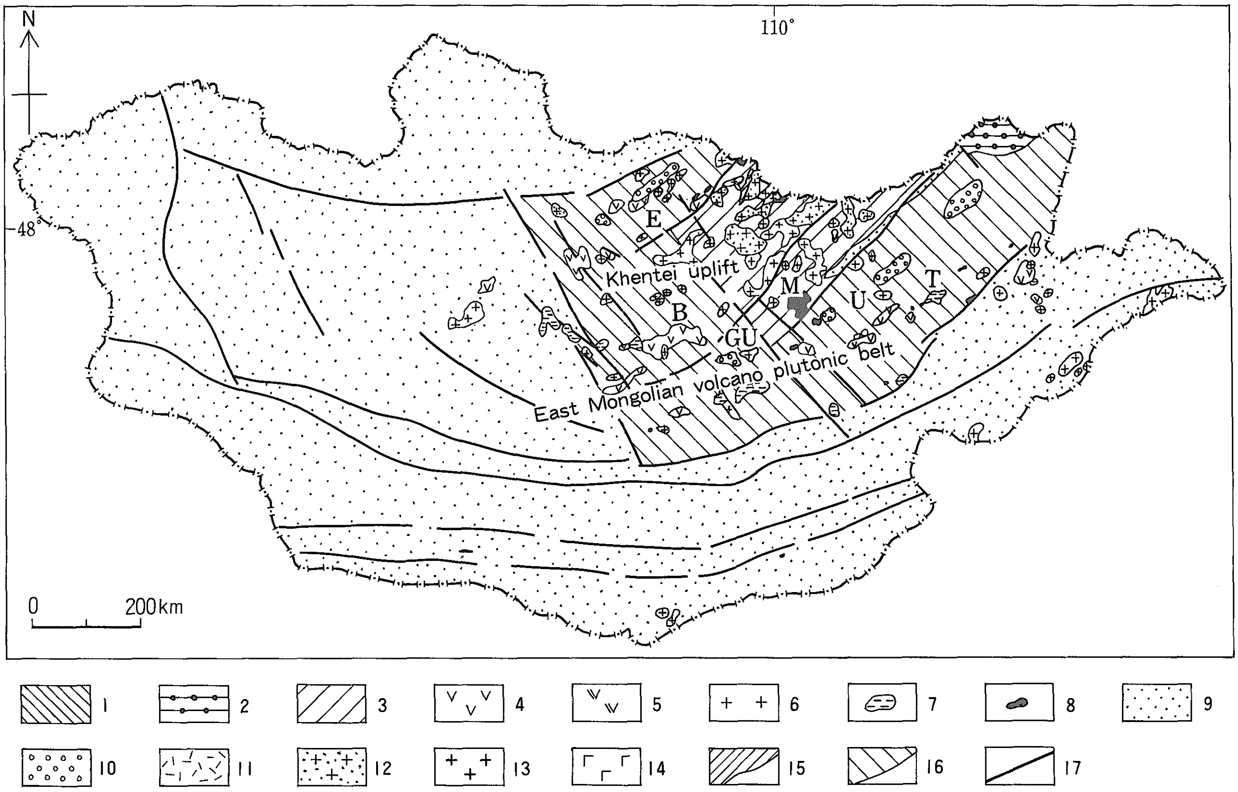

Fig. 2 Granitoid distribution in early Mesozoic (compiled from Kovalenko *et al.*, 1984). Legend see Fig. 1. Examples of deposits and occurrences, J : Janchivlan, E : Erdenetiin Ovoo, B : Bayan Uul, B : Modot, TD : Tsagaan davaa, T : Tumen Tsog, U : Under Tsagaan, GU : Gov Ugtaal (Oortsog Ovoo, Zuun Toirom, etc.).

south Mongolia (Fig. 2). In Late Triassic-Early Jurassic and Late Jurassic-Early Cretaceous time large zoned provinces have been formed (Zonenshain *et al.*, 1973). During Early Mesozoic time the Khenteii uplift with batholitic intrusions formed as a result of continental collision. Distribution of Early Mesozoic rocks is controlled by the Mongol-Okhotsk fault zone. In the core of Early Mesozoic province, calc-alkaline volcanics and intrusive rocks are formed, surroundded by higher-alaklinity volcanic and plutonic rocks and alkaline rocks in the depressions (Zonenshain *et al.*, 1973 ; Gerel, 1990, 1995). Besides the Khenteii province, Early Mesozoic rocks occur in a southeastern corner of Mongolia being controlled by the "Yanshanian fault zone". Similar zoning is distinguished for Late Mesozoic system within the Mongol-Okhotsk fold belt with core of large batholith (Russian part of the Mongol-Okhotsk fold belt), and with small hypabyssal and subvolcanic intrusions of higher alkalinity in the surrounding depressions (Fig. 3). Such alkaline series occur in south Gobi along the Main Mongolian lineament and composed of potassic alkaline series with carbonatite related to rift magmatism. Interpretation of this continental magmatism gave rise many theories and hypotheses, known in Russian literature as activization of the earlier structures (Yanshin, ed., 1974) and could be interpreted as a postcollisional or intracontinental rift-forming magmatism.

3. Features of mineralizing granites

Granitic host rocks for distinctive mineralizations are usually highly fractionated body, and are seen as small hypabyssal and subvolcnic intrusions in calc-alkaline or alkaline complexes. Host rocks of porphyry-type ore are represented by I-type porphyritic intrusions such as quartz diorite, granodiorite-granite or quartz syenite of high alkalinity and concentration of Al, Na, K, Zr, REE, Ni, Cr, Ba and Sr (Koval and Gerel, 1986).

Granites with rare metal mineralization form hypabyssal intrusions and are mainly distributed at the margins of the Khentei uplift. These are represented by highly fractionated granite series such as the Janchivlan body in central Mongolia. This is a multi-stage pluton with porphyritic/coarse-grained biotite granites (phase 1), medium-grained biotite-muscovite granites (phase 2), porphyritic biotite bearing alaskites (phase 3), and microcline-albite/

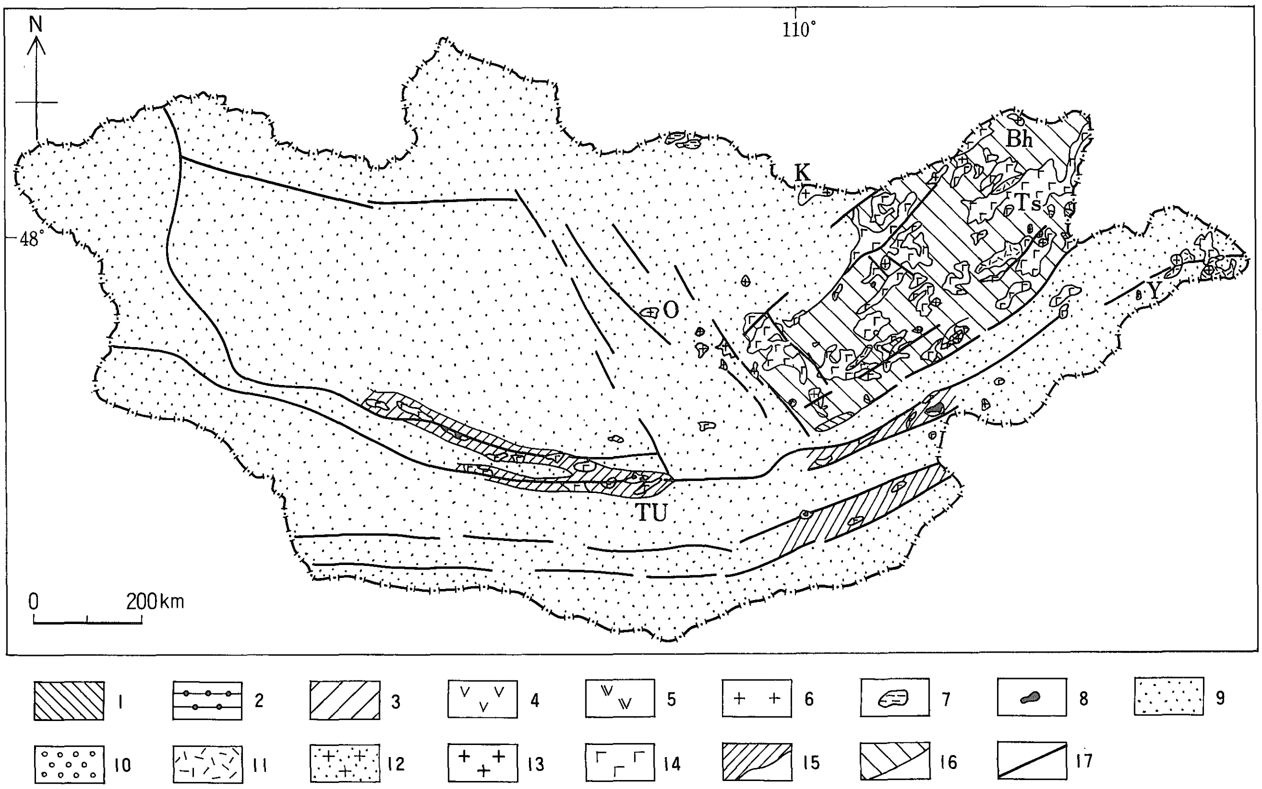

Fig. 3 Granitoid distribution in late Mesozoic (compiled from Kovalenko *et al.*, 1984). Legend see Fig. 1. Examples of deposits and occurrences, Ts : Tsav, O : Yugzer, O : Ongon Khairkhan, K : Kumir, Bh : Berkh, TU : Teg Uul.

amazonite-albite Li-F granites (Kovalenco *et al.*, 1971; Gerel, 1990). These are highly evolved and high alkalinity granites with low content of Ca, high Fe/Mg ratio, higher abundance of F, Li, Rb, Ta, Nb, Sn and W (Gerel, 1990, 1995). Usually latest members of fractionated series include Ta, Nb, Sn, W, and Li mineralizations. These granites have many features which are similar to those of S and A-type granites but typical cases show higher alkalinity than that of S-type. Highly evolved leucogranite with concentration of volatiles (H_2O, F, Cl) and Sn, W, Nb, Ta, Be, Li, Rb and Cs, is sometimes expressed as "plumasitic leucogranite" in Mongolia.

Volcanic analogue of Li-F granite designates "ongonite" in Mongolia. This is quartz-keratophyre with topaz and has high content of Ta, and includes both magnetite and ilmenite series of Ishihara (1977).

Hypersolvus granitic rocks often develop volcano-plutonic complexes with skarn mineralization. The rocks are miarolitic porphyritic intrusions, mainly leucogranite, alaskaite, monzonite and guartz syenite, having low fractionation. High concentration of Zr, Hf, Zn, REE and Cl is characteristic for these rocks (Gerel, 1990).

Granite related Pb-Zn-Ag-(U) mineralization, e. g. Tsav and Ulaan in eastern Mongolia, is concentrated within volcano-plutonic structures of latite association, including latite, trachyandesite, trachydacite, ultrapotassic rhyolite, and subvolcanic monzonite, syenite, and leucogranite with high concentration of Ti, P, Rb, Nb, Zr, Ba, Sr and REE. Mineralization is observed within explosive breccias, porphyry intrusions or rhyolite bodies.

REE, Nb and Zr hosted alkaline granites (e. g. Khalzan büregtee pluton of western Mongolia) form highly fractionated plutons (Kovalenko *et al.*, 1985) with nordmarkite (phase 1), alkaline granite (phase 2), veined alkaline granite (phase 3), veined pantellerite (phase 4), rare metal alkaline granite (phase 5), veined gabbroid (phase 6), rare metal alkaline granite (phase 7) and syenite and leucite basalt (phase 8). Rare metal alkaline granite consists of potassium feldspar, quartz, albite, arfvedsonite, aegirine, fluorite and accessories of elpidite, zircon, pyrochlore, monazite, rare metal fluor-carbonate and polylitionite $KLi_2Al\ (Si_4O_{10})\ (F, OH)_2$, REE, Nb, Ta, Zr and F are enriched in these rocks.

Granites which host alkaline pegmatite such as the Khan bogd pluton in south Mongolia are fractionated plutons with alkaline ribeckite-granite (phase 1), fine-grained aegirine-granite (phase 2) and a ring-dike complex. Twelve ore zones of rare-metal granitoids and pegmatites are recognized. In addition to dykes and veins, layered orebodies with fine-grained granites, pegmatite and melanocratic or leucocratic band are existed in ore zones.

4. Mineral deposit examples

As mentioned above, mineral deposits and occurrences of granitic affinity in Mongolia are represented by rare metal, REE, porphyry copper-molybdenum and Pb-Zn-Ag mineralizations. So-called rare metal deposits in Mongolia include Sn-W vein/stockwork, skarn, intrusive and volcanics-related rare metal deposits. The intrusive and volcanics-related deposits are igneous rock bodies such as Ta bearing Li-F granites and ongonite, REE-Nb-Zr bearing peralkaline granite and pegmatite, nepheline syenite (Kovalenko *et al.*, 1986; Kovalenko and Yarmolyuk, 1995). Genesis of many of these "rare metal deposits" still remains obscure. For example there is a controversy on the genesis of REE-Nb-Zr mineralization which is associated with peralkaline granites and pegmatites between magmatic and metasomatic processes.

Most of the rare metal deposits are spatially and genetically related to calc-alkaline and peralkaline granites and alkaline rocks. Mineralization is concentarted in apical part, or endocontact, sometimes in exocontact of plutons, mainly of hypabyssal or subvolcanic facies and associated with the highly fractionated magma. Some deposits occur in continental environment, i. e. postcollisional land or rift but high-grade deposits are mainly related to Mesozoic magmatism which was originated within collisional intracontinental belt; or are related to active continental margin of middle and late Paleozoic time.

4.1 Porphyry type

Porphyry copper-molybdenum deposit is most important in Mongolia. One of them, the Erdenetiin ovoo deposit, is operating and is well known (see Dejidmaa and Naito in this issue). Copper grade ranges from 0.4 to 0.7 %, molybdenum from 0.002 to 0,007 g/t. Although other localities are not enough studied, copper-gold deposits could have a potential in the South Mongolian and Central Mongolian Belts (Sillitoe *et al.*, 1996). Already occurrences are found at Bayan uul, Shüteen, Tsagaan Suvraga and Ojuut ovoo. These deposits occur in association with felsic to intermediate porphyritic intrusions within volcanics-filled depressions. Genetically these are related to subalkaline andesite volcanics that superimposed on gabbro-syenite-granite series. Volcanics are enriched of Rb, Sr, Ba, REE, Nb, Zr, Ta, Cr and Ni (Koval and Gerel, 1986; Koval *et al.*, 1988). Tectonic setting of such deposit (e. g. Erdenetiin ovoo and Bayan uul) could be interpreted as continental collision in contrast with South Mongolian belt where many deposits and occurrences follow the subduction zone and are controlled by thrust structure. Within each deposit, primary ore consists of pyrite, molybdenite, chalcopyrite, tennantite, galena, sphalerite and enargite. Secondary enrichment zone includes chalkosite, covellite and bornite. (Gavrilova *et al.*, 1984). Propylitic, quartz-sericitic and argillic, partly K-feldspathic alteration is present.

Porphyry molybdenum, tungsten, and tin deposits are spatially and genetically related to felsic porphyritic intusions and includes subtypes of simple molybdenum, tungsten-molybdenum, simple tin and tin-silver. Simple molybdenum subtype is represented by the Arrin nuur, Tsagaan chuluut, Ikh uul, Shar khad, and Zost uul deposits. Tungsten-molybdenum subtype includes Öndör tsagaan, and Yögüzer. Porphyry-molybdenum deposits are associated with anorogenic granites which was emplaced into continental region. The porphyries range in composition from subalkaline granodiorite to monzonite. The depositional environment is epizonal. Principal ore minerals are molybdenite, chalcopyrite, pyrite, sphalerite, magnetite, tetrahedrite, chalcosite, galena, wolframite and cassiterite. Hydrothermal alteration is extensive and the alteration products exhibit zonality. It consists of the inner potassic zone characterized by K-feldspar and outher zone of propylitic alteration that consisits of quartz, chlorite, epidote, calcite, sometimes with argillic overprints.

4.2 Rare metal pegmatite

The majority of commercially interesting pegmatite is of late Palaeozoic or Mesozoic in age. Rare metal pegmatites are mainly associated with leucocratic granites of calc-alkaline series or Li-F granites. Three classes of rare metal pegmatites are known (Kovaleno and Koval, 1984): Li-mica, muscovite (muscovite-albite) and mucsovite-microcline. Two first types are Ta-bearing, and the last is typical cassiterite-tungsten (Kovalenco *et al.*, 1971; Vladykin *et al.*, 1974, 1981; Gerel, 1995). Li-mica pegmatites consist of Ta-Nb minerals, cassiterite, Li-mica, quartz, albite, microcline, apatite, tourmaline, topaz, beryl and othres. The main examples are Khökh del uul, Unjuul. Muscovite-albite type consists of columbite and tantalite, quartz, albite, microcline, muscovite. The main example is Berkh. Muscovite-microcline type includes cassiterite, wolframaite, quartz, microcline and muscovite. The main examples are Tümentsogt, Bayandelger, Bayan ovoo, and Khalzan uul. Many of known rare metal pegmatite deposits occur in the northeast of Mongolia. Pegmatites of Khökh del uul, Önjüül, Berkh and others occur as dike-like or lenticular bodies ranging in size from a few meters to hundreds of meters long, and from 1 to 10 meters wide. Muscovite-microcline type is widespread in relation to sublakline granites. Li, Sn, Be pegmatites (Kovalenko *et al.*, 1986 ; Kovalenko and Yarmolyuk, 1995) consist of Li-mica, Ta and Sn-W mineralization related to postcollisional intrusions that postdate the peak of batholith emplacement. Granites are mainly represented by calc-alkaline and lithium-fluorine leucogranites and their volcanic and subvolcanic analogues.

4.3 Tungsten skarn

This type includes presently non-commercial occurrences which are distributed within northeastern part of Early and Late Mesozoic systems and southeastern part of Mongolia of Early Mesozoic system. Typical examples are the Beis, Bayan ovoo, and Tumentsogt deposits (Koval and Yakimov, 1984). Orebodies are stratiform in shape being extended for 1.2 to 2 kilometres along the lithological contact and 3.5 -7.0 of meters wide (Podlessky *et al.*, 1988), and are usually found within the thermal aureole of Mesozoic granites that have intruded Precambrian metamorphosed carbonate-aluminosilicate rocks. Rarely they are seen at the contact between a Mesozoic pluton and Palaeozoic carbonate-terrigenous or volcanic-terrigenous rocks. Calcareous skarn forms stratabound bodies up to 400 m long and up to 50 m wide. Some skarn bodies are characterized by very complicated structure. These are composed of rhythmically repeated zones of pyrite, arsenopyrite and other sulfides conaining Sn, W and Cu. Clynopyroxen-plagioclase rocks and banded garnet-clynopyroxen, and garnet-vesuvianite skarns are common in this type. These were formed by replacement of carbonate rocks within the contact aureole of quartz syenite intrusion. Intrusive rocks are calc-alkaline felsic plutons and stocks. Leucogranites are most common, related to three phases or two-phases activity, represented by coarse-grained porphyritic biotite granites (first phase), medium-grained biotite-muscovite granites (second phase), and leucogranites (third stage). High content of REE, Zn, and low content of CaO and lithophile elements characterize the granites. The major ore mineral is scheelite with small amount of molybdenite, sphalerite and pyrite. They are seen in altered endoskarn and exoskarn. Scheelite also occurs as impregnation in quartz-feldspar veins in exoskarns. Scheelite-sulphide mineralization is noticed in pyroxen-garnet skarn in association with feldspatization and epidotization. Postskarn gangue minerals are quartz, plagioclase (andesine), epidote and actinolite. Genesis of skarn-like orebodies in the endocontact of the Modot pluton remains obscure. Some geologists are speculating that the Sn-W and Mo mineralization could have been derived not from metasomatism but from quartz-vein and greisen mineralizations.

4.4 Tin-tungsten skarn

Commonly skarn with scheelite and cassiterite mineralization were formed by bimetasomatic proccesses in the contact between crystaline schists, volcanics and granitoids with limestones. Scheelite and cassiterite disseminated ore with small content of sulphides (molybdenite, chalcopyrite, sphalerite) overprints skarns and skarn-like rocks, and is accompanied by postskarn mineral assemblages of quartz-feldspar-(garnet)-(amphibole) and by greisen (quartz, albite, fluorite, rarely muscovite). Skarn is composed of pyroxen, garnet, and is superimposed by later stage silicification, quartz-hematite mineralization, and chalcopyrite-sphalerite mineralization. Deposits and occurrences are known in the Govi ugtaal field.

4.5 W-Mo veinlets in greisen

This deposit type consists of wolframite-molybdenite-(beryl) veins/veinlets with muscovite in greisen zone of leucogranites of subalkaline rocks at hypabyssal level. Greisens are associated with later-stage fractionated granites. Mineralization occurs mainly in endocontact zone. Alteration includes greisen formation, and albitization. Examples of deposit are Yögüzer, Tumentsogt, Tsagaan tolgoi (Koval and Yakimov, 1984).

4.6 W-Mo veins

This type consists of wolframite, molybdenite and beryl in quartz vein and brecciated zone. Vein type carries muscovite, fluorite, carbonates, scheelite, pyrite, arsenopyrite, chalcopyrite, sphalerite, bismuthinite and other accessories. Mineralization mainly occurs in exocontact zone, and sometimes in endocontact zone. Examples are the Yögüzer, Büren tsogt, Chuluun khoroot, and Öndör tsagaan deposit.

4.7 Vein/stockwork of tin and tungsten

This type includes single or multiple vein systems, and stockworks. It is one of the best-studied categories and economically important in Mongolia (Khasin *et al.*; 1977). The deposits occur in or near granitic intusions which were emplaced at relatively shallow level within a tectonic setting of continental collision. Intrusions are calc-alkaline, or subalkaline lithium-fluorine type. Granites are highly fractionated, either of A-or S-type, range from peraluminous to peralkaline in composition and are characterized by high SiO_2 and alkali, Rb, Li, Be, REE, Sn, W, Ta, Nb and F, and depleted in CaO, MgO, Sr and Ba (Gerel, 1990, 1995). Granites are highly fractionated with two or three phases, carrying mineralization in the second or third phase. Deep faults and fissures structurally control such deposits. Individual veins range from less than 1 cm to several meters wide. Vein systems are hundreds of meters wide and more than thousand meters long. Cassiterite, wolframite, chalcopyrite, sphalerite, pyrite and other sulphide minerals are disseminated in greisen-altered rocks. Cassiterite is a principal tin mineral. Wolframite is the main tungsten mineral, but scheelite is also present. Associated minerals include molybdenite, chalcopyrite, sphalerite, pyrite, arsenopyrite, sphalerite, muscovite, fluorite, beryl, topaz, feldspar, quartz, and tourmaline. Greisen is common as hydrothermal alteration product with fluorite, topaz, tourmaline, Li-mica, muscovite, biotite and quartz, with minor minerals such as albite, microcline.

4.8 Tin-tungsten vein

Tin veins are found in and around shallow granitic intrusions. Such intrusions are highly fractionated granites usually two-mica or muscovite leucogranites, and enriched in lithophile elements like Rb, Li, Be, Sn, W, Ta, Nb, REE and F (Kovalenko *et al.*, 1971; Gerel, 1990). Greisen is common as a hydrothermal alteration product (Geology of Mongolian People's Republic, 1977; Ivanova, 1976). Granites were mainly formed during the late Paleozoic and Early/Late Mesozoic time. Mineralization is concentrated in veins and brecciated zones near or in intrusions. The main minerals in tin veins are cassiterite and quartz with muscovite, feldspar, fluorite, pyrite and arsenopyrite. The examples include the Ömnödelger, Bayan tsagaan, Avdrant, and Ulaan bürd depoits.

Tin-tungsten veins usually consist of cassiterite and wolframite with quartz, muscovite, topaz, fluorite, pyrite, arsenopyrite in cassiterite-rich portion, while wolframite-rich part also carries beryl. Mineralization occur in veins, veinlets, stockworks and greisen zones in endocontact or exocontact of plutons. The representatives of tin-rich vein are Modot, Bayanmod, Bayan ovoo, Tsagaan ovoo, Bayankhar, Janchivlan, and Khüjkhaan, and those of tungsten-rich type are Kumir, Tsagaan davaa and Züün tarts gol.

4.9 Tin-sulphide vein

This deposit type is represented by cassiterite-tourmaline mineralization in veins and veinlets of exocontacts of multiple granite-granodiorite intrusions (Kovalenko *et al.*, 1986). Composition of intrusions ranges from calc-alkline to subalkline. The main minerals are cassiterite, quartz, tourmaline, chlorite, carbonates, chalcopyrite, arsenopyrite, sphalerite and molybdenite. The examples are Khökh uul and Zaan Shiree, and Khar morit deposit. The Khar morit is characterized by elongated breccia zones with exocontacts to the subalakline and lithium-fluorine hypabyssal plutons of post orogenic time. The deposits are associated with muscovite-microcline pegmatites, and Sn-W-rich greisen. Tin mineralization occurs in exocontact of plutons. The major components of such veins are cassiterite, galena, sphalerite, pyrite, arsenopyrite, chalcopyrite, muscovite, fluorite, tourmaline, chlorite, and carbonates. Alteration minerals are tourmaline, chlorite, muscovite and quartz.

4.10 Zr, Nb and REE

Deposits associated with peralkaline rocks include the REE-ZR-Nb deposit of the Khalzan büregtee deposit in western Mongolia (Kovalenko *et al.*, 1985), the Khan bogd deposit in south Mongolia (Vladykin *et al.*, 1981) and a number of occurrences in western and southern Mongolia. Mineralization is concentrated in apical part of the cupolas and associated with highly fractionated phases, including peralkaline pegmatites. These granites are composed of potassium feldspar, quartz, albite, arfvedsonite $Na_3(Fe^{2+}, Mg)_4Fe^{3+}Si_8O_{22}(OH)_2$, aegirine, fluorite and various rare metal minerals, such as elpidite $Na_2ZrSi_6O_{15}\cdot 3H_2O$, synchisite $(Ce,La)Ca(CO_3)_2F$, zircon, pyrochlore, monazite, rare earth-bearing fluoro-carbonate, and polylithionite $KLi_2Al(Si_4O_{10})(F,OH)_2$. Alteration includes the formation of epidote, allanite and postmagmatic albite. Mineralization occurs within microcline-albite granite and albitite metasomatite composed of quartz, albite, pyroxen and microcline. Quartz-epidote metasomatite carries zircon, fergusonite, allanite, and titanite in vein-like zone. In this zone fergussonite and zircon concentrate HREE and Y (Kempe *et al.*, 1994; Dandar *et al.*, 1995). Accessory minerals include amphibole, magnetite, zircon, epidote, ilmenite, fluorite, beryl, chevkinite $(Ca, Ce, Th)_4(Fe^{2+}, Mg)_2(Ti, Fe^{3+})_3Si_4O_{22}$, pyrite, and galena (Dandar *et al.*, 1995). According to Kovalenko *et al.* (1985) Zr-REE mineralization has magmatic origin and is concentrated within highly fractionated rare metal granites. Kempe *et al.* (1994) and Andreev *et al.* (1994) suggest the metasomatic origin for this type of mineralization. According to their opinion, the Khalzan büregtee deposit, Tsakhir, Shar tolgoi and Ulaan tolgoi occurrences in Mongolian Altai occur in endocontact of alkaline plutons, composed of metasomatically altered alkaline syenites (nordmarkites), which are host for small intrusions. Ore mineralization is associated with small metasomatically altered intrusions (from fine-grained to pegmatitic). Nordmarkites, dolerites and syenites develop metasomatites. This process is accompanied by emplacement of basic and ultrabasic dikes and volcanics. Ore content is very complicated and includes more than 70 minerals. Rock forming minerals are potassium feldspar, albite, quartz, calcite, zircon and Sr-fluorite. Accessories are pyrochlore, barite, rutile, titanite, epidote, REE-bearing carbonates, and fluorite. Metasomatic rocks contain quartz, epidote, zircon, titanite, fergussonite, pyroxene, chevkinite and others (Tsakhir occurrence). Other examples include Gurvan üneet, Ulaan üneet.

4.11 Ongonite hosted Ta and Li

This deposit type was described by Kovalenko *et al.* (1971), and by Kovalenko and Kovalenko (1976). It is subdivided into volcanic and porphyritic facies (Kovalenko and Yarmolyuk, 1995) and the latter is sometimes called as "plutonic ongonite". Ta, Rb and Nb are the major commodities and Be, Li and Sn are important as by-product. Mineralization occurs within ongonite bodies. Porphyritic ongonite contains phenocrysts of albite, quartz, potassium feldspar, and topaz and litium fengite with fine-grained matrix containing rare metal minerals. This variety is rich in Ta (up to 130 ppm, with an average content of 88 ppm) and Li (average 2,780 ppm) and Rb (average 2,380 ppm). Volcanic ongonite is often vitreous and is poorer in rare elemnet contents (Ta 37 ppm, Nb 170 ppm, Rb 1,040 ppm and Be 90 ppm) than porphyritic ongonite. But this variety forms large edifice such as volcanic cone, stratified body and sheets. The main occurrences are Teeg uul, Dörvöndert uul, in south Mongolia. The niobium content in these type deposits ranges from 0.05 to 0.8 %, zirconium from 0.5 to 5.0 % and REE from 0.3 to 4.5 %. High concentration of Li, Be, Sn and Zn is also characteristic. The Teeg uul area is 1 km^2 in dimension with tuffs thickness up to 10-20 m. In the area is Late Mesozoic rhyolite and ongo-rhyolite of volcanic neck facies are existed within carbonate rocks.

4.12 Ta-bearing granites

Ta-bearing orebodies are in most case product of high differentiation of Li-F granites, and subdivided into two types based on the mica chemistry: one is Li-mica type and the other muscovite type. The former category is represented by Janchivlan, Borkhujir, Baga Gazar, Avdar, Baruun tsogt, and the latter by Yögüzer, Tümentsogt, Baruun tsogt, Üzig and Yargait. Accroding to Kovalenko *et al.* (1981), Ta-bearing granite is found within Li-F-leucogranite, and muscovite type is related to calc-alkaline granites. Albitization sometimes with micriclinization and greisenization is characteristic for both types. Main ore minerals in Ta-bearing granites are columbite-tantalite with microlite, Pb-bearing pyrochlore, and cassiterite. Major rock-forming minerals are albite, microcline, quartz and Li-mica, sometimes topaz, pyrochlor. Muscovite type contains columbite-tantalite and beryl with albite, microcline, quartz and muscovite. W-Mo mineralization is noticed in some deposits and it could be a superimposing product to the Ta mineralization.

5. Concluding remarks

Granitic magmatism in Phanerozoic time is widespread in Mongolia and exhibits a broad spectrum of mineralization, especially in late Paleozoic and Mesozoic Period. Porphyry-copper-molybdenum, skarn, stockwork and vein-type mineralizations represent the mineral deposits and have been studied well. Ta, Nb, REE, Zr mineralizations in peralkaline granites, porphyry copper-gold deposits and epithermal mineralizations could be the main task for further study. Also sedimentary hosted gold mineralization would be another research target in the near future.

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[*1]Preprint is an advanced printing, using in scientific publication of Russia and Mongolia. It is neither reconnaissance report nor unpublished paper, but is an official issue often in preliminary form before the full publication in an academic journal (*Editor's note*).

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モンゴルにおける顕生代のフェルシックマグマ活動と随伴鉱床

O. Gerel

要　旨

シベリアクラトンと華北，タリムプラットフォームに挟まれたモンゴル国の地質は何度も造山運動を経験している．花崗岩活動は主に古生代初期，中期，後期，中生代後期に起こっており，主要鉱化作用は古生代後期と中生代の花崗岩に伴う事が多い．鉱種としてはポーフィリー型に加えて，レアメタル，希土類，ペグマタイト，スカルン，含銀鉛亜鉛鉱床が多い．なお本論では金鉱化作用については述べなかった．