Resolving 3D rheology of northeastern Japan using postseismic deformation following the 2011 Tohoku-oki earthquake

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In the ten years since the 2011 Tohoku-oki earthquake geodetic observations of the postseismic deformation, recorded both onshore and offshore, have revealed a highly complex rheological structure in the subsurface of Japan. In addition to the nation-wide geodetic network (GEONET), Tohoku University deployed dense networks of GNSS stations in the Miyagi-Yamagata and Fukushima-Niigata regions. Observations from these networks illustrate a pronounced heterogeneity in the surface deformation across northeastern (NE) Japan. In particular, the Miyagi-Yamagata region closer to the main rupture area exhibits intense forearc uplift with localized subsidence around the volcanic front (Muto et al., 2019, Sci. Adv.), whereas uplift has been observed throughout the volcanic front and forearc of the Fukushima-Niigata region.

Over the past decade, a number of studies have gleaned new insight from the postseismic deformation of NE Japan, shedding light on the subsurface rheology and the role of coupled interactions between viscoelastic flow in the mantle and stress-driven afterslip on the plate interface (e.g., Agata et al., 2019, Nat. Commun; Freed et al., 2017, EPSL; Hu et al., 2016, JGR; Muto et al., 2019, Sci.Adv.). Recent studies have not only highlighted the presence of small-scale low viscosity bodies beneath a number of Quaternary volcanoes (Muto et al., 2016, GRL), but also the stagnancy and ubiquity of the forearc mantle (Uchida et al., 2020, Nat. Commun). Furthermore, a strong contrast has been observed in the frictional behavior of the megathrust between central areas near Miyagi and southern areas near Fukushima (Nishikawa et al., 2019, Science).

We have taken advantage of newly acquired observations along the Fukushima-Niigata area and utilized these observations to explore three-dimensional rheological heterogeneities in the mantle wedge mechanically coupled to afterslip on the megathrust interface with variable frictional properties. We developed a numerical model using laboratory-derived constitutive laws to reproduce the geodetic observations (Ozawa et al., 2012, JGR; Tomita et al., 2015, Sci. Adv.; Watanabe et al., 2014, GRL). Our results suggest that the rapid uplift in the Miyagi forearc was caused by deep afterslip underlying a narrow cold nose in the mantle wedge, in contrast to a wider cold nose beneath the Fukushima forearc without significant deeper afterslip. The model resolves along-arc rheological heterogeneity in good agreement to the cumulative observations across ten years in both magnitude and azimuth, as well as their time-series over the 5 years. Our results illuminate the forearc mantle rheology highlighting the variability of cold nose geometry and frictional properties on the subduction zone plate boundary along the arc. Therefore, the dense geodetic network, as well as the numerical model based on the laboratory constrained flow laws of rocks contribute to resolve 3D rheological heterogeneity of the NE Japan imaged through the postseismic deformation of the 2011 Tohoku-oki earthquake.

Keywords: 2011 Tohoku-oki Earthquake, Postseismic deformation, Rheology, Viscoelastic relaxation, Afterslip

