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Shear-wave splitting at the edge of the Ryukyu subduction zone

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ABSTRACT

Intraslab events recorded by ocean-bottom seismometers in the Okinawa trough provide an extended depiction of shear wave splitting in the southwest section of the Ryukyu subduction zone. At 100–200 km from the western edge of the subduction system, we observed trench-normal fast polarization direction in the back arc compatible with 2D slab- or rifting-driven corner flow. Towards the edge, the fast directions are sub-parallel to the trench in the arc—back arc region, and rotate to trench-normal within 50 km of the edge. Splitting constrained by land stations with paths mostly in the mantle wedge exhibits similar trench-normal fast directions in the subduction edge zone. Further inland, the dominant component of fast directions becomes roughly parallel to the Taiwan orogenic fabric. Splitting of *P*-to-*S* phases converted at the Moho of the Okinawa trough and of *S* phases from shallow events suggest that crustal anisotropy may affect the measured splitting, but the observed pattern reflects predominantly mantle anisotropy. The variation in splitting along the Okinawa trough cannot be explained by a B-type–A-type olivine fabric transition in the mantle wedge. It may indicate the presence of an along-arc flow in the mantle wedge towards the edge where it is blocked and deflected by the Eurasian lithosphere. This scenario bolsters previous studies suggesting a significant impact of Eurasian lithosphere on the dynamics of the Ryukyu subduction system.

1. Introduction

Mantle minerals deform under ambient shear stresses to various favorable fabrics, which may be oriented coherently, rendering gross anisotropy seismically detectable. Seismic anisotropy thus serves to map the structure of mantle flow. Classic interpretations of mantle anisotropy involve the olivine [100] axis aligned parallel to the shear-stress direction in a low-stress and low-water content mantle environment (e.g., Silver and Chan, 1991), which later was named A-type olivine fabric. Shear-wave splitting occurs with the fast phase polarized along [100] and the slow phase polarized in a perpendicular direction. In oceanic basins, observations of shear-wave splitting reveal the fast polarization direction of the shear wave sub-parallel to the absolute plate motion or the direction of fossil seafloor spreading (Fontaine et al., 2007; Harmon et al., 2004; Kuo and Forsyth, 1992; Wolfe and Solomon, 1998).

In subduction zones, anisotropy is mostly controlled by slab-driven flow modulated by local plate motions (e.g., Bowman and Ando, 1987; Fouch and Fischer, 1996; Hall et al., 2000). However, as observations have expanded, anisotropy has shown other systematic features. In the Tonga and Andes regions, some fast directions were sub-parallel to the trench suggesting along-strike flow either in the mantle wedge or below the slab (Russo and Silver, 1994; Smith et al., 2001; Anderson et al., 2004; Foley and Long, 2011). In northeast Japan and along the Ryukyu arc, trench-parallel fast directions in the fore-arc mantle are indicative of the effect of water (Nakajima and Hasegawa, 2004; Long and van der Hilst, 2005, 2006). In northern Kamchatka, southern Juan De Fuca, and the Calabrian subduction zone, splitting patterns exhibit rotation of the fast direction around the lateral edge that implies asthenosphere material flowing from under the slab to the mantle wedge (Peyton et al., 2001; Civello and Margheriti, 2004; Baccheschi et al., 2007; Zandt and Humphreys, 2008; Druken et al., 2011). Numerical models predict that the around-the-edge toroidal flow is induced by slab rollback and localized near the edge of the subduction system (Kneller and van Kenen, 2008; Jadamec and Billen, 2010).

The southwestern Ryukyu subduction zone presents a unique case in subduction zone edges. The Philippine Sea plate (PSP) is obliquely subducting under the Eurasian lithosphere to the north while colliding with the Eurasian lithosphere to the west (Fig. 1).

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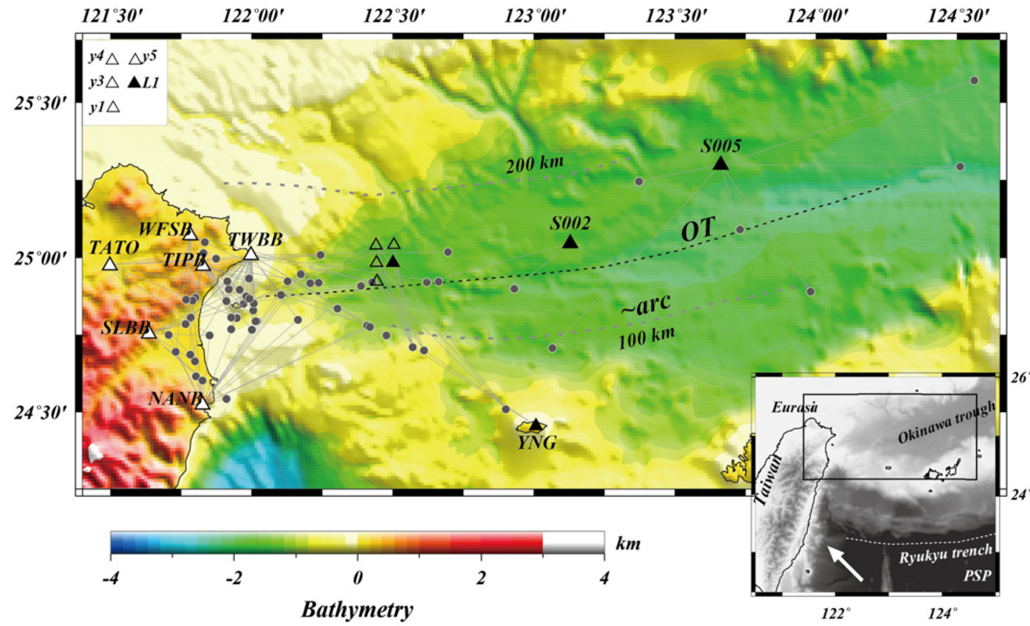

Fig. 1. Bathymetry map showing key tectonic elements of the southwest Ryukyu subduction zone system. The rifting axis of the westward closing Okinawa trough (OT) is drawn as a smooth curve (dotted line), and 100 km and 200 km depth contours of the slab surface are drawn (light dotted line; labeled) (Chou et al., 2006) with the 100 km contour indicating the position of the present-day arc. The OBSs used include the isolated S002 and S005 and the five-unit array (filled and open triangles for broadband and short-period, respectively). The station names of the array are given in the inset on the upper-left corner. BATS (Broadband Array in Taiwan for Seismology) stations and the F-net station YNG (on the Yonaguni island) are labeled. Events and great-circle raypaths are plotted as filled circles and gray lines, respectively. The lower-right inset shows the relative position of the map in the broad Taiwan subduction–collision zone in which the Philippine Sea plate (PSP) is obliquely subducting (white arrow) under the Ryukyu trench (white dotted line).

The subduction–collision junction corner entails complicated evolution and dynamics, with the southerly retreating Ryukyu arc (Nakamura, 2004) and a westward tapering back-arc basin, or the Okinawa trough (OT), still in the rifting stage. The slab and the back-arc basin, along with the mantle wedge, all terminate perpendicularly against the Eurasian plate in the vicinity of NE Taiwan. The Eurasian lithosphere has a dual role: as the overriding plate for the subduction and as the plate blocking the western side of the subduction system. In this paper, we add "overriding" when the Eurasian plate is referred to as in the first role. The thickness of the Eurasian lithosphere in the two roles is likely different. Numerical modeling has demonstrated that the overriding plate is substantially thinned thermally and mechanically by upwelling and rifting (e.g., Lin et al., 2010a).

Because of the oblique subduction, the slab in this section is subject to a dominant along-strike, EW compression and a short-wavelength folding, indicating strong impingement against the Eurasian lithosphere (e.g., Chou et al., 2006). A recent mapping of attenuation structure in this region shows the presence of high *Q* anomalies likely in the mantle wedge abutting the Eurasian lithosphere, suggesting a cold and probably dry edge environment (Ko et al., 2012). The GPS velocity shows a rapid decrease in southward movement from the westernmost islands of the Ryukyu arc (e.g., the Yonaguni and Ishigaki islands) to NE Taiwan, indicating a rapid decrease in trench retreat from offshore towards inland (e.g., Rau et al., 2008). Together with the westward diminishing of the OT, these observations characterize the southwestern Ryukyu system as an edge regime that is heavily influenced by the juxtaposing continental lithosphere.

Despite recent progress, the characteristics of anisotropy in the edge regime remain unknown due to the lack of in-situ sampling. The observations from the land stations in northern Taiwan and the Ryukyu arc leave a gap encompassing the edge zone. In this work we present a unique data set from ocean-bottom seismometers (OBSs) that help fill the gap and constrain the dynamics of the edge of the southwestern Ryukyu subduction zone.

2. Data

Fig. 1 shows the events and stations used in this study. The broadband OBSs at S002 and S005 have a velocity response flat to 120 s and were deployed for 10 months in 2006–2007 and 2008–2009, respectively. The five-unit array consists of one broadband (60 s) and 4 short-period (3 s) OBSs and was deployed for 3 months in 2010. The seismological performance and engineering aspects of these OBSs can be found in Kuo et al. (2009), Lin et al. (2010b), and Wang et al. (2011). These OBS deployments, although sparse, allow a first glimpse into the mantle wedge under the arc and back arc in the edge regime of the subduction zone system. In contrast, The F-net stations (Okada et al., 2004) on the Ryukyu islands are located too near the trench and only allow sampling of the fore-arc mantle for local intraslab events (Long and van der Hilst, 2006). We analyzed data from the F-net station YNG concurrently with the OBS array as a reference.

On the land side, broadband data for 2005–2009 recorded by BATS (Broadband Array in Taiwan for Seismology; http://bats.earth.sinica.edu.tw) stations in NE Taiwan provide a denser constraint across the Eurasian lithosphere-mantle wedge boundary and on the Eurasian lithosphere in NE Taiwan. We measured shear-wave splitting for *S* waves from intraslab events deeper than 70 km to ensure a dominant sampling of the arc and back-arc mantle relative to the overriding plate. Shear waves from events too deep may have long refracting paths through the slab before entering the mantle wedge, and the lower limit of event depth was set at 150 km (Fig. 2).

We used a shear-wave window of 40° for OBSs to avoid the distortion of waveforms at the surface. The shear-wave window is reduced to 25° for the land stations for the following two reasons. First, events far to the east of the land stations may have shear waves traveling long paths within and along the strike of the slab. Second, the lithosphere and crustal structures straddling the continent-mantle wedge boundary zone may be more complicated than beneath the rifting center. Waveforms were deconvolved to