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P-wave anisotropy tomography of central Japan: Insight into subduction dynamics

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ABSTRACT

A P-wave anisotropic tomography under central Japan was determined using a large number of arrival-time data from 22,244 earthquakes recorded by 770 seismic stations on the Japan Islands. The results show that the anisotropy exists widely beneath the study area except for the central portion of the mantle wedge. The fast-velocity directions (FVDs) of the mantle wedge are generally trench-parallel under the fore-arc area and trench-normal under the back-arc area, which may be attributed to the lattice-preferred orientation (LPO) of olivine changing from B-type under the fore-arc area to A-type under the back-arc area with the variation of water content and the occurrence of mantle flow. The subducting Philippine Sea plate (PHS) beneath Tokai is revealed as a high-velocity anomaly dipping northward with NEE to NE–SW FVDs which are consistent with the spreading direction of the PHS during its formation and are inferred as the fossil anisotropy of the PHS. The anisotropy of the upper portion of the Pacific slab under central Japan is also revealed in this study. The FVDs of the upper portion of the Pacific slab are sub-parallel to the Japan Trench and Izu-Bonin Trench at ~60–120 km depths and become almost perpendicular to the trenches below 100–120 km depth. After comparisons with the Mesozoic magnetic anomaly lineations and the principle stresses in the Pacific slab, we propose that the fossil FVDs of the Pacific slab beneath central Japan were already rebuilt by the principle stresses in the slab.

1. Introduction

The Japan Islands are located in the Western Pacific subduction zone where four lithospheric plates are interacting with each other (Fig. 1). The Pacific plate is subducting beneath the Okhotsk plate along Japan Trench and Kuril Trench in northeast (NE) Japan and under the Philippine Sea plate (PHS) along Izu-Bonin Trench to the south of central Japan. The subducting Pacific slab bends beneath central Japan. And the slabs descending along different trenches have different incline directions which are NW for the Pacific slab subducting along Japan Trench and SWW for the Pacific slab subducting along Izu-Bonin Trench (Ishida, 1992; Nakajima and Hasegawa, 2006; Nakajima et al., 2009; Ohmi and Hori, 2000). For convenience, the Pacific slabs beneath central Japan with NW and SWW incline directions are called Japan slab and Izu-Bonin slab, respectively. The Japan slab meets with Izu-Bonin slab along a cusp-like junction (Obayashi et al., 2009) along ~36°N. Beneath central Japan (the open square in Fig. 1), the PHS subducts under the Amur plate and the Okhotsk plate along Nankai trough and Sagami trough, respectively. The Izu-Bonin volcanic arc, as the arc of the Pacific plate subducting under the PHS, also collided with central Japan to the north of Izu Peninsula and formed the Izu collision zone (Soh et al., 1998). The subducting PHS collides with the Pacific plate beneath Kanto. The relative plate motion between the Pacific plate and the Okhotsk plate is NW–SE in NE Japan and changes to almost E–W between the Pacific plate and PHS in central Japan and Izu-Bonin arc (Seno et al., 1993, 1996) as is shown in Fig. 1. Beneath central Japan, there are four plate collision interfaces, PHS-Amur plate, PHS-Okhotsk plate, Pacific plate-Okhotsk plate and Pacific plate-PHS, which makes the deep structure and geodynamic processes beneath central Japan more complicated than those in NE Japan and southwest Japan in the view of plate tectonics.

Seismic anisotropy is quasi-ubiquitous in all tectonic environments and its interpretation can link seismological observations with deformational processes of the Earth's interior (Fouch and Rondenay, 2006; Long and Becker, 2010). Since P_n-wave velocity was observed and proved to having a 2Φ variation with ray-path azimuth in oceanic area (Backus, 1965; Hess, 1964; Raitt et al., 1969), great efforts have been made to reveal the anisotropies inside the Earth and the first-order characteristics of anisotropies of the Earth's interior have been derived by using a wide variety of seismological methods, which greatly improved our understanding for the Earth's interior (for reviews, see Fouch and Rondenay, 2006; Helbig and Thomsen, 2005; Long and Becker, 2010; Maupin and Park, 2007; Savage, 1999). The significant anisotropies distribute mostly in the crust, in the upper mantle, in the D″ layer at the base of the mantle and in the inner core, while most of the lower mantle appears to be isotropic (Long and Becker, 2010). Although exact origins of seismic anisotropy in the Earth's interior are still under debate, shape-preferred orientation and lattice-preferred orientation (LPO) are generally believed to be responsible for the anisotropy inside the Earth (Fouch and Rondenay, 2006; Long and Becker, 2010; Maupin and Park, 2007). The

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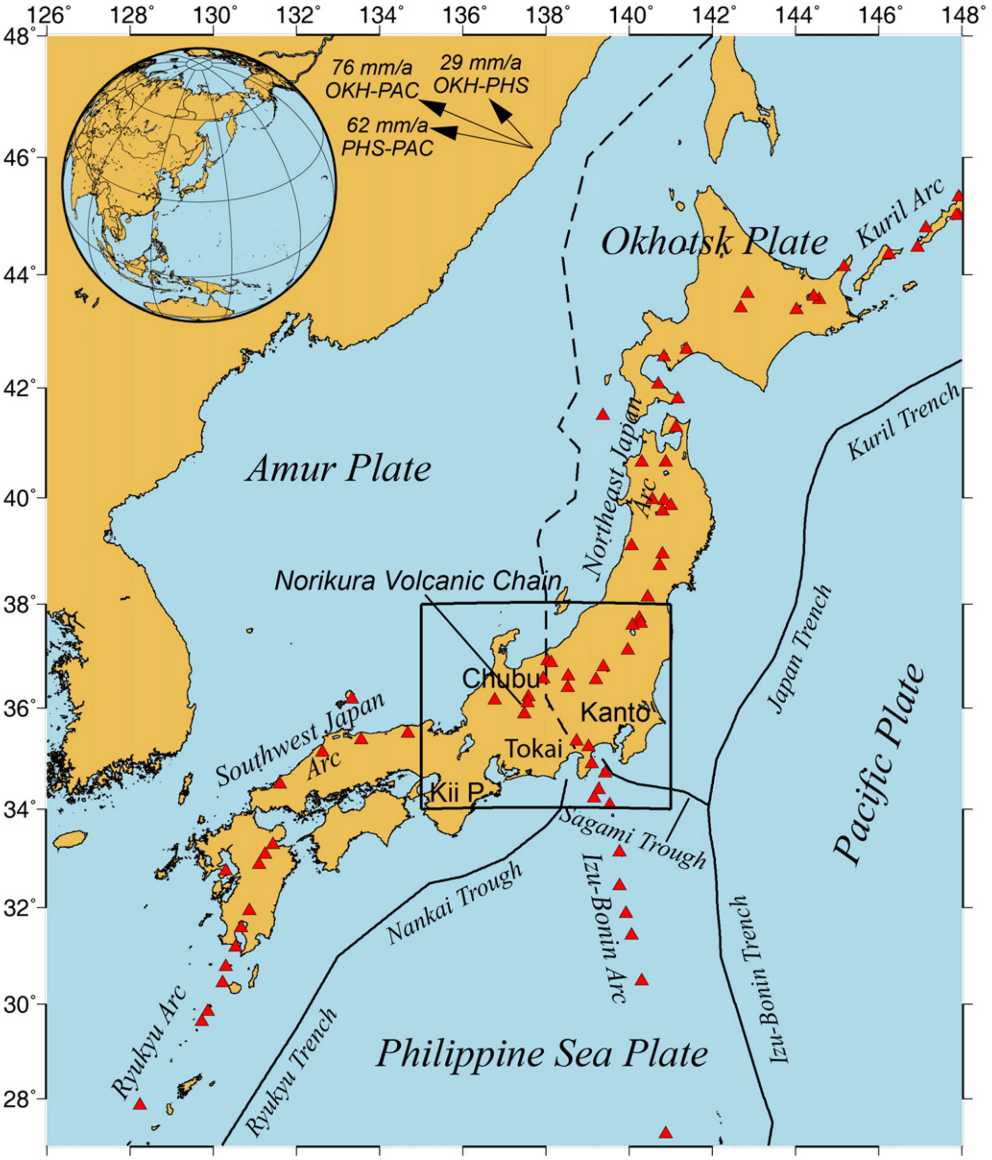

Fig. 1. Tectonic background of the Japan subduction zone. The arrows on the upper-left corner indicate the relative motion directions and convergence rates among the Pacific plate, Philippine Sea plate (PHS) and the Okhotsk plate. The open square denotes the present study area. The red triangles denote the active arc volcanoes.

shape-preferred orientation induced by the fine layering and cracks and faults aligning in responds to regional tectonic stresses dominate the anisotropy in the uppermost crust, especially in oceanic area. Although the shape-preferred orientation may also contribute to the anisotropy in the uppermost mantle and lower crust (Greve and Savage, 2009) and even to those in the D″ region (Moore et al., 2004), it is still generally believed that the key cause of seismic anisotropy in the crust and mantle is the LPO of crystallographic axes of elastically anisotropic minerals. Biotite and hornblende are the primary candidates for the crustal anisotropy. In the upper mantle, olivine, as the main mineral constituent of mantle, is believed to play a dominant role in the generation of upper mantle anisotropy. The LPO of olivine can be drastically modified with the presence of water or melt and the changing of stress and temperature (Fouch and Rondenay, 2006; Holtzman et al., 2003; Long and Becker, 2010; Maupin and Park, 2007).

The seismological method mostly used for the anisotropy study is shear wave splitting, which is unaffected by isotropic wave velocity heterogeneity and has a good lateral resolution. But because it is a path-integrated measurement, it has poor resolution in depth (Long and Becker, 2010). The P-wave anisotropic tomography method takes the isotropic velocity perturbation and anisotropic parameters at each grid node as unknowns and resolves the unknowns by a joint inversion (Wang and Zhao, 2008, 2010). The isotropic velocity perturbation and anisotropy at each grid node can be determined simultaneously, which provides the anisotropic tomography method with relatively good resolutions both in lateral and depth directions.

In this study, we determined the P-wave anisotropic tomography images beneath central Japan using the method of Wang and Zhao (2008, 2010). According to the anisotropic features and isotropic velocity structure of the results, we attempt to uncover the plate deformational processes associate with the complex subductions beneath central Japan.

2. Method and data

Anisotropy is a complex property of elastic materials and can be expressed mathematically by elastic tensor c_{ijkl}, where $i, j, k, l = 1, 2, 3$. The number of subscripts of a tensor denotes the order of the tensor. Elastic tensor c_{ijkl} is obviously a fourth-order tensor. At fully anisotropic condition, elastic tensor c_{ijkl} with a total of 81 coefficients