SEA FLOOR SWELLS AND MANTLE PLUMES

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Most of the intraplate oceanic hot spots are located on the crest of broad topographic swells in the sea floor. These swells have Gaussian-shaped profiles, with up to 1.6 km of relief and half-widths of 200-300 km. Swells are accompanied by positive geoid height anomalies with amplitudes of 6-8 m. In the Atlantic and Pacific basins alone, swells cover an area equal to 10% of the earth's surface. Next to boundary layer contraction, swells are the most important cause of uplift and subsidence in oceanic lithosphere.

Calculation of buoyancy-supported topography and geoid height have been combined with uplift data from laboratory experiments to assess whether sea floor swell can be produced by mantle plumes. The critical constraints are: (i) swell topographic profiles, (ii) geoid height/topographic height ratios, and (iii) uplift rates, estimated to be 0.2 km/ma.

The laboratory experiments, made in strongly thermo-viscous glucose solutions, give information on the characteristics of mantle plumes. The morphology of low viscosity plumes is governed by their interaction with mantle convection. In a convective environment, elongate, continuous plumes are subject to Whitehead instabilities. They break up into chains of nearly spherical Stokes blobs. The blobs rise steadily through the asthenosphere, then decelerate and collapse as they reach the base of the lithosphere. The free surface swells rapidly as the plume approaches the lithosphere, reaches a maximum height, and then subsides on a slow time scale as the plume collapses. At maximum elevation the swell profile is approximately Gaussian. The swell crest relaxes first, producing, during the subsidence phase, a plateau-like topography. It is found that the maximum swell height depends on the thickness of the lithosphere. The maximum swell is approximately the same as predicted for uplift in an isoviscous half space, provided that the plume diameter exceeds the lithospheric thickness. Uplift is reduced if lithospheric thickness exceeds the plume diameter.

Experimentally determined plume ascent and collapse histories are scaled to mantle conditions and are used as input for calculations of the time evolution of sea floor swells. The uplift is calculated for a model consisting of an isoviscous half space capped by an elastic lid, using a Green's function approach. A comparison with data from the Hawaiian Swell and the Bermuda Rise indicates that, in order to support these swells, spherical mantle plumes must be 300-350 km in diameter and must have negative density anomalies of approximately 2%. With these characteristics, mantle plumes ascend at 20 cm/a and generate 1.5 km of uplift in 6 ma. The most difficult constraint to satisfy are the observed geoid/topography ratios, which require a low density source at 50-70 km depth. The ability of mantle plumes to reach these depths by viscous flow depends on the creep rheology of the lower lithosphere. Plumes can creep to 60 km depth in 90 ma old lithosphere if the creep activation energy E* is less than 50 kcal/mole. If E* = 100 kcal/mole, plumes cannot creep above 90 km depth in old lithosphere. In that case some additional mechanism for eroding the lithosphere is needed.