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Extended abstract

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As presented on my poster entitled

A new mechanism for intraplate magmagenesis and petrogenetic variation: the importance of process

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The view that tectonic plates are thin denies the possibility of generating intraplate magmas by splitting them. Even if you believe in plumes there are innumerable occurrences of intraplate magmatism that don't fit a 'plume trace' interpretation, notably alkali basalt near basin margins. That tectospheres actually extend far deeper is supported by petrological and seismological arguments. In particular;

(i) the presence of interstitial melt (LVZ and its deeper equivalent under cratons, below the higher seismic velocity 'lithosphere') deprives the mineral structure of water-weakening and makes it much less mobile, not more (Karato 1986; Hirth & Kohlstedt 1996);

(ii) flattening of the oceanic subsidence rate at ~60Ma is not due to completion of cooling but to reversal, as the plate cools, of the Clapeyron slope of the sp-to-gt peridotite phase change (Wood & Yuen 1983). This change must be a major contributor to thick-plate subsidence, because of the very big contraction per joule extracted. That is why Stein & Stein (1992) found the observed heat flow (2-60Ma) is low in relation to the subsidence rate (Panel 8). The reason it's low, despite high temperature at depth, is that the interstitial melt lowers the LVZ thermal conductivity (Snyder et al 1994).

So a family of plate-splitting magmagenetic models is presented here, treating MORs as the rapid-opening part of the range.

In the general model, the base of a plate may be put into extension mechanically, e.g. by thermal upwarping of its edge (Panel 1), or by the penetration of cooling to the level at which the enhanced contraction rate due to the gt-sp peridotite phase change occurs (Panel 4). Mechanical work done on the material by the stretching raises the temperature and sharply lowers mantle viscosity, which also depends on local composition. This may then result in rapidly concentrated upward-necking of the plate. Sub-plate material thus drawn upward will undergo pressure-relief melting and eventually endow the column with net buoyancy to extend the narrow split to the surface (Panel 1).

Melt segregation will then occur by a log-jam mechanism, well-known to grouting engineers and others, in which, except at very low flow rates, the solids inevitably jam in the crack if they are bigger than 20-25% of the crack width. In our induced diapiric column, the jam forms when wall cooling makes the solids grow again at shallower levels (Panel 2). The diapiric column forces melt through the jam, this depth determining its major-element composition. Continued opening of the crack would be offset by wall accretion; continual re-forming of the jam permits the segregation of flood basalts. Rupturing of jams provides a source of xenoliths; the rupturing force depends on the melt column (lower density) height above the jam, hence the increase in xenoliths from MORB to kimberlite. Xenoliths are widely observed to be intergrowths of cumulate and restite, as is to be expected in this model.

Focusing first on OIB, the self-generated diapiric capability of the column in the crack produces a 'draw zone' at sub-lithostatic pressure around its base. Consequently, without rise of temperature, low-melting, trace-element rich and diffusible-gas mantle

constituents will be drawn from a wider zone than the material currently entering the crack, giving the magma a 'plume' signature (e.g. 3He and 87Sr) that is process-variable and not of lower mantle origin. The 3He diffuses with exponential enrichment (relative to 4He) along the melt channels, not through the solid. The trace element contents of phlogopite, apatite and other low-melting accessory mantle minerals, hitherto largely ignored in the context of mantle melt compositions, now assume great importance.

Once the material is inside the crack, the rapidity of transport and log-jam segregation within it wholly or partly inhibits thermodynamic equilibration between this 'draw zone' signature and the major-element components. In major-element terms, the mechanism offers a simple account of the alk-thol-alk-neph OIB sequence and of alkali basalts that precede or follow tholeiitic flood basalts (Panel 3). In trace-element terms the draw zone provides another 'end-member composition' but all from a single source composition.

MORs. LVZ rigidity enables the narrow wall-accreting crack model to be applied to MORs (Panels 6 & 7). Wall accretion depends on lateral cooling; this gives a direct and unique explanation of the straightness of MOR segments (Panel 5) and, via columnar crystallization of olivine onto the walls, of seismic anisotropy. [Thermal conductivity of olivine a-axis is 1.7 times that on its b-axis (Chai et al 1996) and that of the surrounding melt is >10-fold lower still (Snyder et al 1994)]. The high temperature-profile of the walls ensures shallow log-jam formation and a tholeiitic product. Where the separation rate is too low to yield enough melting and flow velocity for log-jam action, a melt-interlaced peridotite/serpentinite intrusion will result, as observed. Continuity of the MOR process means that the 'draw zone' signature effect becomes self-cancelling over time, but E-MORB is where this has failed. The occasional presence of garnet zone REE distribution in MORB tholeiite segregated at shallow depth is explained. Commonality of process and source with OIB, explains how, but at much slower crack opening rate, alkali OIB volcanoes start to occur close to the EPR crest (Batiza 1991).

The final feature of our magmagenetic model is its provision of eruptive control, involving repeated diapiric entry to the crack. EPR observations show that even in that case intermittent (not continuous) eruption is what we require. This intermittence is provided by the large volume increase per joule associated with solid-state phase change in the crack walls; the heat from each eruption causes local inward-bulging of the crack walls and closure at the phase-change level.

In the MOR case, the bulging not only closes the crack locally but forces the plates apart, inducing an eruption along strike, and so on. The timing of this cycle is probably what limits MOR spreading rates. The push-apart force, being that of solid-state recrystallization, offers a great, and much-needed, increase in ridge push for the support of the Andes and Himalaya and to achieve young-plate ‘flat-slab’ subduction.

In the flood basalt case, if the plate-splitting rate is externally controlled, it could exceed the phase-change wall-bulging rate; eruptive control is then lost.

In the OIB case, the bulging interrupts eruption until dissipation of the heat into the walls reverses the bulging, thus providing periodicity typical of each individual volcano. To the extent that it pushes the walls apart it may propagate the crack in both directions, as seen in some questionable plume traces. Otherwise the crack will normally propagate in the weaker, plate-younging direction, as is seen in most OIB chains and widely interpreted as plate motion over mantle hot-spots.

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