Geophysical Research Abstracts
Vol. 13, EGU2011-6951, 2011
EGU General Assembly 2011

Spatial and Temporal Variation of Dynamic Topography on Earth

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Convective circulation of the Earth's mantle maintains plate motion but we know little about the spatial and temporal details of this circulation. Fortunately, the circulation pattern beneath lithospheric plates generates dynamic topography at the Earth's surface. Accurate maps of the spatial and temporal pattern of dynamic topography will profoundly affect our understanding the the relationship between surface geology and deep Earth processes. However, dynamic topography is difficult to measure because crustal and lithospheric thickness and density changes are the dominant control of surface elevation. As a result, smaller dynamic signals are swamped. Important progress can be made by exploiting our quantitative understanding of the thermal evolution of oceanic lithosphere (Winterbourne et al., 2009). We have analyzed seismic reflection and wide-angle profiles from continental margins worldwide. First, we calculate the water-loaded depth of old oceanic lithosphere adjacent to each margin. Secondly, we estimate residual depth anomalies by comparing our water-loaded depths to the global age-depth curve. These residual depth anomalies are then compared with dynamic topographic predictions made from long-wavelength gravity anomalies. Positive and negative deviations from the global age-depth curve are common and have amplitudes of ±1 km and wavelengths of 10^2–10^4 km. They mostly, but not always, correlate with long-wavelength gravity anomalies. The distribution of dynamic topography throughout the rest of the oceanic realm can be supplemented by using ship-track data in regions with sparse sedimentary cover, by exploiting the mid-oceanic ridge system, and by examining the age-depth relationship in marginal oceanic basins. On the continents, it is more difficult to measure dynamic topography with the same accuracy since the density structure of continental lithosphere is so variable. Progress can be made on three fronts. First, long-wavelength gravity anomalies which straddle continental margins are an obvious and important guide. Secondly, stratal geometries across continental shelves contain key information about surface elevation changes if sea-level variation is known. In several cases, well-calibrated seismic surveys can be used to constrain spatial and temporal patterns of dynamic topography. For example, there is excellent evidence for convectively driven domes along the western margin of Africa. These domes grew rapidly during Neogene times. Finally, Roberts & White (2010) have shown that longitudinal river profiles can be inverted as a function of regional uplift rate history. If used with care, this method can be used to map spatial and temporal patterns of dynamic topography continent-wide.

Roberts, G. & White, N., 2010. Estimating uplift rate histories from river profiles using African examples. Journal of Geophysical Research, 115, B02406.

Winterbourne, J., Crosby, A., & White, N., 2009. Depth, age and dynamic topography of oceanic lithosphere beneath heavily sedimented Atlantic margins. Earth and Planetary Science Letters, 287, 137–151.