CRATONIC AND OCEANIC LITHOSPHERIC MANTLE BENEATH NORTHERN TANZANIA.

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Cratonic peridotite xenoliths from kimberlites in southern Africa have compositions distinct from those carried in alkali basalts which erupt through post-Archean crust. Off-craton, or "oceanic" peridotite xenoliths show increasingly forsteritic olivines with increasing modal olivine content, similar to trends observed in oceanic peridotites and consistent with progressive extraction of basaltic magma. In contrast, cratonic peridotites have high Fo contents over a wide range of modal olivine contents and generally contain high modal enstatite (Boyd, 1989). These mineralogical differences are reflected in higher SiO_2 and lower FeO contents (Hawkesworth et al., 1990, McDonough, 1990) in cratonic xenoliths. Cratonic xenoliths also possess lower concentrations of HREE, Sc, Mn, V (McDonough, 1990), suggesting severe depletion by partial melting. The differences between cratonic and non-cratonic peridotites have been attributed to fundamentally different growth processes of the lithospheric mantle in Archean and post-Archean times (Boyd, 1989, Hawkesworth et al., 1990). In particular, generation of komatiitic magmas in the Archean may have produced a highly depleted, SiO_2-enriched residue that was buoyant in comparison to the surrounding (fertile) mantle. An alternative explanation is that the melt-depleted character and SiO_2-enriched nature of Kaapvaal peridotites may reflect addition of SiO_2 to highly depleted (komatiitic) residues by slab-derived fluids (Kesson and Ringwood, 1989). In this abstract we examine new and published data for garnet and spinel peridotite xenoliths from the Lashaine and Olmani ankaramite volcanoes in northern Tanzania that place constraints on the mode of growth of lithospheric mantle.

The Quaternary Lashaine and Olmani volcanoes lie approximately 30 km from one another near Arusha in northern Tanzania. They lie within the southern extension of the East African Rift and occur in a Proterozoic (ca. 2 Ga) mobile belt in an area of extensive pan-African crustal reworking (Nixon, 1987). The age of crust formation is unknown. The Archean Tanzanian craton lies ~150 km to the west but Archean rocks are unknown in the Arusha area. The Lashaine xenolith suite was extensively described by Dawson and co-workers in the early 1970's (Dawson et al., 1970, Dawson and Smith, 1973, Reid and Dawson, 1972, Reid et al., 1975, Rhodes and Dawson, 1975, Ridley and Dawson, 1975). Their studies document the remarkable freshness of both garnet and spinel peridotite xenoliths from Lashaine in comparison to kimberlite-hosted xenoliths from the Kaapvaal craton. Relatively little published data exist for Olmani xenoliths (Jones et al., 1983), which are typically ultra-refractory (Fo_{93-94}) clinopyroxene-bearing dunites or wehrlites.

Main Features

Both garnet- and spinel-bearing peridotites occur at Lashaine. The garnet peridotites are strikingly similar to low temperature garnet peridotites from the Kaapvaal craton, whereas the spinel peridotites are generally more refractory than typical spinel peridotites from non-cratonic regions. Estimated equilibration pressures and temperatures for the Lashaine garnet-bearing xenoliths are similar to those from Kaapvaal, falling on the ~44 mW/m^2 geotherm. Moreover, the enstatite-rich and refractory character of low temperature Kaapvaal peridotites is also found in the Lashaine garnet peridotites, which have Fo = 90-93, modal olivine = 65-89% (Fig. 1a) and SiO_2 contents higher than spinel peridotites from Lashaine or elsewhere. REE patterns of the Lashaine garnet peridotites mimic those of the coarse granular Kaapvaal peridotites: they are LREE enriched ($(La/Yb)_n$ = 4-67) with harzburgites having lower HREE contents than lherzolites (e.g., McDonough and Frey (1989)).

Spinel peridotites from Lashaine have equilibration temperatures overlapping those of garnet peridotites, but are chemically different from both Kaapvaal and Lashaine garnet peridotites. These spinel peridotites have higher modal olivine contents for the same range of Fo contents and lie at the terminus of Boyd's "oceanic trend" (Fig. 1b); they also have lower SiO_2 and higher MgO contents than the garnet peridotites but exhibit similar overall REE contents and patterns. Compared with spinel peridotite xenoliths world-wide they have lower SiO_2 and higher MgO and Ni contents, suggesting that they are more refractory. In this respect they are most similar to spinel peridotites xenoliths from Olmani.

assemblages. Texturally, at least some of the clinopyroxenes are secondary: they rim spinels and are observed as veins cross-cutting the olivine matrix (see next section and Jones et al (1983)). The peridotites exhibit a range of modal olivine contents, although most contain >80% modal olivine, similar to but at higher Fo-contents than Lashaine spinel peridotites (Fig. 1b). None of these samples contain garnet, but the spinels have extremely Cr-rich compositions (Cr/(Cr+Al) up to 89). This feature, coupled with equilibration temperatures similar to the Lashaine peridotites and "fingerprint" intergrowths of pyroxene and chromite, suggests that some of the Olmani samples may have contained garnet that broke down due to rising temperature or falling pressure. The Olmani peridotites are more refractory than any hitherto reported in the literature, however despite their high MgO and Ni contents, Cr contents are highly variable (500-2500 ppm). These unusually refractory compositions may be the result of partial melting and cumulate processes; partial melting proceeded to where garnet was consumed (≥ 50% melting), leaving behind an olivine (±pyroxene +minor chromite) residue, while ascending magmas may have precipitated forsteritic olivine cumulates at or near their source. These samples may thus be prime candidates for residues and cumulates that have equilibrated with komatiitic magma.

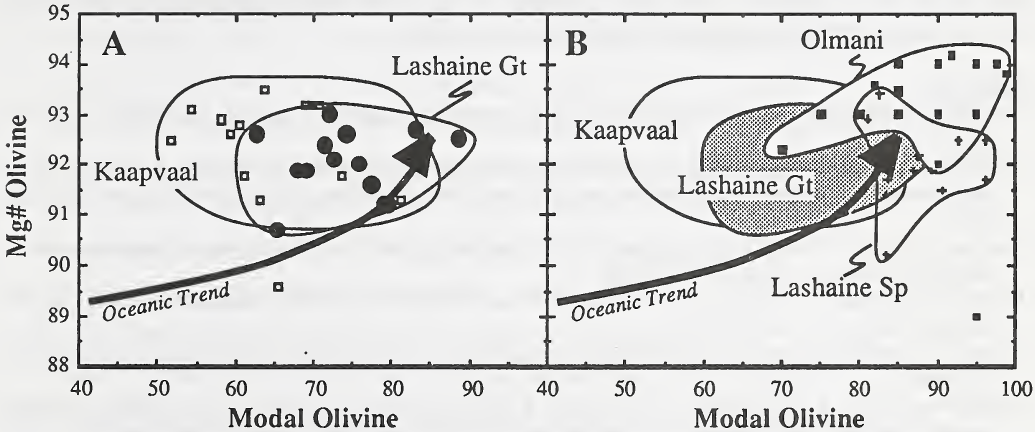

Fig. 1 Modal olivine versus Mg# of olivine (Fo content), after Boyd (1989). A. Garnet peridotites: open squares are low temperature Kaapvaal peridotites, filled circles are garnet peridotites from Lashaine. B. Spinel peridotites: crosses are Lashaine spinel peridotites and small closed squares are Olmani spinel peridotites. Kaapvaal data are from Boyd and Mertzman (1988), Lashaine and Olmani data are from Rhodes and Dawson (1975), Jones et al. (1983) and our unpublished results.

Secondary enrichments

Both Lashaine and Olmani xenoliths exhibit evidence for elemental enrichments following partial melt depletion. At Lashaine this enrichment is manifested by the presence of phlogopite whereas at Olmani the enrichment is associated with growth of secondary clinopyroxene. Anhydrous Lashaine xenoliths exhibit incompatible trace element enrichments comparable to those of some Kaapvaal low temperature garnet peridotites, whereas all phlogopite-bearing xenoliths from Lashaine are enriched in the high field strength elements (HFSE: Nb, Zr, Hf, Ti) relative to REE of similar compatibility, i.e. they have high Nb/La, Hf/Sm, Zr/Sm and Ti/Eu. These fractionations are uncommon in anhydrous peridotites and the converse of that observed in hydrous spinel peridotites from non-cratonic regions (McDonough, 1990). In addition to HFSE enrichments, the phlogopite-forming event also enriched the peridotite in FeO, CaO, and Al_2O_3. These features suggest introduction of phlogopite into depleted mantle peridotite in an open system, probably by interaction with a basaltic melt.

The secondary clinopyroxenes in the Olmani peridotites grew after partial melt depletion, possibly by interaction of the residual orthopyroxene with a carbonatite melt. Such interaction has the potential of adding CaO without Al_2O_3 and FeO (Green and Wallace, 1988, Meen, 1987) and can explain the very high CaO/Al_2O_3 ratios (1.3-8.0) observed in these samples. All Olmani samples are LREE enriched, and two samples exhibit unusual enrichments of LREE. These LREE enrichments occur without comparable enrichments in HFSE, giving the whole rock a strongly HFSE depleted pattern and $(La/Yb)_n$ up to 600. Although HFSE depletions are characteristic of island arc basalts (IAB), such magmas generally do not show fractionated Hf/Sm and Zr/Sm ratios (White and Patchett, 1984), which is in stark contrast to the Olmani samples. The cause of these fractionations are as of yet unknown, however similar

Discussion

The cratonic geochemical characteristics of the Lashaine garnet peridotites suggest that this portion of the mantle is Archean in age, consistent with the very low ε_{Nd} (-24) found in at least one of the garnet peridotites (Cohen et al., 1984) (this is the lowest ε_{Nd} recorded in any peridotite xenolith, including those from southern Africa). We infer that both ancient cratonic and "oceanic" type mantle exist beneath northern Tanzania. In addition, these data imply that the two mantle lithologies bear a close spatial relationship: the lower portion of the lithosphere is refractory garnet peridotite similar to that of the root of the Kaapvaal craton, whereas the shallower levels are also refractory, but contain a large proportion of modal olivine and may represent refractory residues formed in an oceanic environment. This mantle stratigraphy may have formed in one of the following scenarios: (1) the earliest crust may have developed on pre-existing, depleted oceanic lithosphere which was subsequently thickened by underplating buoyant peridotite, refractory after komatiite extraction, (2) an extremely depleted (i.e. dunitic) lithosphere may have been enriched in SiO_2 by addition from below (possibly from fluids off a subducting slab), however these fluids did not interact at shallow levels, or (3) Archean and post-Archean lithospheric mantle may have been juxtaposed through collisional tectonics, with the Archean portion thrust below the post-Archean portion.

References

Boyd, F. R. (1989) Compositoinal distinction between oceanic and cratonic lithosphere. Earth Planet. Sci. Lett., 96, 15-26.

Cohen, R. S., R. K. O'Nions and J. B. Dawson (1984) Isotope geochemistry of xenoliths from East Africa: implications for development of mantle reservoirs and their interaction. Earth Planet. Sci. Lett., 68, 209-220.

Dawson, J. B., D. G. Powell and A. M. Reid (1970) Ultrabasic xenoliths and lava from the Lashaine volcano, northern Tanzania. J. Petrol., 11, 519-548.

Dawson, J. B. and J. V. Smith (1973) Alkalic pyroxenite xenoliths from the Lashaine volcano, northern Tanzania. J. Petrol., 14, 113-131.

Green, D. H. and M. E. Wallace (1988) Mantle metasomatism by ephemeral carbonatite melts. Nature, 336, 459-462.

Hawkesworth, C. J., P. D. Kempton, N. W. Rogers, R. M. Ellam and P. W. van Calsteren (1990) Continental mantle lithosphere, and shallow level enrichment processes in the Earth's mantle. Earth Planet. Sci. Lett., 96, 256-268.

Jones, A. P., J. V. Smith and J. B. Dawson (1983) Glasses in mantle xenoliths from Olmani, Tanzania. J. Geol., 91, 167-178.

Kesson, S. E. and A. E. Ringwood (1989) Slab-mantle interactions 2. The formation of diamonds. Chem. Geol., 78, 97-118.

McDonough, W. F. (1990) Constraints on the composition of the continental lithospheric mantle. Earth Planet. Sci. Lett., 101, 1-18.

McDonough, W. F. and F. A. Frey (1989) Rare earth elements in upper mantle rocks. In B. R. Lipin and G. A. McKay, Eds., Geochemistry and Mineralogy of Rare Earth Elements, p. 99-145. Mineralogical Society of America, Washington, D.C.

Meen, J. K. (1987) Mantle metasomatism and carbonatites; an experimental study of a complex relationship. Geol. Soc. Am. Spec. Paper, 215, 91-100.

Nixon, P. H. (1987) Kimberlitic xenoliths and their cratonic setting. In P. H. Nixon, Eds., Mantle Xenoliths, p. 215-240. John Wiley & Sons, New York.

Reid, A. M. and J. B. Dawson (1972) Olivine-garnet reaction in peridotites from Tanzania. Lithos, 5, 115-124.

Reid, A. M., C. H. Donaldson, R. W. Brown, W. I. Ridley and J. B. Dawson (1975) Mineral chemistry of peridotite xenoliths from the Lashaine volcano, Tanzania. In L. H. Ahrens, J. B. Dawson, A. R. Duncan and A. J. Erlank, Eds., Physics and Chemistry of the Earth, p. 525-543. Pergamon Press, New York.

Rhodes, J. M. and J. B. Dawson (1975) Major and trace element chemistry of peridotite inclusion from the Lashaine volcano, Tanzania. In L. H. Ahrens, J. B. Dawson, A. R. Duncan and A. J. Erlank, Eds., Physics and Chemistry of the Earth, p. 545-557. Pergamon Press, New York.

Ridley, W. I. and J. B. Dawson (1975) Lithophile trace element data bearing on the origin of peridotite xenoliths, ankaramite and carbonatite from Lashaine volcano, N. Tanzania. In L. H. Ahrens, J. B. Dawson, A. R. Duncan and A. J. Erlank, Eds., Physics Chem. Earth, p. 559-569. Pergamon Press, New York.

White, W. M. and P. J. Patchett (1984) Hf-Nd-Sr isotopes and incompatible element abundances in island arcs: implications for magma origins and crust-mantle evolution. Earth Planet. Sci. Lett., 67, 167-185.