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Comparative Study of Mesozoic Granitoids and Related W–Mo Mineralization in Southern Korea and Southwestern Japan*

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Abstract: Jurassic and Cretaceous granitoids are compared in the two areas. The Jurassic Daebo granitoids are dominantly composed of the ilmenite-series and are different from the Jurassic Funatsu granitoids in the Japanese side. The Cretaceous granitoids in the peninsular interior are of the ilmenite-series and weakly magnetic magnetite-series. The cretaceous granitoids of the Gyeongsang basin are predominantly magnetite-series granitoids with no clear separation in the distribution of two types of granitoids, whereas the oceanic side of the ilmenite-series and the marginal sea side of the magnetite-series pair is distinct in the similar volcano-sedimentary basin in the Japanese side.

The Gyeongsang basin is essentially a tungsten province and the wolframite deposits are generally associated with scheelite and molybdenite. These minerals occur separately in the Japanese side. The split-off part of the Gyeongsang basin has not been observed in the northern Kyushu and the western Chugoku districts. It is suggested that magmatism of the Gyeongsang basin occurred in a stable continental margin environment successive to the development of subsided basin in a tensional tectonic setting, whereas that of the southwestern Japan occurred in a floating island arcs where parallel lineaments were developed. The southwestern Japan may have been located at some distance from the Gyeongsang basin during the Cretaceous or Paleogene time.

Introduction

The hypothetical southward drift of a Mesozoic landmass, now the Inner Zone of southwestern Japan (HORIKOSHI, 1972), became plausible after the proposal of SILLITOE (1977), which found in the Gyeongsang basin of southern Korea the same ordering of tungsten (at south) and molybdenum (at north) metallogenic provinces as found in the Inner Zone of southwestern Japan (ISHIHARA, 1971). SILLITOE (1977) also pointed out a late separation of the southwestern Japan from the Asian continent because of the Paleogene age of the molybdenum province. If his proposal is valid, there must be a similarity in the distribution patterns of magnetite-series and ilmenite-series granitoids in the two separated areas, because the tungsten province of the southwestern Japan is dominantly composed of ilmenite-series granitoids, whereas the molybdenum province is predominated by magnetite-series granitoids (TSUSUE and ISHIHARA, 1974; ISHIHARA, 1977).

In this paper, the distribution of the two series of granitoids in southern Korea is compared with that of the Inner Zone of southwestern Japan. The geology of the two areas is most similar in regard to the Cretaceous igneous activity in the southeastern corner of the Korean peninsula (i.e., Gyeongsang basin) and westernmost portion of Honshu island (KATO, 1932). Here, granitic plutonism followed the development of early Cretaceous sedimentary basin and successive volcanic activities. Thus, the igneous activity of the particular parts are considered in detail. The two series of granitoids were identified in southern Korea by their magnetic susceptibility which was measured using Bison Model 3101 (KANAYA and ISHIHARA, 1973)

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Keywords: Magnetite-series granitoids, Ilmenite-series granitoids, Southern Korea, Gyeongsang basin, Southwestern Japan, Tungsten deposits.

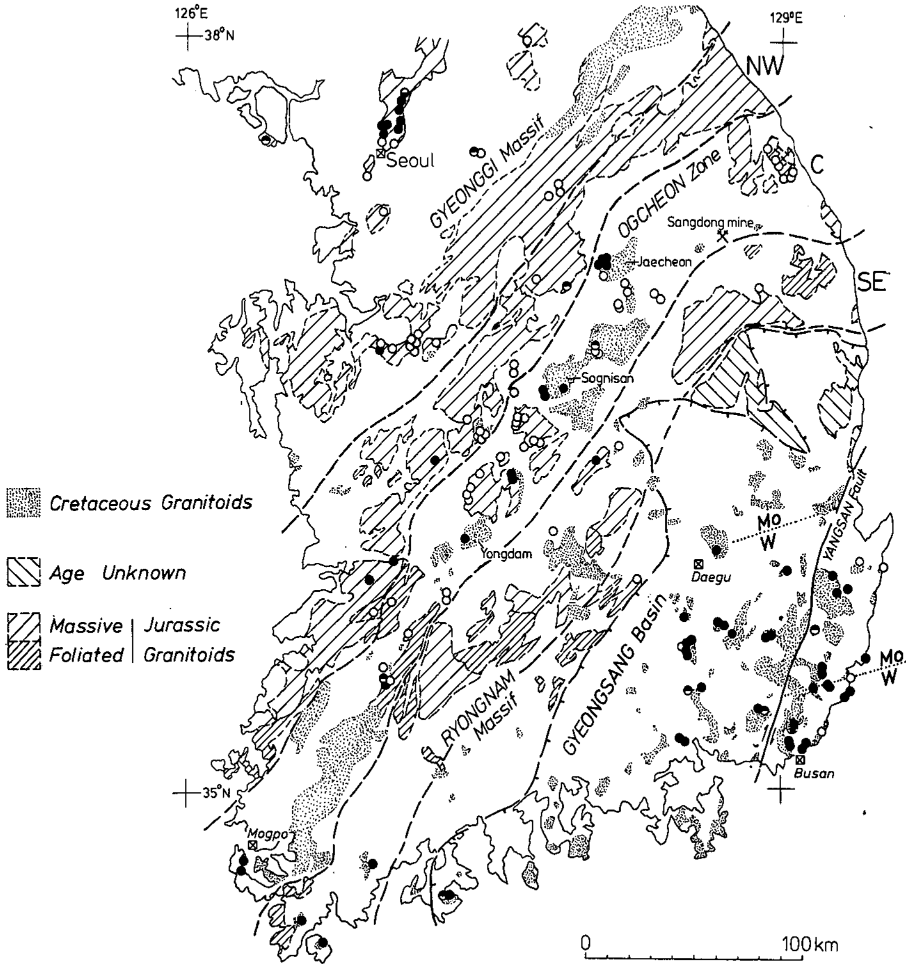

Fig. 1 Distribution of magnetite-series and ilmenite-series granitoids in southern Korea. Solid circle indicates the magnetic susceptibility ($\chi > 100 \times 10^{-6}$ emu/g) of the magnetite-series. Half-filled circle ($\chi \times 50-100 \times 10^{-6}$ emu/g) and open circle ($\chi < 50 \times 10^{-6}$ emu/g) belong to the ilmenite-series. Mo/W with dotted lines separate the molybdenum and tungsten provinces proposed by Sillitoe (1977). NW, C and SE are the northwestern, central and southeastern subzones, respectively, by D. S. Lee (1971).

and Kappameter KT-3 (Ishihara, 1979a). The boundary of the two series is set at 100×10^{-6} emu/g. The total number of the samples studied in southern Korea is 137.

Magnetite-series/Ilmenite-series Granitoids in Southern Korea

Mesozoic-Cenozoic granitoids in southern Korea are classified into Jurassic-early Cretaceous (hereafter abbreviated as Jurassic) granitoids, associated with Daebo orogeny, and Cretaceous-Paleogene (hereafter called Cretaceous) granitoids which are related to Bulgugsa disturbance (O. J. Kim, 1971, 1975). The Jurassic granitoids occur in the Gyeonggi crystalline basement, the Ogcheon geosynclinal zone and the Ryongnam crystalline basement. The Cretaceous granitoids are mainly distributed in the central subzone of the Ogcheon zone (D. S. Lee, 1977) and the Gyeongsang volcano-sedimentary basin (see Fig. 1).

The Jurassic granitoids are divisible, by texture, into massive granitoids and foliated granitoids, the latter of which occur dominantly within the southeastern subzone of the Ogcheon

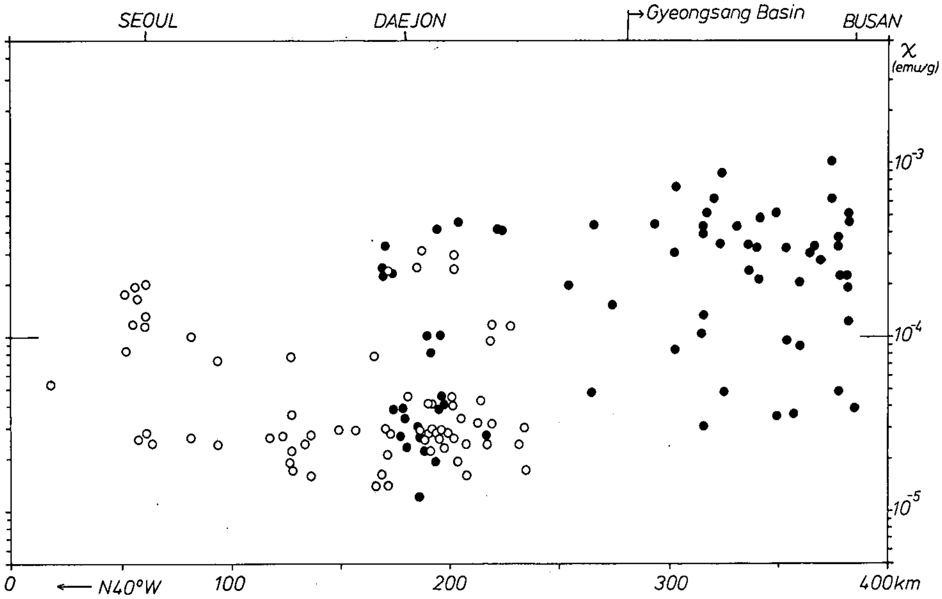

Fig. 2 Magnetic susceptibility of the Korean granitoids as projected on N40°W line. Open circles are Jurassic granitoids; Solid circles are Cretaceous granitoids.

zone. The massive granitoids in the northwestern subzone of the Ogcheon zone include some gabbro and tonalite (D. S. LEE, 1971), but they are mostly granodiorite and granite including two mica variety. The foliated granitoids are composed of granodiorite and granite, and are associated with high-grade metamorphic rocks and migmatite. This general pattern of foliated granitoids occurring in the south and massive granitoids in the north is similar to that observed for the late Cretaceous granitoids across southwestern Japan where a mesozonal, foliated granitoids occur in the Ryoke belt and an epizonal, massive granitoids are present in the Sanyo belt, although the mixed occurrence of the foliated and massive granitoids prevail and even epizonal stocks occur in the Korean side of the foliated granitic terrains.

The Cretaceous granitoids occurring in the Gyeongsang basin consist generally of granodiorite and granite with a sporadic distribution of diorite and tonalite (CHA, 1976; Y. J. LEE, 1980). The granitoids in the peninsular interior tend to have a felsic composition. In the central, Ogcheon subzone for example, they are solely granite, i.e., monzogranite and syenogranite (D. S. LEE, 1977).

The magnetic susceptibilities of these granitoids are shown in Figures 1 and 2. Jurassic granitoids are predominated by ilmenite-series, whereas Cretaceous granitoids belong largely to magnetite-series. The general pattern of the magnetic susceptibility is that the χ-values decrease toward the continental interior which is completely different from the patterns observed across southwestern Japan (ISHIHARA, 1979b) and northern Chile (ISHIHARA and ULRIKSEN, 1980).

Within the ilmenite-series, Jurassic granitic terrains, pink biotite granites found at north of Seoul contain magnetite, but their content is low, giving rise to an average magnetic susceptibility (7 samples) of the magnetite-series as 162×10^{-6} emu/g (0.16 vol.% magnetite, see ISHIHARA, 1979b). This is less than a half of the average magnetic susceptibility of the typical magnetite-series, biotite granite in the Sanin province in southwestern Japan.

Most of the Cretaceous granitoids in the volcano-plutonic Gyeongsang basin and Mogpo area are magnetite-series. The granitoids of the tungsten province of SILLITOE (1977) do not fall in the category of ilmenite-series. The average magnetic susceptibility is 390×10^{-6} emu/g (n=32), which is more or less similar

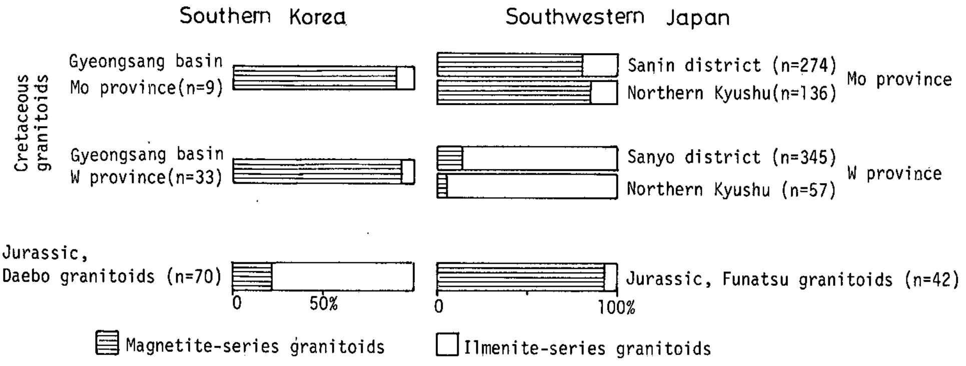

Fig. 3 Ratio of magnetite-series/ilmenite-series granitoids in southern Korea and southwestern Japan. Number of samples in parenthesis. Data from the Sanyo district were taken from Chugoku district (ISHIHARA, 1979b) where Cretaceous sedimentary rocks equivalent to those of the Gyeongsang basin occur.

to the average value of the typical magnetite-series granitoids in the Sanin province. Cretaceous granitoids occurring outside of the Gyeongsang basin are composed of an equal amount by number of the magnetic susceptibility measurement of the magnetite-series and ilmenite-series granitoids. The magnetite-series granitoids are weakly magnetic and are seen dominantly in the Jaecheon (average magnetic susceptibility, $\chi=217\times10^{-6}$ emu/g, n=5), Sognisan ($\chi=127\times10^{-6}$ emu/g, n=6) and Yongdam plutons. Thus, the Cretaceous granitoids are divisible into two groups: one intruded in the Gyeongsang basin while the other occurring in the Ogcheon zone and crystalline basement.

In summary (Fig. 3), the ratios of the two types of Cretaceous granitoids are different in the tungsten provinces of two areas, being dominantly magnetite-series in the Gyeongsang basin but mainly ilmenite-series in southwestern Japan. The Jurassic Daebo granitoids of the ilmenite-series also are different from the Jurassic Funatsu granitoids and those of in the Ogcheon zone (D. S. LEE, 1971) are magnetically and petrographically most similar to the late Cretaceous granitoids in the Sanyo (tungsten province) and Ryoke (barren province) belts.

Comparison with Southwestern Japan

In the upper Cretaceous sedimentary and volcanic Gyeongsang basin, the thick pile of the Gyeongsang Supergroup has been divided into the lower Nagdong and upper Silla Series. They were reclassified into the Sindong Group (lower Nagdong Series) and Hayang Group (upper Nagdong plus Silla Series) by CHANG (1975). These groups are composed of continental clastics and volcanic rocks and are characterized by monotonous and mild structures. The Sindong Group occurs along the crystalline basement dipping eastwards, whereas the Hayang Group, particularly of the upper members, show a circle distribution dipping toward the center of the basin. The volcanic and plutonic rocks tend to occur in a ring-shaped structure made up of the Sindong and Hayang Groups, and occupy less than a half of the area of the sedimentary rocks (Fig. 4).

In southwestern Japan, on the other hand, the sedimentary rocks equivalent to the Sindong and Hayang Groups, the Wakino and Shimonoseki subgroups respectively of the Kanmon Group, are limited in extent. Sedimentary rocks of the Wakino subgroup are highly deformed and deformation and faulting during the sedimentation are assumed (HASE, 1958). Volcanic rocks of the later stages are as equally distributed as granitoids in the Chugoku district but are nearly absent in northern Kyushu. Upper Paleozoic sedimentary and metamorphic rocks not found in the Gyeongsang basin occur widely (Fig. 4). The presence of the Paleozoic limestone is a

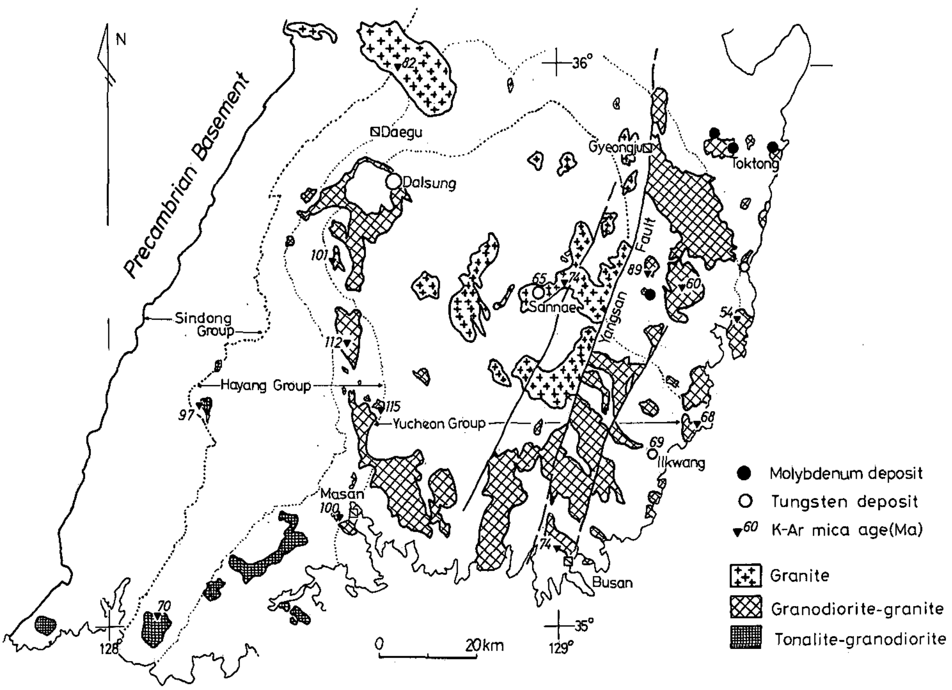

Fig. 4 Distribution of granitoids, their K–Ar mica ages and molybdenum and tungsten deposits in the southern Gyeongsang basin. The granitoids are dominantly magnetite-series. Data are taken from 1/250,000 scale geological map, "Busan" and "Andong", CHANG (1975), Y. J. LEE (1980), FLETCHER and RUNDLE (1977), PARK (1980), and distribution map of Korean working mines in 1935 (1/1,000,000 scale).

major cause of the many skarn-type deposits in the Japanese side. Middle Paleozoic or even older granitoids and metamorphic rocks (MURAKAMI et al., 1977) occur along the Nagato tectonic line as squeezed-out lenses. The Cretaceous southwestern Japan apparently was located in a tectonically complex environment, while the Gyeongsang basin formed in a stable continental margin.

The ratio of volcanic to sedimentary rocks indicates that the late Cretaceous magmatism of southwestern Japan appears to be more intense than that in the Gyeongsang basin. Volcanic rocks of the Gyeongsang basin include andesites but rhyo-dacitic lavas and pyroclastics prevail, whereas those of southwestern Japan are dominantly rhyo-dacitic ignimbrites. The plutonic rocks are also similar in bulk composition, but those of the Gyeongsang basin appear to be more alkaline than those of the Sanyo belt (JIN et al., this issue).

In the Gyeongsang basin, granodiorites show a circular distribution cored by monzogranite. Tonalite and granodiorite occur in the southwestern margin of the basin (Fig. 4). Many smaller ring structures have been reported (see JIN et al., this issue). In southwestern Japan, such circular patterns are scarce (MURAOKA and HASE, 1980), but a few calderas of Paleogene age have been confirmed at Tamagawa and Hamada (MURAKAMI, 1973; MATSUHISA et al., 1980). The Hikihara caldera of Cretaceous age is somehow related to the tin-polymetallic mineralization of the Akenobe mine (ISHIHARA et al., 1981). A long-known arched distribution of pyrophyllite deposits (KINOSAKI, 1963) in the most productive, Mitsuishi area, Okayama Prefecture, appear to be products of the Cretaceous hydrothermal activity which occurred along the eastern edge of a large caldera (15 **km** in diameter) in the Wake-Katagami area.

Recently Y. J. LEE (1980) reported 36 K-Ar age determinations on whole rock, biotite and

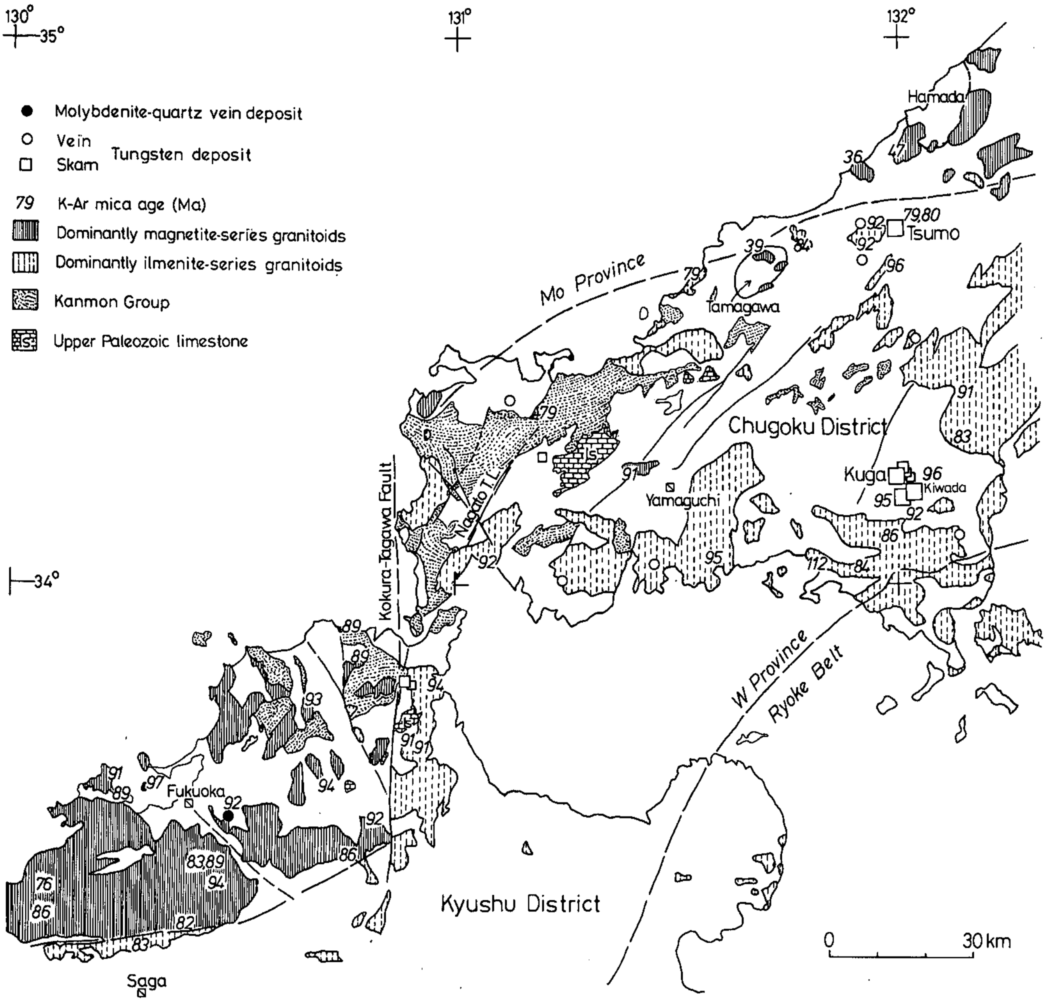

Fig. 5 Distribution of Kanmon Group, granitoids, their K–Ar mica ages and molybdenum and tungsten deposits in the westernmost part of the Inner Zone of southwestern Japan. Geological data mostly taken from 1/500,000 scale map of "Fukuoka" but partly revised. Studied points of the magnetite-serie /ilmenite-series granitoids is given in Ishihara et al. (1979). Three classes of size designation for the tungsten and molybdenum deposits are based on the total production of 2,000–500 tons, 500–50 tons and less than 50 tons. The age data from Kawano and Ueda (1967) and Shibata and Ishihara (1974). There are many whole rock K–Ar ages around Tsumo mine (MMAJ 1977), from which two determinations are taken. Kanmon Group is composed of lower Cretaceous Wakino subgroup which is correlated to Sindong subgroup and upper Cretaceous Shimonoseki subgroup which is correlated to Hayang subgroup of the Gyeongsang basin. The Wakino subgroup occurs dominantly in the west and the Shimonoseki subgroup becomes dominant to the east. Exposure of the Kanmon Group is very limited in outside of the this map. Dotted flowage implies the general strike of the bedding. From Paleozoic formations, large limestone plateau (ls) is shown.

feldspars of the Cretaceous granitoids from the Gyeongsang basin and divided them into Cretaceous granitoids (115–68 Ma) which are further subdivided into 5 groups and Tertiary granitoids (63–41 Ma). In Figure 4, his biotite ages and two sericite ages of Fletcher and Rundle (1977) are shown. Older ages are seen in the middle-western part of the basin and younger ages are dominant in the eastern area; this migration of plutonic activity could have followed that of the sedimentation (CHANG, 1975). There is no north-south variation that crosses SILLITOE's boundary between the molybdenum and tungsten provinces.

K-Ar mica ages of granitoids in the tungsten province of southwestern Japan lie between 95 and 65 Ma, while those of the molybdenum province are 65 to 30 Ma (SHIBATA and ISHIHARA, 1974), thus yielding north-south variation. In the westernmost part (Fig. 5), however, the ages are similar in the two provinces in the northern Kyushu district and change abruptly from 80 Ma to about 50 Ma in the Chugoku district. This sharp contrast is not observed in the Gyeongsang basin. The ages of tungsten mineralization in the westernmost part range from 96 to 80 Ma and do not accord with those of the Ilgwang and Sannae deposits.

Molybdenum and tungsten provinces of southwestern Japan can be identified not only by the number of molybdenum and tungsten deposits (KINOSAKI, 1953) but also by the quantity of these metals (ISHIHARA, 1971). A single deposit can be either a molybdenum or a tungsten deposit. In the Gyeongsang basin, tungsten is much more abundant than molybdenum in the past record of production, because of the outstanding Dalsung deposit whose production until 1973 is 4,400 tons of tungsten concentrates (CHUNG, 1975). Molybdenum production from the Gyeongsang basin is reported to be small (IIZUKA, 1937; GALLAGHER, 1963).

The Sannae tungsten deposit is classified in the same size class of ore deposits as the Dalsung deposit (PARK, 1981) and is very rich in molybdenum (average ore grade, 0.89% WO_3 and 0.58%MoS_2, unpublished data of KIER, 1979). This mixture of tungsten and molybdenum appears to be a characteristic of Korean tungsten deposits in the case of scheelite-bearing wolframite quartz vein type and many examples are seen in other areas (KASAI, 1937; GALLAGHER, 1963). Production figures of tungsten and molybdenum of southern Korea before the present Sangdong orebody was opened for production in 1940 indicate that its W/Mo ratio is about 5. Similar or higher ratios may be expected in the Gyeongsang basin.

The Dalsung tungsten deposit is a breccia pipe occurring in andesitic rocks. This kind of ore deposits, as well as the Ilgwang breccia in monzogranitic stock (FLETCHER, 1977), does not occur in southwestern Japan. Tungsten and copper mineralization of small size is seen in southwestern Japan as the skarn deposits in Kuga and Tsumo areas, respectively (Fig. 5). The Ilgwang stock is similar magnetically to granitoids of the tungsten province in southwestern Japan. A number of magnetic susceptibility measurement on rocks collected by M. S. JIN indicate that the marginal granodiorite is weakly magnetic but the central monzogranite has magnetite-free values; thus similar to the intermediate series of the Sanyo belt (ISHIHARA, 1979b).

Both regional and local samples were studied in the Sannae mine area. They belong to the magnetite-series. The sericite age of 65 Ma from this mine is similar to that of Stage I molybdenum mineralization in southwestern Japan, which has some similarity to the tungsten province (ISHIHARA, 1978). Small molybdenum deposits in the Deogdong area, east of Gyeongju, are purely molybdenite-bearing (average ore grade, 0.35%MoS_2) and may be similar to typical molybdenum deposit (Stage II) in the central Sanin district (SILLITOE, 1977). Only local samples were available which are gently altered and give us magnetite-free values. Detailed petrographical studies and age determination are necessary to discuss their similartities.

Discussion and Conclusions

The Jurassic Daebo granitoids occurring in the crystalline basement in Korean Peninsula are dominantly the ilmenite-series granitoids. Cretaceous granitoids of the Ogcheon zone are also of the ilmenite-series or weakly magnetic magnetite-series and are different from those in the Gyeongsang basin. Since crustal carbon appears to have played significant role in generation of the ilmenite-series magmas (ISHIHARA, 1977), these ilmenite-series granitoids in the peninsular interior may have been born anatectically or interacted a great deal with the underlying graphite-bearing metamorphic rocks. Foliated granitoids tend to occur toward the Jurassic magmatic front where the magma was most reduced because of tectonic shearing of the continental blocks and also deeper level of the erosion.

The Cretaceous granitoids in the Gyeongsang basin, on the other hand, are of the magnetite-series containing magnetic susceptibility of the typical magnetite-series granitoids. WONES (this issue) emphasizes that such an oxidized magma needs to have an oxidized source material, as altered volcanics. These materials are avilable in the host, Gyeongsang strata, but these rocks are considered to have less than 10,000 meters thickness and underlain by Paleozoic sedimentary and Precambrian metamorphic rocks which may contain coal and graphite, respectively. Thus the oxidized magma must have been brought up from the depth. A candidate is altered oceanic floor basalt (SASAKI and ISHIHARA, 1979) brought up into the Gyeongsang basin by subduction processes, as evidenced by very positive isotopic values of the ore sulfur (see SATO et al., this issue). The magnetite-series granitoids of the Ogcheon zone are less oxidized than those of the Gyeongsang basin. There, similar magmas may have been brought up, but because of thicker continental crust than in the Gyeongsang basin and relatively compressional tectonic setting developed during the Cretaceous, the magma was interacted with crustal components and reduced partly by the graphite.

The thick pile of the Gyeongsang Supergroup developed at first along the north-northeast lineaments indicates that the basin was subsided along the edge of the Ryongnam massif. Such subsidence may be expected by rifting of the crystalline basement under tensional environment, which could have been related to mantle convection connected with subduction of the proto-Pacific plate. The sedimentation began from west to east on the sliced Ryongnam massif. Volcanism and plutonism occurred later in this tensional tectonic basin, shifting the center of the magmatism toward the east-southeast, but during the latest stage, the ovoidal shape of the Gyeongsang basin was formed as an independent basin. The large circular intrusion of the granitic masses is considered to be related to this basin structure. Associated tungsten and molybdenum deposits show no linear regional separation, because of lack of parallel lineaments developed at this stage.

In the western part of the Chugoku district, the upper Cretaceous sedimentary basins were developed in a block-faulted island arc system where parallel lineaments prevailed. Subsequent volcanism is characterized by subareal rhyo-dacite. The granitoids and related tungsten and molybdenum deposits are clearly separated parallel to the island arc; the magnetite-series granitoids and molybdenum deposits occur along the marginal sea side, regardless of their ages, wheareas the ilmenite-series granitoids and wolframite (in non-calcareous host) and scheelite (in clacareous host) are present along the oceanic side. Thus the magmatism of the western Chugoku district is different from that of the Gyeongsang basin.

The southwestern Japan may have been located near the Gyeongsang basin at one time, but must have been within the island arc framework, which may have drifted back and forth around the eastern sea-off of the continental margin.

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韓国と西南日本内帯における中生代花崗岩類と W-Mo 鉱床についての比較研究

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要旨：韓国におけるジュラ紀の大宝花崗岩類は，主としてチタン鉄鉱床系の花崗岩類からなり，両雲母花崗岩を含み，W(-Mo) 鉱床を伴う，などの点において日本側で同時期の船津花崗岩類と異なり，むしろ山陽-領家帯の花崗岩類に類似する．白亜紀の佛国寺花崗岩類は内陸の沃川帯などに産出する珪長質の弱磁性の磁鉄鉱系と，慶尚盆地トナール岩～花崗岩質の磁鉄鉱系に分けられ，共に W-Mo 鉱化作用を伴う．前者は日本側には産出せず，後者に相当するものは西日本に広くあらわれる．

佛国寺花崗岩は上部白亜紀の慶尚層群の堆積，引続く火山岩活動の後，この広域的張力場の中心に貫入したものと考えられる．西日本では慶尚層群に相当する関門層群堆積時には地殻が複雑にブロック化していたものと思われ，堆積後の火山活動では多量の流紋岩類を陸上に噴出した．花崗岩類は縁海側で磁鉄鉱系，大洋側でチタン鉄鉱系が産出するゾーニングを示し，関連鉱化作用においても，Mo, W 鉱床の分離がよい．一方慶尚盆地では，花崗岩類はほぼ環状の堆積盆地に沿って貫入し，チタン鉄鉱系帯に相当するものがほとんどなく，Mo とW鉱物が共産することが多い．慶尚盆地の片割れ的なものは西日本には存在せず，日本海拡大以前に両地域はそれぞれ独自の地質環境，すなわち慶尚盆地では比較的安定した大陸縁辺部に NNE 系の断裂帯が発達して沈降を伴った状態，西日本では大陸地殻が細切れ的で個々の沈降と隆起とが著しい島弧的な環境にあったものと考えられる．