Discussion of

The OIB paradox

by

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10th January, 2007, James H. Natland

Since OIB-like lavas occur on so many features that are not age-progressive linear island chains, such geochemistry does not by itself require a deep mantle plume anywhere else. - Natland and Winterer (2005, p. 688)

We suspect that geochemistry will not deliver the silver bullet for proving or disproving plumes – Hofmann and Hart (2006, p. 40)

Do these two epigraphs and discovery of the OIB paradox by Fitton (this volume) mean that we all agree?

Those of us who are old enough to have been trained as petrologists rather than geochemists will certainly recall the alkaline olivine-basalt volcanic association of Turner and Verhoogen (1960). They divided the association into two types, one on the continents, the other in the ocean basins, treated the petrogenesis of lavas of both under one general discussion, and noted certain features in common such as development of feldspathoidal differentiates and the presence of ultramafic xenoliths in the basalts. Turner and Verhoogen (1960) also recognized a separate association of tholeiitic and alkalic olivine-basalts in both the ocean basins (Hawaiian province) and on continents (Hebridean province), another association of tholeiitic flood basalts (Deccan, Karoo, Columbia River), and yet another of potash-rich volcanic rocks (western African rift). Today, we recognize both continental and oceanic occurrences of all of these, even the last (e.g., Davis et al., 2002; Hirano et al., 2006), and many geochemists see the plume hypothesis as one way to link them, even to the extent that hypothetical plume heads can be flattened and distended at the base of the lithosphere for thousands of kilometers away from linear island chains, and feed seamounts near distant ridges (Niu et al, 1999).

The OIB paradox, as Fitton (this volume) describes it, is simply a renewed recognition that the alkalic olivine-basalt association of continents and ocean basins is a valid way to frame the problem of the petrogenesis of those lavas. However, instead of peering at it from the continents outward, use of the terms OIB (ocean island basalt) and OIB-like makes the ocean basins the frame of reference. The term OIB itself is a misnomer (Natland and Winterer, 2005), since it refers to rocks that can only be sampled on foot, whereas it clearly occurs on thousands of both tall and short seamounts, most of them not parts of linear island chains. The difficulty is compounded by application of OIB to many tholeiites, and discovery that so-called enriched mid-ocean-ridge basalt (E-MORB) at ridges resembles certain OIB. Since some E-MORB are indeed nepheline normative alkalic olivine basalt, we could as well say that the association of tholeiitic and alkalic olivine basalt extends to spreading ridges themselves, and not just islands like Hawaii and rift provinces like the Hebridean. Obviously, if we are faced with using E-MORB for alkalic olivine basalt on a spreading ridge, and OIB for an identical rock on a seamount or island, and OIB-like for the same rock in a continental rift, we have a curious and confusing problem with terminology. The old rock name, which does not reference locality even symbolically with an acronym, is clearly better, and so, probably, is the Turner and Verhoogen (1960) approach to discussing their petrogenesis.

Fitton (this volume) tackles the E-MORB problem by proposing use of his ΔNb criterion as a basis for definition. I am surprised that a procedure developed primarily to distinguish Icelandic tholeiite from depleted N-MORB should work so well for so many locales where the contrasting rock types are, or at least include, alkalic olivine basalt (positive ΔNb) on the one hand and depleted abyssal tholeiite (now negative ΔNb by definition) on the other. But E-MORB has never been systematically or consistently defined before, so this is a step in the right direction. However, I believe that classification in terms of a single parameter based on trace elements oversimplifies the problem and that the general petrological (e.g., normative) character of the rocks should always be established and borne in mind. I am also impressed that outside of Iceland, trends on a ΔNb diagram (log Zr/Y versus log Nb/Y) shown by Fitton (this volume) for the ocean basins are almost systematically oblique to the line for ΔNb = 0. This would show up even more dramatically, for example, along the southern superfast East Pacific Rise had Fitton included existing data for Garret Fracture Zone in the evaluation. Such oblique trends and other geochemical attributes are evidence that magma mixing between disparate alkalic and tholeiitic end-members has occurred in all of these regions. Exclusion of differentiated compositions (andesites, trachytes, rhyolites, etc.) also makes it impossible to assess whether such magmas have mixed in small proportions with any of the basalts. This would tend to flatten data arrays, making them parallel to ΔNb = 0, usually at positive ΔNb (Natland, this volume).

31st January, 2007, Jason Phipps Morgan and W. J. Morgan

This paper notes that E-MORB, Ocean Island Basalt (OIB)-like basalts, are often erupted at mid-ocean ridges remote from known sites of the plume upwelling which provides the proposed source material for OIB volcanism. Fitton (this volume) interprets this "OIB Paradox" to show that "plume" material can somehow make it into the source of some mid-ocean ridge (and continental) basalt sources where "mantle plumes cannot provide a plausible explanation". This is not a paradox in our preferred scenario of a plume-fed asthenosphere. If most of the mantle upwelling at plumes has its most incompatible-element-rich components tapped at least to a small degree by plume melting, then OIB will be more incompatible-element-rich and more isotopically-enriched than the typical MORB created by melting the asthenospheric leftovers to plume melt-extraction (Phipps Morgan, 1999; Phipps Morgan and Morgan, 1999). If, however, the cooler rim-material of mantle plumes does not pressure-release melt during plume upwelling but becomes part of the asthenosphere, then it will melt when it starts to ascend beneath a mid-ocean ridge, making E-MORB (Phipps Morgan and Morgan, 1999, discuss this observation and its resolution by a plume-fed plum-pudding asthenosphere).

Lateral flow within a plume-fed asthenosphere also offers an explanation for why both OIB and MORB have similar “flavors” within a given geographic area, e.g. the Dupal anomaly shared by both hotspot OIB and MORB within the Indian Ocean province, which is explored in more detail by Yamamoto et al. (this volume). Likewise, the preferential melting of easiest-to-melt plum components during lateral flow and upward-drainage beneath a lithospheric thin-belt provides a conceptually simple explanation for the Cameroon Line (Ebinger and Sleep, 1998). A plume-fed asthenosphere is also consistent with — although not required by — OIB-like basalts erupting during the initial phase of continental rifting. Lateral flow of plume-fed asthenosphere does, however, provide a simple explanation for the often-abrupt transition between “rift” OIB to “drift” N-MORB volcanism during continental rifting (Reston and Phipps Morgan, 2004). Note too, that in the plume-fed asthenosphere scenario plumes are not much hotter on average than the plume-fed MORB-source, but both plume material and the plume-fed asthenosphere are hotter than the average underlying mantle. Thus these “OIB Paradoxes” are only paradoxes in scenarios where plumes are a small-mass-flux addition to the asthenosphere; they are to be expected in the scenario of a plume-fed asthenosphere.

31st January, 2007, Don L. Anderson

Phipps Morgan and Morgan (comment of 31st January, 2007) argue that a plume-fed asthenosphere can explain one of the paradoxes associated with the standard version of the plume paradigm, the fact that EMORB occurs at ridges unaffiliated with hotspots. This explanation also removes the rationale for “correcting” or “filtering” ridge data to avoid the influence of plumes. This opens up the narrow chemical spectrum that has long been attributed to “depleted upper mantle” so that it now includes chemical attributes that have been assigned to “hotspots”, or OIB. The concept of “the convecting mantle” has been associated with mid-ocean ridges and MORB; this is shorthand for “well stirred homogeneous mantle”. The idea behind this nomenclature is that inhomogeneities introduced into the upper mantle rapidly get stirred into it. The rationale is that homogeneous MORB requires a homogeneous source, which itself is a fallacy (Meibom and Anderson, 2003).

The arguments given by Phipps Morgan and Morgan in their comment earlier today also apply to the mafic blob models where the low-melting point constituents are introduced from above (delamination, off-scaping of the lower crust, tectonic erosion, abandoned arcs and mantle wedges and so on), as in the Galileo Thermometer model (Anderson, this volume). Melting anomalies are then due to low-melting eclogite, rather than to lower-mantle plumes. The amount of melt depends on the fertility of the mantle, not the absolute temperature. It is the homologous temperature (temperature divided by melting temperature) that is important. Eclogite blobs are dense at their starting (crustal) temperatures but become buoyant and partially melted at ambient mantle temperatures. They then deliver heat and magma to the surface. They can also get entrained in the asthenosphere counterflow, which sweeps them toward ridges and hotspots. In this respect, the fertile blob model differs from the plume fed asthenosphere model; flow is toward, not away from, hotspots.

The concerns regarding the isothermal nature of MORB are addressed in my comment of January 28th, 2007 on the chapter by Falloon et al. (this volume). MORB does seem to be extracted from a common depth and temperature region, but this need not be the "top of the adiabatic convecting mantle". It is likely to be the depth of the intersection of the solidus with the conduction geotherm; the thermal boundary layer can be thicker than this. Variations in magma temperatures can be due to variations in depth, potential temperature or lithology.

7th February, 2007, J. Godfrey Fitton

Natland's neat summary of Turner and Verhoogen's (1960) view of basalt associations, together with the other discussion comments and those of the paper by Yamamoto et al. (this volume), nicely encapsulate the OIB paradox. No single model, nor even a plausible combination of models, can yet explain all the occurrences of OIB and OIB-like basalt. Heterogeneous asthenosphere, whether fed from below via plumes (Phipps Morgan and Morgan, comment of 31st January, 2007) enriched from above via delamination etc. (Anderson, comment of 31st January, 2007), might be able to provide an inexhaustible source of both OIB and MORB, but only with the application of some special pleading in critical examples. Two of these, cited by Phipps Morgan and Morgan serve to illustrate this.

Phipps Morgan and Morgan claim that lateral flow of plume-fed asthenosphere can provide a simple explanation for the abrupt transition from OIB-like rift magmatism to oceanic N-MORB. This, however, requires that the onset of sea-floor spreading and N-MORB magmatism be triggered by the arrival of plume-fed asthenosphere when the developing continental rift connects to the global mid-ocean ridge network, right at the point of continental separation (Reston and Phipps Morgan, 2004). The other example is the Cameroon line, a volcanic lineament that has been randomly and virtually continuously active for the past 66 Ma, composed largely of OIB on its oceanic sector and of compositionally indistinguishable basalt on the African mainland. Morgan and Phipps Morgan (this volume) appeal again to lateral flow of plume-fed asthenosphere, this time beneath a lithospheric thin-belt. They offer no explanation for why the lithosphere should be thin along the Cameroon line, or why it has remained thin for 66 Ma. There is no evidence for rifting; its continental volcanic edifices are built on uplifted basement rocks. Solving the mystery of the origin of this enigmatic feature may one day help to resolve the OIB paradox.

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