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Seismic imaging of the Southwest Japan arc from the Nankai trough to the Japan Sea

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ABSTRACT

Detailed three-dimensional P- and S-wave velocity (Vp and Vs) models of the entire Southwest Japan arc from the Nankai trough to the Japan Sea are determined for the first time using a large number of high-quality arrival-time data from local earthquakes. The suboceanic earthquakes used in the tomographic inversion were relocated precisely using sP depth phase data. Our results show that strong lateral heterogeneities exist in the interplate megathrust zone under the Nankai forearc. Large interplate earthquakes mainly occurred in or around high-velocity (high-V) patches in the megathrust zone. These high-V patches may represent asperities formed by the subducted oceanic ridges and seamounts. Low-velocity (low-V) zones in the megathrust zone may contain sediments and fluids associated with slab dehydration and so become weakly coupled areas. Our results also show that the coseismic slip distributions of some megathrust earthquakes are not limited in the high-V patches (asperities) where the ruptures initiated. Because of the weak interplate coupling in the low-V areas, the rupture of an interplate earthquake could unimpededly pass through the low-V anomalies and so result in a great megathrust earthquake.

1. Introduction

Along the Nankai trough off Southwest (SW) Japan, a relatively young (ca. 15–50 Ma) oceanic plate, the Philippine Sea plate, has been subducting beneath the Eurasian plate since ca. 15 Ma (Deschamps and Lallemand, 2002; Hall, 2002; Sdrolias et al., 2004) (Fig. 1). Many active arc volcanoes exist on this continental margin and form a clear volcanic front (Fig. 1). Earthquakes in the SW Japan region occur to a depth of ~200 km under Kyushu Island and ~80 km beneath Shikoku and SW Honshu. Deeper earthquakes under this region take place within the subducting Pacific slab, which is located beneath the Eurasian plate and the subducting Philippine Sea slab (Fig. 1).

Many seismic tomographic studies have been made to characterize this active continental margin (see a recent review by Zhao et al., 2011a). A recent teleseismic tomography shows that the Philippine Sea slab has subducted aseismically down to ~430 km depth under the Japan Sea and the East China Sea (Zhao et al., 2012). P-wave anisotropy tomography revealed trench-normal fast-velocity directions in the mantle wedge under Kyushu, which may reflect corner flow driven by the active subduction of the Philippine Sea plate (Wang and Zhao, 2012). These previous tomographic studies mainly focused on the inland region of the Nankai subduction zone, where the dense seismic network (Fig. 2a) allows for high-resolution seismic imaging. Although many two-dimensional seismic profiles and local three-dimensional (3-D) seismic reflection data have been acquired in the forearc region under the Philippine Sea (e.g., Kodaira et al., 2000, 2002; Bangs et al., 2009), detailed 3-D velocity images of the entire SW Japan arc, from the Nankai trough to the Japan Sea, have not been determined because few ocean-bottom-seismometer (OBS) stations are deployed in the Philippine Sea and the Japan Sea (Fig. 2). Therefore, the suboceanic earthquakes cannot be located accurately with the routine procedure of the land-based seismic network.

The suboceanic earthquakes that occurred outside a seismic network could be located precisely (with hypocenter uncertainty <3 km) using the sP depth-phase data which are very sensitive to the focal depth because the bouncing point of the sP depth phase is very close to the earthquake epicenter (Umino et al., 1995; Zhao et al., 2002, 2007; Gamage et al., 2009; Huang et al., 2010). P-wave arrival times from the suboceanic earthquakes precisely relocated with sP depth phases were used to determine the 3-D Vp structure under the northeast Japan forearc region beneath the Pacific Ocean, and this approach was suggested to be a way of tomographic imaging outside a seismic network (Zhao et al., 2002, 2007). The sP depth-phase data were also used in suboceanic earthquake location (Bai et al., 2006; Tahara et al., 2006) and tomographic imaging (Wang and Zhao, 2006a,b) in some areas of the Nankai subduction

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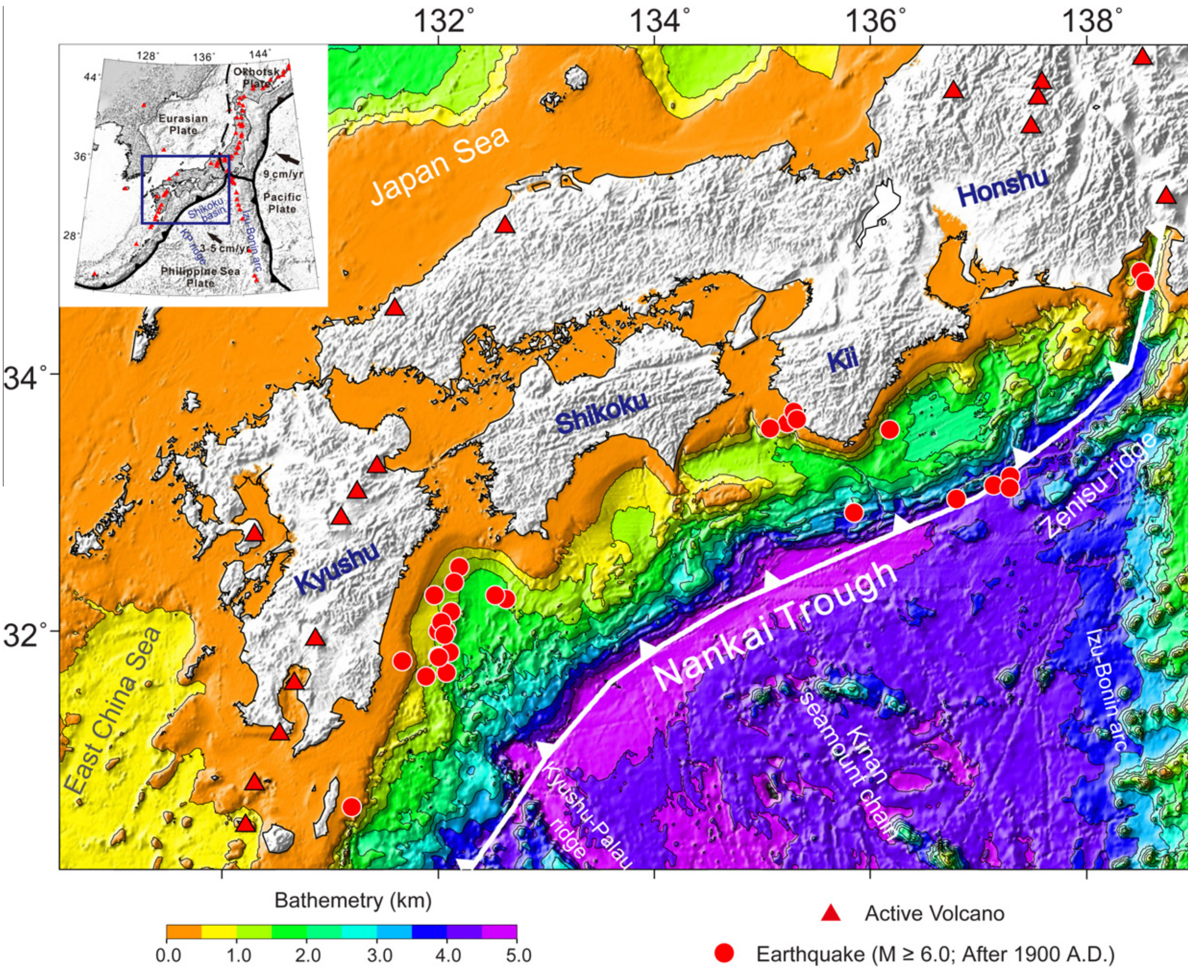

Fig. 1. Tectonic background of the Nankai subduction zone. The white bold sawtooth line denotes the Nankai trough. The inset map shows the simplified tectonic background of the study area (blue box). The black and dashed bold lines on the inset map denote the plate boundaries. The topography data are derived from the GEBCO_08 Grid, version 20100927, http://www.gebco.net. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

zone. Results obtained with this method have revealed a close relationship between structural heterogeneities and large earthquake nucleation in the megathrust zone, such as the great 2011 Tohoku-oki earthquake (Mw 9.0) (Zhao et al., 2011b).

In this work we have determined, for the first time, detailed 3-D images of Vp and Vs under the entire Nankai subduction zone from the Nankai trough to the Japan Sea using a large number of high-quality arrival-time data from many local inland earthquakes as well as suboceanic events which are relocated with sP depth phases. We have made great efforts to collect and use much more data than any of the previous tomographic studies in this region, and so our present results shed new light on the arc magmatism, seismotectonics and dynamics of the Nankai subduction zone.

2. Data and method

In this study we used 876 permanent seismic stations (Fig. 2a) which belong to the Japanese Kiban seismic network (Okada et al., 2004). We selected 6622 earthquakes from all the available events that occurred in the study region during 1997–2012 (Fig. 2). These events are composed of four groups. The first group includes 2838 events that occurred during October 1997 to October 2007 under the seismic network on the Japan Islands (green dots in Fig. 2), which are selected from the data set used by Zhao et al. (2011a). This data set contains more P- and S-wave arrival times than those released by the Japan Meteorological Agency (JMA) Unified catalog, thanks to the great efforts made by the staffs of Tohoku University who picked up all the clear P and S arrivals from the original seismograms. The second group consists of 1557 earthquakes (yellow dots in Fig. 2) that occurred under the seismic network on the Japan Islands from June 2002 to March 2012, which were directly selected from the JMA Unified catalog. The uncertainties of the hypocenter locations of these two groups are estimated to be smaller than 2 km. The third group contains 1675 shallow suboceanic events (light red dots in Fig. 2) that occurred beneath the East China Sea and the Philippine Sea during June 2002 to September 2011, which are selected from the data set used by Liu et al. (in review). This data set contains 4018 sP depth phases and more P- and S-wave arrival times than those released by the JMA Unified catalog.

The fourth group includes 552 shallow suboceanic earthquakes (red dots in Fig. 2) that occurred beneath the Philippine Sea and the Japan Sea during June 2002 to March 2012. Following the criteria established by the previous studies for the collection of sP depth phases (e.g., Umino and Hasegawa, 1994; Umino et al., 1995; Wang and Zhao, 2005, 2006a,b), we examined a large amount of three-component seismograms of over 2500 shallow earthquakes ($M_{JMA} \geqslant 2.0$) that occurred beneath the Philippine Sea and the Japan Sea. As a result, we selected 552 events to form the fourth group for which 1559 sP depth phases were collected (Fig. 3). The picking accuracy of the sP depth phases is estimated to be 0.1–0.2 s. In order to improve the ray path coverage in the area outside the