Impact of the Pangean mantle flow on current plate tectonics

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Abstract :

Two Large Low Shear wave Velocity Provinces (LLSVPs) in the lower mantle of the Pacific and Pangean systems are isolated from one another by the circum-Pacific slabs that outline the degree-2 structure of the present-day Earth (Davaille et al., 2005; Zhong et al., 2007). At least the Pangean LLSVP may have remained at a steady location for hundreds Myrs (Torsvik et al., 2008). At the onset of the opening of the Atlantic Ocean, the curtain of slabs that circumscribes the Panthalassa system gradually started making the Pangean cell expand at the expense of the Panthalassa system (Collins, 2003), a situation that intensified during the Cenozoic, after the closure of the Tethys and the aggregation of many continents into a partial supercontinent (Eurasia, Africa, Arabia, India and Australia). This period coincides with the massive orogenic growth until present-day.

The force balance on the lithospheric shell at present-day can be evaluated by different means. Indirectly, the kinematics of the deforming plate boundaries does result from that force balance. In other words, mountain belts can be used as dynamometers; in the Pangean system, they amount to ~5×10^{12} to 10^{13} N per unit length of plate boundary. Those resisting forces have to be balanced by driving forces that can be evaluated directly. Our model of mantle flow, driven by density anomalies inferred from seismic tomography, indicates that the shear stresses, integrated across the Atlantic Ocean to a magnitude that overshoots the resistance at plate boundaries as revealed by the kinematics of orogenesis.

Technically, we use two models to achieve this: the first one considers density-driven mantle flow in a sphere whose surface is rigid; the second one is driven by the current plate motion above a viscous mantle without density heterogeneity. The sum of the two gives the net force available to open the Atlantic basin. The divergence that is observed in the Atlantic Ocean primarily arises from the western coast of Africa, above the Pangean superswell. This suggests that the Pangean superswell could very likely have made the Atlantic open: because Africa is thought to have only moderately moved above the mantle, the mid-Atlantic ridge at the time of initial rifting was therefore located just above that superswell. Model results, together with kinematic observations and the timing of orogenesis in the Pangean cell, suggests that the superplume is a good candidate to explain the Atlantic growth and Pacific shrinkage.

However, because of their thermochemical nature, whether superswells actively contribute to mantle flow remains uncertain (e.g. McNamara & Zhong, 2004). In any case, thermochemical plumes may at least supply heat to the mantle above them and drive upwelling above them. To test the incidence of the superplumes, we explore two additional models wherein mantle flow is alternatively only excited by downwellings, i.e. chiefly the subducting slabs, and upwellings (superplumes). The patterns of the resulting mantle flows in the Pangean cell are very similar to one another and to that resulting from a mantle driven by both downwellings and upwellings. Only the magnitude changes by a factor or 2 or so, which does not affect our conclusions. This indicates that upwellings and downwellings mutually combine to form a consistent cell.

The fact that the current mountain belts chiefly developed during the Cenozoic indicates that the resistance to the opening of the Atlantic grew bigger and bigger at this time. The coeval aggregation of many continents onto a larger supercontinent suggests that this development gradually resisted the expansion of the driving forces from the convecting mantle. A variety of observables, including trench migration rates, the timing of orogenesis in North and South Americas, the triangular distribution of seafloor age, and the decreasing rates of lithospheric production at ridges, are compatible with this result.

Collins, 2003; Slab pull, mantle convection, and Pangaean assembly and dispersal, EPSL, 205, 225-237.

Davaille et al., 2005; Convective patterns under the Indo-Atlantic box, EPSL, 239, 233-252.

McNamara & Zhong, 2004; Thermochemical structures within a spherical mantle: Superplumes or piles?, JGR, 109, doi:10.1029/2003JB002847.

Torsvik et al., 2008; Longitude:LinkingEarth'sancientsurfacetoitsdeepinterior, EPSL, 276, 273-282.

Zhong et al., 2007; Supercontinent cycles, true polar wander, and very long-wavelength mantle convection, EPSL, 261, 551-564.