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Big mantle wedge, anisotropy, slabs and earthquakes beneath the Japan Sea

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ABSTRACT

The Japan Sea is a part of the western Pacific trench-arc-backarc system and has a complex bathymetry and intense seismic activities in the crust and upper mantle. Local seismic tomography revealed strong lateral heterogeneities in the crust and uppermost mantle beneath the eastern margin of the Japan Sea, which was determined using P and S wave arrival times of suboceanic earthquakes relocated precisely with sP depth phases. Ambient-noise tomography revealed a thin crust and a thin lithosphere beneath the Japan Sea and significant low-velocity (low-V) anomalies in the shallow mantle beneath the western and eastern margins of the Japan Sea. Observations with ocean-bottom seismometers and electromagnetometers revealed low-V and high-conductivity anomalies at depths of 200–300 km in the big mantle wedge (BMW) above the subducting Pacific slab, and the anomalies are connected with the low-V zone in the normal mantle wedge beneath NE Japan, suggesting that both shallow and deep slab dehydrations occur and contribute to the arc and back-arc magmatism. The Pacific slab has a simple geometry beneath the Japan Sea, and earthquakes occur actively in the slab down to a depth of ~600 km beneath the NE Asian margin. Teleseismic P and S wave tomography has revealed that the Philippine Sea plate has subducted aseismically down to the mantle transition zone (MTZ, 410–660 km) depths beneath the southern Japan Sea and the Tsushima Strait, and a slab window is revealed within the aseismic Philippine Sea slab. Seismic anisotropy tomography revealed a NW-SE fast-velocity direction in the BMW, which reflects corner flows induced by the fast deep subduction of the Pacific slab. Large deep earthquakes (M > 7.0; depth > 500 km) occur frequently beneath the Japan Sea western margin, which may be related to the formation of the Changbai and Ulleung intraplate volcanoes. A metastable olivine wedge is revealed within the cold core of the Pacific slab at the MTZ depth, which may be related to the deep seismicity. However, many of these results are still preliminary, due to the lack of seismic stations in the Japan Sea. The key to resolving these critical geoscientific issues is seismic instrumentation in the Japan Sea, for which international cooperation of geoscience communities in the East Asian countries is necessary.

1. Introduction

The Japan Sea is a back-arc basin separating the Japanese island arc from the Korean Peninsula and the NE Asian continent (Fig. 1). This marginal sea is a part of the western Pacific trench-arc-backarc system and has a complex bathymetry, heterogeneous crustal structure and intense seismic activities (e.g., Sato et al., 1986; Hirata et al., 1989, 1992; Ohtake et al., 2002) (Fig. 2). So far, many geophysical and geological studies have been made to investigate the formation and evolution processes of the Japan Sea, and now it is generally considered that this marginal sea was produced by back-arc opening associated with subduction of the Pacific plate beneath the Eurasian plate. Paleomagnetic researchers proposed that the formation of the Japan Sea was caused by fan-shaped opening during 21 to 12 Ma (e.g., Otofuji et al., 1985, 1991). However, other workers suggested that a pull-apart opening occurred along shear zones in the eastern and western margins of the Japan Sea (e.g., Lallemand and Jolivet, 1985; Jolivet et al., 1995). Later, many more studies have been made to investigate the timing of the back-arc spreading in the Japan Sea, and the results generally show that the spreading took place during a period of 21–15 Ma (e.g., Kaneoka et al., 1992; Tominaga et al., 2000; Kano et al., 2007; Nohda, 2009). However, the detailed processes of the back-arc spreading are still not well understood.

During the past three decades, many researchers have investigated the crustal structure beneath the Japan Sea by conducting

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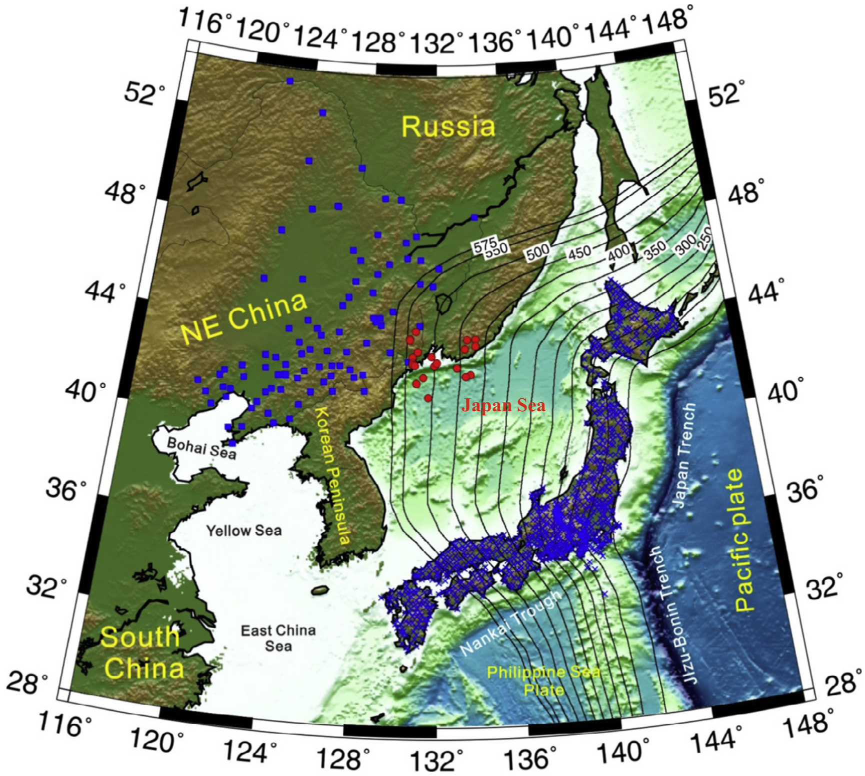

Fig. 1. Tectonic background of the Japan Sea and surrounding regions. The colors show the surface topography and bathematic relif. The black contour lines show the depths to the upper boundary of the subducting Pacific slab. The blue squares and blue crosses denote seismic stations in NE China and the Japan Islands, respectively. The red dots denote some deep earthquakes. Modified from Jiang et al. (2015). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

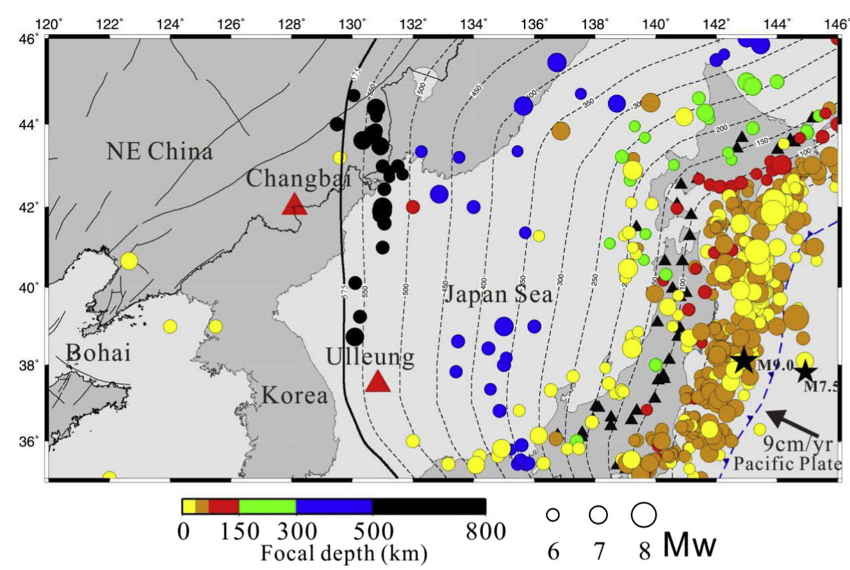

Fig. 2. Distribution of large earthquakes (M ≥ 6.0) that occurred from January 1900 to September 2009 compiled by the International Seismological Center. The earthquake magnitude scale is shown at the bottom. The color of the dots denotes the focal depth; its scale is shown at the bottom. The black stars represent the Tohoku-oki main shock (Mw 9.0) and an aftershock (Mw 7.5) in the outer-rise, which occurred on 11 March 2011. The contour lines show the depths to the upper boundary of the subducting Pacific slab down to 575 km depth, while towards the west the Pacific slab becomes flat in the mantle transition zone. The blue sawtooth line denotes the Japan Trench. The red triangles denote the active Changbai and Ulleung intraplate volcanoes. The black triangles denote active arc volcanoes on the Japan Islands. The black lines in China denote the major active faults. After Zhao and Tian (2013). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

active-source seismic experiments and adopting various geophysical approaches. These studies have revealed significant lateral variations in the crustal thickness and strong structural heterogeneities in the crust and uppermost mantle beneath the Japan Sea (e.g., Katao, 1988; Hirata et al., 1989, 1992; Shinohara et al., 1992; Kurashimo et al., 1996; Kim et al., 1998; Nishizawa and Asada, 1999; Nishisaka et al., 2001; Sato et al., 2004, 2006a,b; Kulinich and Valitov, 2011; Nakahigashi et al., 2013). At the same time, global and regional tomographic studies have revealed large-scale mantle structures beneath East Asia including the Japan