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Lithospheric flexure at the Hawaiian Islands and its implications for mantle rheology

Shijie Zhong (1) and Anthony Watts (2)

(1) Department of Physics, University of Colorado, Boulder, USA (shijie.zhong@colorado.edu), (2) Department of Earth Sciences, University of Oxford, Oxford, UK (tony@earth.ox.ac.uk)

The response of the lithosphere to long-term geological loads such as volcanoes, sediments and ice provide important insights to both plate mechanics and mantle dynamics. One of the largest loads on Earth's surface are the shield volcanoes that comprise the Hawaiian Islands in the Central Pacific Ocean. We have developed a 3-D finite element model for calculating the flexure and stress associated with the emplacement of an arbitrary-shaped volcano load on a crust and mantle with realistic non-linear viscoelastic rheology, including frictional sliding, low-temperature plasticity, and high-temperature creep. By comparing model predictions with seismic reflection and refraction observations of the depth to the top of the oceanic crust and the depth dependence of seismicity at the Hawaiian Islands, we have been able to constrain the long-term rheological properties of intraplate, plume influenced, Late Cretaceous (83-96 Ma) oceanic lithosphere. Our calculations show that while the load-induced surface flexure is insensitive to high-temperature creep, it is sensitive to both the frictional sliding and low-temperature plasticity laws. Results show that a frictional coefficient ranging from 0.25 to 0.70 and a low-temperature plasticity law that is significantly weaker than ones recently proposed from experimental rock mechanics data are required in order to account for the observations. For example, a frictional coefficient of 0.1 weakens the shallow part of the lithosphere so much that it causes the minima in strain rate and stress to occur at too large depths to be consistent with the observed depth distribution of seismicity while the low-temperature plasticity law of Mei et al (2010) strengthens the deep part of the lithosphere so much that it predicts too small an amplitude and long a wavelength flexure compared to the observed. Our best fit model suggest the maximum stress that accumulates in the flexed lithosphere beneath the Hawaiian Islands is 100-200 MPa, and therefore this stress may be viewed as among the largest that Earth's lithosphere is capable of supporting on long geological time-scales.