Zonal distribution of Cretaceous to Tertiary granitic rocks in Southwest Japan

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Introduction

In Japan, Jurassic is the age of accretion movement. It is considered that the big accretionary blocks were added to Japanese Islands possibly from south to north. Igneous activity in this age is recorded only in thin intercalations of intermediate to acid tuff within the sedimentary formations. On the other hand, in Cretaceous time, violent magmatism began, especially prominent in Southwest Japan.

This paper is the summarized result on the structural and petrochemical investigations on the Cretaceous to Paleogene igneous rocks from the Inner Side of Southwest Japan.

Outline of igneous activity

Southwest Japan is separated by the Median Tectonic Line into two sides, Inner Side and Outer Side as seen in Fig. 1. In the Outer Side, relatively small granitic masses largely of Miocene age are distributed sporadically from northeast to southwest along the Pacific coast. They are found also in the island areas on the northwestern side of the Inner Side, as small stocks and dikes. These granitic rocks are sometimes accompanied by the acid to intermediate volcanic rocks.

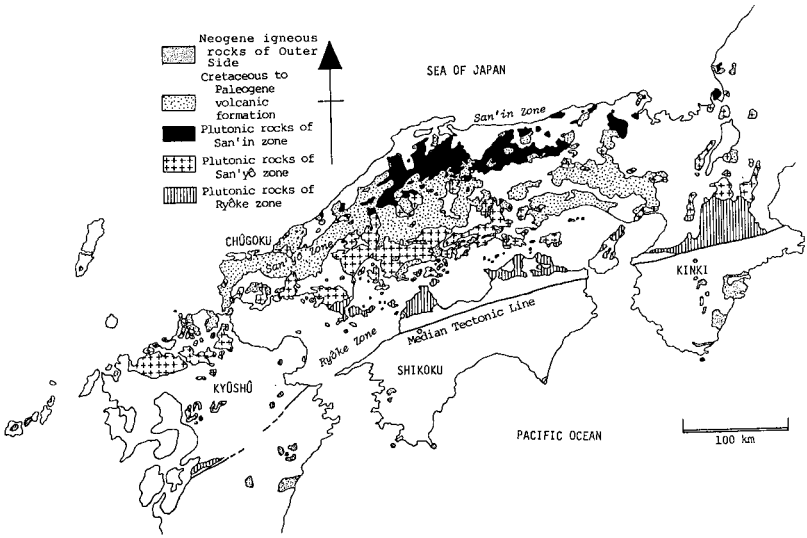

Fig. 1. Distribution of Cretaceous to Neogene granitic and related volcanic rocks from Southwest Japan.

Comparing to the Outer Side, the igneous activity is highly extensive in the Inner Side. The component rocks of this side are divided into three zones extending from ENE to WSW, Ryoke, San'yo and San'in from south to north (Fig. 1).

Ryoke Zone is the amphibolite-facies low pressure-type regional metamorphic terrain and composed mainly of strongly to weakly foliated granitic rocks, lacking volcanic equivalents. No great difference in radioactive age can be recognized between the granites from Ryoke Zone and those from San'yo Zone, but the Ryoke granites are always intruded by the San'yo granites at many outcrops without exception.

The main components of the San'yo Zone are broadly distributed rhyolitic to andesitic volcanic rocks and coarse- to medium-grained granitic to granodioritic rocks. The plutonic rocks constitute a large

discordant batholith named Chugoku Batholith, around southern (Setouchi) area. On the other hand, the volcanic rocks of this zone constitute the cauldron-like basin structure in the earlier stage, elongated form of cauldron structure in the middle stage, and large volcano-tectonic depression structure bounded by NE-SW to ENE-WSW faults with basement rocks in the later stage. Radioactive ages are about 80-100 Ma.

San'in Zone is composed chiefly of andesitic to dacitic volcanic rocks and granodioritic to granitic plutonic rocks characterized by several shallow facies features. In the earlier stage, the plutonic rocks constitute the characteristic cauldron structure with annular outline. The NE-SW trend along the Sea of Japan together with NW-SE one is evident in the distribution of these cauldrons (Fig. 3). Radioactive ages of the component rocks are about 25 to 70 Ma, indicating Oligocene to latest Cretaceous.

Fig. 2 shows the succession of the igneous activity in West Chugoku, Southwest Japan. This represents also the age relations among three zones, Ryoke, San'yo and San'in. Fig. 3 is the summarized volcano-

Table 1. Rock type, mode of occurrence and radioactive age of component igneous rocks in three zones of Inner Side of Southwest Japan.

Zone	Plutonic rocks	Volcanic rocks	Characteristic mode of occurrence	Radioactive age (Ma)
San'in	Shallow facies GD-Gr-QD	An-Rh	Cauldron with annular outline Stock, dike, ring dike, discordant batholith	25-70
San'yo	Coarse-grained Gr-GD-(QD)	Rh-An	Volcano-tectonic depression, cauldron with elongated form Discordant batholith, stock, dike, ring dike	80-100
Ryoke	Strongly to weakly foliated GD-Gr	Lacking	Accompanied by low-pressure-type regional metamorphic rocks Concordant batholith, stock	85-100 (always intruded by San'yo pl.)

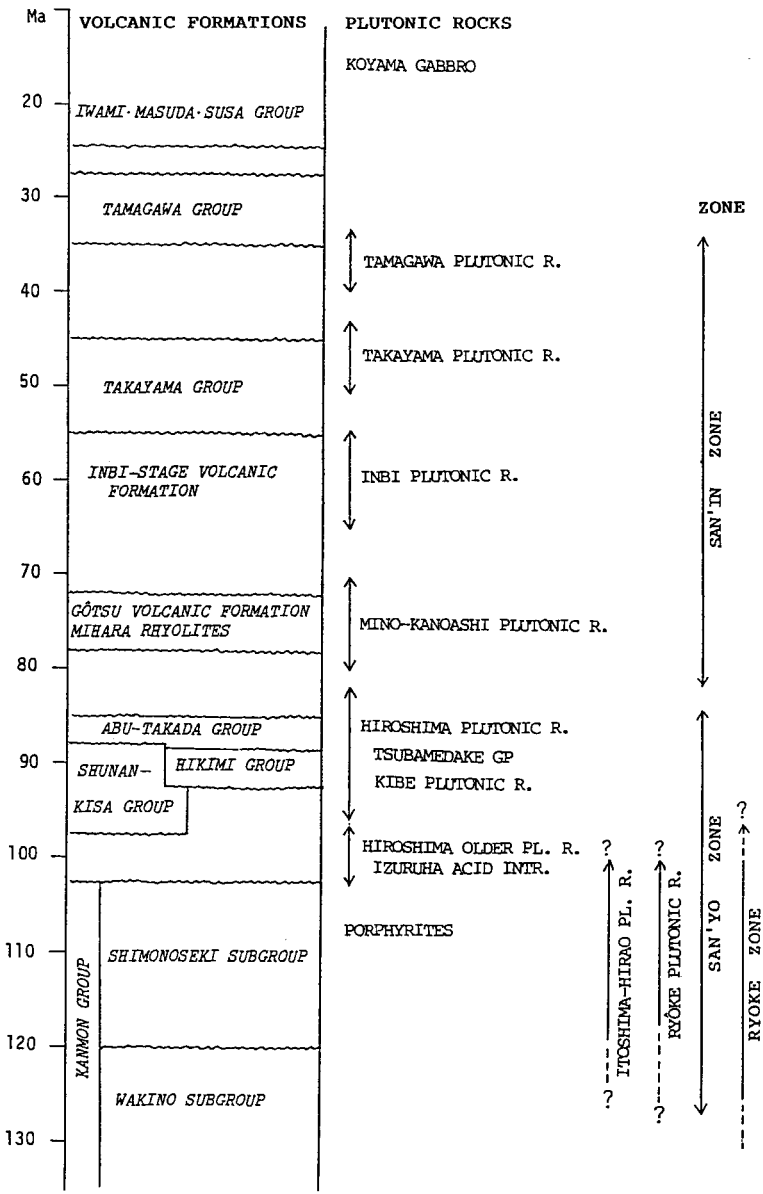

Fig. 2. Showing the succession of Cretaceous to Miocene volcanism and related plutonism.

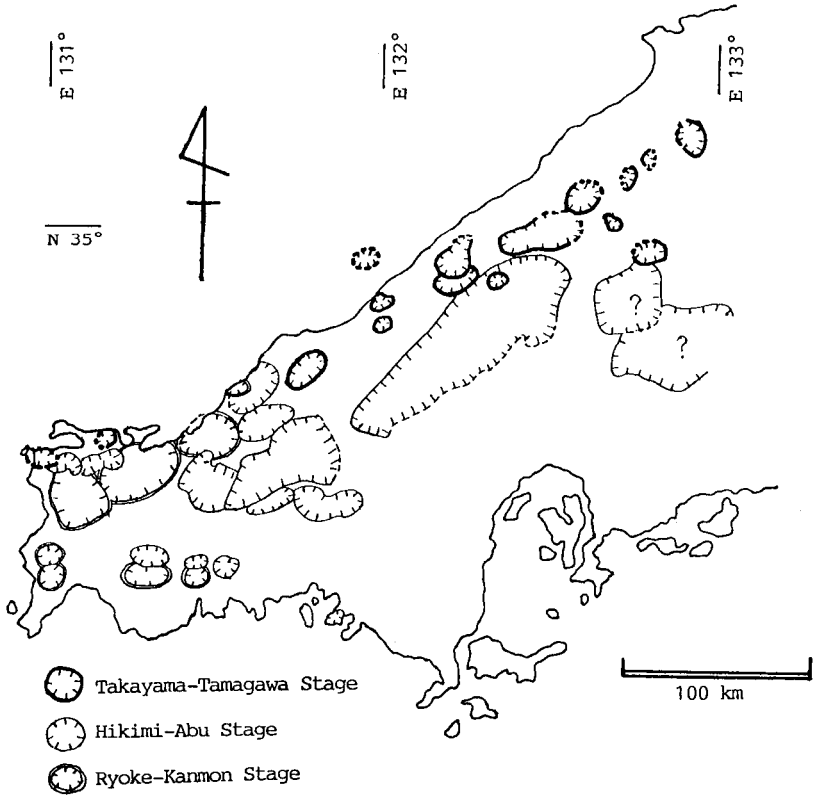

Fig. 3. Distribution of Cretaceous to Paleogene cauldrons and cauldron-like structures in West Chugoku, Southwest Japan.

tectonic map of the Cretaceous to Paleogene volcanic rocks in West Chugoku, Southwest Japan, in which the cauldron and cauldron-like structures are shown together by the annular to elliptical outline. The divergence of the form and scale of these structures among different stages of igneous activity is also clearly seen in this map.

Petrochemical features of igneous rocks

The variation of mode of occurrence with age in the igneous rocks from Southwest Japan is closely associated with the variation in petrochemistry. In major elements, the most prominent is the variation of K_2O/Na_2O and Fe_2O_3/FeO ratios. Besides this, relatively small variation is recognized also in FeOtotal/(FeO_{total}+MgO) and normative C/Wo ratios (Murakami, 1985).

Generally, the K_2O/Na_2O ratio is highest in the earlier stage of the San'yo Zone, and lowest in the later stage of the San'in Zone, although the ratio is intermediate in the Ryoke granites. Consequently, it can be said that the K_2O/Na_2O ratio tends to decrease continuously from Cretaceous to Paleogene in the San'yo and San'in Zones.

The Fe_2O_3/FeO ratio is fairly high in the earlier to middle stage of the San'yo Zone, wheras it becomes lower in the later stage of the San' yo Zone and also in the Ryoke granites. During Paleogene, it increased gradually with age and attained to the highest value in the later stage of the San'in Zone. The variation of Fe_2O_3/FeO ratio is intimately related to the magnetic susceptibility. This value is highest in the later stage of the San'in Zone, and lowest in the later stage of the San'yo Zone. In the middle stage of the San'yo Zone, this value is intermediate, as already suggested by Ishihara (1979), and Imaoka and Nakashima (1983).

In minor elements, the variation of Rb content is characteristic. It tends to decrease continuously from Cretaceous to Oligocene. Similar tendency is also recognized in the REE content, especially in LREE content (Murakami,1985).

These mean that the igneous rocks in the later stage of the San'in Zone are highly poor in lithophile elements, comparing to those in other

stages.

The variation of chemistry of igneous rocks is associated with that of isotopic data such as $^{87}Sr/^{86}Sr$ and $^{18}O/^{16}O$ (Murakami,1979). Fig. 4 illustrates the relation between Sr isotopic initial ratio and age of the Cretaceous to Paleogene igneous rocks from Inner Side of Southwest Japan. As seen in this figure, the ratio tends to become higher with time during Cretaceous. In Paleogene, however, this ratio lowers rapidly.

This may mean that the source of magma became shallower with age or the contamination of magma by crustal rocks increased with age during Cretaceous time. In Paleogene, however, the source of magma became deeper, and the contamination of magma by crustal rocks decreased.

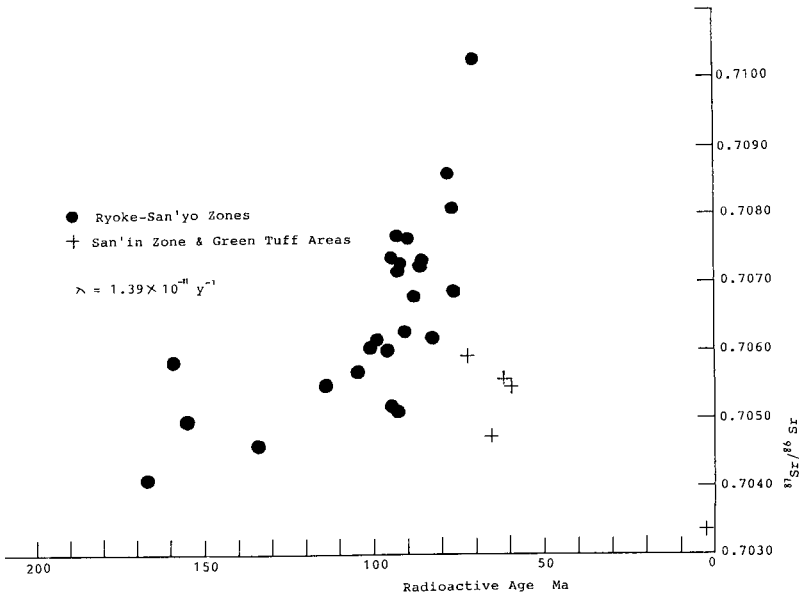

Fig. 4. Variation of strotium isotopic initial ratios with age in Cretaceous to Tertiary igneous rocks from Southwest Japan.

Discussion and conclusion

Above described data suggest the change of magma and related tectonic movement with change of age from Cretaceous to Paleogene.

In the Ryoke Zone, we consider that the source of magma was shallow and contamination by water derived from the sedimentary wall rocks was fairly high, because this zone lacks volcanic rocks and Al_2O_3 content of component rocks is predominantly high. In addition to this, the component granites of this zone are poor in constituent amphibole content, comparing to the granitic rocks in San'yo and San'in Zones (Murakami, 1985). Consequently, in this zone, the magma might have been generated at comparatively shallow level in the crust under the regional compressional force from south to north.

At almost the same age, San'yo Zone was subsided under extensional condition. After the deposition of thick non-marine sediments, this zone was changed to the site of violent volcanism characterized by the eruption of andesitic to dacitic volcanics. The magma is considered to have been derived from deeper level in the crust or upper mantle (Murakami, 1985), as schematically shown in Fig. 6 (Kanmon Stage).

In the middle stage of the San'yo Zone, Southwest Japan began to rise, continuing to rise till the later stage. Many large arch- or dome-like structures with an ENE-WSW to NE-SW extension were formed.

Following this, voluminous amounts of acid to intermediate magma was generated within the crust and migrated upwards along the ENE-WSW to NE-SW extensional fractures. Fairly large parts of them were extruded on the surface as pyroclastic flow to constitute the volcano-tectonic depression structures, although many small rhyolite lava domes were also formed. The rest of the magma was solidified at relatively shallow depth to form the batholithic masses and other

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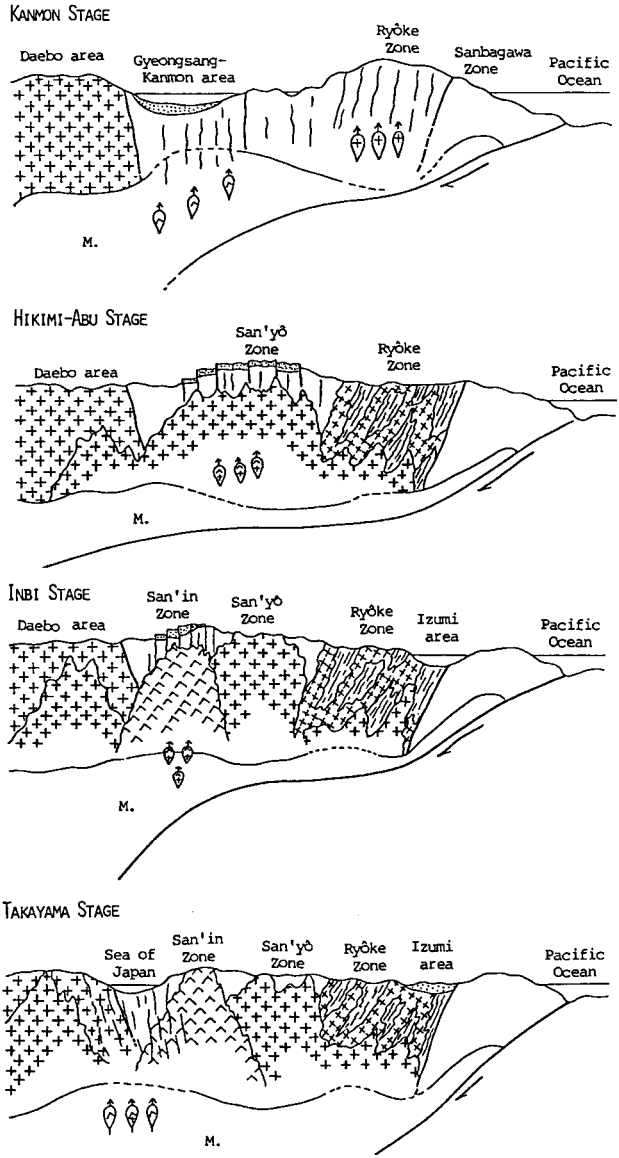

Fig. 5. Schematic profile showing the variation of modal occurrence of igneous rocks, source of magma and plate boundary in late Cretaceous to Eocene igneous activity of Southwest Japan.

stock-like masses (Fig. 5: Hikimi-Abu Stage).

In the earlier stage of the San'in Zone (Paleocene), magma was generated at deeper level than in the later stage of the San'yo Zone. The magma moved toward shallower level, leading to the extrusion of the thick pyroclastic flow deposits. The rest of the magma was emplaced as batholithic intrusives. The upheaval movement was continued till this stage, but the San'yo and Ryoke Zones have already suffered denudation (Fig. 5: Inbi Stage).

In the later stage of the San'in Zone (Eocene to Oligocene), many deep faults of NE-SW trending together with NW-SE one cut the crust to form the graben structure. Intermediate to acid magma was derived from deep source, possibly from upper mantle as deduced from the Sr isotopic initial ratios and so on. A large part of the magma was poured out as pyroclastic flow and lava flow. Many cauldron and cauldron-like structures distinguished by circular to elliptical outline were formed. This was followed by the subsidence in the area of the present Sea of Japan (Fig. 5: Takayama Stage).

We have no reasonable interpretation to explain the change of source of magma and related crustal movements during Cretaceous to Paleogene in Southwest Japan. However, there are some attempts to solve this problem. Uyeda and Miyashiro (1974) tried to interprete the unusually wide zonal distribution of late Mesozoic to Paleogene igneous rocks by postulating the very low dip of the underthrusting slab (hot spot) beneath the continental plate ranging from Japan to North China. Recently, Kinoshita and Ito (1988) considered that the heat source was caused by the subducted Kula-Pacific ridge. Fig. 5 represents one model modifying these plate theories, in which the dip of the descending slab varies with age from Cretaceous to Eocene. I think the deep faults and fractures in the later stage of the San'in Zone might have been connected with the opening of Japan Sea as suggested by Lallemond and

Jolivet (1986).

These considerations are thought to be important for clarifying the deep geologic structure of Southwest Japan.

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