EVIDENCE FROM SATELLITE ALTIMETRY FOR SMALL-SCALE CONVECTION IN THE MANTLE

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Small-scale convection can be defined as that part of the mantle circulation in which upwellings and downwellings can occur beneath the lithosphere within the interiors of plates, in contrast to the large-scale flow associated with plate motions where upwellings and downwellings occur at ridges and trenches. The two scales of convection will interact so that the form of the small-scale convection will depend on how it arises within the large-scale flow. Observations based on GEOS-3 and SEASAT altimetry suggest that small-scale convection occurs in at least two different ways.

Filtered geoids and smoothed topography have been constructed for the world's oceans using GEOS-3 altimetry and digital bathymetry (Parsons et al., 1983; Watts et al., 1984). Residual depth and geoid anomalies were derived by removing the variations in geoid and depth that result from changes in the thermal structure of the plates. The resulting geoid and depth anomalies in the wavelength band 300-4000 km vary in a coherent way over large parts of the oceans. This coherent behaviour, the amplitude of the geoid (~10 m) and depth (~1 km) anomalies and their wavelength (2000-3000 km) can be simply explained as the result of convection beneath the lithosphere in a layer driven by heating from below.

The principal contributions to calculated geoid and depth anomalies for convection beneath an elastic conducting lid come from horizontal temperature variations occurring just beneath the bottom of the lid. This is reflected in the effective depth of compensation determined from the geoid-depth relationship. An effective depth of compensation smaller than the thermally-defined plate thickness requires a viscosity structure such that the bottom part of the thermally-defined plate can also form the upper thermal boundary layer of the small-scale convection. This then allows the short timescales associated with the uplift of mid-ocean swells like Hawaii, the appropriate time-scale being that of advection across the upper thermal boundary layer.

A second, different form of small-scale convection is suggested by the lineated pattern of short-wavelength (200-500 km) undulations observed in SEASAT-derived data in the central Pacific Ocean (Haxby and Weissel, 1983). The lineated pattern can be seen clearly in SEASAT altimetry on descending arcs that has been bandpassed for wavelengths in the range 40-500 km or in the deflection of vertical along the same arcs smoothed to remove wavelengths shorter than 90 km. The pattern shows a number of distinct features. It is aligned with the direction of "absolute" motion of the Pacific plate. The pattern occurs over ocean floor that varies in age from 5 Ma to 65 Ma and is oblique to the fracture zones over pre-Miocene seafloor. The deflection of the vertical derived along arcs near the East Pacific is quiet in the 200-500 km wavelength range compared to arcs over ocean floor older than 5 Ma.

The lineated pattern can be interpreted as an expression of small-scale instabilities beneath the lithosphere that result from the cooling of the plate as it moves away from the ridge (Parsons and McKenzie, 1978). If the instability is to develop by ages as young as 5 Ma a low viscosity zone approximately 100 km thick beneath the plate with a viscosity lower by three orders of magnitude than the values obtained from studies of post-glacial uplift is required. The alignment of the instabilities with the direction of motion of the plate would then be a result of the shear flow that would be concentrated within this low viscosity zone.

The availability of GRM-derived gravity would enable the possibility of small-scale convection beneath stable continental regions to be investigated, e.g., in the area around the intra-plate volcanism in North Africa. Also a uniform gravity data set extending across continent-ocean boundaries would facilitate the analysis of gravity regardless of whether continental or oceanic tectonics was the primary concern.

References

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