Goldschmidt 2000
September 3rd–8th, 2000
Oxford, UK.

Journal of Conference Abstracts
Volume 5(2), 1001

Extremely Magnesian Olivines in Phanerozoic Picrites Signify Transient High Temperatures During Mantle Plume Impact

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All currently active mantle plumes appear to be in the steady-state stage of their evolution. Thus, geophysical and geochemical methods of estimating their potential temperatures (Tp) give only the steady-state values. Information about Tp in the impacting heads of former new plumes can be derived from their melt products. Although the dense, Mg-rich, high-temperature melts from Phanerozoic plumes that impacted beneath continents were inevitably trapped beneath the continental crust, evidence of their existence -- in the form of forsteritic olivines carried as cognate macrocrysts in less-magnesian magmas -- occasionally reached the surface. Picrites with Fo_{93+} olivine macrocrysts have previously been reported from the ~88 Ma Gorgona and ~60 Ma West Greenland volcanics.

In the Early-Cretaceous magmatism of the Southern Etendeka region, NW Namibia, swarms of ~132 Ma mafic dykes include picrites of the Horingbaai suite that contain olivine macrocrysts as magnesian as $Fo_{93.3}$, with CaO in the magmatic (not mantle) range and average Cr_2O_3 = 0.13%. Using Kd values of Ulmer (1989) and seismic evidence of local crustal thickness at 132 Ma (Gladczenko et al., 1997), we calculate that the melt which precipitated these olivine macrocrysts was a komatiite with ~24% MgO. The largest variable in this calculation is the redox state of the magma. Olivine-spinel equilibria give sub-solidus temperatures and fO_2 values 4-8 log units below FMQ in the Namibian dykes. Parallel calculations for Hawaii and comparisons of olivine Cr_2O_3 with experimental equilibria (Li et al., 1995) show that redox conditions in the Namibian melts were similar to those measured in Hawaii. After calculating the theoretical 1-atmosphere liquidus of the Horingbaai komatiite to be 1480ºC, the potential temperature (Tp) of the mantle that underwent decompression melting to produce the Horingbaai komatiite was calculated, using a P-T diagram for peridotite KLB-1 (Figure 1) and the procedure of M^{c}Kenzie & Bickle (1988). The result is: Tp = 1680ºC; melt fraction at base of lithosphere = 44%; beginning of melting at ~6 GPa. Parallel calculations for olivine macrocrysts in Mauna Loa picrite give Tp = 1525ºC beneath Hawaii, which is within the range proposed by others. Picrites with Fo_{93+} olivine at Gorgona and in West Greenland require similar conditions in the initial heads of the Galapagos and Iceland plumes, unless their redox conditions were substantially different from Hawaii and Tristan. Such potential temperatures are ~150-250 ºC higher than those calculated for steady-state Phanerozoic plumes and ~400 ºC above ambient. If a large fraction of the Tristan plume head at 132 Ma had been so hot, decompression melting would have led to the thickness of the volcanic products in NW Namibia being far larger than is observed (directly and by offshore seismology). Non-Newtonian plume models (e.g. Larsen et al., 1999) seem to give the best scenarios for delivering relatively small volumes of extremely hot mantle to the sub-lithospheric impact zone of a plume.

Both the elemental and isotopic compositions of most Horingbaai suite basalts and picrites have been affected by upper-crustal contamination during their uprise and emplacement. Minimally affected samples show substantial geochemical similarities to MORB (e.g. εNd >8) and this has led to widespread supposition that they are melting products of upper (MORB-source) mantle, entrained by the Tristan plume head. Some of the geochemical criteria often used to identify magma sources (e.g. total Fe, $^{207}Pb/^{204}Pb$, Δ Nb) show that the Horingbaai suite is, in fact, not strictly MORB-like; as also the Gorgona and West Greenland plume-head picrites and komatiites. Extremely high calculated Tp gives another convincing reason for seeking the source of these magmas within the plume, rather than entrained by it. In each Phanerozoic example they appeared during or just after the climax of plume-impact magmatism. It therefore seems prudent to consider such komatiitic melts as possible cryptic components of continental flood basalts, obscured by other contributions from crustal and lithospheric mantle sources. Perhaps these light-REE depleted compositions "emerge" in CFB mixed-source geochemical models (e.g. Gibson et al., 1995) because they exist.

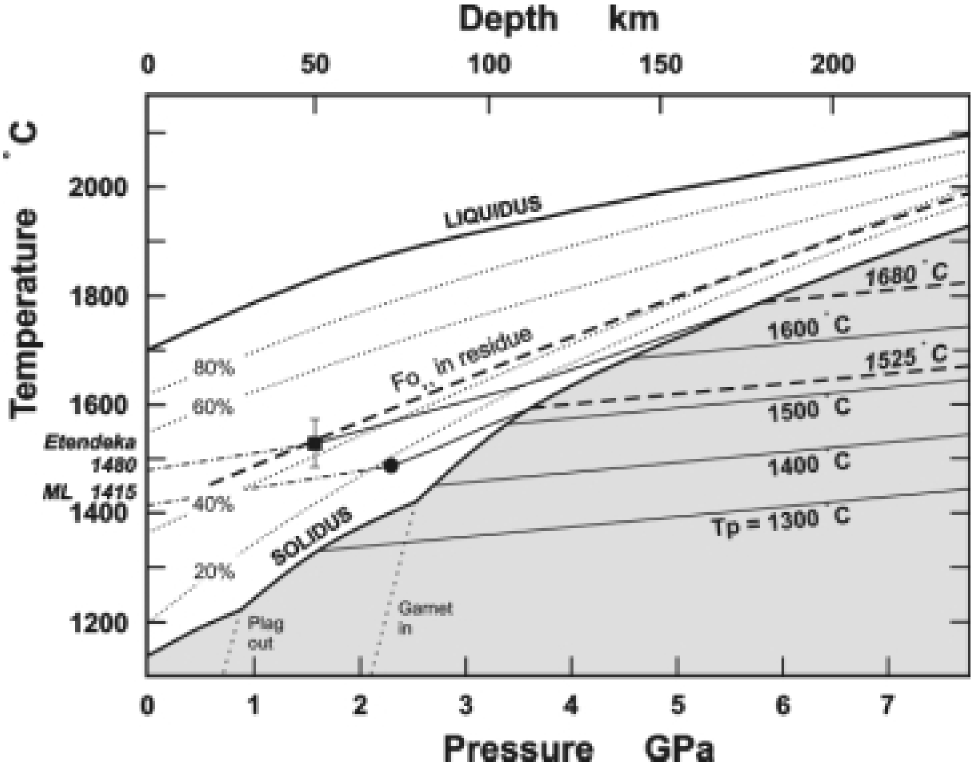

Figure 1: P-T diagram for peridotite KLB-1, showing the calculated decompression melting path for Etendeka komatiite, together with a comparative calculation for the melt in equilibrium with the most forsteritic macrocryst olivine reported from Mauna Loa (ML), Hawaii, picrites. Melt fraction isopleths are in percent. Thompson & Gibson (in press) give sources for the plot, details of the calculations and analysis of the accumulated error shown by the error bar.

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