

EXPERIMENTAL MELTING REACTIONS IN AMPHIBOLE- AND PHLOGOPITE-BEARING MANTLE VEIN ASSEMBLAGES AND THE TRACE ELEMENT COMPOSITIONS OF DERIVED PARTIAL MELTS

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Background: Melting of Veined Lithosphere

The origin of alkaline magmas such as lamproites and kimberlites by partial melting of veined lithospheric mantle successfully explains the unusual liquidus relationships of these magmas described from numerous experimental studies (summarized by Foley 1990, Edgar & Vukadinovic, 1992). This model of magma genesis proposes a heterogeneous source consisting of clinopyroxene- and phlogopite-rich veins in garnet- or spinel-lherzolite wall-rocks (Foley, 1992). The vein assemblages depend on the composition of the melt from which they crystallized, but may contain accessory phases which need not be in equilibrium with peridotitic mantle. This removes the severe restrictions on stable mantle assemblages which apply if the mantle is homogeneous on a large scale.

Beneath a craton of Archean age, each part of the mantle can be expected to experience the passing of convective upwelling every few hundred Ma, so that several episodes of partial melting within the mantle may have occurred. Melting in the asthenosphere during these heating episodes results in intense veining of the underside of the cratonic lithosphere and the focussing of incompatible element-rich low-degree melts from a wide area of the asthenosphere into spatially restricted vein assemblages in the lower lithosphere. This scenario is compatible with models for the origin of oceanic basalts by accumulation of very low melt fractions from a large source area (McKenzie & Bickle, 1988), and with the expected transition beneath continents from an asthenospheric porous flow regime to a lithospheric channelled flow regime (Sleep, 1988; Foley, 1992). Later heating episodes reactivate veins leading to intrusion of later vein generations with modified geochemistry to higher levels in the lithosphere.

Remelting of veined mantle during later reheating events is initially focussed on the vein assemblages due to the concentration of volatile and incompatible components. However, the initial melt, which is alkaline due to the character of the vein assemblage, does not simply move along the vein, but becomes sucked into the wall-rock along grain boundaries driven by a combination of surface energy minimization and a chemical potential gradient. Once in the wall-rock, the melt is in strong disequilibrium with its surroundings and assimilates components of the peridotite wall-rock (Foley, 1992). An important feature of the model is that considerable reaction between the vein-derived melt and the wall-rock occurs at a temperature *below* the solidus of the wall-rock. Further heating leads to dilution of the vein-derived components by an increasing volume of basaltic melt derived from the peridotite.

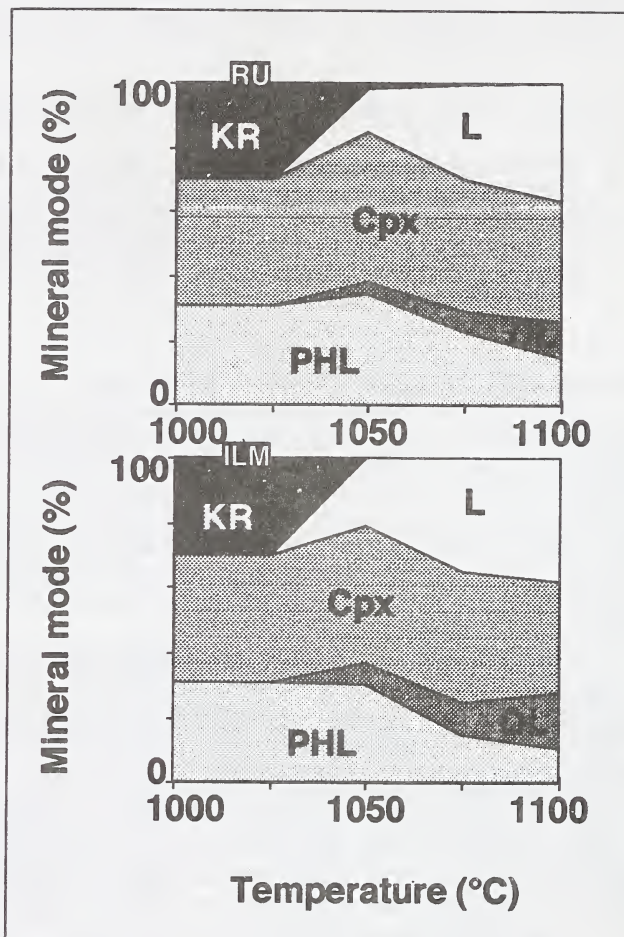
This report describes the initial stages of an experimental study aimed at determining the melting temperatures and melt compositions of a variety of likely vein assemblages. For this purpose, veins are assumed to contain abundant clinopyroxene and phlogopite, in agreement with near-solidus assemblages in experiments on alkaline rock compositions at mantle pressures. We are placing emphasis on determining the melt compositions for many elements, so that chemical interactions between melts and wall-rocks can be modelled at a later stage for incompatible trace elements as well as major elements. For this reason we are employing melt extraction traps and in-situ Laser-ICP-MS analyses of experimental charges.

Experimental details

Two series of experiments are being conducted at pressures of 1.5 and 5 GPa:

(1) Series 1: Determination of solidus temperature: The first series experiments contain mixtures of one third each of Clinopyroxene (Cpx), Phlogopite (PHL) and K-Richteritic amphibole (KR) plus lesser amounts (5 or 15%) of rutile (RU), ilmenite (ILM) or apatite (AP). Further details of these natural mineral compositions, the mixtures and the Series 1 experiments are given by van der Laan & Foley (1994). This first series of experiments permits determination of the solidus temperature for the investigated assemblage as well as the phase relationships close to the solidus. Fig.1 shows that the melting reaction at 1.5 GPa proceeds by incongruent melting of KR (and minor PHL) to form olivine. All accessory phases are eliminated close to the solidus, regardless of their abundance. The formation of olivine rather than orthopyroxene by incongruent melting indicates that these melts will be very reactive with respect to orthopyroxene and garnet when drawn into the wall-rock peridotite.

Figure 1: Melting reactions at 1.5 GPa indicated by changes in modal mineralogy as a function of temperature.



(2) Series 2: Determination of melt composition: A second series of experiments contains the same starting mixtures as in the first series with the addition of a melt extraction trap consisting of crushed carbon glass. During the experiments at high pressures, the melt is drawn into the pore space in the extraction trap where it can be quenched into glass pools which are large enough to analyse by electron probe and Laser-ICP-MS, thus bypassing problems caused by quench growth onto residual crystals. It is important that the amount of pore space does not exceed the volume of melt, so that equilibrium through continuous contact may be maintained. Since the approximate degree of melting and temperature close to the solidus is known from Series 1, the amount of material for the extraction trap can be estimated without the need for a large number of trial experiments.

Laser-ICP-MS analysis was performed at the Memorial University of Newfoundland using techniques described by Jackson et al. (1992), although a new Fisons Plasmaquad II+(S) ICP-MS instrument is now used. Results are shown in Fig.2 as primitive mantle-normalised abundance plots for two experiments in which ILM (run 137) or RU (run 138) were added to the starting mixture of Cpx+PHL+KR. These patterns can be viewed as OIB-like patterns (Sun & McDonough, 1989) onto which unusual enrichments in several elements, especially alkalis and high-field strength elements, are superimposed. The highly enriched elements reflect the identity

of the minerals which contribute substantially to the melt (Fig. 1), because the olivine formed during melting does not take up these trace elements to any significant degree. The high contents of alkalis are derived from KR, as is the positive anomaly for Sr (Foley et al., this volume), whereas the pattern for Nb, Ta > Zr, Hf corresponds approximately to that expected for ilmenite and rutile.

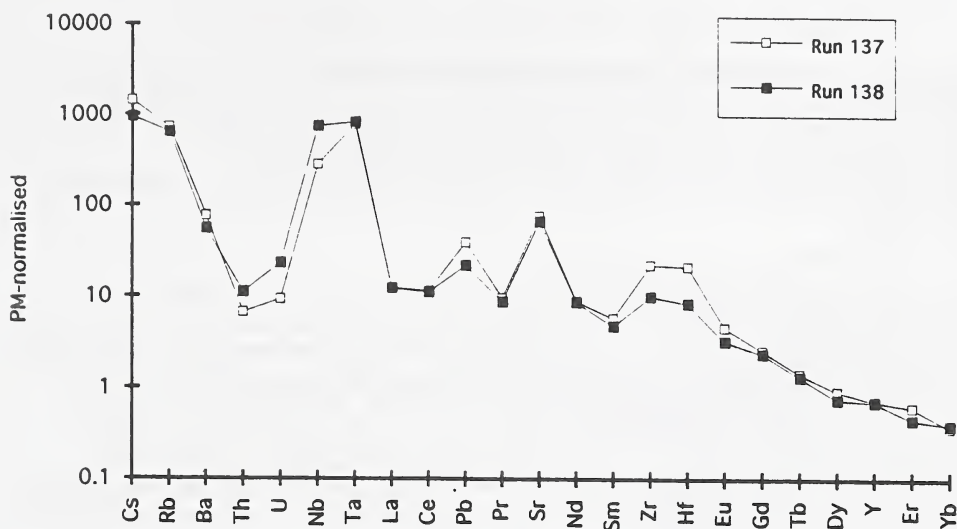


Figure 2: Abundances of trace elements in two 1.5 GPa melts normalised to primitive mantle (values of Sun & McDonough, 1989). Both starting compositions consisted of CPX+PHL+KR with the addition of ILM (run 137) or RU (run 138).

Implications

These first results appear to indicate that the trace element contents of melts from veins within the lithosphere may be closely predictable from mineral/melt partition coefficients. The trace element composition of the melts is controlled principally by the accessory phases: the phlogopite and clinopyroxene do not supply more than the underlying OIB-like signature in Fig. 2 onto which the characteristics of the accessory phases are superimposed. This means that trace element patterns of highly incompatible element-enriched rocks such as kimberlites or lamproites depend to a large extent on the accessory phase identities and abundances. The addition of apatite to the assemblages depicted in Fig. 2 should lead to considerable enrichment in U, Th and the rare earth elements (especially LREE), so that the strongly enriched patterns typical of lamproites and kimberlites would be produced. The presence and magnitude of negative anomalies for Nb, Ta, Zr, Hf and Ti in lamproites (Foley and Wheller, 1990) may thus be due to varying apatite/titanate abundances in the vein assemblages.

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