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On the actual variety of plate dynamical mechanisms and how mantle evolution affected them through time, from core formation to the Indian collision

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If horizontal plate motions were driven by thermal convection of the mantle, they would display the action of slow-to-change body forces. Yet rapid changes of spreading rate and direction, and ridge jumps, are well-documented for the past 130Ma. Also convection cannot readily cause rotations of a plate (e.g. Africa) about a pole within the plate or near it. And plate motions, especially that of India, scarcely fit a convective pattern.

To address these problems we look first at mantle motivation at both ends of earth history, beginning with core formation. I then introduce 3 important properties of mantle materials, whose neglect by mantle modellers has surely impaired the value of their work, but whose recognition illuminates the present plate dynamical situation and provides the Earth with a heat engine that is not thermal convection. Finally I sketch the intervening changes in behaviour over time, the sharpest of which brought about the rise of atmospheric oxygen at $\sim$2.25Ga.

Core formation. As the very high specific angular momentum of mean planetary material ($>10^5$-fold relative to solar) can only be achieved if the planets were wholly accreted in presence of the nebula [1], the iron percolation model is ruled out, because it takes too long. This validates the A.E.Ringwood model (1960-1978) involving nebular H reaction with erupting FeO. The iron then loads the downgoing limb of what is then not a truly thermal convection system. Huge volumes of reaction water were produced, giving the early Earth a wet mantle, a (diminishing) feature that we'll see has constrained mantle behaviour ever since.

Plate dynamics since 150Ma. Multiple plate dynamical evidence [2], which will be rapidly re-presented here, shows that currently (a) the Earth has a 2-layer mantle system with a boundary at $\sim$660km and (b) that most cratons have tectospheric keels that reach right to that boundary, or nearly so. The argument is the simple and persuasive one (even to seismologists) of mantle volume disposal if two such cratons approach one another (e.g. Caucasus), and of the provision of mantle volume to put under the growing ocean if they separate, e.g. S Atlantic, Arctic opening. In the latter case, W Siberia offers a major gap between the Russian and Angara keels and it is through this gap that Arctic-bound upper mantle flow is seen to have acted on India's cratonic keel and caused its powerful collision with Asia, rejuvenating many intervening ranges. This has 'put Asia in a crusher' and is contrary to the plate tectonics dictum of plate boundary interaction. Manifesting this 'suction' upon the Indian keel there is around S India by far the deepest dent in the geoid.

The 3 neglected mantle properties we need for understanding this behaviour are:-

(1) The garnet-to-spinel peridotite phase change, typically occurring at 70-90km depth, converts one joule into $\sim$50 times more volume increase than simple expansion and does so with the big force of solid-state recrystallization. The density drop across the phase change can approximate that of simply heating the rock through $\sim$1000K so it should never have been neglected by modellers.

(2) Interstitial melt has much lower thermal conductivity than its parent solid, so overall thermal conductivity is reduced by >10% per 1% of non-migrating melt, i.e. by $\sim$30% for typical oceanic LVZ conditions.

(3) If the water-weakening of the mantle mineral structure (in the form of dislocations by H atoms) is not too high, that weakening will be stripped out by partitioning into any interstitial melt that is present, stiffening the rock by up to 2 orders of magnitude [3]. This contradicts the precept of seismologists and mantle modellers that lowered seismic *Vs* automatically signifies asthenospheric mobility.

Since *Vp-Vs* relationships in the oceanic LVZ and at >180km under cratons are closely similar, the recognition of (3) explains both the dynamically evident strength of cratonic deep keels and offers a new basis for modelling the MOR process. Instead of convectively driven divergent mantle flow, this has a deeply extending laterally accreting narrow (20cm?) mantle crack below the axis and the gt-sp peridotite phase change (1) is present in the walls at some level. Heat from an eruption up the crack causes a lot of extra volume increase in the walls at that level, which closes the crack and wedges the plates apart with great force. This push-apart is responsible both for MOR rift valleys above and for inducing more mantle into the crack from below. It is this 'suction' which appears responsible for the above-mentioned plate dynamical behaviour and for the geoid dent around India. This MOR mechanism is a powerful heat engine but it is not convection.

That cratonic keels may 'rub' on the highly viscous lower mantle at the 660 offers a means of coupling polar core-to-mantle electromagnetic coupling torque to the plate system and thereby to provide rotations. Probable examples are the clockwise rotation of Antarctica since Tierra del Fuego was extracted (150Ma?) from the Weddell Sea, the linked CCW rotation of Africa, and other geomag-related changes of plate motion [4].

From an Earth history perspective, it appears that during the Archaean the mantle was wet enough for vigorous whole-mantle convection to remove the early radiogenic heating. But, as this waned and the evolution of ocean water reduced the water-weakening, the lock-up condition prescribed in (3) was reached soon after 2.5Ga, and plate tectonics halted for $\sim$230Ma, before restarting in the present 2-layer mode. The collapse of MORs during this hiatus correlates with major geological and atmospheric changes including the primary rise in oxygen to which we owe our existence [2].

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