Imaging melting of Philippine-Sea Plate subducting beneath central Japan

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The central Japan is a globally unique seismo-tectonic zone with the complex interaction of the Eurasian, North American, Pacific (PAC), and Philippine-Sea Plate (PHS). Thermal and petrologic models predict that the oceanic crust of the young (<20 Ma) PHS subducting beneath central to south-west Japan is ~300^{o} to 500^{o}C warmer than that of the old (~100 Ma) PAC subducting beneath northeast Japan, and is thus more prone to melting. Deriving a high-resolution image of the slab melting is a key to understand the basics of plate tectonics and magma genesis.
Although several structural models of the PHS, based on travel-time tomography (Hirose et al., 2008) and receiver function analyses (Shiomi et al., 2004), detected the gross features of subduction zone, the melting in PHS, at a scale on the order of seismic wavelength, is yet to resolve from the tomography image of the slab due to the coarser spatial resolution. The high-resolution waveform analysis and numerical simulation of wave propagation are alternatives to obtain such images of complex subduction zone. In this direction, Padhy et al. (2014) recently detected slab thinning/tearing in PAC by analyzing deep-focus earthquakes beneath central Japan. Similarly, Lin et al. (2013) proposed slab melting as one of the probable causes for the observed spindle-shaped, highly scattered waveforms from mantle earthquakes in central Japan. Their study is, however, based on mere observation of only two mantle earthquakes recorded at few stations. To build on this work, we extensively analyzed waveforms of intermediate (50-300 km) to deep (>300 km) intra-slab moderate-sized (M4-6) earthquakes occurring in central Japan and conducted numerical simulation to derive a fine-scale PHS model, incorporating slab melting in the model.
Spindle-shaped seismograms with strong excitation of slowly decaying, long-duration high-frequency coda are observed for a group of PAC events occurring in northern part of central Japan recorded by Hi-net. These waveform anomalies can be explained by the 2-D finite difference method (FDM) simulation of high-frequency (up to 10 Hz) seismic waves in subduction zone containing features such as the melting in PHS crust, serpentinized mantle wedge, and the heterogeneous PAC. Comparison of observations and simulations shows that the data are primarily explained by the presence of an anomalous low-velocity zone in upper mantle, that focuses the high-frequency energy, which is further guided through multiple forward scattering by the overlying heterogeneous PHS. These anomalies inside the PHS exhibit the net strong effect of scattering of high-frequency seismic waves. The data are also moderately explained by melting, mainly in the basaltic crust of PHS; features like melting of the eclogitic crust and serpentinized wedge have a minimum effect on waveforms. By further conducting a suite of simulations by changing the shape and location of the mantle anomaly, as constrained by both findings of very similar study on PAC thinning/tearing (Padhy et al., 2015), as well as the gradual change in waveform anomaly in the region, we find that all the models explain the observations, although the vertically elongated mantle anomaly is more effective for stronger focusing over a longer distance range. We also examined the influence of thickness of melt and its location in relation to the plate bending on waveform changes. The simulation results show that the melt zone, especially in the basaltic crust, has to be thicker than 10 km to produce a detectable waveform effect. The findings of this study have important implications for our understanding of the mechanism of intermediate to deep earthquakes under the dehydration embrittlement hypothesis.

Keywords: Wave propagation, Finite-difference method simulation, Philippine-sea plate, Melting

