4/22/10

Comment on:

Mantle Flow Drives the Subsidence of Oceanic Plates, by Claudia Adam & Valérie Vidal, *Science*, **328**, 83 (2010)

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The subsidence of the sea floor is usually considered to be a consequence of its passive cooling, from above, since its formation at a ridge. However, bathymetry is a unique function of plate age only if the underlying mantle is isothermal and homogeneous. The cooling plate model (*McKenzie & Bickle*, 1988; McK&B) assumes that cooling cannot occur deeper than about 100 km; in effect, the thermal conductivity below that depth is assumed to be zero. This has always been an *ad hoc* and unsatisfactory solution to the bathymetry flattening problem. There is no reason why the mantle, prior to the creation of at a mid-ocean ridge, or the break-up of a continent, should be isothermal, adiabatic or homogeneous. Thermal boundary layers can be built atop older thermal boundary layers and plates can migrate over hotter or colder mantle. But all previous models for seafloor flattening are based on the hypothesis that the thermal structure of the oceanic lithosphere is determined entirely by its age, i.e. the time elapsed since its creation at a ridge. If the thermal boundary layer never gets thicker than 100 km then this implies that the mantle to this depth under new ridges is replaced by isothermal mantle. The lateral temperature gradients that drive mantle convection must be below this depth. McK&B argue that subplate temperature differences are only about 40˚C. Alternatively, the cooling plates and slabs drive themselves and drag the underlying mantle. The density gradients that drive plate tectonics and mantle convection are therefore primarily in the outer 200 km and mantle temperature gradients are due to insulation and cooling from above. There is very little tomographic power below 200 km depth; this favors the passive mantle flow model.

Recently, *Adam & Vidal* (2010), hereafter AV, argue that mantle convection and the history of plate motions determines the thermal structure of the plates and the subsidence of the seafloor, rather than cooling from above. Sea-floor depth varying as the square root of the distance from the ridge is a consequence of mantle convection and flattening after about 70 Ma is a consequence of changes in mantle convection. This implies that the plate is mechanically (but not thermally) decoupled from the mantle and that the cooling times of the plate and the underlying mantle differ.

AV use the term “lithosphere” for the thermal boundary layer (TBL) or the layer that cools by conduction, rather than the “strong or elastic layer”. They note that convection calculations with the usual boundary conditions include a surface boundary layer that thickens with time and with distance from an upwelling. They assume, therefore, that a TBL, their “lithosphere”, requires a convecting system. They argue that a drastic change in mantle convective will either thicken or thin the “lithosphere” if the temperature at its base, defined by the new convective system, is cooler or hotter than it was previously. After several tens of million years, the "lithosphere" will adopt the structure of the thermal boundary layer for the new underlying mantle, independently of the initial state or the age of the plate. In other words, the TBL thermal structure is controlled from below, and on a relatively short time scale.

To model mantle convection they choose the NNR (No Net Rotation) reference frame and assume that this is more than just a convenient arbitrary reference; it actually accurately describes the motions and temperatures of the subplate mantle. Motion vectors in this frame differ from those defined by ridges, fracture zones and magnetic stripes and, according to AV, define the true motion of the upper 100 km of the mantle and the lower part of the "lithosphere". The model is based on the hypothesis that mantle convection, and not cooling from an initial state, drives the subsidence of the oceanic floor.

AV argue that plate motion directions, as indicated by magnetic stripes and fracture zones, are not the same as the motions of the immediately underlying thermal boundary layer, as inferred from the assumption of the no net rotation hypothesis. They view the thermal boundary layeras the top of the convecting mantle, which is not moving with the plates, or at least that part that contains the magnetic stripes and the fracture zones. The plates are therefore decoupled from the shallow underlying mantle and, as they slide around they can encounter hotter or colder mantle, or mantle that has cooled more or less than the plate above. The plate then adopts the temperature of the underlying mantle and the age of the crust is not the same as the thermal age of the plate.

The lithosphere has been defined as the strong outer shell of the mantle, the high seismic velocity lid over the low velocity zone, the thermal boundary layer, the surface boundary layer of mantle convection, the plate, the depth to the 1300˚C isotherm, and the depth to "the horizontal isotherm". Since a high thermal gradient and conductive cooling have little to do with strength or seismic velocity it is not useful to use "lithosphere" in the above senses. The multiple uses of the term "lithosphere" creates confusion, particularly when it is used for "thermal boundary layer", which also has multiple usages.

The high velocity seismic lid thickens as the square root of age, from the East Pacific Rise out to the subduction zones of the Pacific (*Maggi et al*., 2006; *Ritzwoller et al*., 2004; *Priestley & McKenzie*, 2006). This rules out the AV model as well as all other explanations for flattening. But continued cooling of the mantle does not mean continued densification. The flattening is controlled by density, which is affected by chemistry, melting, melt migration and lithology, as well as by temperature. Interestingly, this can mean that the lower part of the thermal boundary layer can be hotter than the mantle that provides mid-ocean ridge basalts but can also be positively or neutrally buoyant. Plate-driven flow, from above, is usually laminar, but at fracture zones and lithospheric roots, as under oceanic swells, can disrupt the laminar flow and elevate the hotter deeper portions of the thermal boundary layer to the surface. Since the thermal gradient in a conduction layer is about 10˚C/km this means that midplate basalts that are 100-200˚C hotter than MORB need only come from 10-20 km deeper in the thermal boundary layer.

References

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