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Seismic anisotropy in the wedge above the Philippine Sea slab beneath Kanto and southwest Japan derived from shear wave splitting

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ABSTRACT

We conduct shear wave splitting measurements on waveform data from the Hi-net and the broadband F-net seismic stations in Kanto and SW Japan generated by shallow and intermediate-depth earthquakes occurring in the subducting Philippine Sea and Pacific slabs. We obtain 1115 shear wave splitting parameter pairs. The results are divided into those from the shallow (depth < 50 km) and the deep (depth > 50 km) events. The deep events beneath Kanto are further divided into PHS1 and PHS2 (upper and lower planes of the double seismic zone in the Philippine Sea slab, respectively), PAC1 and PAC2 (western and eastern Pacific slab, respectively) events. The results from the shallow events represent the crustal anisotropy, and their fast directions are more or less aligned in the σ_{Hmax} directions, implying that the anisotropy is produced by the alignment of the vertical cracks in the crust induced by the compressive stresses. In Kanto, Kii Peninsula and Kyushu regions, the results from the deep events suggest a contribution from the mantle wedge anisotropy. Events from all groups beneath Kanto show NW, NE and EW fast directions. This complex pattern seems to be produced by the corner flows induced by both the WNW PAC plate subduction and the oblique NNW PHS slab subduction with the associated olivine lattice-preferred orientations (LPOs), and the anisotropy frozen in the PHS slab. The deep events beneath Kii Peninsula show NE and NW fast directions and may be produced by the corner flow produced by the NNW PHS slab subduction with the associated olivine LPOs. The NE directions might also be produced by the segregated melts in the thin layers parallel to the PHS slab subduction. The deep events beneath N Kyushu show NNW fast directions, which may result from the southeastward flow in the upper mantle inferred from the stresses in the upper plate. Results from the deep events beneath middle-south Kyushu show dominantly E–W fast directions, in both the fore- and back-arcs. They may be produced by the corner flow of the westward PHS slab subduction with the olivine LPOs. Because the source regions with multiple fast directions are not resolved in this study, further detailed analyses of shear wave splitting are necessary for a better understanding of the stress state, the induced mantle flow, and the melt-segregation processes.

1. Introduction

Shear wave polarization anisotropy above small earthquakes within the continental upper crust has been observed in many places with various tectonic and geologic settings (Booth et al., 1985; Crampin and Booth, 1985; Kaneshima et al., 1987, 1989). It can provide us with useful information about the *in-situ* stress state in the crust. The presence of anisotropy in the crust and upper mantle beneath subduction zones has also been well established (e.g., Ando et al., 1983; Kaneshima and Ando, 1989; Kaneshima, 1990; Fischer and Yang, 1994; Yang et al., 1995; Fouch and Fischer, 1996; Hiramatsu and Ando, 1996; Iidaka and Obara, 1995; Okada et al., 1995; Fischer et al., 1998, 2000; Park and Levin, 2002; Long and van der Hilst, 2005, 2006; Nakajima et al., 2006, and many others). A diverse range of splitting behavior has been associated with different subduction zones. Both trench-parallel and trench-perpendicular fast directions have been recorded in many subduction zones (e.g., Russo and Silver, 1994; Yang et al., 1995; Fouch and Fisher, 1996; Park and Levin, 2002; Levin et al., 2004; Nakajima and Hasegawa, 2004; Long and van der Hilst, 2005), whereas in some areas of other subduction zones no splitting is observed (Fischer et al., 1998).

Around the Japanese islands, the Pacific (PAC) plate is subducting beneath northern Honshu and Hokkaido along the Japan Trench (Fig. 1), whereas in southwest (SW) Japan the relatively

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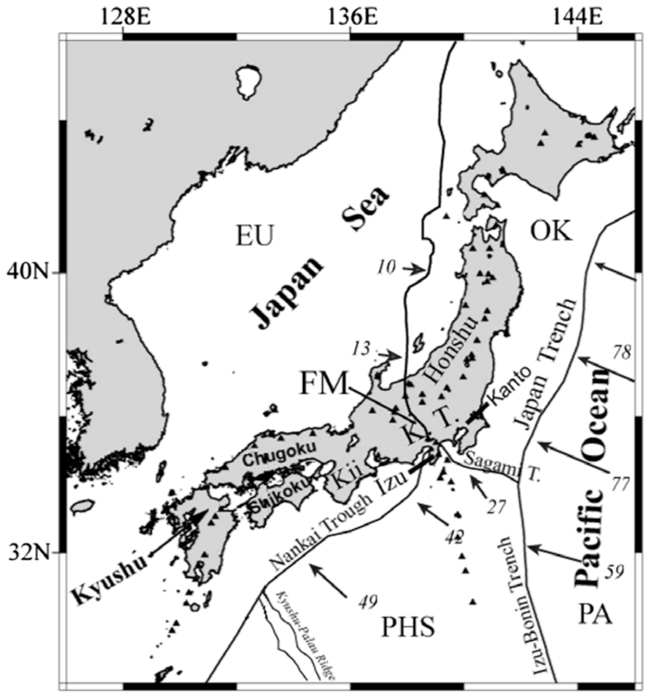

Fig. 1. Distribution of active and Quaternary volcanoes on the Japan Islands. Curved lines show the trenches which represent the major plate boundaries around the Japanese region. Arrows and attached numerals show the direction and rate of movement (mm/yr) of the Pacific (PAC), and Philippine Sea (PHS) slabs. EU: Eurasian plate; OK: Okhotsk plate; KT: Kanto-Tokai districts; FM: Fossa Magna.

young (15–26 Ma) segment of the Philippine Sea (PHS) plate is subducting beneath the Eurasian plate (Seno et al., 1993, 1996). Active arc volcanoes exist in Hokkaido, Honshu, and Kyushu (Yokoyama et al., 1987), which are associated with the subduction of the PAC and PHS plates. A number of shear wave splitting studies have been conducted beneath SW Japan (e.g., Ando et al., 1983; Kaneshima and Ando, 1989; Fouch and Fischer, 1996; Iidaka and Obara, 1995). However, the source areas are mostly concentrated in the wedge above the PAC slab, or in the crust.

Our goal in this study is to investigate the subduction-related processes such as stresses and associated deformation in a rather shallow part of the crust–mantle wedge above the subducting PHS slab by the use of shear wave splitting measurements mainly from the PHS intraslab events. In this region, these processes are still not well elucidated and even the actual pattern of mantle flow above the subducted slab is not well known. For example, although the B-fabric of the olivine lattice-preferred-orientations (LPOs) (see Jung and Karato, 2001 for fabrics) is inferred to be preserved in the mantle wedge beneath SW Japan (Mizukami et al., 2004), it has not been detected by the shear wave splitting. Detailed examination of seismic anisotropy in the wedge above the PHS slab, combined with estimated induced flows by the PHS subduction and the stress state, may help resolve these problems (e.g., Park et al., 2002). In order to achieve part of this target; we hereby use digital waveform data generated by local shallow and intermediate-depth earthquakes recorded at dense seismic networks to study the fine seismic anisotropy structure above the PHS slab beneath SW Japan.

2. Data

We use digital waveform data from the High Sensitivity (Hi-net) and the Full Range (F-net) Seismograph Networks operated by the National Research Institute of Earth Sciences and Disaster Prevention (NIED), Japan. The Hi-net consists of more than 600 seismic stations covering whole Japan for detecting microearthquake activity (Obara, 2002). Each station consists of a three-component velocity-type seismometer with a natural frequency of 1 Hz installed at the bottom of a borehole at a depth of 100 – 200 m. The data are digitized at each station with a sampling frequency of 100 Hz, and then the data packets attached with the absolute time information from a Global Positioning System clock are transmitted to the data center. The F-net is composed of more than 70 stations nationwide over Japan and is capable of detecting very weak to strong ground motions in broadband frequency range. At each station, seismometers are installed at the end of vault with a length of about 40 m to avoid the temperature effect on the sensor response. The broadband F-net was installed in or before 2001 and was collectively known as the FREESIA array (e.g., Long and van der Hilst, 2005). Both the Hi-net and the F-net data are made available on the web by NIED (www.hinet.bosai.go.jp & www.fnet.bosai.go.jp). We use data at 189 Hi-net and 14 F-net seismic stations (Fig. 2). The station spacing in some parts of the study area is as close as 20 km, allowing us to detect variations in the seismic anisotropy structure on a very short length scale.

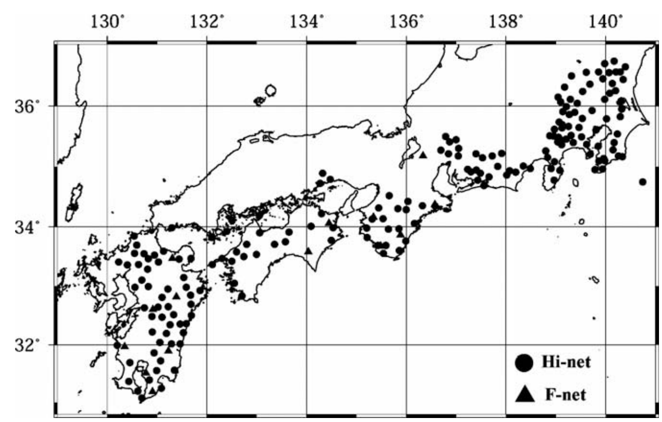

Fig. 2. Distribution of the 189 Hi-net (solid circles), and the 14 F-net (solid triangles) seismic stations used in the present study.

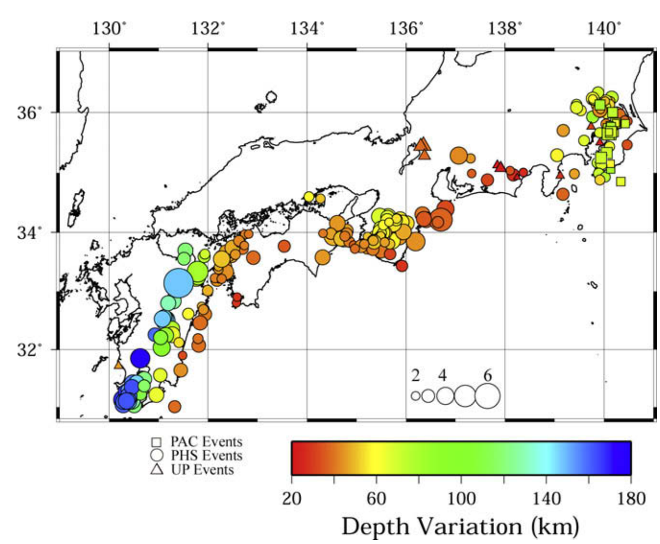

Fig. 3. Epicentral distribution of the 287 events used in this study shown as circles (PHS; Philippine Sea slab events), squares (PAC; Pacific slab events), and triangles (UP; upper Eurasian plate events). Event symbols vary in color according to focal depth and in size according to magnitude.