Weak Base of the Upper Mantle Revealed by Postseismic Deformation Following a Deep (~560 km) Earthquake

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Mantle rheology is one of the least constrained properties despite its importance in mantle dynamics. In this study, we introduce a new approach to understand the viscosity structure by examining the Earth's response to deep earthquakes occurring near the bottom of the upper mantle. We utilize seismically constrained earthquake source properties and combine numerical modeling of viscoelastic deformation of upper mantle and the GPS observation of post-seismic deformation from deep earthquakes.

Major challenge in utilizing the post-seismic deformation from deep earthquakes, however, is on the observation side. So far, most GPS observations have been limited to shallow earthquakes since the amplitude of the surface deformation from deep events is relatively small. Here, we take advantage of data processing techniques such as independent component analysis to extract post-seismic signals from deep earthquakes. We examine the GPS data of one of the largest deep earthquakes ever recorded, 2018 M_W 8.2 Fiji earthquake which occurred at ~560-km depth. We detect a large scale post-seismic deformation that has been taking place for about two years. The overall directionality and amplitude of the deformation strongly suggest the presence of rheologically weak structure (with viscosity of 10^{17}-10^{18} Pa·s) on top of the lower mantle. Such a weak zone could explain slab flattening and orphaning observed in numerous subduction zones, which are otherwise challenging to explain in the whole-mantle convection regime. The low-viscosity layer may result from superplasticity induced by the post-spinel transition, weak $CaSiO_3$ perovskite, high water content, or dehydration melting.

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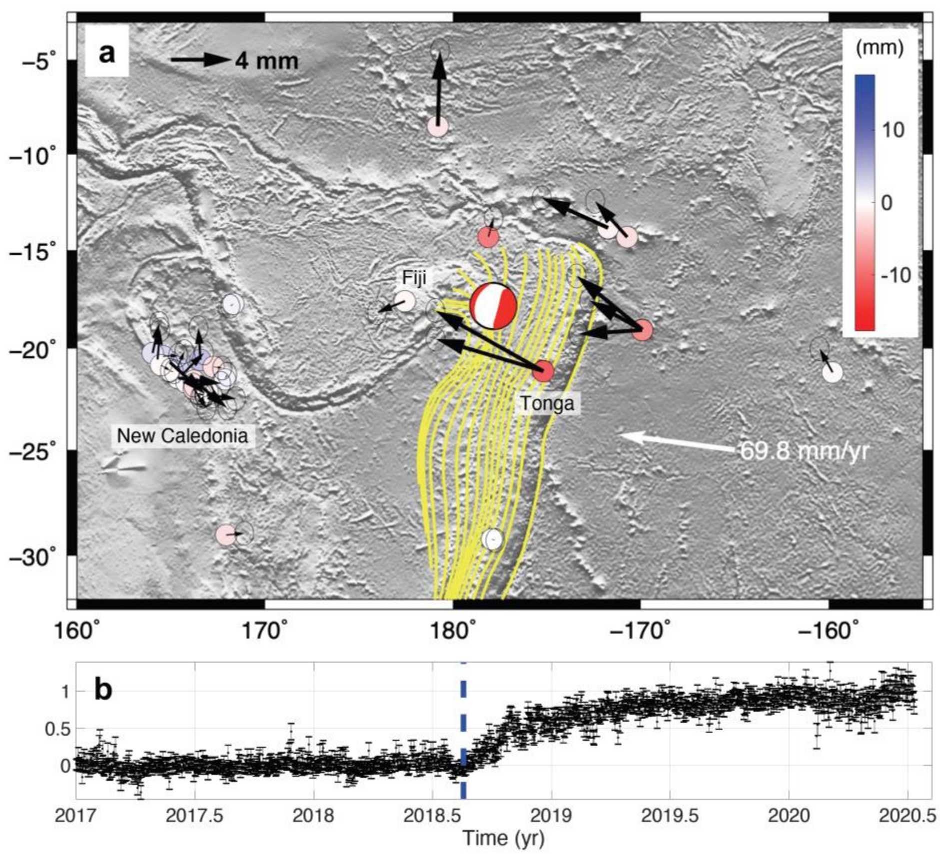

a. Deformation detected at GPS stations (circles) following the ~560-km deep, 2018 Fiji earthquake (red and white beach ball). Colors of the circles represent the vertical displacements, while black arrows represent the horizontal displacements. Contours of the downwelling flow (yellow lines) and the Pacific plate motion (white arrow) with respect to the Australian plate are shown.

b. The normalized time evolution of the detected deformation over a ~2-yr period. The timing of the earthquake is shown with the blue dashed line.