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Seismic velocity structure around the Hyuganada region, Southwest Japan, derived from seismic tomography using land and OBS data and its implications for interplate coupling and vertical crustal uplift

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Abstract

The Hyuganada region, a forearc region of Southwest Japan, is characterized by several interesting geological and geophysical features, i.e., significant aseismic crustal uplift of ∼120 m during the past ∼120 thousand years at the Miyazaki Plain, negative free-air gravity anomalies with the maximum magnitude of −130 mgal, and relatively less cohesive interplate coupling compared with that for off the Shikoku and Kii Peninsula. In order to examine the causes of these observations, we determined a detailed three-dimensional seismic velocity structure based on the seismic data observed by ocean bottom seismometers (OBS) and land stations. P- and S-wave tomographic velocity structures clearly indicate the subducting slab and also the zones of high Poisson's ratio at 25–35 km depth along the coastline of the northeastern part of the Hyuganada. The region with high Poisson's ratio may correspond to the serpentinized mantle wedge as suggested for other mantle wedges, and appears to be coincident with the zone for observed aseismic slips such as the slow-slip and after-slip events. Also, the detection may be related to a relatively weak interplate coupling in the Hyuganada region. The tomographic structures also indicate low velocity zones with a horizontal scale comparable to the Kyushu-Palau Ridge in and around the subducting slab. If we assume that the low velocity zones correspond to the subducted Kyushu-Palau Ridge, then the predicted gravity anomaly due to the density contrast between the low velocity zones and the surrounding region can explain about 60% of the gravity anomaly in the Hyuganada region. The buoyancy is probably an important factor for the crustal uplift observed in the Miyazaki Plain, the steep bending of the subducting slab and the normal fault-type earthquakes around the Hyuganada region.

Keywords: Seismic tomography; Interplate coupling; Gravity anomaly; Philippine Sea plate

1. Introduction

In the Southwest (SW) Japan, the Philippine Sea plate is subducting beneath the Eurasian plate at the Nankai Trough (Fig. 1a), resulting in a number of major earthquakes around the plate boundary (Ando, 1975; Seno et al., 1993). Several geological and geophysical phenomena are, however, not uniform along this island arc (see Nakada et al., 2002). The Hyuganada region between the Miyazaki Plain and Hyuga Basin, eastern part of Kyushu (Fig. 1a), is characterized by both significant negative free-air gravity anomaly with a minimum peak of −130 mgal (Kono and Furuse, 1989; Geological Survey of Japan, 2000)

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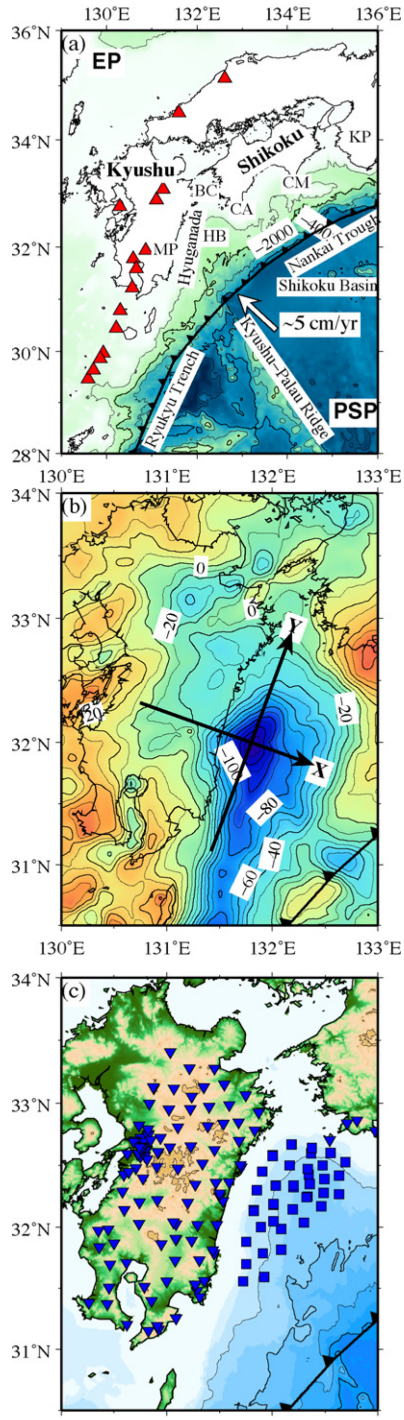

Fig. 1. (a) Location map used in this study. Red triangles show the active volcanoes. The convergence rate of the Philippine Sea Plate under the Eurasia Plate is ~5 cm year^{-1} (Seno et al., 1993). Water depth contours are in meters. EP, Eurasian Plate; PSP, Philippine Sea Plate; BC, Bungo Channel; MP, Miyazaki Plain; HB, Hyuga Basin; CA, Cape Ashizuri; CM, Cape Muroto; KP, Kii Peninsula. (b) Observed gravity anomalies (mgal) digitized from the map by Kono and Furuse (1989) (Bouguer gravity anomalies with a terrain correction density of 2670 kg m^{-3} for land region and free-air gravity anomalies for ocean region). The co-ordinate system (*X*–*Y*) shown in this figure is used throughout this study (see Fig. 3a). (c) Map view of seismic stations on land and ocean bottom seismometer (OBS) used in this study. Inverted triangles and filled squares indicate the land stations and the locations of OBS, respectively (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.).

(Fig. 1b) and aseismic crustal uplifting of ~120 m during the past ~120 000 years (kyear) (Nagaoka, 1986; Nagaoka et al., 1991). In addition, earthquakes with magnitude from 6.5 to 7.5 usually occur at 10–20 years interval and the maximum magnitude is at most 7.5 (Utsu, 1974). The maximum magnitude for off the Shikoku is, however, greater than 8 and its recurrence interval is 100–200 years (Ando, 1975; Kumagai, 1996). As a result, Cape Muroto and Ashizuri in Shikoku (Fig. 1a) have been uplifted by these earthquakes and the uplift reaches ~150 m during the past ~120 kyear (Ota and Omura, 1991). It is important to examine the causes of lateral heterogeneities for interplate coupling and crustal movement along the Nankai Trough (e.g., Ito et al., 1999). This is a main purpose of this study.

In the Hyuganada region, there are a few small asperities in contrast to large asperities corresponding to M8 class interplate earthquakes for off the Shikoku (e.g., Kawasaki, 2004). In northeastern Japan, the typical size of individual asperities is M7 class, and M8 class earthquake appears to occur when several asperities are synchronized (Yamanaka and Kikuchi, 2004). However, such phenomena have not been observed in the Hyuganada region. In addition, after-slips associated with events for 19 October 1996 and 3 December 1996 in the Hyuganada region were observed, and a silent earthquake was observed in 1997 at Bungo channel (Fig. 1a), the northern side of the Hyuganada (e.g., Yagi and Kikuchi, 2003). Yagi and Kikuchi (2003) suggested that the after-slip (post-seismic slip) may play an important role on triggering large earthquakes and the depth range of aseismic slip may be controlled by not only a thermal effect but also some other factors such as lateral heterogeneities of hydro-pressure and serpentinization. Thus, the aseismic slips might have been associated with the seismogenic mechanisms in this region.

Kamiya and Kobayashi (2000) determined three-dimensional P- and S-wave tomographic velocity structures in the Kanto-Tokai district, central Japan, and detected an area with low velocities and high Poisson's ratio greater than 0.3 at 20–45 km depths. They attributed the area to serpentinized peridotite, because the serpentinite has a higher Poisson's ratio than other rocks in the crust and upper mantle (Christensen, 1996). They also indicated that the high Poisson's ratio area is associated with low seismicity and weak interplate coupling, which is consistent with the ductility of serpentinite. The serpentinized mantle wedge may exist in the Hyuganada region, because the Hyuganada region is relatively a weak interplate coupling area.

The seismicity in the Hyuganada region may be related to the gravity anomaly. In order to examine the relationship between the gravity anomaly and the seismicity pattern, Tahara et al. (2006) determine the focal depths more accurately using sP depth phases. By using relocated focal depths and moment tensor (MT) solutions by National Research Institute for Earth Science and Disaster Prevention (NIED), they confirmed that most normal fault type events, with *T*-axes parallel to the plate boundary, occur in the crust or around the plate boundary of the forearc in cluster and the epicenters coincide with the peak position of negative gravity anomalies. However, they could not discuss the cause for normal fault type earthquakes.