

Carbonatitic metasomatism & liquid immiscibility: A Bell (Keith) ringer's resolve to mantle solutions

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Keith Bell was an early luminary in the front guard of those questing to probe the upper mantle using the natural products of volcanism. And as outlined in his insightful preface to the one day conference proceedings volume on Carbonatites in 1986, he reviewed the state of the mantle probe community as follows: "new phase equilibria studies show the possibility of immiscibility for a wide composition range of silicate melts; Nd, Pb, and Sr isotope studies clearly indicate the mantle as a source of carbonatite magmas; mantle metasomatism lurks in the background as a precursor to carbonatite genesis and its near surface analogue fenitization, are areas closely intertwined with carbonatite genesis and evolution; stability of exotic minerals formed by metasomatism under mantle conditions, coupled with the possibility that carbonated silicate melts might play a major role in metamorphic fluids, bring us closer towards an understanding of the role of volatiles in deep-seated processes." These concepts, although widely recognized, had few ardent supporters for over two decades. That, thankfully, is changing. A resurgence in accepting carbonatitic and related COHNS fluid-magmatic, mantle metasomatism and liquid immiscibility has not only come full circle, but now also embraces these enigmatic modifiers as crucial to the petrogenesis of kimberlite-clan rocks, the origin of diamonds, diamond inclusions, and the more sensible P-T placement of sulfide minerals— that are *not* derived from Earth's core but logically bear the isotopic DNA signature of mantle metasomatism.

In dedicating this review to the Hon. Keith Bell, aspects of old testament observations, related to silicate-carbonate metasomatism, are resurrected to underscore the important role of minerals hosting LIL and HFSE, others that are hydrous, and those that are S-bearing. The new testament documents irrefutable evidence for a relationship between kimberlites and carbonatites, and for immiscible liquids of carbonates and silicates that intimately incorporate oxide and sulfide minerals. There is seemingly little room for early subduction but abundant evidence for primordial fluids tapped by mantle plumes and core superplumes. The quest is far from complete but Keith's carbonatite volcanic probe has helped enormously in unraveling the complex frozen products and evolution of Earth's deep and ancient interior.

Controls on the volatile systematics of the Lau Basin

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The Lau Basin has a complex history of interaction involving different mantle sources. The Valu Fa Ridge and Mangatolu Triple Junction (MTJ) region shows lavas with arc-like characteristics, the Central and Eastern Lau Spreading Centers (CLSC and ELSC) erupts MORB-like volcanics, whereas the Rochambeau Bank (RB) has features akin to OIB. To characterize the volatile systematics of these various regions, we report a comprehensive study of 39 submarine lavas from the MTJ, CLSC, ELSC, and RB encompassing analysis of the noble gases (He, Ne, and Ar) and carbon (CO₂) – both isotopes and abundances - together with other major volatile phases (H₂O, S, Cl, and F).

Helium isotope ratios of the CLSC and ELSC are MORB-like whereas those of RB are considerably higher (10-23 R_A). The influence of 'plume-like' sources in the RB is also apparent in Ne isotopes: RB samples follow a trend similar to Hawaiian basalts in 3-isotope neon space. However, RB lavas have lower ⁴⁰Ar/³⁶Ar (300-730) and higher [³⁶Ar] than CLSC and ELSC, suggesting greater air contamination. Magmatic CO₂ and δ¹³C fall in the range 7-350 ppm and -28 to -6‰. RB lavas have less [CO₂] and slightly lower δ¹³C than CLSC and ELSC. The lowest values are found among MTJ lavas. These lavas also have the greatest slab influence. There is little difference between CLSC and ELSC despite the proximity of the latter to the Tonga arc.

We tested several degassing models (equilibrium and non-equilibrium) to explain our volatile data. Observed variations in ⁴He/⁴⁰Ar* could be accommodated by a spectrum of models: however, wide variations in CO₂/³He could only be explained by non-equilibrium degassing incorporating elemental fractionation due to diffusive loss [1]. Identifying non-equilibrium degassing as a major control on the volatile systematics allows us to map regional source variations throughout the basin. For example, we estimated parental magmas to have [CO₂] of 0.39% and 0.22% for RB and CLSC samples. We can now evaluate mantle mixing relationships in the Lau Basin with more confidence.

[1] Gonnerman & Mukhopadhyay (2007) *Nature*.