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Mantle properties and the MOR process: a new and versatile model for mid-ocean ridges

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Introduction. First I summarize the reasons why a radical departure from the current MOR model is now essential. I then outline the new model and its apparent versatility, not only in providing the observed contrasting spreading-rate-dependent characteristics but also some of the other common features of the MOR system which warrant clearer explanation. Ophiolites have been thought to provide on-land guidance but turn out to be a non-mid-ocean variant, outside the scope of this presentation.

Seismic anisotropy and mantle mobility. Ever since the 1969 discovery [1] of seismic anisotropy in the uppermost oceanic mantle, this has been attributed to the shearing of olivine in a convectively driven MOR-divergent flow beneath the flanks. This would imply a high degree of rheological mobility of this mantle, but new constraints on its rheological properties and dynamical behaviour have come from two directions and need to be taken into account in forming a model.

1. Contrary to the seismologists' rule-book, the oceanic seismological Low Velocity Zone (LVZ) is no longer to be thought of as mobile, because the presence of interstitial melt strips out the water-weakening of the mineral structure [2, 3]. So we require a substitute for the divergent-flow model for MORs which, we find, also has other, apparently unrecognized, dynamical inconsistencies. One of these [4] is that there are in the record many rapid changes of spreading rate and direction, and ridge jumps. This cannot happen with a process driven by slow-to-change body forces, such as thermal convection.

2. My work on the global dynamic pattern for the past 150Ma (I will show examples) has shown [4 - 7] that the tectospheres of cratons must extend to very close to the bottom of the upper mantle (660km). The metasomatism of kimberlite xenoliths from >180km depth suggests that the reason for this downwards extent of 'keels' is the same as [3].

Phase changes. Another geodynamically important property apparently overlooked by mantle modellers is the presence of two phase-changes (PCs) in the uppermost mantle - (a) garnet peridotite-to-spinel peridotite at say 90km depth; (b) spinel peridotite-to-plagioclase peridotite at say 10km depth. The total density change across the (a) boundary can approximate that of 800K change by pure thermal expansivity, so should never be ignored by modellers [4].

Primary features of the new model. This has a deep, narrow subaxial crack between walls of now-stiff LVZ mantle, to which thermal accretion from the magma ascending the crack offsets the separation rate. This crack (20 cm nominal) offers special properties:- (i) Cooling-controlled differential accretion to the opposite walls of a non-straight crack will make the *MOR segment become straight* and orthogonally segmented [8]; (ii) Columnar growth of olivine at the crack walls, due to its high a-axis thermal conductivity [9], emphasized by the low thermal conductivity of surrounding melt [10] will, by crystallization, *build in seismic anisotropy* at the start. Olivine crystals that chance to have their a-axis perpendicular to the wall will extract latent heat and grow fastest, giving columnar structure [8, 11]. Crystals with other orientation get crowded out. Also seen at margins of exhumed magma chambers (CH Donaldson pers comm 1997).

Magma segregation - Log-jam segregation of magma rising in the crack. Upward-decreasing wall temperature increases cooling of the flow; the solids grow again by cumulate intergrowth until they form a jam in the crack through which the melt is forced diapirically [12, 13]. *PT* at the jam depth defines the major-element composition. Accreting crack walls are very hot, so the jam forms at shallow depth and tholeiite is the result.

Ridge-push mechanism - Solid-state phase-change (PC) push-apart of the walls. A fresh eruption up the crack will heat the walls. Thermodynamic calculations show that these PCs cause >50 times more volume increase/joule than thermal expansivity, so the walls bulge inward and make contact at the PC level, forcing open the crack along strike. This, alternating along strike, induces flow into the crack intermittently and also creates the **suction** that we will show is required by plate dynamics. The solid-state recrystallization mechanism gives our MOR model >10-fold greater ridge-push than the divergent flow models, and the plate is thick enough to transmit it without crumpling.

Structural dependence on spreading rate.

(A) Medium rate, e.g. MAR. The push-apart PC is the *gt-sp* (a) at ∼90km depth. Above that the walls are laterally unsupported, normal faulting occurs and a rift valley is formed. The volume increase at PC depth is partly and intermittently relieved upward to uplift the valley sides and create the rugged flank topography. **(B) Fast, e.g. EPR.** The high rate results in high temperature around the crest, so the *sp-plag* PC is involved in push-apart at shallow depth, little or no rift faulting occurs and the flanks have the rounded abyssal hill topography. **(C) Ultraslow, e.g. Gakkel, SWIR.** The low rate at which mantle is drawn into the crack means melting is insufficient for the log-jam mechanism to work, so there is no segregated basalt, negligible crust, but wide peridotite extrusion (very wide crack), laced with melt veins, appears at surface. Again, because melting in the crack is so low, the two wall-accretion consequences (axis straightness and orthogonal segmentation; seismic anisotropy by crystallization from melt) are weak or absent. Push-apart force is highest for ultraslow because of the near-solidity of the material involved in the push-apart action.

Other properties.

(i) Axis curvature at ridge-transform intersections (RTIs). The differential wall-accretion we propose as responsible for axial straightness actually orients the crack perpendicular to the lateral cooling gradient. At RTIs, additional cooling is coming from the older plate across the transform. **(ii) Offset spreading centres (OSCs).** The curvature at RTIs signifies asymmetrical wall-accretion. At some point between a pair of similar-handed RTIs that asymmetry must swap sides, resulting in an OSC. **(iii) Fracture Ridges.** These rise rapidly as they come opposite a heat-providing MOR axis, and fade later. The *gt-sp* PC at ∼90km depth is likely responsible, implying the plate there is at least that thick.

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