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Imaging of V_p, V_s, and Poisson's ratio anomalies beneath Kyushu, southwest Japan: Implications for volcanism and forearc mantle wedge serpentinization

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Abstract

We determine detailed 3-D V_p and V_s structures of the crust and uppermost mantle beneath the Kyushu Island, southwest Japan, using a large number of arrival times from local earthquakes. From the obtained V_p and V_s models, we further calculate Poisson's ratio images beneath the study area. By using this large data set, we successfully image the 3-D seismic velocity and Poisson's ratio structures beneath Kyushu down to a depth of 150 km with a more reliable spatial resolution than previous studies. Our results show very clear low V_p and low V_s anomalies in the crust and uppermost mantle beneath the northern volcanoes, such as Abu, Kujyu and Unzen. Low-velocity anomalies are seen in the mantle beneath most other volcanoes. In contrast, there are no significant low-velocity anomalies in the crust or in the upper mantle between Aso and Kirishima. The subducting Philippine Sea slab is imaged generally as a high-velocity anomaly down to a depth of 150 km with some patches of normal to low seismic wave velocities. The Poisson's ratio is almost normal beneath most volcanoes. The crustal seismicity is distributed in both the high- and low-velocity zones, but most distinctly in the low Poisson's ratio zone. A high Poisson's ratio region is found in the forearc crustal wedge above the slab in the junction area with Shikoku and Honshu; this high Poisson's ratio could be caused by fluid-filled cracks induced by dehydration from the Philippine Sea slab. The Poisson's ratio is normal to low in the forearc mantle in middle-south Kyushu. This is consistent with the absence of low-frequency tremors, and may indicate that dehydration from the subducting crust is not vigorous in this region.

Keywords: Kyushu; Southwest Japan; Shikoku; Philippine Sea; Seismic tomography; Poisson's ratio; Serpentinized forearc mantle; Low-frequency tremor; Volcano

1. Introduction

At present, beneath the Japanese Islands, the Philippine Sea plate (PHS) is subducting beneath the Eurasian plate along the Nankai Trough and the Ryukyu Trench in a ~N50°W direction at a rate of 4–5 cm/yr, while the Pacific plate is subducting from the east beneath the PHS and the Okhotsk plate at a rate of 6–8 cm/yr (Fig. 1, Seno et al., 1993, 1996). Beneath Kyushu, the subducting PHS forms intraslab seismic activity down to a depth of about 200 km (Fig. 2). Associated with this subduction, active volcanoes form a volcanic front in the central part of the island (Figs. 1 and 2). Quaternary volcanoes also exist along the coast of the Sea of Japan in Chugoku (Yokoyama et al., 1987). It was first believed that these Quaternary volcanoes are also associated with the subduction of the PHS, and that they form a continuous volcanic front from Kyushu (Sugimura, 1960). Later, petrological and geochemical studies indicated that the volcanoes in Chugoku and those in NW. Kyushu, including Unzen, have been formed from more fertile magma sources deep in the mantle (e.g., Nakamura et al., 1989; Iwamori, 1991; Nakada and Kamata, 1991; Sumino et al., 2000). On the other hand, Yoshida and Seno (1992) argued that the Aso

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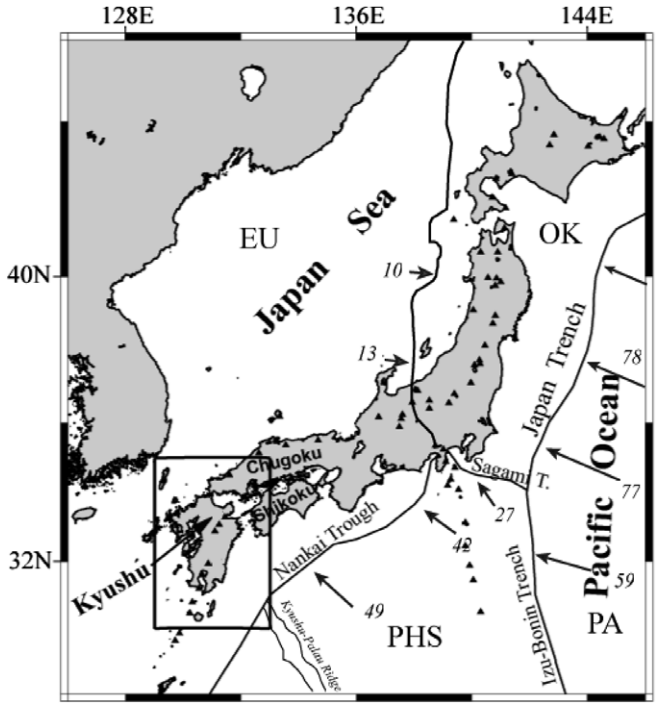

Fig. 1. Distribution of active and Quaternary volcanoes on the Japan Islands. Curved lines show the trenches, which represent the major plate boundaries around the Japanese region. Black rectangle shows the present study area. Arrows and attached numerals show direction and rate of movement (mm/yr) of the Pacific (PA), and Philippine Sea (PHS) slabs. EU, Eurasian plate; OK, Okhotsk plate.

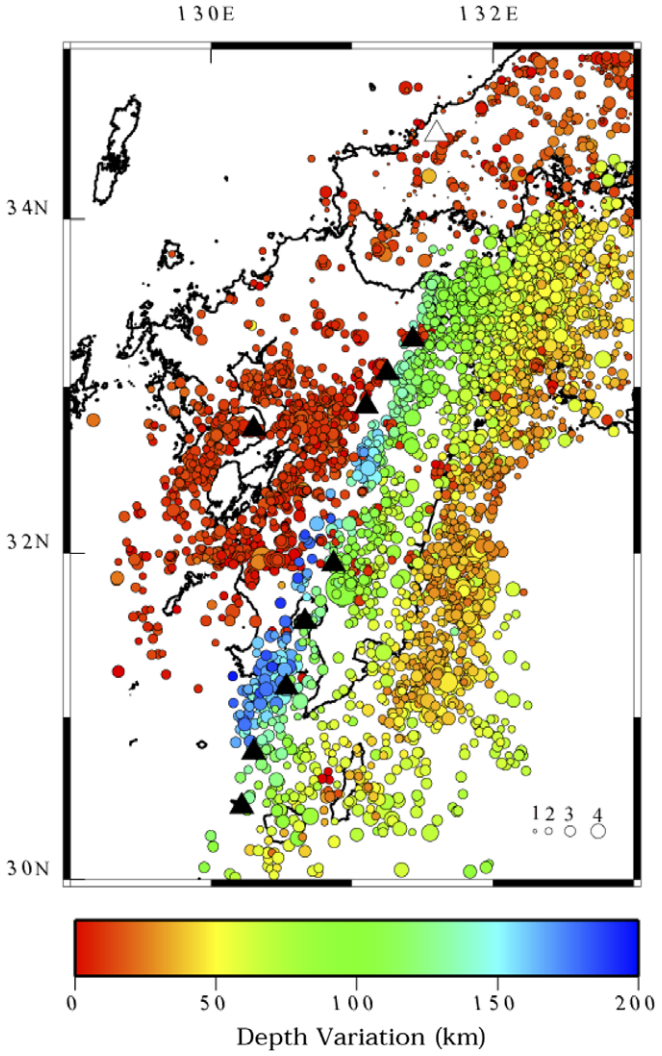

Fig. 2. Distribution of the 4224 events used in this study shown as circles. Event symbols vary in color according to focal depth and in size according to magnitude. Open and solid triangles denote Quaternary and active volcanoes, respectively.

volcano is distinct from other volcanoes at the volcanic front, such as Kirishima, because the seismic slab does not reach the depth beneath it, and, thus, might not be related with the PHS subduction, along with other volcanoes in north (N.) Kyushu – Chugoku, such as Unzen, Kujyu, and Abu.

Seismic tomography results provide useful information about the production, transfer, and distribution of fluids and/or melts in subduction zones in addition to other details of the subduction process. Thus, many authors have studied both the velocity and/or attenuation (Q) structures beneath Japan (e.g., Hirahara, 1981; Zhao et al., 1992a, 2000a,b; Tsumura et al., 2000; Nakajima et al., 2001a; Hasegawa et al., 2005). All these studies confirmed the existence of high-velocity/low-attenuation subducting slabs and low-velocity/high-attenuation anomalies landward, indicating an ascending flow from the deep mantle in the backarc side to the crust beneath active volcanoes. However, most of these studies were concentrated in the northeastern (NE) Japan subduction zone or in wide areas. Therefore, seismic tomography studies in Kyushu would provide useful information on the subduction process of the PHS, and on seismicity and volcanism.

Previous seismic tomography studies, revealing mostly large-scale 3-D seismic structures, had a low resolution beneath Kyushu (Hirahara, 1981; Zhao et al., 1994, 2000a; Sadeghi et al., 2000; Honda and Nakanishi, 2002; Nakamura et al., 2002). Zhao et al. (2000a) showed a P-wave velocity structure in Kyushu, using earthquake data of the Japan University Network Earthquake Catalogue (JUNEC) during 1993. They showed low P-wave velocity anomalies in the mantle beneath the Kujyu volcano both in the backarc and forearc sides. The number of events used is, however, only 486, recorded by few seismic stations, which is barely adequate to reveal the detailed structure. Sadeghi et al. (2000) analyzed P-wave arrivals covering a wide area from southwest (SW.) Japan to eastern China. They found no significant low-velocity anomalies just beneath the volcanic front in Kyushu, and found them rather in the upper mantle west (W.) of Kyushu. The resolution of these tomographic studies, however, seems too low to satisfactorily discuss the volcanism in Kyushu.

Recently, high Poisson's ratio regions have been found in the forearc mantle in Kanto – SW. Japan (Kamiya and Kobayashi, 2000, 2006; Honda and Nakanishi, 2003). These high Poisson's ratio regions have been interpreted as serpentinized mantle hydrated by water released