Geophysical Research Abstracts
Vol. 17, EGU2015-14525, 2015
EGU General Assembly 2015

Magma explains low estimates of lithospheric strength based on flexure of ocean island loads

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One of the best ways to constrain the strength of the Earth's lithosphere is to measure the deformation caused by large, well-defined loads. The largest, simple vertical load is that of the Hawaiian volcanic island chain. An impressively detailed recent analysis of the 3D response to that load by Zhong and Watts (2013) considers the depth range of seismicity below Hawaii and the seismically determined geometry of lithospheric deflection. These authors find that the friction coefficient for the lithosphere must be in the normal range measured for rocks, but conclude that the ductile flow strength has to be far weaker than laboratory measurements suggest. Specifically, Zhong and Watts (2013) find that stress differences in the mantle lithosphere below the island chain are less than about 200 MPa. Standard rheologic models suggest that for the $\sim$50 km thick lithosphere inferred to exist below Hawaii yielding will occur at stress differences of about 1 GPa. Here we suggest that magmatic accommodation of flexural extension may explain Hawaiian lithospheric deflection even with standard mantle flow laws.

Flexural stresses are extensional in the deeper part of the lithosphere below a linear island load (i.e. horizontal stresses orthogonal to the line load are lower than vertical stresses). Magma can accommodate lithospheric extension at smaller stress differences than brittle and ductile rock yielding. Dikes opening parallel to an island chain would allow easier downflexing than a continuous plate, but wound not produce a freely broken plate. The extensional stress needed to open dikes at depth depends on the density contrast between magma and lithosphere, assuming magma has an open pathway to the surface. For a uniform lithospheric density ρ_L and magma density ρ_M the stress difference to allow dikes to accommodate extension is: $\Delta\sigma_{xx}$ (z) = g z (ρ_M - gρ_L), where g is the acceleration of gravity and z is depth below the surface. For reasonable density values (i.e. ρ_L = 3300 Kg/m^3 and ρ_M = 2800 kg/m^3) this 'magmatic yield stress' is 250 MPa at 50 km depth. Dikes accommodating flexing below Hawaii would be at most about 2 km wide. This amount of intrusion would significantly heat the lithosphere, leading to lower stress differences below the islands. Since Hawaii marks the highest magma flux on Earth today it seems that 'magma assisted flexure' offers a viable alternative to extremely weak lithospheric rheology as an explanation for low stresses below this load.