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Geology and K-Ar Ages of the South, Huh Bulgiin Hundii, Saran Uul, Taats Gol and Han Uul deposits in the Bayankhongor Region, Mongolia

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Abstract: The Bayankhongor region in central Mongolia consists of a Paleozoic subduction system including Precambrian microcontinents (Baidrag and Burd Gol zones), obducted ophiolites and accretionary sedimentary rocks (Bayankhongor and Dzag zones), and forearc sedimentary rocks (Khangay zone). Arc magmatism in the Bayankhongor region is characterized by dominance of Early Paleozoic ilmenite-series and Late Paleozoic magnetite-series granitoids. These granitoids accompany many hydrothermal deposits of such various types as porphyry, skarn and vein. K-Ar dating on four deposits in the region revealed that the South porphyry Cu-Au, Huh Bulgiin Hundii skarn Cu-Au, Han Uul shear zone-hosted Au and Taats Gol pegmatite W-Au deposits formed at 240±5 Ma, 252±5 Ma, 283±6 Ma and 329±7 Ma, respectively.

Thus the former three are related to the Permian to earliest Triassic magnetite-series granitoids, whereas the W-Au pegmatite at Taats Gol to the Early Carboniferous ilmenite-series granitoids. Porphyry and skarn Cu-Au mineralization occurred at latest Permian to earliest Triassic, when the Andean-type arc magmatism was immediately followed by the collision between the Baidrag and Tarbagatai microcontinents.

1. Introduction

Mongolia is situated between the Siberian and North China platforms and includes several Precambrian continental blocks, which are fringed by Paleozoic and Mesozoic magmatic arcs, accretionary complexes and trapped oceanic crusts (Sengör et al., 1993). A number of porphyry, skarn and vein-type hydrothermal deposits have been discovered along these extinct magmatic arcs through regional geological mapping (Jargalsaihan, 1996). These deposits form several metallogenic belts, which are genetically related to regional magmatism and tectonics (Distanov and Obolenskii, 1994; Dejidmaa, 1996). Although geology, alteration and mineralization of these deposits have been described in explanatory reports of geological maps (e.g., Zabotkin, 1988), only a few geochronological studies have been undertaken for hydrothermal deposits (Sotnikov et al., 1974, 1995; Lamb and Cox, 1998; Murao et al., 1998). The scarcity of age data for ore deposits makes it difficult to comprehend metallogeny in Mongolia.

The Geological Research Center of Mongolia conducted a comprehensive project that re-examined geology (Teraoka et al., 1996), magmatism (Takahashi et al., 1998) and mineral deposits in the Bayankhongor region in central Mongolia (Fig. 1), where many hydrothermal deposits are associated with granitoids. This paper presents geology and K-Ar ages of the South, Huh Bulgiin Hundii, Saran Uul, Taats Gol and Han Uul deposits in the Bayankhongor region, and discusses metallogeny related to Paleozoic magmatism in the region.

2. Geology of the Bayankhongor Region

The Bayankhongor region is located about 600 km west-southwest of Ulaanbaatar, and occupies the middle of the U-shaped Tuva-Mongolia microcontinent unit (Fig. 1; Zorin et al., 1993). This region is divided into Baidrag, Burd Gol, Bayankhongor, Dzag and Khangay zones from

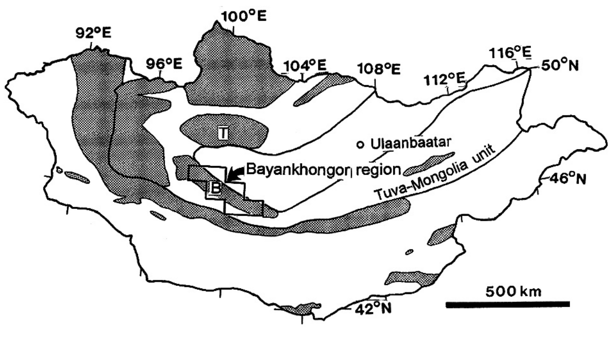

Fig. 1 Distribution of the Precambrian and Cambrian continental blocks (shaded part), after Lamb and Badarch (1997), and the location of the Bayankhongor region. Tuva-Mongolia unit (a folded zone sandwiched by thick lines) is taken from Sillitoe et al. (1996). T: Tarbagatai microcontinent, B: Baidrag microcontinent.

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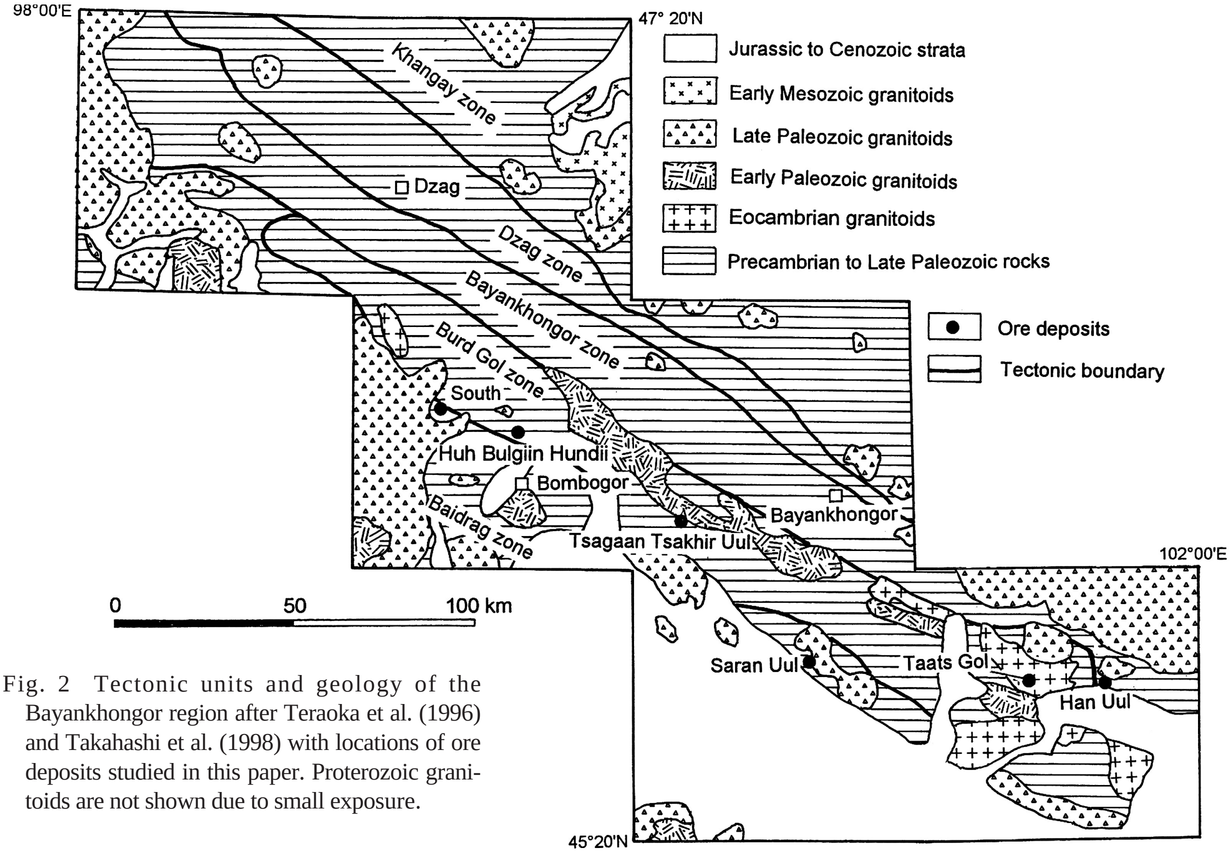

Fig. 2 Tectonic units and geology of the Bayankhongor region after Teraoka et al. (1996) and Takahashi et al. (1998) with locations of ore deposits studied in this paper. Proterozoic granitoids are not shown due to small exposure.

southwest to northeast (Fig. 2; Teraoka et al., 1996). These zones are separated from each other by northwest-southeast striking north-vergent thrust faults (Zorin et al., 1993).

The Baidrag zone consists of gneiss, amphibolite, charnockite and gneissose granites of granulite or amphibolite facies of Late Archean to Early Proterozoic age. The Burd Gol zone is characterized by dominant greenschist-facies pelitic schist with subordinate psammitic schist and chert of Late Proterozoic age. The pelitic schist contains olistoliths of metabasalt, limestone, amphibolite and pelitic schist. The Bayankhongor zone is composed of mafic schist, limestone, sandstone and basalt with subordinate gabbro and serpentinite of latest Proterozoic to Cambrian age. The Dzag and Khangay zones consist of Cambrian to Ordovician pelitic and psammitic schist, and Devonian to Carboniferous sandstone and mudstone, respectively (Teraoka et al., 1996; Kurimoto et al., 1997, 1998; Geology Group of Institute of Geology and Mineral Resources Project, hereafter abbreviated as Geology Group of IGMR Project, 1999). These Paleozoic rocks are overlain by Jurassic and Cretaceous continental sedimentary rocks composed of coal-bearing mudstone, sandstone, conglomerate and terrestrial volcanic rocks (Geology Group of IGMR Project, 1999).

The tectonic zones in the Bayankhongor region include several episodes of granitoid intrusions; Proterozoic, Eocambrian, Early Paleozoic, Late Paleozoic and Mesozoic. The Proterozoic, Eocambrian and Early Paleozoic granitoids are distributed in the Baidrag and Burd Gol zones. Late Paleozoic granitoids, showing wider distribution than any granitoid intrusions of the other ages, occur in all the zones, whereas Mesozoic granitoids are only in the Khangay zone (Takahashi et al., 1998).

3. Ore Deposit Geology

Associated with the granitoids, Au and Cu deposits are distributed in the Bayankhongor region. Particularly due to the abundance of Au-bearing quartz veins and placer Au deposits, the region has been called as “Bayankhongor Au metallogenic belt” (Jargalsaihan, 1996). A representative gold deposit in the region is Tsagaan Tsakhir Uul (Fig. 2), which consists of gold-bearing quartz veins of mesothermal-epithermal origin (Jargalan and Murao, 1998). The deposit is the only one that has been dated in the Bayankhongor region, although the reported ages widely vary between 234 Ma and 193 Ma, and are younger than the age (268 Ma) of the granodiorite near the deposit (Japan International Cooperation Agency and Metal Mining Agency of Japan, 1997). The copper deposits in the region include porphyry, skarn and vein types. Granitoid-related Sn and W deposits also occur in the region (Takahashi et al., 1998). Geology, alteration and mineralization of five prospects studied are described below.

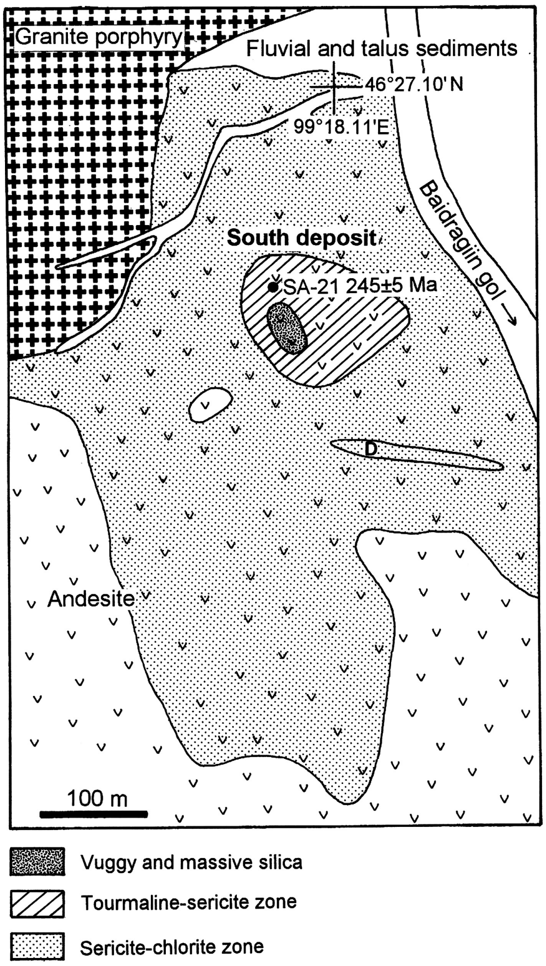

Fig. 3 Geology and alteration of the South prospect. D: diorite. Granite porphyry of the Late Paleozoic Shar Us Gol complex intruded the Late Carboniferous andesite lava.

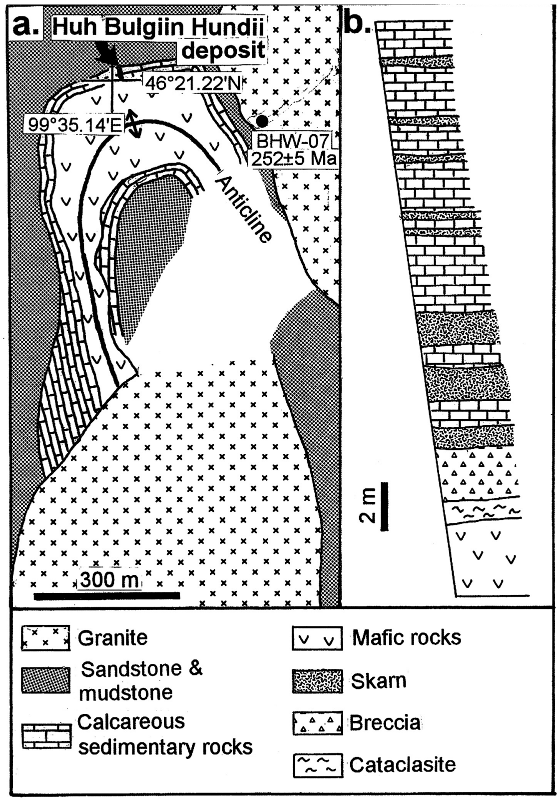

Fig. 4 Geology of the Huh Bulgiin Hundii prospect. a: Areal geological map, b: Rock facies in a trench of the main ore body (plan view). Late Proterozoic mafic rocks, possibly metamorphosed basalt and dolerite, calcareous sedimentary rocks and alternating beds of sandstone and mudstone of the Burd Gol zone are intruded by Late Permian granite.

3. 1. South

The South prospect is located 30 km northwest of Bombogor (Fig. 2). Late Carboniferous andesite lavas and diorite dikes underlie the prospect area, and granite and granite porphyry of the Late Paleozoic Shar Us Gol complex intruded into the andesite (Fig. 3).

Hydrothermal alteration spreads over an area of 600 m by 400 m in the andesite in contact with the granite. Vuggy and massive silica zone is centered in the alteration, fringed by tourmaline-sericite zone with peripheral sericite-chlorite zone (Fig. 3). Sericite is more dominant than chlorite in the sericite-chlorite zone, whereas this zone includes masses of chlorite-dominant andesite. A slight amount of pyrophyllite is detected at the outer margin of the sericite-chlorite zone. Gypsum, jarosite, halloysite and montmorillonite occur as supergene minerals in all of the alteration zones. Pyrite is disseminated in the tourmaline-sericite and sericite-chlorite zones. The massive silica contains about one ppm Au, and malachite is disseminated along rock fractures in the tourmaline-sericite and sericite-chlorite zones.

The presence of sericite and tourmaline with disseminated pyrite and malachite is a characteristic of phyllic alteration in porphyry Cu systems (Lowell and Guilbert, 1970).

3. 2. Huh Bulgiin Hundii

The Huh Bulgiin Hundii prospect is 15 km north of Bombogor (Fig. 2). It is widely underlain by metamorphosed mafic rocks, possibly derived from basalt and dolerite, calcareous sedimentary rocks and alternating beds of sandstone and mudstone of the Burd Gol zone (Fig. 4a). Graded structures in the sedimentary rocks indicate that the mafic rocks are situated stratigraphically beneath the 20-100 m thick calcareous bed, which gradually changes into the sandstone and mudstone upwards. Overturned sequences are common around the prospect and a refolded anticline is recognized in the mafic-rock layer. Granite intruded in the sedimentary rocks after the deformation, resulted in hornfels near the contacts with the sedimentary rocks.

The major ore body of the deposit (Fig. 4a) is 80 m

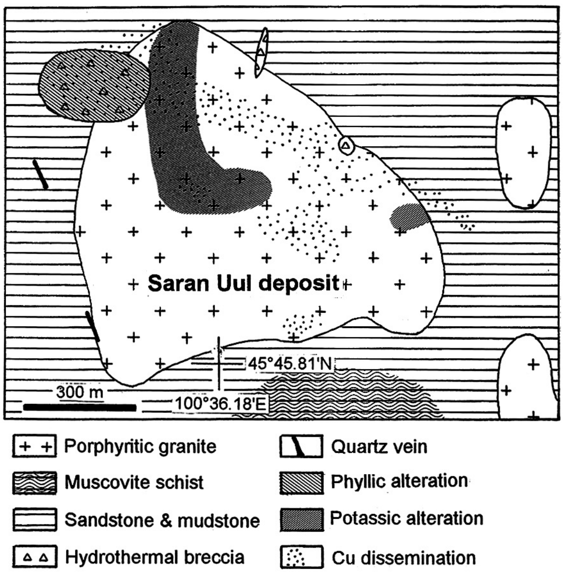

Fig. 5 Geology and alteration of the Saran Uul prospect. Early Silurian sedimentary rocks of sandstone, mudstone and muscovite schist are intruded by granite porphyry of the Late Paleozoic Saran Uul complex.

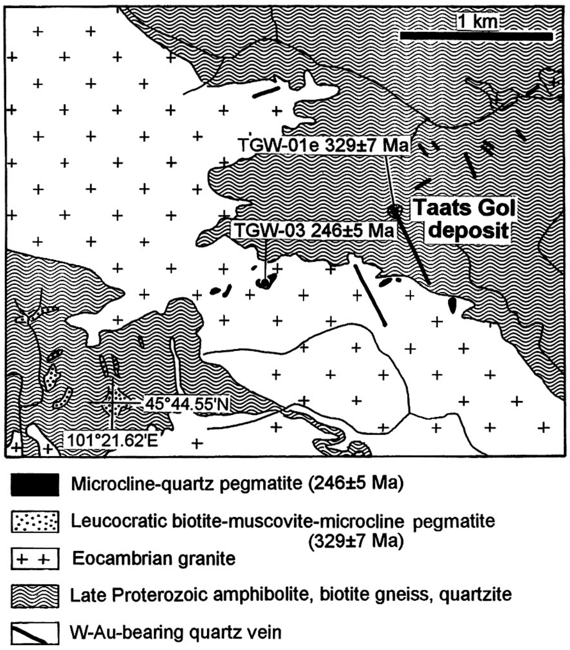

Fig. 6 Geology of the Taats Gol prospect, modified from Zabotkin (1988). Diorite and granite dikes of the Shar Us Gol complex and small bodies of the early-stage pegmatite and two-mica "Eocambrian" granite in the Late Proterozoic rocks are not shown due to small exposure.

by 20 m in plan. Slight skarnization and mineralization occur in layers parallel to the bedding plane in the calcareous rocks (Fig. 4b). The skarnized rocks include chalcopyrite, bornite, cubanite, pyrrhotite, native gold, arsenopyrite, bismuthinite, native bismuth, pyrite, sphalerite, enargite and cassiterite (Andreas and Mihael, 1968). Oxidized ore includes malachite, covellite and chalcocite.

3. 3. Saran Uul

The Saran Uul prospect is located 40 km south of the town center of Bayankhongor (Fig. 2). The area is underlain by Early Silurian sedimentary rocks of sandstone, mudstone and red chert. A part of the sedimentary rocks is metamorphosed into muscovite schist. The Late Paleozoic Saran Uul complex, which consists of tonalite and granite porphyry (Takahashi et al., 1998), intruded in these sedimentary rocks. The mineralized granite porphyry in the prospect is approximately 1 km in diameter (Fig. 5). Hornfels occurs in the sedimentary rocks near the contact of the granite porphyry. The porphyry consists of large euhedral phenocrysts of plagioclase and K-feldspar with granular biotite, quartz and amphibole. Post-mineralization latite dikes, several meters thick, intruded in the granite porphyry and sedimentary rocks.

The granite porphyry is partly underwent potassic alteration in which plagioclase is replaced by K-feldspar. Hydrothermal breccia, cemented with quartz and/or barite, is found in places along the margin of the granite porphyry. Sericite alteration is limited in the largest body of hydrothermal breccia (Fig. 5) in the northwest of the area. Quartz veins occur on the west of the largest body of granite porphyry. Malachite is disseminated along joints in the northeast of the intrusive body (Fig. 5). Although no sulfide mineral is observed on the surface, a drill core survey revealed that quartz veinlets in the largest intrusive body and surrounding sedimentary rocks contain pyrite, chalcopyrite and molybdenite (Zabotkin, 1988).

3. 4. Taats Gol

The Taats Gol prospect is located 75 km southeast of Bayankhongor (Fig. 2). Late Proterozoic amphibolite, biotite gneiss, quartzite and marble underlie the area. Garnet-bearing muscovite-biotite granite of "Eocambrian" age intruded in the Proterozoic rocks, and small diorite and granite dikes of the Shar Us Gol complex intruded in the north and south of the area, respectively. Two stages of pegmatite formation are distinguished (Fig. 6; Zabotkin, 1988). The early one is leucocratic biotite-muscovite-microcline pegmatite in the Proterozoic metamorphic rocks and "Eocambrian" granite. The later is muscovite-bearing microcline-quartz pegmatite with a graphic texture, and is distributed in the "Eocambrian" granite.

A number of quartz veins, several meters thick and several hundred meters long, are associated with the small bodies of the two-mica granite and the early-stage pegmatites. These veins strike north-northwest and northeast, and contain pyrite, galena, native gold, tetrahedrite, arsenopyrite, sphalerite and scheelite (Zabotkin, 1988).

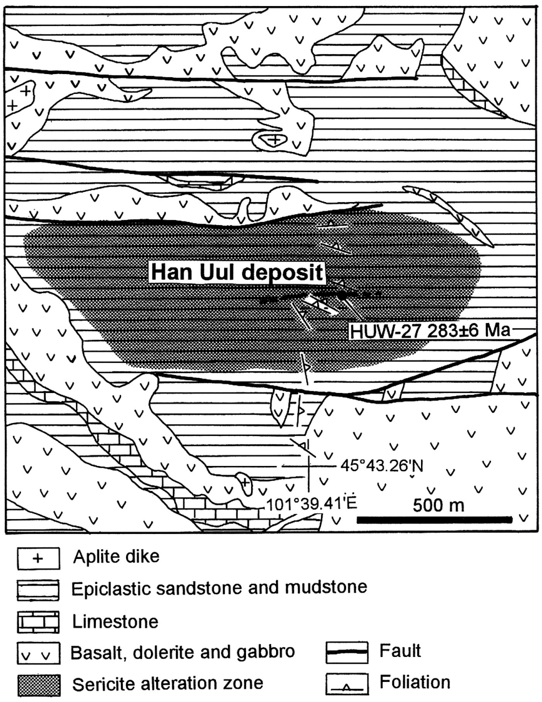

Fig. 7 Geology of the Han Uul prospect, modified from Zabotkin (1988).

3. 5. Han Uul

The Han Uul prospect is located 90 km southeast of Bayankhongor (Fig. 2). The area is underlain by the Ulziit Gol Formation, which consists of mafic igneous rocks (basalt, dolerite and gabbro), and epiclastic mudstone and sandstone of basalt origin with limestone beds and blocks. The mafic rocks and epiclastic rocks are partly metamorphosed into chlorite-epidote and muscovite schists. The age of the Ulziit Gol Formation is inferred as Vendian to Early Cambrian (Zabotkin, 1988). Aplite dikes of east-west strikes intrude in the formation. East-west striking vertical faults cut the Ulziit Gol Formation (Fig. 7).

Hydrothermal alteration occurs in the Ulziit Gol Formation at the central part of the area. The alteration zone extends for 1,500 m along east-west direction and 500 m along north-south direction. The altered rocks gradually change into non-altered rocks along the southern margin, whereas they are in N80°E-striking fault contact with non-altered rocks along the northern margin. Major alteration minerals are sericite, calcite and geothite that replace chlorite and epidote in the non-altered rocks. Although pyrite occurs in the altered rocks, it is mostly replaced by geothite. These alteration minerals mainly occur in layers of sandstone and psammitic schist. The alteration zone includes several quartz veins that extend for several hundred meters. At the center of the zone is a N80°W-striking fault, along which rocks are heavily oxidized and sericitized (Fig. 7). The change in foliation strike from N-S to WNW-ESE towards the fault suggests left-lateral strike-slip movement along the fault. Association of sericite and calcite suggests low-sulfidation hydrothermal environment for the prospect.

The main orebody is the heavily oxidized part in the center of the alteration zone. Native gold occurs as grains of which size varies from 0.1 to 5 mm (average 0.8 mm) in diameter. The most geothite-rich part is 7 m thick, and contains 0.8-6.2 g/t (average 2.4 g/t) of Au and up to 6 g/t of Ag (Zabotkin, 1988).

Table 1 K-Ar ages of hydrothermal and igneous minerals from the mineral prospects in the Bayankhongor region.

Prospect name	Sample No.	Mineral analyzed	K wt (%)	Ar nL/g	Ar % (rad)	Age (Ma)
South	SA-21	sericite	1.86	18.26	75	237±5
			1.88	18.87	71	242±5
						240±5
Huh Bulgiin Hundii	BWH-07	biotite	5.12	52.96	90	249±5
			5.16	54.92	91	255±5
						252±5
Taats Gol	TGW-01e	muscovite	7.77	109.2	95	330±7
			7.77	107.9	93	327±7
						329±7
	TGW-03	microcline	5.95	61.58	97	249±5
			5.90	59.17	98	242±5
						246±5
Han Uul	HUW-27	sericite	3.79	45.14	92	283±6
			3.82	45.34	86	283±6
						283±6

Decay constants ^{40}K: λ_β=0.4962×10^{-9}yr^{-1}, λ_e=0.581×10^{-10}yr^{-1} ^{40}K/K=0.01167 (atomic). Errors are two standard deviations.

4. K-Ar Age

Five samples from four of the prospects were prepared for K-Ar dating. They are; sericite (SA-21) from the tourmaline-sericite zone in the South prospect, biotite (BWH-07) from the granite body to the east of the Huh Bulgiin Hundii prospect, muscovite (TGW-01e) in the early-stage pegmatite and microcline (TGW-03) in the late stage pegmatite from the Taats Gol prospect, and sericite (HUW-27) from the oxidized zone in the Han Uul prospect (Table 1). Sample locations are shown in Figures 3, 4, 6 and 7. The dating was performed by Michelle Burgess in the Institute of Geological and Nuclear Sciences of New Zealand. Duplicate age data were obtained for each sample, and their average was employed as the K-Ar age of the sample.

5. Discussion

5. 1. Interpretation of the K-Ar ages

The muscovite age (240±5 Ma) of the South prospect indicates that the hydrothermal alteration occurred in the earliest Triassic. Because this age is younger than that of the host, Carboniferous andesite, the alteration of the prospect may have been related to the intrusion of granite or granite porphyry of the Late Paleozoic Shar Us Gol complex.

The intimate relation of skarn and granite in the Huh Bulgiin Hundii prospect suggests that the biotite age (252±5 Ma) of the granite is contemporaneous with the mineralization age of the prospect.

The ages of the muscovite (329±7 Ma) and microcline (246±5 Ma) in the Taats Gol prospect indicate that the early- and late-stage pegmatite formed in Early Carboniferous and Late Permian, respectively. The association of W-Au-bearing quartz veins with the early pegmatite suggests that the W-Au mineralization in the prospect occurred in Early Carboniferous. The intimate association of the "Eocambrian" granite with the early-stage pegmatite also suggests that at least a part of the granite is Carboniferous in age. Although the late-stage pegmatites are mainly distributed in the "Eocambrian" granite, the age is similar to that of the Shar Us Gol complex, of which diorite and granite dikes are exposed in the north and south of the area.

The sericite age (283±6 Ma) in the Han Uul prospect suggests that the hydrothermal alteration associated with Au mineralization occurred in Early Permian.

5. 2. Metallogeny in the Bayankhongor region

Takahashi et al. (1998) studied granitoid series of each epoch in the Bayankhongor region. They indicate that the Late Proterozoic and most of the Early Paleozoic granitoids are ilmenite-series, whereas minor magnetite-series granitoids occur at the southwestern margin of the region during the Early Paleozoic. In contrast, during the Late Paleozoic, magnetite-series granitoids dominantly intruded in the Baidrag and Dzag zones, and ilmenite-series granitoids in the Khangay zone (Arakawa et al., 1999). Distribution of the Mesozoic granitoids is limited in the Jurassic ilmenite-series Egiin Davaa complex in the Khangay zone (Takahashi et al., 1998).

The K-Ar ages indicate that the metallic mineralization at South, Huh Bulgiin Hundii, Taats Gol and Han Uul in the Bayankhongor region mainly occurred during Carboniferous and Permian ages. The South, Huh Bulgiin Hundii, Saran Uul and Han Uul deposits accompany magnetite-series granitoids (Takahashi et al., 1998; Fig. 8). The W-Au mineralization at Taats Gol is related to the Early Carboniferous pegmatite associated with "Eocambrian" ilmenite-series granitoids.

Thus the ilmenite-series granitoids are rarely related to the metal mineralization in the Bayankhongor region. Major Au and Cu mineralization is related to the Permian magnetite-series granitoids. The relation of the mineralization and granitoid series in the Bayankhongor region is consistent with that W mineralization is related to both magnetite- and ilmenite-series granitoids, whereas

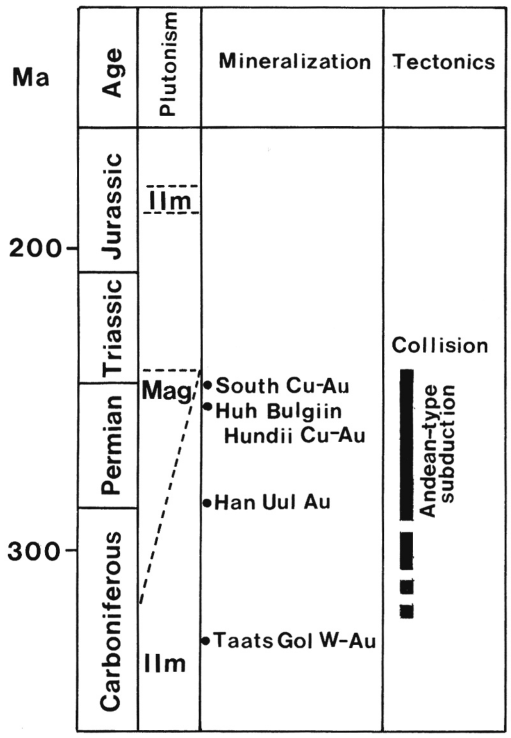

Fig. 8 Relationship among plutonism (Takahashi et al., 1998), mineralization age and regional tectonics. Ilm: ilmenite series, Mag: magnetite series.

Cu mineralization is related to magnetite-series granitoids in the Circum-Pacific region (Ishihara, 1977; Thompson et al., 1999).

5. 3. Tectonic implication for the Permian metallogeny

The presence of the Precambrian continental crust in the Baidrag zone, obducted ophiolitic sequences in the Bayankhongor and Dzag zones, and Devonian to Permian marine sedimentary rocks in the Khangay zone, as well as dominance of magnetite-series magmatism in the Baidrag and Dzag zones, suggests an Andean-type subduction system existed in the Bayankhongor region during the Late Paleozoic. This subduction system was followed by the collision between the Baidrag and Tarbagatai microcontinents at the earliest Mesozoic. This is supported by (1) disappearance of plutonism after 240 Ma, except the activity of Jurassic ilmenite-series granitoids (Takahashi et al., 1998), (2) absence of Jurassic to Cretaceous submarine sedimentary rocks, (3) accumulation of Jurassic to Cretaceous continental sedimentary rocks (Geology Group of IGMR Project, 1999), and (4) formation of north-vergent thrust and fold belts in the Bayankhongor region (Zorin et al., 1993).

Porphyry Cu-Au and skarn Cu-Au mineralization at South and Huh Bulgiin Hundii occurred at the latest magmatic activity related to the Late Paleozoic Andean-type subduction prior to the collision in the Bayankhongor region. This is similar to the 240 Ma mineralization at the Erdenetiin Ovoo porphyry Cu-Mo deposit in northern Mongolia, where the mineralization was followed by the collision between the Tuva-Mongolian unit and the Siberian block (Watanabe and Stein, in prep.). Formation of porphyry deposits followed by collisions of continental blocks in the earliest Triassic in Mongolia is consistent with the settings in American Cordillera where porphyry mineralization occurred during an increase in regional compressional stress (Watanabe, 1998). This suggests that porphyry mineralization favors non-extensional stress settings, as pointed out by Sillitoe (1980).

6. Summary

The ages of hydrothermal mineralization in the Bayankhongor region are from Early Carboniferous to earliest Triassic. The period of the mineralization corresponds to the period of subduction-related arc magmatism in the region. The W-Au pegmatite mineralization was associated with ilmenite-series granitoids, and the Cu-Au mineralization with magnetite-series granitoids in the region. This relation is consistent with that in the Circum-Pacific magmatic regions. The porphyry and skarn Cu-Au mineralization occurred at latest Permian to earliest Triassic, when the arc magmatism was immediately followed by the collision between the Baidrag and Tarbagatai microcontinents. This suggests that the porphyry and skarn mineralization occurred during an increase in regional compressional stress in a non-extensional stress setting.

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