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A new model of slab tear of the subducting Philippine Sea Plate associated with Kyushu–Palau Ridge subduction

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ABSTRACT

We suggest that the Kyushu–Palau Ridge (KPR) plays a key role in the subduction process of the Philippine Sea Plate (PSP) and the origin of the Abu volcano in the southwestern Japan. The 3-D P-wave velocity structure was imaged to approximately 300 km beneath the Abu volcano using a large number of P-wave arrivals from local earthquakes and teleseismic events. Our results indicate that a high-velocity anomaly beneath the Abu volcano is associated with the subducting PSP; however, the anomaly is not continuous, being interrupted apparently by a low-velocity anomaly zone extending northwestwards from 80 km to great depth. The PSP appears to be tearing and then forms a 'slab window' corresponding to KPR subduction at ca. 2 Ma. The low-velocity anomaly may indicate hot upper mantle material rising through the slab window and causing partial melting both of the lower crust of the overriding plate and the oceanic crust of the subducted KPR. A new model is presented for slab tearing of the PSP associated with the subduction of the buoyant, wide and thick KPR and directional change in the motion of the plate, contributing to better understanding of the Abu volcanism.

1. Introduction

'Slab tear' has aroused considerable interest among earth scientists since the late 1970s, when Dickinson and Snyder (1979) suggested that a subducting slab intersecting an active spreading ridge might break at some point to form a 'slab window'. Slab windows or tears have subsequently been discovered in several regions along the Eastern Pacific Rim where active ridges are subducting beneath the North and South American continents, including California, Mexico, Costa Rica, Patagonia and the Antarctic Peninsula (McCrory et al., 2009), and along the Western Pacific Rim where arcs or plateaux collide with trenches, such as in the southern part of the Mariana Arc (Miller et al., 2005) and in the southwestern Japan (Huang et al., 2013), and also in some regions of sharply discontinuous slab dip, such as in the northwestern corner of the subducting PSP (Lin et al., 2013).

The recent studies of the mechanism of slab tears indicated that the main factors in their formation include rapid trench rollback (Rosenbaum et al., 2008), flattening of subducting plates in the transition zone (Obayashi et al., 2009) and arc or ridge subduction (Miller et al., 2005). When a plate broke at shallow depth, asthenospheric material may well up through the slab window and modify the geochemical signal in lavas (Gasparon et al., 2009; Miller and Lee, 2008; Russo et al., 2010). Therefore, studies of slab windows and their genetic mechanism furthered our understanding of the seismotectonics, volcanism and geodynamics of subduction zones.

The subduction zone in the southwestern Japan is characterized by the KPR-Japan arc collision in which the KPR is subducting beneath the Kyushu Arc. The KPR is a remnant conjugate arc of the active Izu-Bonin-Mariana (IBM) arc system resulting from the spreading of the Shikoku Basin during ca. 30–15 Ma (Kobayashi and Nakada, 1978; Okino et al., 1994). After basin spreading ceased around 15 Ma, the northern margin of the KPR reached the southwestern Japan and continued to subduct northwards (Watanabe, 2005). Some reports have suggested that this activity ceased between 10 and 6 Ma (Kamata, 1992; Uto, 1989) or between 14 and 8 Ma (Taira, 2001). At ca. 6 Ma, the direction of the PSP subduction changed from N to NNW (Seno, 1989), and the KPR moved northwestwards along the Nankai Trough (Mahony et al., 2011). At ca. 2 Ma, the subduction direction of the PSP shifted from NNW to NW (Matsuda, 1980; Nakamura et al., 1984; Okamura, 1988) and the KPR migrated southwestwards to its present position, shown by the olive-colored zone in Fig. 1. The age of the slab, which is bound up with slab's density and thermal condition, is different on either side of the KPR; to its east is the younger Shikoku Basin with the age 15–26 Ma (Okino et al., 1994, 1999), and to its west is the older West Philippine Basin with the age 37–115 Ma (Hilde and Lee, 1984; Shibata et al., 1977); see Fig. 1. Since the KPR is such a major structural feature within the incoming PSP, the role that the KPR played in the configuration of the PSP warrants further investigation.

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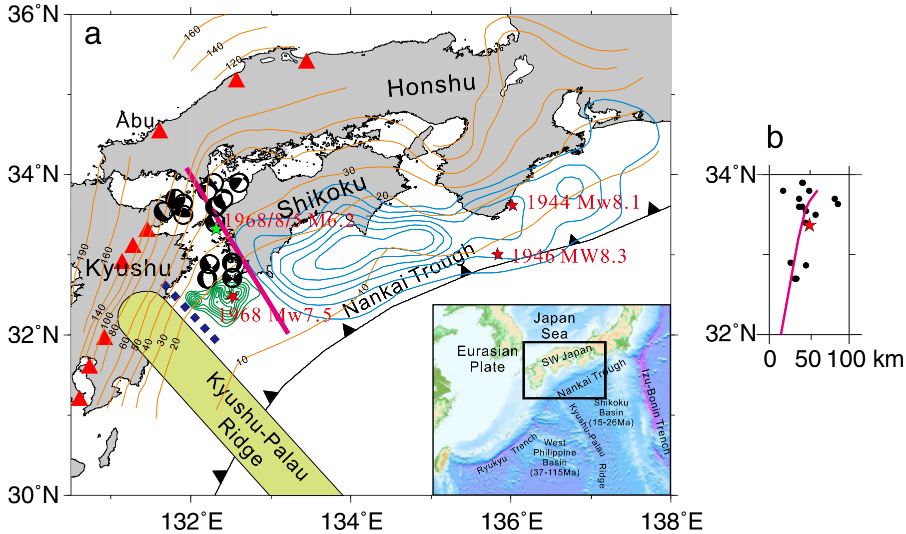

Fig. 1. (a) Overview of the plate tectonics of the southwestern Japan since 2 Ma. The sawtooth line indicates the Nankai Trough. Orange lines outline the depth contours of the upper surface of the PSP (Nakajima and Hasegawa, 2007; Zhao et al., 2012). The olive-colored zone marks the inferred KPR beneath the toe of the forearc accretionary wedge (Park et al., 2009). The heavy blue dotted line corresponds to the inferred slab fracture at the northeastern flank of the subducted KPR, as proposed by Yagi et al. (1998) and Park et al. (2009). Gray spheres show the focal mechanism (Mw > 5) from the Global CMT catalog for 1976–2010, and for Mw > 3.5 from Hi-net in the period 2009–2012. The coseismic slip contours of the 1968 Hyuga earthquake (M = 7.5), the 1944 earthquake (M = 8.1) and the 1946 earthquake (M = 8.3) are shown in green (Park et al., 2009; Yagi et al., 1998) and blue (Sagiya and Thatcher, 1999), respectively. The green star corresponds to the 1968/8/5 earthquake (M = 6.2). The red triangles denote currently active volcanoes. (b) Vertical distribution of the earthquakes (beach balls) along the pink line shown on (a).

Extensive focal mechanism, seismic reflection, tomographic and geochemical studies have investigated the geological and tectonic evolution of the southwestern Japan (e.g., Nakajima and Hasegawa, 2007; Park et al., 2009; Zhao et al., 2012). It has been deduced from recent tomographic images that the PSP subducted aseismically down to the depth of approximately 430 km, with intermittent subduction within the high-velocity zone beneath the southwestern Japan (Huang et al., 2013; Zhao et al., 2012). A low-velocity region which cut through the subducting high-velocity plate beneath the Abu volcano was also imaged and might be a sign for the existence of a slab window (Huang et al., 2013). However, the reasons that caused this phenomenon have no further discussions by them and are significant indication of the evolutionary history of the PSP. An investigation of the role of the KPR-Kyushu Arc collision in the configuration of the PSP, along with the dynamics and evolution of the PSP subduction zone, is consequently considered to be most important.

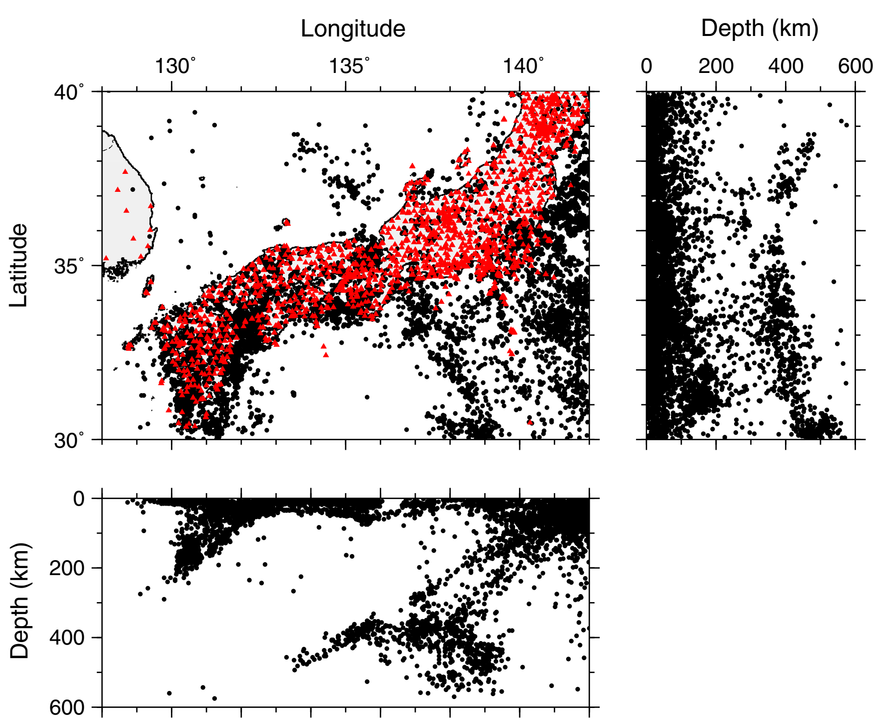

Fig. 2. Distribution of the local earthquakes (black circles) and seismic stations (red triangles) used in this study.