The granitoid series in the Circum-Pacific Phanerozoic Orogenic Belts

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Recent measurement on magnetic susceptibility and the study of opaque minerals of granitoids (Ishihara , 1979; Tainosho et al., 1989; Whalen and Chappell 1988; Gastil et al., 1990; Bateman et al., 1991), have clarified the regional distribution of the oxidized, magnetite-series and reduced, ilmenite-series granitoids in the Circum-Pacific orogenic belts. The distribution patterns and their geneses are briefly reviewed here, based on regional identification of the two series of granitoids.

Jurassic-Quaternary granitic rocks in the Japanese Islands, occur in several narrow (80-100 km) belts in different tectonic units. A paired belt of fore-arc ilmenite-series (Sanyo-Ryoke Belt) and back-arc magnetite-series (Sanin Belt) granitoids are a basic pattern of the largest granitic unit of the late Cretaceous-Paleogene Southwest Inner Zone batholith. The whole batholith is calculated to consist of 67 % ilmenite series and 33 % magnetite-series granitoids, based on the measurement of magnetic susceptibility (n=2,030). The paired belt is also seen in the Miocene-Quaternary magmatic region.

On the contrary to the Japanese Islands situation, granitic magmatism occurred in much wider portions of continental regions of Far East Asia (300-500 km). Jurassic-Paleogene granitoids are known in the Sikhote Alin and Okhotsk regions of the Russian Far East. Here ilmenite-series rocks are predominant in the Mesozoic granitic terranes, and magnetite-series rocks prevail only during the final, late Cretaceous-Paleogene stage, of magmatic activity. Thus, over the whole region, ilmenite-series granitoids appear to be dominant, whereas magnetite-series rocks are limited to the coastal area.

In the Jurassic-Cretaceous granitoids of the southern Korean Peninsula (Jwa, 1998), the magnetic susceptibility tends to decrease from the Gyeong- sang Basin northward but increase again in North Korea. In southern China, the Early Yanshanian Jurassic granitoids consist of 74 % ilmenite series and the Late Yanshanian Cretaceous rocks of 68 %. Late Yanshanian granitoids of the Fujian coastal volcano-plutonic belt, which are southwestern extension of the Gyeongsang Basin granitoids in South Korea, are strongly magnetic; oxygen fugacity of the granitoids must have been high because of hematitization reported on the rock-forming magnetite of the granitoids. Magnetite-series granitoids occur further inland along the Yangtze folded belt. These granitoids are alkaline and thus were likely to have a high oxygen fugacity.

The regional pattern of the coastal and back-arc magnetite-series granitoids facing the marginal basins in the western Pacific led Ishihara (1981) to propose a genetic model related to the back-arc spreading. In the subduction-related continental margin and island-arc environment, mantle-derived magmas that are oxidized with high $Fe3+/Fe2+$ ratios, ascended without any crustal contamination in the back-arc basins due to the extensional tectonic setting of the marginal basins. In contrast, along the compressional tectonic setting of the arc front, the magmas may have been modified while passing through the continental crust, by assimilation of crustal material, which contain various quantities of C-bearing sediments. Thus, the reduced ilmenite-series magmas were formed.

In the Caledonian granitoids of the Lachlan Fold Belt, southeastern Australia, magnetic susceptibility measurement by Tainosho et al. (1988) indicates that all the S type and 45 % of the I type granitoids belong to the ilmenite-series, whereas the A types belong to the ilmenite series. Overall, the measurements imply 67 % ilmenite-series and 33 % magnetite-series rocks at surface. Magnetic susceptibilities of the magnetite-bearing I-type granitoids in Australia are lower than the average values of typical magnetite-series granitoids of the Sanin Belt in Japan. The Lachlan granitoids seem to be more reduced than the Japanese granitoids.

In contrast to the western Pacific rim, the Cordilleran granitoids of North and South America are characterized by narrow granitic belts with different distribution patterns. A *magnetic study in northern Chile indicates that the late Paleozoic granitoids are* composed of both magnetite- and ilmenite-series, but the Jurassic-Paleogene granitoids are strongly magnetite bearing (98 % magnetite series). These rocks have low magnetic susceptibilities in the west and high values in the east. In the Peru-Bolivian transect, the coastal batholith is I-type magnetite series but the inner Sn-mineralized granitic belt is I-type ilmenite series.

In the Peninsular Range batholith, magnetic susceptibility of these plutonic rocks are high in the west and low in the east. Accordingly, Gastil et al. (1990) drew the magnetite-ilmenite boundary in the middle of the batholith where the coastal gabbroids and tonalites are magnetite bearing and meta-aluminous, and the eastern granitoids are magnetite free and peraluminous. The regional variations are also shown in the initial Sr ratio of 0.7025 in the west and 0.708 in the east, and oxygen isotopic ratio of 6.0 permil d18O to the west and 13.0 permil to the east (Silver et al., 1979). These isotopic data indicate that the plutonic rocks originated from deep mafic material and supracrustal sedimentary rocks plus some hydrothermally altered oceanic crust. Granitic plutons located east of the main batholith again revert to magnetite series. Gastil et al. (1990) proposed a depth-dependent model for the generation of the three zones of magmas along a subduction plane.

In the Sierra Nevada batholith of California, magnetic susceptibilities of the granitoids are generally low in the western foothills, and high to the east. As a whole, the magnetite-/ilmenite-series ratio is 73/27. In the western foothill area, ilmenite series are common around the Coarsegold roof pendant. Based on d34SCDT values of the whole rock sulfur, Ishihara and Sasaki (1989) suggested that granitic magmas of the Sierra Nevada batholith were essentially I-type magnetite-series, and the ilmenite series in the western foothills were formed by local reduction caused by reduced species, such as of carbon and sulfur assimilated from the wall rocks. Bateman et al. (1991) argued that, in the N-S transect work of the Coarsegold roof pendant, the initial Sr ratios do not correlate with the magnetic susceptibility values, and they proposed an alternative, deep-seated reduced source of the ilmenite-series granitoids.

Available data indicate that the regional distribution patterns of the magnetite- and ilmenite-series granitoids differ on both sides of the Pacific Ocean. Magnetite-series granitoids tend to occur along the continental margin of the western Pacific, but ilmenite-series rocks may prevail in the Cordilleran continental margin. These regional patterns reflect the intrinsic redox state of the granitic magmas; several models have been proposed for geneses of the differing redox state. The redox-status of the Circum-Pacific granitoids is still poorly known in many other regions, and we need further field studies to improve our understanding of the two series of granitoids and also genetic examination of the granitic magmatism.