12th International Workshop on Modeling of Mantle Convection
and Lithospheric Dynamics

August 20th to 25th 2011, Döllnsee Germany
©Authors(s) 2011

Interpreting sea level and stratigraphic records over long time-scales on a dynamic Earth

Michael Gurnis[1], Sonja Spasojevic[1]
[1]*Seismological Laboratory, California Institute of Technology, Pasadena, CA, United States*
gurnis@gps.caltech.edu
skisin@gps.caltech.edu

Dynamic topography could have an important influence on sea level fluctuations and in turn be recorded in the sedimentary record on continents and passive margins. By inverting the problem, we show that the Phanerozoic rock record can be used as an important constraint on mantle dynamic processes.

Since the emergence of plate tectonics, a simple connection between mid-oceanic ridge volume and 'sea level' has been made. Although there is general agreement between the inundation since the Late Cretaceous inferred from remaining marine sediments on continental platforms and that inferred from volume of ocean basins in plate tectonic reconstructions, the model fails to conserve mass. We consider conservation of mass along with the physics of dynamic topography from flow in a viscously dominated fluid. A more expansive theoretical view of sea level in principle predicts the vertical motions of continents since the Late Cretaceous that are discrepant from the overall trend, i.e. epeirogenic motions versus global sea level. However, dynamic topography is essentially a regional, relative sea level change and simple models suggest unconformities should be an important long-term expression of dynamic topography.

Details of regional vertical motions provide guidance on how the rock record can be connected to models. We describe case studies from North America, Australia, New Zealand, and Indonesia using different combinations of present day residual topography maps, isopachs, paleoshorelines, tectonic subsidence curves, and rock uplift inferred from low temperature thermochronology. Several different kinds of signals over length scales of $<$ 100 km to $>$2,000 km and with amplitudes $>$100 m can be identified. Both long-wavelength tilting as well as the spatial migration of sediment depocenters are evident. In the case a signal on the east coast of the United States since the Eocene, we argue that it has been misinterpreted as a 'eustatic' signal.

The vertical motions inferred from the rock record is intimately tied to local sea level and therefore the record should be interpreted in terms: (a) evolving mantle convection and subduction (and by consequence evolving topography and the geoid); (b) plate motions with respect to this changing mantle (since the rock record is carried by the plates); and (c) the carrying capacity of the oceans which is a function of sea floor ages, dynamic topography, and the changing surface area of continents. We have embodied these ideas in a workflow linking a paleogeographic system with spherical mantle convection. Both forward and inverse models of mantle convection matching present day seismic tomography and the geoid are used in our analyzes.

For North America since the Cretaceous the model that best fits an extensive set of tectonic subsidence curves and paleo-shorelines is consistent with the putative flat lying slab associated with the Laramide orogeny. A significant east-ward shift of a depocenter is consistent with a high resolution set of tectonic subsidence curves from Utah to Colorado. The dynamic topography effect continued to shift eastward, such that today we predict that the east coast of the US should be dynamically subsiding, potentially consistent with the mismatch between relative sea level curves on the east coast and putative eustatic curves. With a forward approach, we have been able to integrate anomalous observations from the New Zealand-Antarctica conjugate margins including the large Ross Sea geoid low and 0.5-0.9 km of excess tectonic subsidence of Campbell plateau since the Cretaceous.

In some global models, self-consistency between buoyancy of subducted material and the paleo-ages of oceanic crust overcomes mass conservation issues in earlier concepts of sea-level change. In general, the common-component to sea-level change due to dynamic topography experienced by all continents tends to increase since the Late Cretaceous, although the effects is dependent on mantle viscosity and the strength of lower mantle upwellings. This effect partially compensates the sea-level fall driven by the changing age distribution of the sea floor. In order to match the marine flooding globally, we find that a common component to sea-level change, mostly driven by the age distribution of the sea floor, is required, although for many continents the dynamic topography signal may dominate.