Unzen Volcano : the 1900-1992 eruption

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5. Geological and Tectonic Setting of Unzen Volcano

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Introduction

Kyushu Island occupies a geologically important position in the Japanese Islands, because it is located just at the intersection between the Honshu and Ryukyu Arcs, both of which represent typical volcanic arcs in terms of plate tectonics (Fig.5-1). Kyushu Island is, therefore, characterized by the most spectacular volcanic activity in the Japanese Islands, as shown by Unzen Volcano, Aso Volcano and Sakurajima Volcano.

Among these very active volcanoes, Unzen Volcano had been dormant for 198 years until sudden violent eruption took place in the fall of 1990. Aso and Sakurajima Volcanoes have been vigorously smoking for many years.

It is interesting to point out that Unzen Volcano is located at the western tip of the Central Kyushu Rift Valley or Beppu-Shimabara Graben, which divides Kyushu Island into northern and southern blocks (Figs.5-1,5-2). Also noteworthy is that Aso Volcano, with the world's largest caldera, is at the center of the rift from where the Kirishima volcanic belt seems to extend southwards through Sakurajima Volcano to the inner belt of the Ryukyu Arc. In parallel with the Ryukyu Arc, an active rifting zone called the Okinawa Trough, seems to be connected with the Central Kyushu Rift Valley. Therefore, Unzen Volcano provides us with copious information not only on late Cenozoic volcanism but also on tectonics.

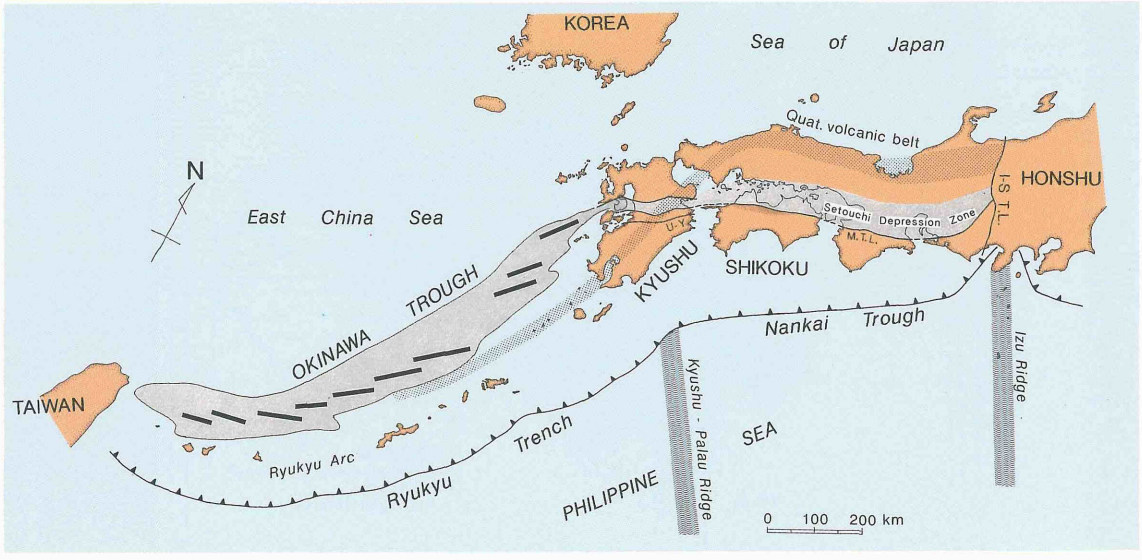

Fig. 5-1. Map showing the general geological feature of Southwest Japan.
I-S T. L.: Itoigawa-Shizuoka Tectonic Line
M. T. L.: Median Tectonic Line
U-Y: Usuki-Yatsushiro Tectonic Line
Thick lines in the Okinawa Trough indicate the rifting axis.

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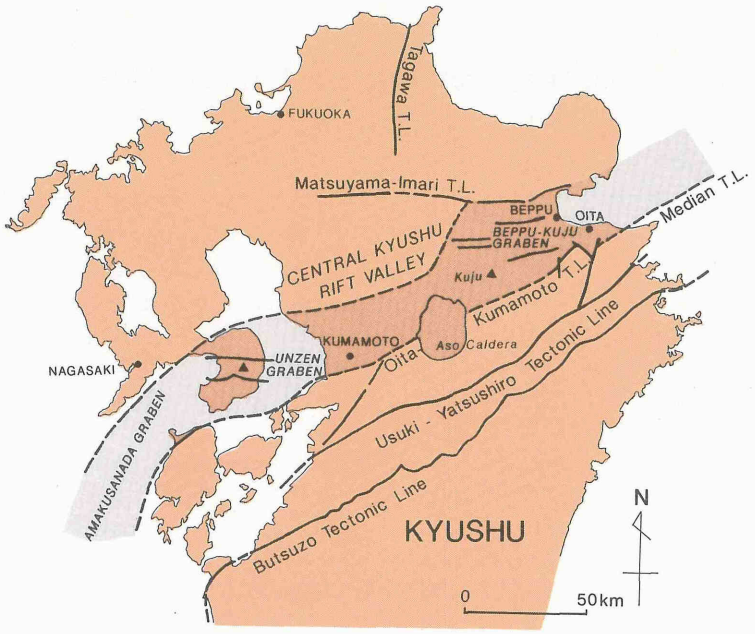

Fig. 5-2. Map showing the Central Kyushu Rift Valley (shaded) and main tectonic structures.

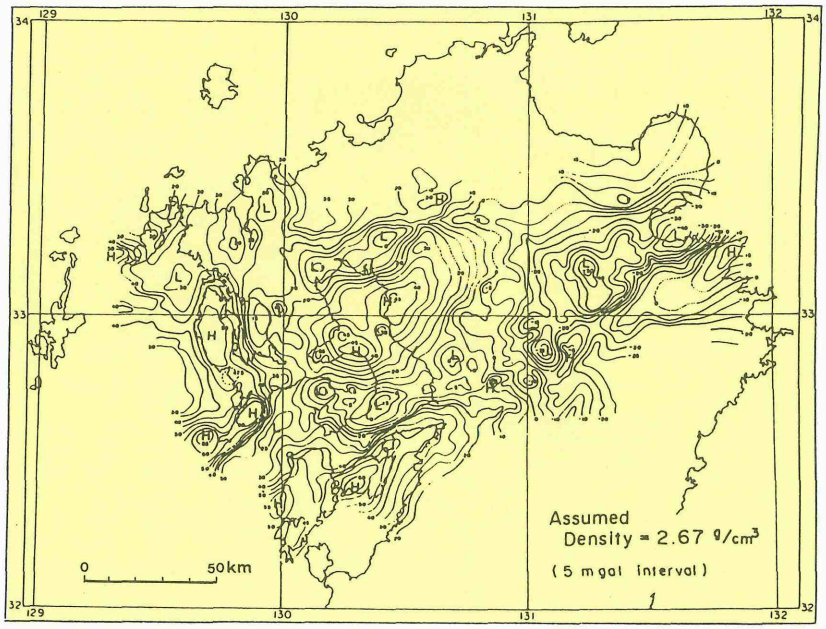

Fig. 5-3. Bouguer anomaly map in central Kyushu (after Kubotera et al., 1976).

Central Kyushu Rift Valley and Unzen Volcano

The Beppu-Shimabara Graben was proposed for the first time by Matsumoto (1979) as a large depression structure running east-west in central Kyushu, based on such geological features as the presence of active faults, distributions of the pre-Miocene and Quaternary rocks, depth of pre-Miocene basement rocks, gravity anomaly, characteristics of Cenozoic volcanism, and so on.

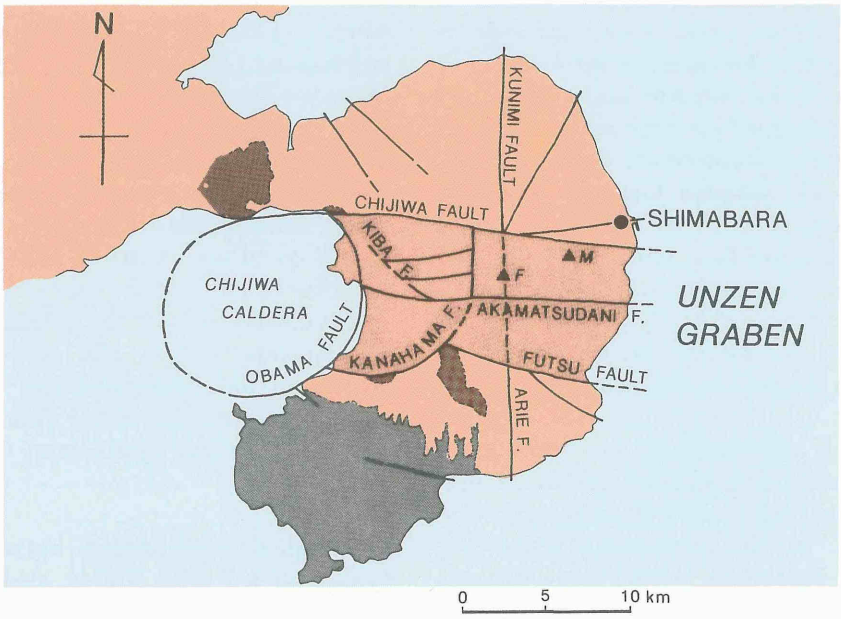

Fig. 5-4. Map of the Shimabara Peninsula showing the Unzen Graben (light-shaded) and main faults (compiled from Ohta, 1987).
Dark shaded parts indicate basement rocks. F : Fugendake, M : Mayuyama.

Okada (1991) called the Beppu-Simabara Graben the Central Kyushu Rift Valley.

This depression structure of about 20 to 30 km in width extends over 200 km in NNE-SSW direction, from Beppu to the east to the Shimabara Peninsula to the west. This structure, according to Matsumoto (1984), is divided into four major segments: Beppu-Kuju, Aso, Unzen, and Amakusanada Grabens (Fig.5-2).

Beppu-Kuju Graben: The Beppu-Kuju Graben is well defined with three faults: Oita-Kumamoto Tectonic Line, Matsuyama-Imari Tectonic Line and Tagawa Fault. This depression is also well recognizable on the Bouguer anomaly map (Fig.5-3). The Beppu-Kuju Graben is bounded by a very clear right lateral strike-slip fault on the south, called the Oita-Kumamoto Tectonic Line. This tectonic line seems to be an extension of the Median Tectonic Line on Shikoku Island, which divides Southwest Japan into the Inner Zone and Outer Zone. On the north, however, the Matsuyama-Imari Tectonic Line is not so clearly defined, except for the Minoh Fault with an E-W trend to the west and minor grabens of the Beppu Bay Graben and Yufuin Graben to the east (Fig.5-2).

The cross-section of the Beppu-Kuju Graben shows rather a half-graben structure with much deeper depression along the Oita-Kumamoto Tectonic Line. It is interesting to note that low gravity anomaly areas occupy a rectangular area of the southern part of the Graben, in particular, very low gravity anomaly spots along the Oita-Kumamoto Tectonic Line.

Such a depression structure associated with a low gravity anomaly area may be ascribed mainly to a pull-apart process caused by right-lateral strike-slip faulting along the Median Tectonic Line taken place in the pre-Miocene basement rocks (Kamata,1991). This depression area is also characterized by huge amounts of volcanic materials called the Hohi volcanic rocks which are composed of rhyolite, dacite, hornblende andesite, pyroxene andesite, and basalt. The Hohi volcanic activity started about 5 Ma B.P.

Unzen Graben: Shimabara Peninsula is topographically demarcated by some tensional faults running E-W, among which the Chijiwa Fault to the north and the Kanahama and Futsu Faults to the south constitute the central depression structure. This E-W depression is called the Unzen Graben (Ohta,1973; Fig. 5-4).

The Unzen Graben, about 7 to 9 km wide, is connected with the Aso-Kumamoto Graben to the east and with the Amakusanada Graben to the west. At the junction between the Unzen Graben and the Amakusanada Graben, there seems to be the Chijiwa Caldera, which is indicated topographically by the half-circular coastal line of Chijiwa Bay. Ohta (1987) insisted that this circular topographic feature should have been originated from a volcanic caldera, because he successfully postulated geologically and geophysically a magma chamber beneath Chijiwa Bay.

The vertical displacement of the Unzen Graben is estimated as about 200 m (Ohta, 1987).

The basement rocks are well exposed in the southern part of the peninsula, which are constituted by Paleogene marine shale deposits (Sakasegawa Formation), shallow marine to deltaic and fluvial deposits (Kuchinotsu Formation) of Early Pleistocene, and Middle Pleistocene pyroxene andesite and basalt. The Unzen volcanic edifices have been mainly constructed in the Unzen Graben since Middle Pleistocene, which are composed chiefly of hornblende andesite and dacite lavas and pyroclastics.

Geological relationship between the Central Kyushu Rift Valley and the Okinawa Trough

Extensive ship-board surveys on the continental shelf area between Taiwan and Kyushu by Emery and his co-workers (Emery et al., 1969; Wageman et al., 1970) have revealed plenty of geological information on bathymetry, seismic profiles and magnetic anomalies of the sea floor. They discriminated ridges, troughs, basins, and trenches as major structural patterns, indicating that many of these structures are well traceable continuously from Taiwan to Southwest Japan. One of them is the Okinawa Trough. Emery et al. (1969) clearly showed that the Okinawa Trough is connected with the Amakusa Folded Zone corresponding to the Central Kyushu Rift Valley. This notion has been developed by many later workers (Nash,1979; Kimura, 1983; Tada, 1984; Letouzey and Kimura, 1986).

Herman et al. (1978), Lee et al. (1980), Kimura (1983, 1985), Tada (1984) and Letouzey and Kimura (1986) explained on the origin of the Okinawa Trough that it is a back-arc basin of the Ryukyu Arc generated by rifting and spreading of continental margin since Miocene time. Kimura(1983,1985) and Letouzey and Kimura (1986) showed that rifting systems related to the formation of the Okinawa Trough are arranged en echelon and that the northernmost spreading axis is connected with the Unzen Graben (Fig.5-1). Katsura (1989) also showed submarine structural lineament patterns supporting the structural continuity of the Okinawa Trough to the Amakusanada and Unzen Grabens.

Geological relationship between the Central Kyushu Rift Valley and the Setouchi Inland Sea area

The half-graben depression called the Beppu-Kuju Graben in East Kyushu, as stated in the preceding section, is filled up with large amounts of andesitic pyroclastics and lava flows and lacustrine deposits mainly represented by the Miocene Kusu Formation and Lower Pleistocene Oita Group. This depression area is interpreted to be connected with the Setouchi Depression Zone, which extends to the Ise Bay area in central Honshu (Shuto, 1970; Fig.5-1). The Setouchi Depression Zone in the present Seto Inland Sea area, is characterized by the late Early-early Middle Miocene First Setouchi Group (marine phase) and the Pliocene Second Setouchi Group (non-marine phase). The latter is further characterized by the Setouchi volcanics represented by high magnesian andesite (12 Ma).

Recent geophysical surveys in the Beppu Bay area have revealed that the south border of the Beppu-Kuju Graben is expressed with a sharp strike-slip fault (Median Tectonics Line) separating the Sanbagawa rocks from the Ryoke rocks. On the contrary, the northern border of the Graben is characterized by stepwise minor listric faults with E-W trend.

Geological relationship between the Central Kyushu Rift Valley and the East China Sea continental shelf area

The general structural feature of the Central Kyushu Rift Valley seems to be closely related to the Oita-Kumamoto Tectonic Line or Median Tectonic Line and Usuki-Yatsushiro Tectonic Line, all of which run roughly in parallel with each other. Among them, the Median Tectonic Line is dated back to Early Cretaceous in origin (Ichikawa, 1980). Therefore, the Median Tectonic Line and its related faults gave intense tectonic stress to the basement rocks of the Central Kyushu Rift Valley.

It is interesting to note that always on the north side of the Median Tectonic Line are developed Early Cretaceous to Late Cretaceous sedimentary basins along the tectonic line. The depocenters of the sedimentary basins migrated eastwards and got younger to the same direction. These basins are characterized by typical half-graben structure (Tanaka, 1980).

Sedimentary basins with a half-graben structure are also characteristic of Cretaceous basins on the continental shelf area of the East China Sea (Yu, 1991) as well as in the Korean Peninsula (Lee and Paik, 1990). Therefore, basin-formation process at the eastern margin of the Asian continent controlled the central Kyushu area as well.

Origin of the Central Kyushu Rift Valley

Systematic geodetic surveys of the Central Kyushu area have revealed that the crust is spreading in the N-S direction at the spreading rate of 1.4 cm/year and at the subsidence rate of 2.5 mm/year during the past 90 years and the Central Kyushu Rift Valley plays a role of the spreading axis (Tada, 1984).

The structural continuity and rifting nature between the Central Kyushu Rift Valley and the Okinawa Trough have been discussed by many workers as stated elsewhere, even if the start of rifting was different between them. This rifting structure may be ascribed in origin to oblique subduction of the Philippine Sea Plate which has been active since 15 Ma (Seno and Maruyama, 1984).

Kimura (1985) and Letouzey and Kimura (1986) suggested a tectonic link between the collision of Taiwan and the opening of the Okinawa Trough owing to the activated subduction of the Philippine Sea Plate in the early Miocene time. Earlier opening of the Trough took place in the southern and central parts of the Trough and later in the northern part. Miki et al. (1990) clarified from the paleomagnetic study of the south Ryukyu Arc that the southern part rotated counterclock-wise by 19° with respect to Eurasia during the past 10 Ma. This rotation was caused by a wedge-shaped back-arc opening of the southern part of the Okinawa Trough.

The opening of the Sea of Japan around 15 Ma (Otofuji and Matsuda, 1987) and the collision of the Kyushu-Palau Ridge at the Late Miocene time (Kodama et al., 1991) caused the oblique subduction of the Philippine Sea Plate beneath the Southwest Japan Arc, which activated and accelerated right-lateral strike-slip faults such as the Median Tectonic Line, Oita-Kumamoto Tectonic Line, Matsuyama-Imari Tectonic Line, and so forth. Such strike-slip faults may have produced pull-apart basins represented by the Beppu-Kuju Graben and others.

Kamata and Kodama (1992) insisted that this right-lateral tectonic movement had become most active around 6 Ma, when the Hohi volcanism was also active.