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The granitoid series in Bayankhongor area, central Mongolia

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Abstract: The granitoid series in Bayankhongor area, central Mongolia, has been investigated using magnetic susceptibility and chemical data. In Riphean, the ilmenite-series granitoids were dominant. In early Paleozoic, the ilmenite-series granitoids were dominant, but the magnetite-series granitoids were also distributed in southwestern part of the study area. In late Paleozoic, the magnetite-series granitoids were predominant. The boundary between magnetite-and ilmenite-series granitoids shifted northeastward in early Paleozoic to late Paleozoic. Shifting of the boundary between the two series may be genetically related to the development of the Khangay Zone, which consists of middle to late Paleozoic strata. Mesozoic granitoids are ilmenite-series granitoids.

In late Paleozoic, Cu and Au deposits are distributed within the magnetite-series granitoids area. Sn and W deposits occur around the boundary between the two series and in the ilmenite-series dominant area. These distribution patterns indicate that the redox potential decreases from southwest to northeast in late Paleozoic granitoids of the study area.

1. Introduction

The greatest contribution to the granite petrology during the last quarter of century is considered to be the proposition of the granitoid series and genetic types. In the granitoid series classification, the granitoids are divided into magnetite- and ilmenite-series (Ishihara, 1977). The magnetite-series granitoids are characterized by the presence of magnetite and high Fe^{3+}/Fe^{2+} whole-rock ratio and crystallize under the oxidizing condition. The ilmenite-series granitoids are characterized by the lack of magnetite and low Fe^{3+}/Fe^{2+} whole-rock ratio and solidify under the reducing environment. Practically, the granitoid series is often investigated using modal ratio of opaque minerals property (Ishihara, 1977) and magnetic susceptibility (Ishihara, 1979). On the other hand, Chappell and White (1974) recognized two different granite types; I-type and S-type. The I-type granitoids are characterized by the occurrence of Ca-bearing mafic minerals and low $Al_2O_3/(Na_2O+K_2O+CaO)$ ratio and the S-type granitoids by the presence of aluminous minerals and high $Al_2O_3/(Na_2O+K_2O+CaO)$ ratio. The I-type granitoids are contributed by igneous rocks in the process of their magmatic genesis and the S-type granitoids by pelitic sedimentary rocks. In addition, A-type (alkaline and anorogenic) granitoids and M-type (upper mantle origin) granitoids have also been proposed as derivatives of the I-type granitoids (Loiselle and Wones, 1974; White, 1979). The granitoid series and I-S-A-M types have been employed as tools for mineral exploration, because they are closely associated with particular metal deposits (Ishihara, 1981; Blevin and Chappell, 1995; Sillitoe, 1996).

We are currently engaged in the metallogenic map project of the Bayankhongor area, central Mongolia, as a part of the technical transfer program of the Japan International Cooperation Agency (JICA). The Proterozoic to Mesozoic granitoids and many metal deposits occur in this area, but petrological consideration based upon the above mentioned schemes have not yet been performed.

For the granitoids in the Bayankhongor area, we now elaborate petrological characteristics and magnetic susceptibility, in particular. And we discuss the spatial variations of the granitoid series and infer the relationships between granitoid series and ore

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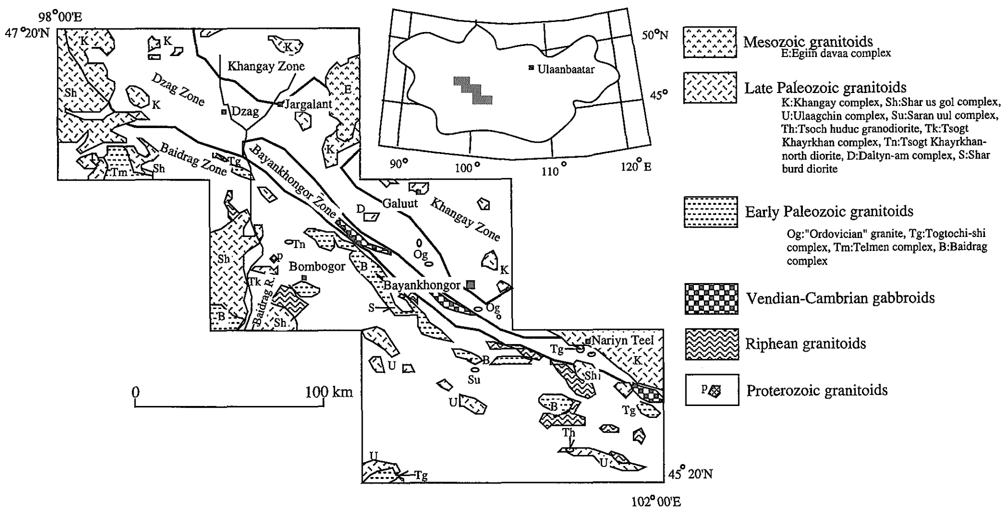

Fig. 1 Geologic map. Simplified and based upon Byamba (1985), State Geological Fund (1995) and Tungalag (1997).

deposits in the area.

2. Geologic setting

The Bayankhongor area has been geologically studied by many geologists (*e.g.*, Kopteva *et al.*, 1984; Kepezhinskas and Zhirakovsky, 1987; Teraoka *et al.*, 1996). Recently, Tungalag (1997) geotectonically divided the district into Baidrag, Bayankhongor, Dzag and Khangay Zones from south to north. Simplified geologic map is shown in Fig. 1.

The Baidrag Zone consists of Archean high-grade metamorphic rocks ranging from amphibolite to granulite facies and Proterozoic metamorphic rocks of greenschist facies. The Bayankhongor Zone is latest Proterozoic to Cambrian geologic unit. It consists of psamitic, pelitic and basic schists with calcareous and quartzose rocks. In addition, the ophiolitic rocks such as ultramafic rocks, gabbro, sheeted dike and pillow lava are also exposed. These rocks sometimes occur as allochthonous structure. The Dzag Zone consists mainly of Cambrian to Ordovician sandstone associated with conglomerate and mudstone. The Khangay Zone consists of Devonian to Carboniferous turbidite sediments. Many granitic bodies intrude these zones. These granitic bodies have been named after local geographical names in the geologic map sheets 1:200,000 (Zabotkin, 1988; Davaa, 1989; Bayarsaihan, 1990; Tomurchodor, 1990;) as shown in the legend in Fig.1.

3. Geology, magnetic susceptibility and chemistry of the granitoids

3.1 Description of geology and magnetic susceptibility

Lower Proterozoic granite: Exposures of these rocks are confined in comparatively small area east of the Baidrag River. The U-Pb zircon radiometric ages from these rocks range from 1825 to 2646 Ma (Kepezhinskas and Zhirakovsky, 1987). Medium- to coarse-grained granite is exposed at 20 km northwest of Bombogor and medium-grained leucocratic granite at 10 km northwest of Bombogor. These granites intrude the gneiss of the Baidrag Zone with conformable contact. These granitic rocks are strongly deformed. Magnetic susceptibility of these rocks is less than 1×10^{-3} SIU (SI unit).

Riphean granite: Riphean granite is restricted in distribution; 15 km southwest and 40 km east of Bombogor and the area 10 to 50 km south of Nariyn Teel. This granite is distributed in the metamorphic rocks of the Baidrag Zone. The Pb-Pb age data range from 1000 to 1222 Ma (Zabotkin, 1988; Tomurchodor, 1990). Most of the rock types are medium- to coarse-grained leucocratic granite, but rarely fine-grained. Some of them are deformed and foliated. In addition, dioritic facies is locally exposed. Magnetic susceptibility of the Riphean granite is mostly less than 1×10^{-3} SIU and partly 2 to 7×10^{-3} SIU.

Early Paleozoic granitoids: The early Paleozoic granitoids are Cambrian to Ordovician batholithic bodies and "Ordovician" small granitic bodies. The batholithic bodies are named Baidrag complex, Telmen complex and Togtochi-shi complex in the usual geologic map sheets (*e.g.*, Zabotkin, 1988; Davaa, 1989).

The Baidrag complex (B in Fig.1) is widely exposed in central to eastern part of the study area. This complex intrudes the metamorphic rocks of the Baidrag Zone. Ages of the complex are Cambrian to

Ordovician (Andreas, 1970; Zabotkin, 1988; Takahashi and Delgertsogt, 1997). It mainly consists of partly porphyritic medium- to coarse-grained biotite granite. In eastern area, medium-grained leucogranite is dominant. Magnetic susceptibility of the rocks is less than 1 x 10^{-3} SIU in most of the area, but is 7 x 10^{-3} SIU in foliated facies at 18 km southwest of Bayankhongor City. Dioritic body is exposed at 10–15 km south of Bombogor as mafic facies of the Baidrag complex. Magnetic susceptibility of the dioritic body is in the range of 0.3–2.9 x 10^{-3} SIU.

The Telmen complex (Tm) is exposed at 60 to 70 km WSW of Dzag. This complex intrudes the metamorphic rocks of the Baidrag Zone. The main rock type of the complex is heterogeneous foliated coarse-grained biotite tonalite. It sometimes includes fine-grained melanocratic gneissose rocks and shows migmatitic appearance due to the obscure margins of the inclusions. Its magnetic susceptibility is up to 18 x 10^{-3} SIU.

The Togtochi-shi complex (Tg) is mainly distributed near Nariyn Teel in eastern part of the study area. It is also locally cropped out at about 25 km south of Dzag in northern part. The complex mainly consists of weakly foliated fine- to medium-grained biotite granite. This granite sometimes contains garnet. Magnetic susceptibility of this complex is less than 1 x 10^{-3} SIU.

The "Ordovician" granites (Og) are small granitic bodies (mostly a few hundred meter across) cropped out in the Bayakhongor and Dzag Zones. Most of them are medium- to coarse-grained granite and altered, that is, boitite is totally chloritized. These bodies discordantly intrude the sedimentary rocks of the Bayankhongor and Dzag Zones. Though no radiometric age of these bodies is known, they are geologically considered to be Ordovician or possibly even Silurian. Magnetic susceptibility of these rocks is less than 1 x 10^{-3} SIU.

Late Paleozoic granite-diorite complex: In late Paleozoic, some dioritic or diorite-granite complexes intruded into the Baidrag and Bayankhongor Zones. They have been named Shar burd diorite, Daltyn-am complex, Tsogt Khayrkhan-north diorite, Tsogt Khayrkhan complex, Tsoch huduc granodiorite, Saran uul complex, and Ulaagchin complex (Zabotkin, 1988; Tomurchudor, 1990; Takahashi *et al.*, 1997). They are generally stock-like intrusive bodies and a few km across. They generally show high magnetic susceptibility.

The Shar burd diorite (S in Fig. 1) crops out at about 40 km west of Bayankhongor. It intrudes the Baidrag complex. The Shar burd diorite was dated 341 Ma by K-Ar method (Borzakovskii and Suprunov, 1990) and 250 Ma by Rb-Sr whole rock method (JICA and MMAJ, 1997). The rock is medium-grained monzodiorite (Takahashi *et al.*, 1997). Magnetic susceptibility of this rock is 16 to 26 x 10^{-3} SIU.

The Daltyn-am complex (D) crops out at about 70 km northwest of Bayankhongor. It intrudes discordantly into the basic schist of the Bayankhongor Zone. It consists mainly of diorite and granite. Diorite often includes gabbroic rocks. Medium-grained granite intrudes medium-grained diorite to quartz diorite with leucocratic medium-grained granite margin (a few centimeters width). Magnetic susceptibility of this complex is 2 to 9 x 10^{-3} SIU in granitic facies and 4 to 14 x 10^{-3} SIU in dioritic facies.

The Tsogt Khayrkhan-north diorite (Tn) is distributed as a small intrusive body in the Bayankhongor Zone, about 30 km northwest of Bombogor. This diorite is tentatively called Tsogt Khaykham-north diorite (Takahashi *et al.*, 1997). Magnetic susceptibility of the diorite is 12 to 19 x 10^{-3} SIU.

The Tsogt Khayrkhan complex (Tk) crops out at 15 km west of Bombogor and intrudes metamorphic rocks of the Baidrag Zone. Izokh *et al.* (1990) have investigated this complex in detail and named it Baidrag massif. However, name "Baidrag" has been used in other geological units such as Baidrag Zone and Baidrag complex. Takahashi *et al.* (1997) renamed the Baidrag massif to Tsogt Khayrkhan complex to for avoiding any confusion. The complex has been dated 312 Ma by K-Ar method (Izokh *et al.*, 1990). This complex consists of gabbro and diorite. Magnetic susceptibility of the complex is 8 to 17 x 10^{-3} SIU in dioritic facies and 17 to 33 x 10^{-3} SIU in gabbroic facies.

The Tsoch huduc granodiorite (Th) crops out at about 50 km south of Nariyn Teel. This bounds to the Ulaagchin complex and is covered by younger sediments. It consists of medium-grained granodiorite. Its magnetic susceptibility is 20 to 23 x 10^{-3} SIU.

The Saran uul complex (Su) is located about 50 km south of Bayankhongor. It consists of tonalite, granite porphyry and andesite. Magnetic susceptibility of tonalite is 4 to 10 x 10^{-3} SIU.

The Ulaagchin complex (U) is distributed in various places in southern part of the study area. It intrudes the metamorphic rocks in Baydrag Zone with discordant boundary. For example, it intrudes gneiss with leucocratic margin and cuts the structure of the gneiss at about 60 km south of Nariyn Teel. This complex shows granitic and dioritic facies. Magnetic susceptibility of the Ulaagchin complex is high; 10 to 34 x 10^{-3} SIU in dioritic facies and 13 to 16 x 10^{-3} SIU in granitic facies.

Khangay complex: The batholithic granitic bodies, which are mostly distributed in the Khangay Zone, have been called Khangay complex or Khangay granites (*e.g.*, Davaa, 1988). In the study area, this complex (K in Fig. 1) crops out around Nariyn Teel, Galuut and northwestern district. This complex discordantly intrudes strata of the Khangay and Dzag Zones. The radiometric ages of the complex are 256 Ma by K-Ar biotite method (Heraskov, 1966) and 200–250 Ma by Rb-Sr method (Tomorchudor, 1990). The Khangay complex consists mainly of coarse-grained granite and partly of medium- to coarse-grained diorite. Generally, these rocks are equigranular and massive, but locally foliated (*e.g.*, in Nariyn Teel). Magnetic susceptibility of the complex is mostly less than 1 x 10^{-3} SIU, but locally more than 10 x 10^{-3} SIU in northern area.

Shar us gol complex: The batholithic reddish granitic bodies, which are mostly distributed in the Baidrag Zone, have been hitherto called Shar us gol complex (e.g., Davaa, 1989). The Shar us gol complex (Sh in Fig. 1) crops out widely in the study area. This complex mostly intrudes discordantly into metamorphic rocks of the Baidrag Zone. This complex intrudes Permian volcanic rocks, too. Radiometric age of the complex is 216 Ma by K-Ar method (Zabotkin, 1988). The complex consists mainly of coarse-grained granite and partly of fine-grained granite. It has been observed that the fine-grained granite intrudes the coarse-grained facies at 10 km south of Nariyn Teel. In central part of the study area, the dioritic rocks crop out as marginal facies of the complex. The coarse-grained granite has a characteristic of reddish colored K-feldspar and sometimes shows porphyritic texture. Magnetic susceptibility of the complex is generally high; 10 to 24 x 10^{-3} SIU.

Mesozoic granitoids: The Mesozoic granitic body in the study area is called Egiin davaa complex (Bayarsaihan, 1990). It crops out at about 20 to 40 km east of Jargalant. Radiometric ages are 124 to 175 Ma by Rb-Sr method and 101 Ma by K-Ar method (Bayarsaihan, 1990). It consists of weakly foliated equigranular fine- to medium-grained granite. Its magnetic susceptibility is less than 1 x 10^{-3} SIU.

3.2 Granitoid series based upon magnetic susceptibility

The magnetite- and ilmenite-series rocks can be distinguished by means of their different magnetic susceptibilities. The magnetite-series rocks show high values (more than 100 x 10^{-6} emu/g, Ishihara, 1977) while the ilmenite-series rocks show low values (less than 100 x 10^{-6} emu/g). Magnetic susceptibility was previously measured in powdered samples, and CGS units (emu/g) was used (*e.g.*, Ishihara, 1977). Recently, the magnetic susceptibility can be easily measured in field with Kappameter and SI unit is adopted. Ueno (1987) worked out conversions between SI and CGS units for rock magnetism. The relationship between the volume magnetic susceptibility κ_{SI} in SI units and the specific magnetic susceptibility χ_{CGS} in CGS units is given by the formula $\kappa_{SI}=4\pi\rho\chi_{CGS}$, where ρ is the density of rocks. The densisty of granitoids is around 2.7 g/cm^3. Therefore, the value of the boundary between magnetite- and ilmenite-series granitoids is $\kappa_{SIU}=4 \times 3.14 \times 2.7 \times 100 \times 10^{-6}=3.3 \times 10^{-3}$. Because the Kappameter shows X. X (x 10^{-3} SIU), the magnetite-series granitoids are defined in the case of value over 3.3 and the ilmenite-series in the case of value less than 3.3.

Riphean granitoids: Magnetic susceptibility of Riphean granitoids is mostly less than 1 x 10^{-3} SIU. Some of them show magnetic susceptibility around 5 x 10^{-3} SIU. It has been observed that the ilmenite-series granitoids are dominant in Riphean.

Early Paleozoic granitoids: Magnetic susceptibility of the early Paleozoic granitoids is shown in Fig. 2. Most of the granitoids show low magnetic suscep-

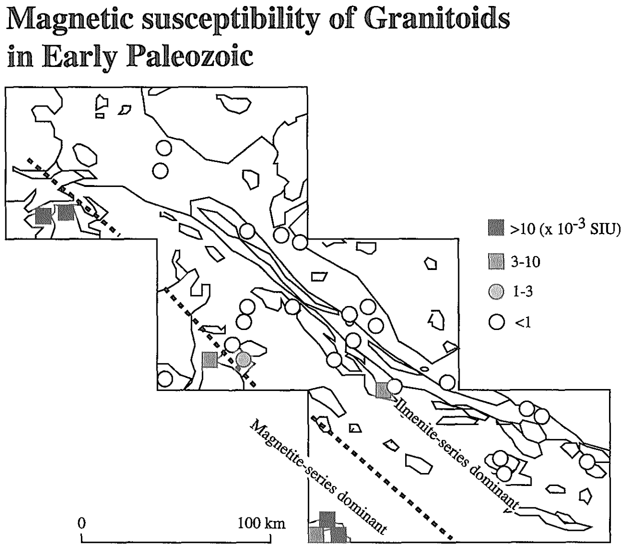

Fig. 2 Magnetic susceptibility of the granitoids in early Paleozoic.

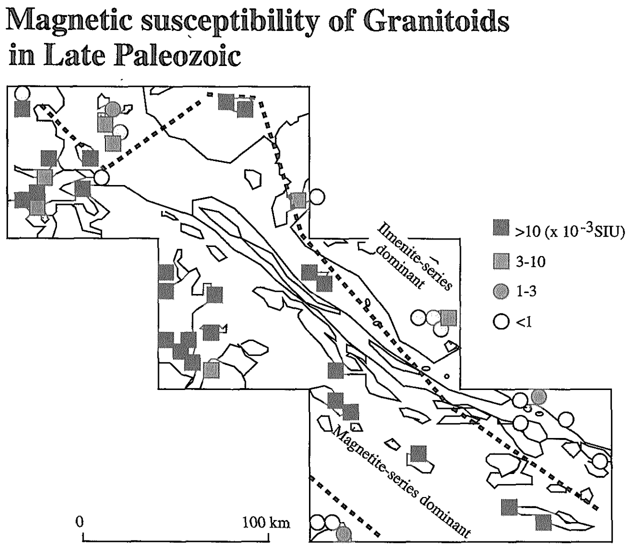

Fig. 3 Magnetic susceptibility of the granitoids in late Paleozoic.

tibility and, in other words, belong to the ilmenite-series. However, in northwestern (Telmen complex) and southern side (a part of Togtokh-shil complex), magnetite-series granitoids are distributed. The boundary between magnetite- and ilmenite-series granitoids runs from about 60 km west of Dzag to about 90 km southwest of Bayankhongor. This boundary is at 20 to 80 km distance from northern margin of the Baidrag Zone.

Late Paleozoic granitoids: Magnetic susceptibility in the late Paleozoic granitoids is shown in Fig. 3. The magnetite-series granitoids are dominant in stock-like granite-diorite complex and the batholithic Shar us gol complex, and the ilmenite-series granitoids are dominant mostly in the Khangay complex. The ilmenite-series granitoids are also distributed in the mountains 100 km southwest of Bayankhongor. The boundary between the magnetite- and ilmenite-series granitoids runs from about 40 km south of Nariyn Teel to about 30 km west of Dzag. This boundary matches with southern margin of the Bayankhongor Zone in eastern part, northern margin of the Dzag Zone in central part and southern margin of the Bayankhongor Zone in northwestern part of the study area.

Mesozoic granitoids: Mesozoic granitoids are distributed only in east of Jargalant. They show low magnetic susceptibility and, therefore, are ilmenite-series granitoids.

3.3 Chemistry of the Paleozoic granitoids

As mentioned above, the spatial variation in the Paleozoic granitoid series is recognized. Such kind of variation should also be examined for chemical features. Fortunately, many chemical data have been published in the explanation texts of the geological map sheets (*e.g.*, Zabotkin, 1988; Davaa, 1989; Bayarsaihan, 1990; Tomurchodor, 1990). We arranged these data and our unpublished data to understand petrochemical characteristics of the granitoids in the study area.

Aluminum saturation index (ASI): The granitic rocks could be derived from two contrasting types of source rocks: igneous and sedimentary (the I- and S-types), which were firstly recognized in southeastern Australia by Chappell and White (1974). The I-S scheme is not petrographic, but a genetic classification. Thus, features of each granite type are not in themselves diagnostic. Nevertheless, we tried to compare our data with the rocks in southeastern Australia.

Figure 4 shows relationship between ASI and total Fe as FeO in the granitoids in the Bayankhongor area. In this figure, areas of I- and S-type granitoids of Lachan Fold Belt in southeastern Australia are also drawn. The granitoids in the Bayankhongor area are not always distinctive in I-S scheme, be-

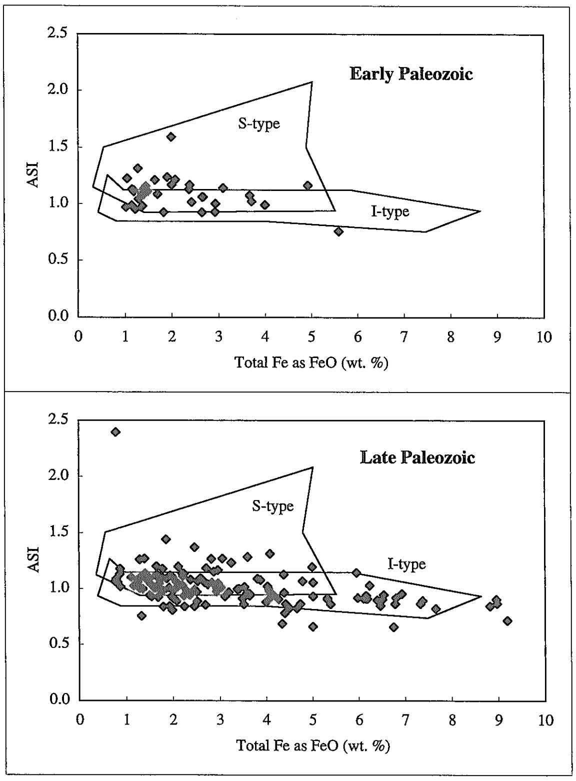

Fig. 4 Relationship between Aluminum Saturation Index (ASI) and total Fe as FeO of the granitoids Regions of I- and S-types are cited from Blevin and Chappell (1995).

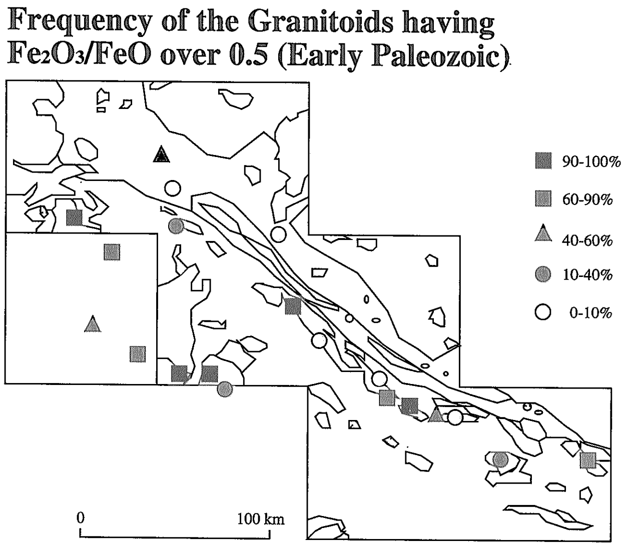

Fig. 5 Frequency of the granitoids having Fe_2O_3/FeO ratio higher than 0.5 (Early Paleozoic).

cause most of them are felsic. However, high FeO rocks in late Paleozoic granitoids show I-type characteristics.

Fe_2O_3/FeO ratio: The magnetite- and ilmenite-series of Ishihara (1977) are also recognized by chemistry. That is, the granitoid series can be defined based upon Fe_2O_3/FeO ratio in addition to presence

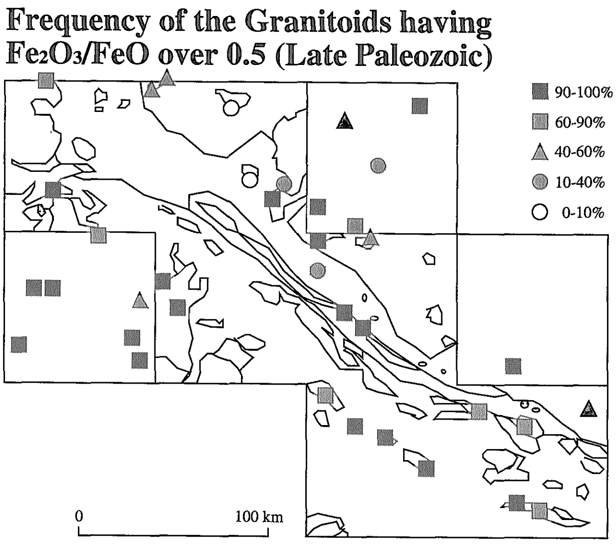

Fig. 6 Frequency of the granitoids having Fe_2O_3/FeO ratio higher than 0.5 (Late Paleozoic).

or absence of magnetite and magnetic susceptibility (Takahashi, 1985). In general, the rocks with Fe_2O_3/FeO ratio higher than 0.5 belong to magnetite-series and the rocks with the ratio less than 0.5 belong to ilmenite-series.

The frequency of the rocks having Fe_2O_3/FeO ratio more than 0.5 in sub-area, divided suitably for each granitic body, is shown on the map (Figs. 5 and 6). The frequency higher than 60% indicates that the magnetite-series granitoids are dominant, while the frequency lower than 40% shows that the ilmenite-series granitoids are dominant. The granitoids with the frequency 40 to 60% are trasitional. The distributions of magnetite- and ilmenite-series granitoids based upon chemistry are generally conformable with those based upon magnetic susceptibility, though the boundaries of the two series do not match perfectly.

4. Discussion

4.1 Spatial variation in the granitoid series

As mentioned above, the granitoid series has changed in each period. This is summarized as follows. In Riphean, the ilmenite-series granitoids were dominant. In early Paleozoic, ilmenite-series granitoids were dominant, but magnetite-series granitoids appeared in southwestern part of the study area. In late Paleozoic, the magnetite-series granitoids were dominant in the study area and the ilmenite-series granitoids were distributed only in northeastern part. As a result, the boundary between the magnetite- and ilmenite-series granitoids shifted northeastward in Paleozoic. The Mesozoic granitoids in the area were ilmenite-series.

In these variations, the northeastward shifting of the boundary between two series in Paleozoic is interesting from the view point of tectonic development of the area. Paleozoic strata show northeastward younging, that is, from Dzag Zone in early to middle Paleozoic to Khangay Zone in middle to late Paleozoic. This younging polarity indicates that subduction occurred during Paleozoic in north of the study area, and location of subduction shifted northeastward with the formation of the Dzag and Khangay Zones. According to Unrug (1996), the Siberia and North China cratons were separated in Paleozoic, and the subduction under continent might have begun and continued around the study area. This global tectonic setting also supports our inference. In short, it is concluded that spatial variation in granitoid series in Paleozoic can be explained with development of the Khangay Zone.

The above mentioned results are conformable with the studies in Japan. In Cretaceous to Paleogene granitoids in southwestern Japan, the ilmenite-series granitoids are dominant in oceanic side and the magnetite-series in the inner continental side (Ishihara, 1981). Horikoshi (1976) suggested that the magnetite-series granitoids are roots of volcanic belt under tensional stress field. In the study area, the ilmenite-series granitoids are dominant in north. This fact indicates younging northward oceanic side as shown in the strata. In addition, the magnetite-series granitoid (Shar us gol complex) intrudes Permian volcanic rocks, which means volcanic belt.

4.2 Relationship between granitoid series and metal deposits in late Paleozoic

Now, the granitoid series in the area will be discussed from the view point of mineral resources. Information on the mineral resources in the study area can be gathered from "Mineral Resources Map of

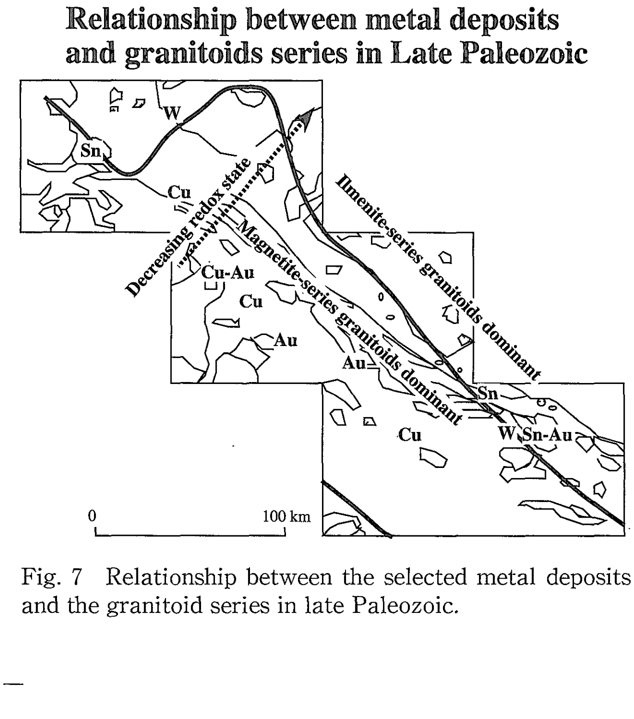

Fig. 7 Relationship between the selected metal deposits and the granitoid series in late Paleozoic.

Bayankhongor Zone" prepared by Borzakovskii and Suprunov (1990). In this map, the mineral resources are divided into three levels; i.e., deposit, ore showing, and mineralized point in decreasing order of size. We selected the mineral resources from deposit and ore showing related to late Paleozoic igneous activity. Minerals of Cu, Sn, W and Au have been used for our discussion. Even though Mo is also important, the metal occurs only as mineralized points in the study area.

Figure 7 shows the relationship between ore deposits and granitoid-series in late Paleozoic. The Cu and Au deposits are distributed within the magnetite-series granitoids area. On the other hand, Sn and W deposits occur around the boundary between the magnetite- and ilmenite-series granitoids or in the ilmenite-series dominant area. These zonal arrangements of the mineral resources and granitoid series may be interpreted with redox state of the granitic magma.

Sillitoe (1996) summarised the control of selected metal deposits by the degree of fractionation and redox state of genetically related granitic rocks. In Fig. 2 of Sillitoe (1996), the Cu-Au, Au, Cu-Mo and Mo metal deposits have been related to the magnetite-series granitoids and the W, Sn and Sn-W to the ilmenite-series granitoids. The W-Mo deposit is located in the boundary of the two series. Judging from these relationships, we infer that the redox potential decreases from southwest to northeast in late Paleozoic granitoids of the study area.

5. Summary

The granitoid series in Bayankhongor area, central Mongolia, were investigated using magnetic susceptibility and chemical data. In Riphean, ilmenite-series granitoids were dominant. In early Paleozoic, ilmenite-series granitoids were dominant, but magnetite-series granitoids appeared in southwestern part of the study area. In late Paleozoic, magnetite-series granitoids were predominant. The boundary between magnetite- and ilmenite-series granitoids shifted northeastward during Paleozoic. Mesozoic granitoids were ilmenite-series granitoids.

These variations are interesting from the view point of tectonic developments in the area. Among these, Paleozoic granitoids in the study area may be products associated with subduction. The shifting of boundary between magnetite- and ilmenite-series granitoids is conformable with the development of the Khangay Zone in middle to late Paleozoic.

In late Paleozoic granitoids, Cu and Au deposits are distributed within the magnetite-series granitoids area. Sn and W deposits occur around the boundary between the magnetite- and ilmenite-series granitoids or in the ilmenite-series dominant area. These distributions indicate that the redox potential decreases from southwest to northeast in late Paleozoic granitoids of the study area.

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モンゴル中央部，バヤンホンゴル地域における花崗岩系列

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要　旨

モンゴル中央部バヤンホンゴル地域における花崗岩系列を帯磁率と化学組成から調べた．リフェアンにはチタン鉄鉱系花崗岩類が卓越する．古生代前期にはチタン鉄鉱系花崗岩類が卓越するが，わずかに調査地域南西部に磁鉄鉱系花崗岩類が分布する．古生代後期には磁鉄鉱系花崗岩類が卓越する．磁鉄鉱系とチタン鉄鉱系花崗岩類の境界は古生代前期から後期にかけて北東に移動した．この移動は古生代中後期のハンガイ帯の発達と関係づけられる．中生代花崗岩類はチタン鉄鉱系である．

古生代後期には銅及び金鉱床が磁鉄鉱系花崗岩類地域に分布する．錫及びタングステン鉱床は磁鉄鉱系とチタン鉄鉱系花崗岩類の境界付近かチタン鉄鉱系花崗岩類地域に分布する．これらから調査地域の古生代後期花崗岩類は南西から北東へ還元的になることが示唆される．