GRANITES IN RELATION TO TECTONICS AND MINERALIZATION IN KOREA

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ABSTRACT  Granite intrusion, tectonism, and mineralization in the Korean peninsula are closely related of an identical energy source. Genetically two types of granite occur in the peninsula, i.e., granites of magmatic origin derived from a compressional boundary by crystallization of magmas derived by fractional crystallization of subducted oceanic crust, and granites of synkinematic in origin derived from an intracontinental geosynclinal basin by anatexis. The petrography, petrogenesis, and petrochemistry of the two types, which are quite distinct, are discussed. ** These two genetic types of granite lead to formation of juvenile and assimilated types of ore deposits. Occurrences, mechanism, geochemistry, and ore genesis of the metallic mineral deposits which are genetically related to petrogenesis, petrochemistry, and differentiation processes of the related granites in the peninsula, are discussed.

INTRODUCTION  Plutonism, tectonism, and mineralization are genetically counterpar reactions of an identical energy source. Since the Korean peninsula is situated within the active zone between the Asian and Pacific Plates, some of the granites in the peninsula are closely related to the plate motion, while others are related to the intracontinental orogeny. Mineralization in the land is also genetically related to the origin as well as the tectonics of the granites.

Recently, some geologists attempted to correlate granites and ore deposits, such as Lee (1972), Lee et al. (1974), Jin et al. (1982), Tsusue et al. (1981), and Lee et al. (1982), but ore genesis studies based on petrogenesis and tectonism of the related granites left much uncertainty. The present study is aimed at the genetic correlation between granites, tectonics, and mineralization.

GRANITES  Granites in the Korean peninsula are widespread throughout the land. They include Precambrian, Triassic-to-Permian, Jurassic, and late Cretaceous-to-early Tertiary granites. The Precambrian granites known as Kokurian (Kobayashy, 1953), are widely distributed throughout the country and they were intruded into the early Precambrian metamorphic basement. These granites suffered multiple metamorphism and they are now of gneissic character and gradational to the metasediments due to the subsequent regional metamorphism and anatexis.

The radiometric age determinations of these granites range from 808 to 2,925 Ma. (Geologic Survey or Korea, 1972). They can be correlated to pre-Machineonryeong or early Proterozoic, post-Yeongcheon or middle to late Proterozoic, and post-Sangweon or late Proterozoic.

The Triassic-to-Permian, Jurassic, and late Cretaceous-to-early Tertiary granites, are called Songrim, Daebu and Bulgugsa granites, respectively. Songrim granites are mostly restricted to the northern part of the peninsula whereas Bulgugsa granites are mostly in the central part of the land, along regional anticlinal axes and gradational with the meta-sediments. These facts may indicate that the Daebu granites are of synkinematic origin and they are different from the circular and cross-cutting Songrim and Bulgugsa postkinematic granites in their occurrence and genesis. The early Tertiary granites are sometimes called separately as Masanites. Radiometric age data for these granites show time ranges of 190-225 Ma., 135-183 Ma., and 68-120 Ma., respectively.

Petrographic and petrochemical characteristics of the granites  A wide range of rock phases, ranging from quartz monzonites to alkali granites, and of grain size occur in the Bulgugsa granites whereas a narrow range of rock phases (tonalite to granite) and a more or less homogeneous grain size in the Daebu granites are characteristic.

On the other hand, while the Daebu granites contain biotite, without primary muscovite, microcline, commonly as phenocrysts with myrmekite and no perthite, plagioclase, seldom with oligoclase and andesine, the Bulgugsa granite contains biotite and/or hornblende, oligoclase (instead of microcline) without normal zoning, and rare myrmekite, with as accessories, magnetite, apatite, and fluorite. These mineralogical differences between them seems to have a genetic significance.
Petrochemical differences between the granites also indicate their genetic significance. The studies by Lee et al. (1982) indicate that the alkali-lime indices are 56.6 for Daebo granites and 59.5 for Bulguga granites, corresponding to alkalic calc-alkalic and calcic calc-alkalic rock series, respectively. The AKF plots show that Daebo granite analyses are distributed nearer to the A vertex than those of the Bulguga granite. The Daebo granite is relatively richer in potash as shown in the plots of $K_2O/Na_2O$ versus $SiO_2$ wt. %. Normative of Q-Or-An diagram show that the Bulguga granites have a higher crystallization temperature, $1,200^\circ C$, as against $1,000^\circ C$ for Daebo. Plots of $Na_2O$ versus $K_2O$ (wt. %) and $Fe_2O_3$ versus $FeO$ (wt. %) indicate that most of the Bulguga granites lies in the field of the I-type granite whereas Daebo granite overlaps considerably into the S-type. In addition, the mineralogical composition of the Bulguga and Daebo granites indicates they are of magnetite- and ilmenite-series granites, respectively.

GRANITES IN RELATION TO TECTONICS  Granite genesis in the Korean peninsula, as well as in its related regions, is closely related to the global tectonics. The age of granites in the peninsula decrease from north to south. Triassic-to-Permian granites occur exclusively in the north, Jurassic granites in the central region, and late Cretaceous-to-early Tertiary granites in the south-eastern portion of the peninsula.

Likewise, in central Japan, Cretaceous granites mainly occur to the north, and Tertiary granites to the south of the Median Tectonic Line, although local exceptions are recognized. To the north of the Line, granites occur in the Hida region, southern Honshu and northern Kyushu areas as well as Sedonaikai and Abukuma mountain regions are composed of Cretaceous granites, whereas the granites of southern Shikoku and southern Kyushu regions to the south of the Line are of Tertiary age (Kawano & Ueda 1967).

This general tendency of the north to the south migration as the age of the granites decreases, is also traced in southeastern China, i.e., from north to south, Hsiuning granite of the Hsuehfang orogeny (908 Ma), Shangyu granite of a Caledonian orogeny (385 Ma), and Yunhsiao granite of a Yenshanian orogeny (112 Ma.), (reported by Nanking University 1974).

Granites in the Korean peninsula, as well as in its related regions are closely related to the global tectonics. Geotectonically, the region is situated in the transitional zone between the so-called S.E. Asian Plate and Pacific Plate, lying within the active zone between them. The transitional zone may be traceable through the Kamchatka trench — Kurile island — Japanese islands, and its western margin, perhaps, lies from west of Cathaysia of southern Chine to the Gyeongsang basin on the southeast corner of the Korean peninsula, and further northeast to the tip of Siberia, Chukotsuku.

Granites and Tectonics  Granite intrusions in the Korean peninsula are genetically related to the formation of the island arcs in Japan. Two pairs of island arcs are recognized in central Japan, the inner arc consisting of low-pressure Hida and high-pressure Sangun metamorphic belts, and the outer arc of low-pressure Ryoke-Abukuma and high-pressure Sanbagwa metamorphic belts. The former pair lies on the continental side, close to the Korean peninsula, whereas the latter pair is on the oceanic side. They are of Triassic to Permian and Cretaceous in age respectively. The lateral migration of granites in the Korean peninsula, Triassic to Permian granites in the north and Cretaceous granites in the south, is a counterpart reaction to the formation of the island arcs, respectively, during the plate collisions in Triassic to Permian and Cretaceous times.

When descending plates of basaltic oceanic crust undergo partial fusion, they produce calc-alkaline magmas which undergo fractional crystallization as they rise, emplacing granite intrusion at the continental margin. During the subduction of oceanic crust in the Triassic to Permian time, this fractional crystallization gave a rise to an emplacement of granites in the north of the peninsula, while an island arc was formed in Japan. As the island arcs retreated southwestwards, the latter granite intrusions derived from the second subduction were emplaced to the south of the peninsula during the Cretaceous time at the same time of the outer island arc formation.

On the other hand, the Jurassic granites which lie in the central region of the peninsula are genetically related to the development of the Ogcheon geosyncline. Magmas generated at the base of the geosyncline rose up along the anticlinal axes of the regional structure during the accompanying orogeny. These granites, which now occur...
as a long linear outcrops across the peninsula, run NE–SW direction (Sinian Direction). This synkinematic granite is genetically different from the Triassic-to-Permian and Cretaceous postkinematic granites of that were related to plate tectonics.

**GRANITES IN RELATION TO MINERALIZATION**

Burke (1960) attempted a correlation between granites and their associated mineralization in Korea. However, he failed to show a genetic correlation between the related granites and their ore deposits. For the correlation, Burke classified the granites into three different types, such as schistose, long, and round granites, and considered them related to high-, medium-, and low-temperature crystalline regimes, respectively. This classification fails in a petrogenetic correlation to ore genesis, i.e., the schistose and long granites are synkinematic with a lower temperature anatectic origin; the circular granites are of magmatic origin of higher temperature origin. These two different genetic types of granite and their related mineralization should be treated separately.

Lee (1982) examined the relationship between the granites and their related mineralization based on genetic consideration. Among 384 metallic mines, about 90% of the copper deposits, 85% of iron deposits, 75% of lead-zinc ore deposits, and 40% of tungsten-molybdenum ore deposits are considered genetically related to Bulgugsa granite of magmatic origin. On the other hand, about 30% of gold-silver ore deposits and 20% of tungsten-molybdenum ore deposits are related to Daebo granite of anatectic origin. The gold-silver ore deposits are genetically related mostly to the Precambrian Kokurian granites. None of the copper deposits are associated with the Daebo granite.

Recently, many works on the correlation of geochemistry and ore deposits in Korea have been published (Lee 1972, Lee et al. 1974, Jin 1980, Jin et al. 1982, and Tsusue et al. 1981). However, a clear correlation between mineralization and petrogenesis is needed to lead to an understanding of the nature of the ore deposits.

**Granites and Mineralization**

Genetically two different types of metallic mineralization are related to the granites of Korea. A juvenile mineral is related to Bulgugsa granite of magmatic origin, whereas Daebo granite of anatectic origin is characterized by assimilated mineralization. The terminology, juvenile and assimilated is from Smirnow (1968).

The juvenile ore deposits occur as vein types, replacement types and contact metasomatic deposits in and/or contact to the granite bodies, whereas the assimilated type of ore deposits is mostly concentrated at the margin of the granite owing to the redistribution and migration ore-forming components from pre-existence sources. Oxidation and hydration of the pre-existing minerals, such as reduction of hematite to magnetite and recrystallization of dolomite to tac, (which includes silicification), are also characteristic in the latter.

The juvenile type of ore deposits are characterized by differentiation processes, such as rock phases in Bulgugsa granite. In the copper deposits, gold-silver-bearing deposits are genetically associated with acidic phases, such as granite porphyry, whereas cobalt-bismuth-bearing deposits are closely related to the later rock phase of the granite or granodiorite. Masanites, thought to be the later phase of the Bulgugsa granite (Park 1975), are closely associated with magnetite deposits. This indicates that iron may be enriched towards the late stage of the differentiation. Jin (1981) indicates that FeO3 relative to MgO is enriched in later stages of the differentiation.

Most of the copper deposits are associated with the Bulgugsa granite or biotite granite. This can be explained that Fe+++ in the biotite ionic size, like Cu++ and Zn++, but this only applies to the ions in the silicates and as stated on the conclusions, there is often no correlation between Cu++ and Zn+++ in granite or biotite and the presence of mineralization. Studies of correlation between major oxides and trace elements of the Bulgugsa granite are reported by Lee (1982).

As a whole, the chemical correlation between the related granite and ore can be traced each other. However, it is uncertain whether this principle can be applied to all of the elements or not, as questioned by Bradshaw (1967) and Theodore et al. (1973). Hawley & Nichol (1961) states that only Co, Ni, Ag, and Pb in the pyrite, pyrrhotite, and chalcopyrite could be related to that of the related granites. Bradshaw (1967) studied Sn and Pb concentration in biotite and muscovite in connection with the corresponding mineralization.

Trace elements like Co, Cu, Zn, Pb, Mo, W, and Ni show a relatively high concentration, 1,7-5.8 times, in the mineralized related granites compared with that of barren granites in Korea. Chlorine concentrations in the mineralized Bulgugsa granite are 138 ppm, and in the mineralized granite, 87 ppm while fluorine concentrations are 87 ppm and 177 ppm, respectively. Jin et al. (1982) reported that the average content of chlorine and fluorine in Bulgugsa granite is 238 ppm and 340 ppm, respectively. The chlorine content in the biotite, hornblende, and apatite in the Bulgugsa granite are relatively high, whereas the biotite of the Daebo granite is essentially chlorine free (Tsuasue et al. 1981).

**CONCLUSIONS**

Granite intrusion, tectonism, and mineralization are genetically counterpart reactions of an identical energy source. Genetically two types of granite occur in the Korean peninsula, i.e., granites of magmatic in origin, Songrim and Bulgugsa granites, derived from a compressional plate boundary by fractional crystallization of subducted oceanic crust and those of synkinematic in origin (Daebo granite) derived from an intracontinental geosynclinal basin by anatexis.

The lateral migration of the magmatic granites, Triassic-to-Permian Songrim granite in the north and Cretaceous Bulgugsa granite in the south is a counterpart reaction to the formation of the island arcs in Japan, respectively, during the continent and oceanic plate collisions in Triassic to Permian and Cretaceous times.

The petrographic, petrogenetic, and petrochemical studies between the magmatic granite or Bulgugsa granite and the anatectic granite (Daebo granite) are quite distinct. A wider range of rock phases and grain size, normal zoning of plagioclase, presence of plerite, lower initial ratios of Sr87/Sr86 (0.704-0.707), normal magmatic trend I-type and magnetite series of the granite are characteristics to the Bulgugsa granite, whereas a more or less homogeneity of rock phases and grain size,
presence of microcline and commonly of myrmekite and no perthite, higher initial ratios of Sr$^{87}$/Sr$^{86}$ (0.7104-0.717), relatively high concentrations of aluminum and potassium oxides, and a more or less S-type and ilmenite series of the granite are the characteristic to Daebo granite.

Genetically two types of metallic mineralization, i.e., those related to magmatic granite (juvenile ore deposits) and assimilated ore deposits associated with anatectic granite were distinguished. The former type of ore deposits occur as vein and replacement types, and contact metasomatic ore deposits, whereas the latter type of ore deposits are mostly concentrated at the margin of the granite owing to the redistribution and migration of recrystallized ore minerals from pre-existing sources. Oxidation and hydration of the pre-existing minerals are also a characteristic in the latter.

The juvenile type of ore deposits are characterized by differentiation phases such as rock phases in the granite.

Gold-silver bearing copper deposits are closely related to acidic phases or granite porphyry, whereas cobalt-bismuth-bearing copper deposits are closely associated with the later rock phase of granodiorite.

Bulgusa granite contains a relatively high chlorine content, whereas Daebo granite is essentially chlorine-free. This suggests that most hydrothermal base metal deposits are closely related to the juvenile ore deposits. Trace elements like Co, Sn, Zn, Pb, Mo, W, and Ni show a relatively high concentration in the granites compared with that of barren granites. Most of the copper deposits are associated with Bulgusa granite of biotite phase which can be explained by the geochemical preference for Cu$^2+$, Zn$^{2+}$, etc., to be easily substituted for Fe$^{2+}$ in the biotite of the granite. Magnetite deposits which are closely associated with the later phase of Bulgusa granite or Masanites, indicate that iron may be enriched towards the late stage of the differentiation.

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