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On alternative models for the origin of time-progressive volcanic chains

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The time-progressive character of some volcanic chains is well known for decades and is proven with a different degree of reliability for many of them. The recent overviews of the primary data can be found in the papers of O'Neil et al. (2005), Clouard and Bonneville (2005), enhanced by some additional information (e.g. Geldmacher et al., 2005). A couple of dozens of such chains is a real challenge for anyone who works at the problem of origin of melting anomalies.

One of explanations was suggested by T. Wilson (1963) as a hypothesis of "hot spots" – surficial manifestations of immovable deep mantle melting anomalies, the idea developed later by W. Morgan (1971) as a theory of plumes – convective upwelling streams of a light hot mantle substance coming from the core-mantle boundary. It was a smart explanation, and still is, though the idea of an absolute horizontal immobility of plumes is disproved now by paleomagnetic and geodetic data, and details of melting processes still need a lot of research and thinking.

The recent passionate, and in some important aspects, well-founded scepticism of many authors concerning the plume theory has brought back to life an almost forgotten theory of J. Dana, that of a propagating crack. Recently the idea has found its new adherents among adversaries of plume tectonics. It might seem that most evident approach to a propagating crack model is in a suggestion of an existence of a maximum horizontal tensile stress normal to the crack and ensuing volcano chain. But in the most evident example of Hawaii-Emperor and other likely chains of the Pacific, the ideas of classical plate tectonic forces and deformations (subduction slab pull and rollback, mantle drag and ridge push) can not explain the orientation of the corresponding cracks if any. It had been shown at a global scale (Zoback et al., 1989), that the maximum horizontal stress is usually subparallel to the direction of absolute plate motion, suggesting that the forces driving the plates also dominate the stress distribution in the plate interior. Probably because of it, a different approach was undertaken (Stuart et al., 2007). Plate tectonic forces were not taken into account at all, and “a thermoelastic stress rate for present-day cooling of the Pacific plate using a spherical shell finite element representation of the plate geometry” was calculated. A needed result had been obtained, at a price of ignoring of classical plate tectonic forces, a price probably too great to be acceptable. Over and above, still more questions must be answered by the crack propagation supporters before the hypothesis becomes a theory: 1. Why the propagation of time-progressive chains in all oceans is always oriented as predicted by plume-and-plate tectonics? 2. Why the crack propagation is not affected by the strongest anisotropy of oceanic, transitional and continental lithosphere, crossed by many chains? 3. Why the Reunion and Kerguelen time-progressive volcanic chains overrode the active MOR, if they are propagating cracks?

Another alternative model is that of easily melting magma sources (pyroxenite “blobs”), drifting in an asthenosphere (Anderson, 2007). The model, worked out in detail by M. Cuffaro and C. Doglioni (2007), suits the Pacific chains, but at a global scale it fails because it is contradicted by the behavior of time-progressive chains in the Eastern Atlantic and Indian oceans. On the other hand, the very idea of a pyroxenite “blob” (basic in composition) hanging in asthenosphere for many tens of Ma, conflicts with the nature of asthenosphere, the latter demonstrating readily the effects of the Archimedes law. When situated deeper than 50 km, the “blob” exists as an eclogite which is much denser that the ambient peridotite and must sink, if not supported by a plume upwelling. When situated higher than the phase transition zone, it turns into gabbro which is much lighter than the peridotite and therefore must finally strike the bottom of lithosphere.

By itself, the idea of pyroxenite as an easily melting component of the Earth’s mantle seems to be very promising. It really can be of a great benefit for the plate tectonic approach in explanation of shallow, top-asthenospheric decompression-induced melting anomalies (Foulger, 2007; Anderson, 2007). But it can be also extremely useful for the real plume model as it became evident recently from an example of the deep-sourced Hawaiian magmas (Sobolev et al., 2005; Yaxley, Sobolev, 2007).