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'Missing' Dynamic Topography: Geodynamic Evidence Against Deeply Layered Mantle Convection

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Two-layer convection models have zoomed back into vogue with the recent suggestion that it may be possible to reconcile seismic images of the mantle with a dense 'primitive' mantle layer in the bottommost ~1/3 of the mantle (Kellogg et al., 1999). While this type of model may be able to reconcile current geochemical evidence (elsewhere we will present results of geochemical modelling tests of this hypothesis), it appears to have a fundamental problem in satisfying a basic geodynamic observation - that Earth's geoid has an amplitude of ~±100 m, while Earth's dynamic topography (as best measured by deviations of ocean floor topography from the depth variations due to cooling ocean lithosphere) is at most several hundred meters (RMS) in amplitude. As first noted by Thoroval et al., this lack of dynamic topography is best explained if the deep mantle geoid-sources (as they are imaged by seismic topography) are compensated by relief at a shallower internal density interface. Thoroval et al. suggested that this interface could be the 660-km boundary, an even shallower asthenosphere horizon would do an even better job of reducing surface dynamic topography while still producing the strong observed geoid anomaly.

Here we present our best estimate of Earth's dynamic topography beneath oceans and continents. We show how a dynamic asthenosphere 'layer', fed by upwelling plumes and consumed by the growth and subduction of overlying lithosphere, is compatible with current seismic, geoid, and topography evidence. This 'asthenosphere' may extend to as deep as 660-km, but it is NOT isolated from underlying mantle, so that material stays for <200-600 Ma within the asthenosphere before processing at a mid-ocean ridge. The recent 'deep' two-layer model requires a similar 'asthenosphere' layer to satisfy geoid and dynamic topography constraints. We will also discuss how our preferred 'whole mantle + asthenosphere' evolution scenario is compatible with current estimates of Earth's heat production and heat loss.