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Aseismic deep subduction of the Philippine Sea plate and slab window

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ABSTRACT

We have made great efforts to collect and combine a large number of high-quality data from local earthquakes and teleseismic events recorded by the dense seismic networks in both South Korea and West Japan. This is the first time that a large number of Korean and Japanese seismic data sets are analyzed jointly. As a result, a high-resolution 3-D P-wave velocity model down to 700-km depth is determined, which clearly shows that the Philippine Sea (PHS) plate has subducted aseismically down to ~460 km depth under the Japan Sea, Tsushima Strait and East China Sea. The aseismic PHS slab is visible in two areas: one is under the Japan Sea off western Honshu, and the other is under East China Sea off western Kyushu. However, the aseismic PHS slab is not visible between the two areas, where a slab window has formed. The slab window is located beneath the center of the present study region where many teleseismic rays crisscross. Detailed synthetic tests were conducted, which indicate that both the aseismic PHS slab and the slab window are robust features. Using the teleseismic data recorded by the Japanese stations alone, the aseismic PHS slab and the slab window were also revealed (Zhao et al., 2012), though the ray paths in the Japanese data set crisscross less well offshore. The slab window may be caused by the subducted Kyushu-Palau Ridge and Kinan Seamount Chain where the PHS slab may be segmented. Hot mantle upwelling is revealed in the big mantle wedge above the Pacific slab under the present study region, which may have facilitated the formation of the PHS slab window. These novel findings may shed new light on the subduction history of the PHS plate and the dynamic evolution of the Japan subduction zone.

1. Introduction

The Philippine Sea (PHS) plate is one of the marginal sea complexes in the western Pacific and it started to subduct northwestwards about 40 Ma ago when the Pacific plate changed its direction of motion from NNW to WNW (Karig, 1971; Seno and Maruyama, 1984). Along the Nankai Trough off Southwest Japan, the PHS plate is composed of several blocks with ages increasing from the east to west, which are the Izu-Bonin arc and back-arc (0–2 Ma), Shikoku Basin (15–30 Ma), Kyushu-Palau Ridge, and Amami Plateau (40–49 Ma) (Hilde and Lee, 1984; Hall et al., 1995). In the present study region (Fig. 1), the PHS plate is actively subducting beneath Southwest Japan and the Ryukyu arc from the Nankai Trough and Ryukyu Trench at a rate of 3–5 cm/year (e.g., Bird, 2003; DeMets et al., 2010). The Korean Peninsula and western Japan belong to the Eurasian (or Amur) plate. According to the recent regional and global tomographic studies (e.g., Hasegawa et al., 2009; Zhao, 2004; Wei et al., 2012; Zhao et al., 2012, 2013), the Pacific plate is subducting beneath the Japan Islands and the PHS plate, and then it becomes stagnant in the mantle transition zone (MTZ). Hence the stagnant Pacific slab exists beneath the present study region (see Fig. 12 on the geometry of the Pacific slab). Analyses of teleseismic data show that the Pacific slab is 85–100 km thick under the Japan Islands and the Japan Sea (e.g., Zhao et al., 1994, 2012; Abdelwahed and Zhao, 2007; Jiang et al., 2008; Jiang and Zhao, 2011). The strong interactions of these lithospheric plates on the Earth's surface and at depth have lead to complex structures in the crust and upper mantle as well as intensive seismic and volcanic activities in the study region. In addition to many active arc volcanoes on the Japan Islands, a few active intraplate volcanoes exist in and around the Korean Peninsula, such as Changbai, Jeju and Ullung (Siebert and Simkin, 2002; Kim et al., 2008; Zhao et al., 2009; Wei et al., 2012) (Fig. 1). It is very important to study the detailed three-dimensional (3-D) structure of the crust and upper mantle so as to improve our understanding of seismotectonics, volcanism and geodynamics of the study region.

So far the 3-D seismic velocity structure of the crust and upper mantle under the Japan Islands has been studied extensively by using various seismological methods (see Hasegawa et al., 2009

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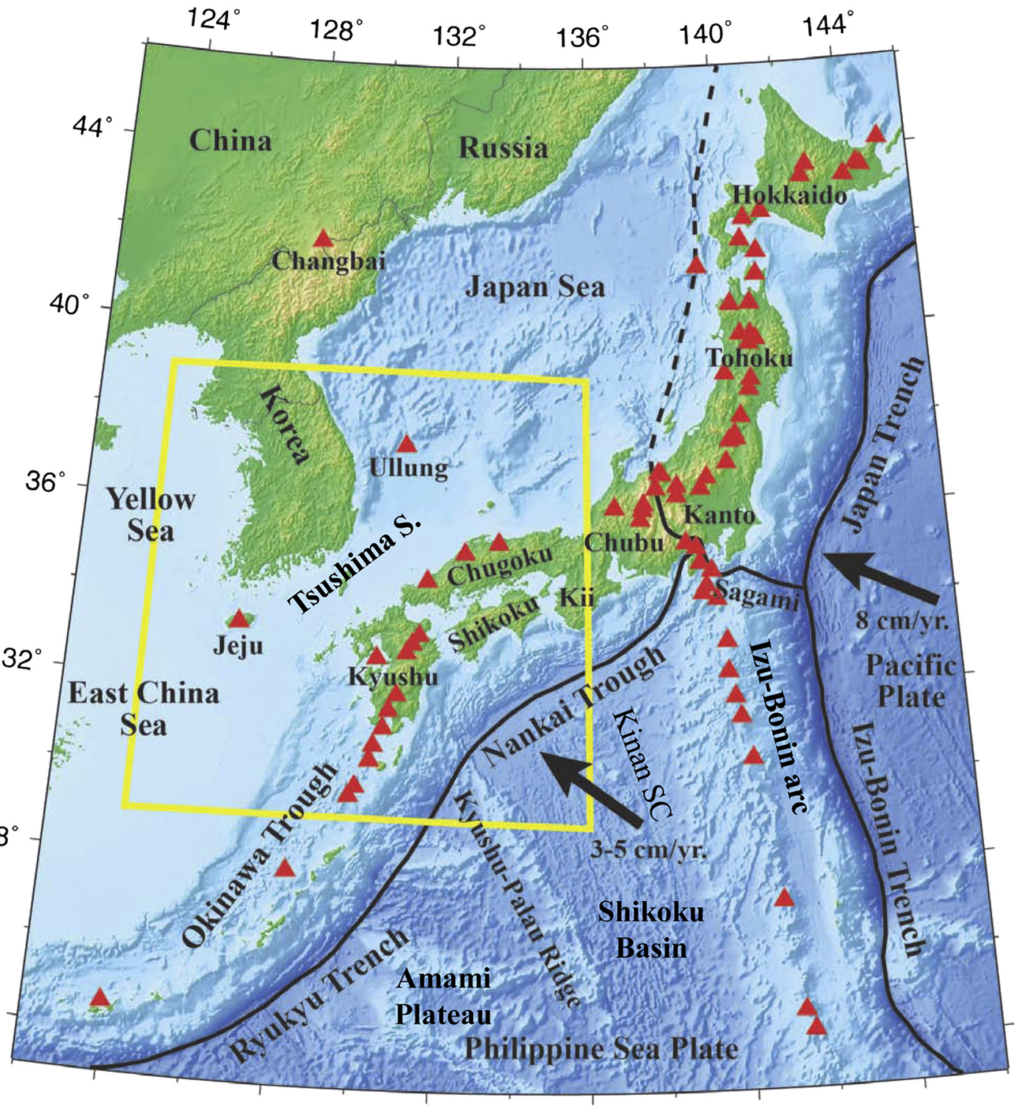

Fig. 1. Map showing the tectonic setting in and around the Korean Peninsula and the Japan Islands. The colors show the surface topography. Red triangles show the active volcanoes. The solid and dashed black lines show the major plate boundaries. Kinan SC: the Kinan Seamount Chain. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

for a recent review). Recently, a joint inversion of local and teleseismic data revealed that the PHS slab under Southwest Japan has subducted aseismically down to ~430 km depth under East China Sea off Kyushu, Tsushima Strait, and the Japan Sea off western Honshu (Zhao et al., 2012). However, this result was obtained by using the data recorded by only the Japanese seismic network, and so the aseismic PHS slab was not constrained very well. To resolve this problem, in the present work we have made great efforts to collect and combine a large number of high-quality arrival-time data of local earthquakes and teleseismic events recoded by the dense seismic networks in both West Japan and South Korea (Fig. 2), which enable us to determine a detailed 3-D P-wave tomography of the crust and mantle down to 700 km depth under the study region (Figs. 1 and 2). To the best of our knowledge, this is the first time that a large number of Korean and Japanese seismic data sets are analyzed jointly. The present results shed new light on the deep structure and dynamics under the Korean Peninsula and western Japan, in particular, on the aseismic deep subduction of the PHS plate, slab window, and their tectonic implications.

2. Data and method

In this work we used arrival-time data from both local earthquakes and teleseismic events recorded by the local seismic networks in South Korea and West Japan. Fig. 2 shows the distribution of seismic stations we used, which include 116 stations located in South Korea operated by Korea Meteorological Administration, Korea Electric Power Research Institute, Korea Institute of Nuclear Safety, and Korea Institute of Geoscience and Mineral Resources (Park, 2008), as well as 905 seismic stations in West Japan operated by Japan Meteorological Agency, Japanese national universities, and National Research Institute for Earth Science and Disaster Prevention (Okada et al., 2004). For details of the Korean and Japanese seismic networks, see Park (2008) and Okada et al. (2004).

Among the great number of earthquakes recorded by the local seismic networks in the study region, we selected a best set of events for our tomographic study. The study area is divided into cubic blocks with a size of $30 \times 30 \times 20$ km^3. The local events are selected by a specific scheme of selection according to the