COEXISTING CARBONATITIC, ULTRAMAFIC AND MAFIC MELTS IN THE LITHOSPHERE: EVIDENCE FROM SPINEL LHERZOLITE XENOLITHS, NW SPITSBERGEN

H.E.F. Amundsen

Mineralogisk-Geologisk Museum, Sars gt. 1, 0562 OSLO 5, Norway

Abundant xenoliths of lower crust and upper mantle material occur in Quaternary volcanic centres on NW Spitsbergen. Xenolith P/I data indicate a thin (27 km) continental crust and high geothermal gradient (9kb/950^oC - 17kb/1150^oC; Amundsen <u>et al.</u>, 1987). Spinel herzolite xenoliths contain quenched liquids representing three different origins: 1) Melts introduced into the lherzolite material shortly prior to or during eruption; 2) Melts formed by incipient fusion of the lherzolite assemblage; 3) Trapped melts associated with amphibole + apatite + phlogopite.

Shortly prior to or during eruption, Ti, Na, K, P - rich basaltic melt (L_B) infiltrated the lherzolite material along cracks and grain boundaries. L_B locally carries abundant immiscible droplets of (H₂O + CO₂) - rich ultramafic silicate melt (L_U) and Mg - rich carbonatite melt (L_C). During quenching both L_U and L_C crystallized spherulitic ankerite + dolomite + magnesite, leaving a residual H₂O - rich ultramafic silicate melt (silicate melt (eg 58.0% SiO₂, .03% TiO₂, .08% Al₂O₃, .02% Cr₂O₃, 3.9% FeO, 26.9% MgO, .22% NiO, .38% CaO, .07% Na₂O, .08% K₂O, 10.2% LOI) in droplets of L_U. Some samples show infiltration of L_U alone.

Melts formed by incipient fusion of the lherzolite assemblage (L_B^*) typically occur surrounding corroded spinel grains, or are associated with breakdown of amphibole + phlogopite. Ly + L_C commonly occur as immiscible droplets in these melts, indicating that incipient fusion may have been promoted by introduction of Ly + L_C alone, shortly prior to or during eruption. Ly showing this mode of occurrence ranges from carbonate – bearing (Fig.1) to carbonate free.

Amphibole + apatite + phlogopite occur in some lherzolites, either evenly distributed or concentrated in amphibole - rich selvedges. Trapped melts are ubiquitous in these samples, occurring both interstitially in large (up to 1 mm) polygonal cavities, and as rounded inclusions in lherzolite phases and in amphibole. Ly and Mg to Ca rich L_C both show this mode of occurrence, and petrographic evidence indicates that they are residual after crystallization of the hydrous phases. Ly in these samples is compositionally similar to Ly in the infiltrating fluid assemblages, but is usually carbonate - free and may contain small amounts of Al, Ca, K and up to 3% NiO (eg 53.3% SiO₂, .11% TiO₂, 4.7% Al_{O2}, .12% Cr₂O₃, 8.9% FeO, 21.4%MGO, 2.1% NIO, 1.0% CaO, .06% Na₂O, .28% K₂O, 7.9% LOI). Similar trapped fluids also occur in several anhydrous lherzolites.



Fig. 1: Droplets of carbonatebearing L in L_p* in incipiently melting lherzolite. U = Ultramafic glass; Ca = ankerite: Cd = dolomite; Cm = Magnesite. Scale bar = .05 mm.

Modification of the infiltrating melts by resorption of lherzolite phases, and fractional crystallization of Cpx + Ol + Sp, make direct comparisons between L_B and host basalts (basanites - hawaiites) difficult. However, host basalts resemble L_B with regard to Ti, Al, Na. K, P, and they themselves contain scattered, apparently immiscible, droplets of L_U + L_C. Both L_U and L_C have much lower densities than L_B, and L_U + L_C occur alone in several xenoliths, infiltrating along cracks and grain boundaries, as immiscible droplets in partial melts or as inclusions in minerals, indicating that gravitational separation of immiscible liquids has occurred at depth both prior to and during the eruption. It seems unlikely that the assemblage of melts infiltrationg the xenoliths could have migrated any significant distance without separating. This suggests the existence of a homogeneous "protomelt", which unmixed into immiscible L_B + L_U + L_C, at some stage during upwards migration. It seems likely that the host basalt at some stage originated by gravitational separation from an assemblage of melts similar to that infiltrating the xenoliths. The onset of immiscibility, and subsequent liquid fractionation, may be the prerequisite factor triggering explosive alkaline volcanism.

Reconstruction of the protomelt by reintegrating the melt assemblage infiltrating xenoliths is not straightforward. However, $L_{\rm U}$ + $L_{\rm C}$ constitute up to 30 - 50% of the infiltrating melts, indicating a strongly undersaturated protomelt with kimberlitic or lamproitic affinities (rich in Mg, Ni, CO₂, H₂O).

Coexisting L_B (or L_B^{*}) + L_U + L_C define a previously unknown field of liquid immiscibility, occurring in primitive (CO₂ + H₂O)-rich magma compositions under upper mantle P/T conditions. This field covers a range of compositions, which include ultramafic lamprophyres, kimberlites, carbonatites and some alkaline basalts. Petrographic evidence shows that L_U may contain considerable amounts of L_C - component and (to a lesser extent) vice versa, indicating closure of the immiscibility - field along the L_U-L_C boundary, most likely with increasing T and/or P. Coexisting L_B^{*} + L_U + L_C from and Roedder (1973) in figure 2.



Fig. 2: Pseudoternary Greig diagram showing coexisting $L_B^{*} + L_U + L_C$ from two representative samples ($L_U - L_C$ tielines omitted); stippled outline shows compositions og L_B and L_B^{*} coexisting with $L_U + L_C$. Also shown are compositional fields for ultramafic lamproites from western Australia (L) and Kimberlites (K). Inserted figure shows two - liquid fields occurring in the system leucite-fayalite - SiO₂ (Weiblen and Roedder 1978) for comparison.

Major and minor elements and volatiles are strongly fractionated between the coexisting liquids: Ti, Al, Na, K, P are partitioned into L_B (or L_B^*); Mg, Ni, H₂O + CO₂ are partitioned into L_U ; Mg, Fe, Ca, show variable partitioning into L_C . The strong partitioning of incompatible elements into L_U has important implications for storage and migration of Ni (and other siderophile elements ?) in the upper mantle. The existence of ultramafic melts, resembling high degrees of melting of residual mantle material, in apparent equilibrium with an amphibole lherzolite assemblage, puts a new perspective on interpretations of komatiites. Formation of such melts could be linked to relatively low – T processes in a (CO₂ + H₂O) – rich primitive mantle.

Mass balance calculations, combined with constructed immiscibility fields, show that introduction of basanite $(L_B) + L_U + L_C$, with subsequent crystallization of amphibole + apatite + phlogopite, may account for the observed association of these phases and trapped līquids. Thus, the presence of amphibole + apatite + phlogopite in these lherzolites may be due to interaction between mantle wallrock and kimberlitic liquids, migrating up from a deeper source in the underlying mantle. A similar origin has been proposed for amphibole - apatite rich xenoliths from Kiama, Australia (eg Wass et al., 1980).

The NW Spitsbergen lherzolite xenoliths show that both carbonate - silicate and silicate - silicate immiscibility are important processes under upper mantle P/T - conditions, and suggest a genetic link between introduction of kimberlitic liquids in the upper mantle and the generation of carbonatites and alkaline basalts.

References:

Amundsen, H.E.F., Griffin, W.L. and O'Reilly, S.Y. (1987) The lower crust and upper mantle beneath northwestern Spitsbergen: evidence from xenoliths and geophysics. In prep.

Wass, S.Y., Henderson, P and Elliot, C.J. (1980) Chemical heterogeneity and metasomatism in the upper mantle - evidence from rare earth and other elements in apatite rich xenoliths in basaltic rocks from eastern Australia. Roy.Soc.Lon. A, 297, pp 333-346.

Weiblen, P.W. and Roedder, E. (1973) Petrology of melt inclusions in Apollo samples 15598 and 62295, and of clasts in 67915 and several lunar soils. <u>Proc.Fourth Lunar Sci</u>. Conf., Geochim.Cosmochim.Acta Suppl.4, Vol.1, pp681-703. Pergamon Press.