Collision-induced mantle flow during Tethyan closure: a link between magmatism, lithosphere ‘escape’, and arc-trench rollback?

Martin F.J. Flower

Department of Earth & Environmental Sciences, University of Illinois at Chicago, Illinois 60607-7059, U.S.A., (+1 312 996-9662, Email: flower@uic.edu)

The transition from pre- to post-collision settings is marked by sequences of calcalkaline, potassic, and basaltic magmatism each representing thermal and compositional probes of the convecting upper mantle. This pattern characterizes recent collisions between migrating fragments of Gondwana (Africa, Arabia, India, and Australia) and accreting Eurasia, and match lithospheric collision responses that include crustal shortening and thickening, post-orogenic collapse, and continental escape tectonics. Syn- and post-collision potassic magmas include shoshonites, lamproites, and (rarely) kamafugites which typically coincide with the inception of continent-scale shearing (as recorded by Ar-Ar thermochronology). Tomographic and S-wave splitting studies also suggest potassic magmatism corresponds with post-collision slab detachment and incipient continental crust subduction . Post-collision basaltic phases typically comprise tholeiites, alkali basalts, basanites, and nephelinites and are confined largely to pull-apart basins and extinct offshore spreading axes. Usually post-dating major shearing events they correspond with continuing shifts in transtensional stress fields representing late stage adjustments to ‘escape’-related block rotations.

Complex isotopic and trace element enrichment-depletion histories characterize magmatic sources of both types, indicating contributions, via both subduction and lithospheric mantle delamination, of sialic components and hydrated, refractory peridotite. At a regional scale, Tethyan magmatism taps compositionally distinct mantle domains whose boundaries with each other and with contiguous Atlantic and Pacific N-MORB domains have migrated with time in accord with global plate motions. For example, as northward-moving Africa approached Eurasia in the early Mesozoic, HIMU-rich mantle infiltrated beneath Neo-Tethyan marginal basins, accreting western Eurasia, and eastern parts of the Atlantic Ocean. At about the same time, Indian Ocean spreading centers began tapping EM1-contaminated ‘DUPAL’ mantle, the latter infiltrating beneath remnant Neo-Tethyan basins - preserved in central and eastern Eurasian ophiolites - and eastward-propagating western and southwestern Pacific back-arc basins**.**

The HIMU-rich western domain has been ascribed to north-northeast-directed channeling of a high-$^{238}U/^{206}Pb$ Central Atlantic plume while eastern Tethyan DUPAL mantle was also attributed to deep plumes – the latter invoked as the principal cause of Gondwana breakup. Mantle plume models are problematic for several reasons, however. Lower mantle low velocity anomalies inferred beneath Indian and Atlantic Ocean ‘hot spot’ loci are probably suspect, given the relatively poor resolution of deep mantle tomography. Secondly, if, as is commonly assumed, plumes are stable and persistent features, the spatial-temporal distributions of Tethyan volcanic centers do not match those expected from recorded lithospheric plate motions. Finally, mantle flow fields inferred on the basis of geochemical tracers and S-wave splitting studies are at variance with the domain boundary migrations implied by Atlantic and Indian Ocean plume models. While low-$^{206}Pb/^{208}Pb$ DUPAL contaminants have been interpreted to represent lithospheric detritus accumulated at the core-mantle interface, they may be more plausibly explained by selective delamination of dispersed Gondwana cratonic roots in a context of shallow-level mantle convection. This type of model is supported by new thermobarometric and isotopic data for continental mantle xenoliths, suggesting that substantial thinning of Gondwana cratons has occurred since the early Paleozoic.

Most current or recent Tethyan volcanism corresponds with shallow mantle (< c. 300 km) P- and S-wave velocity minima which indicate 'swell-' rather than plume-like upper mantle thermal anomalies. Potential temperatures inferred from melt thermobarometric data are mostly $\leq 200^{o}C$ above those expected beneath undeformed continental lithosphere. Accordingly, the observed scale of mantle melting requires both rapid asthenosphere decompression and lithosphere stretching. Significantly, the spatial extent of shallow tomographic anomalies may define laterally-continuous flow channels linking regions of collision-displaced asthenosphere (e.g. beneath the Himalayas and Tibet) with those underlying: 1) extensional volcanic centers (e.g. eastern China and Indochina), 2) retreating intra-oceanic forearcs (e.g. the Izu-Bonin-Mariana terrain), and 3) their conjugate marginal basins (e.g. the Parece Vela Basin and Mariana Trough).
While Tethyan continental basalts tap variably (if slightly) contaminated fertile asthenosphere, the potassic magmas tap strongly contaminated sources in mantle 'wedge' regions. Geochemical studies indicate two major types of contamination accompany the transition from plate convergence to collision: 1) refractory serpentinized peridotite, delaminated from the overriding plate, following its rheologic 'conversion' and incorporation by asthenospheric corner-flow, and 2) continental crust, either delaminated from thickened orogenic crust or introduced by subduction as slivers or metasomatic melts. Hithereo subduction-driven flow will be substantially modified if post-collision slab detachments allow fresh asthenospheric influx from below.

In summary, mantle wedge flow paths represent a critical aspect of collision-related mantle dynamics the evidence for widespread 'non-plume' magmatism, Neo-Tethyan marginal basin propagation, and concomitant infiltration of thermally and compositionally anomalous asthenosphere offers a compelling case for continent-scale, collision-induced mantle extrusion. This model is in accord with upper mantle thermal structures and uniquely explains the observed kinematic and temporal relationships between plate collisions, intra-plate magmatism, and distal arc-trench rollback processes. Mantle extrusion also provides a plausible driving mechanism for lithosphere escape tectonics. Petrologic interpretations of mantle thermal and compositional will be developed as a template for understanding collision-related mantle flow, amenable for testing by geophysical methods, tectonic facies analysis, and numerical simulation.