

IS ECLOGITE IN THE SUB-CONTINENTAL LITHOSPHERE THE RESIDUE FROM MELTING OF SUBDUCTED OCEANIC CRUST? EXPERIMENTAL CONSTRAINTS AND IMPLICATIONS FOR THE ORIGIN OF THE ARCHEAN CONTINENTS.

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Introduction

Eclogite xenoliths in kimberlites, although representing only a small proportion of the total xenolith population, may contain important information on the petrologic processes responsible for the initial stabilization and growth of the continents (cratonization) in the Archean, and the nature and chemical evolution of the sub-continental lithospheric mantle (continental roots). The fact that some mantle eclogites possess oxygen isotope ratios similar to hydrothermally-altered oceanic crust supports the idea that these samples may represent metamorphosed remnants of subducted basaltic crust, possibly modified by melting (MacGregor and Manton, 1986; Jacob et al., 1994). Low-degree partial melts of hydrated metabasalt (i.e., "wet eclogite") are virtually identical geochemically to the tonalite-trondhjemite-granodiorite (TTG) suite of granitoids that are the dominant felsic component of Archean high-grade gneiss and granite-greenstone terrains (Rapp and Watson, 1995). These observations suggest a genetic link between eclogite xenoliths in the lithospheric mantle beneath the Archean cratons, and the granite magmatism responsible for their stabilization. In order to evaluate this relationship, melting experiments were conducted at 2-11 GPa on a number of natural olivine tholeiite metabasalt compositions (amphibolites), and the major, minor and trace element characteristics of the melt products and crystalline residues were determined by a combination of electron and ion microprobe analysis. These measurements form the basis for comparisons between the eclogitic residues produced in the melting experiments with eclogite xenoliths from beneath the South African and Siberian cratons. What are the distinctive geochemical features of eclogites that are residues of basalt melting?

Results

From 20% to 40% TTG liquid coexists with eclogitic residual assemblages at 2-4 GPa and temperatures between 1050°C and 1150°C. Between 5 and 11 GPa, a much smaller proportion of granitic liquid (<10%) is present. Garnet-clinopyroxene pairs in eclogite residues at these conditions, from several different basalt compositions, fall within a broad envelope defined by xenolith suites, in terms of Ca-Mg-Fe components (Fig. 1). Shown for comparison are the fields for garnet-clinopyroxene pairs for diamond inclusions and mantle eclogites, from Jacob et al., 1994. For mantle eclogites, major element composition is clearly not diagnostic of partial melting, and a diversity of protoliths must be assumed (Jerde et al., 1993). The correlation in Figure 1 between eclogite mineral inclusions in diamonds and the experimental residues of basalt melting may or may not be coincidental.

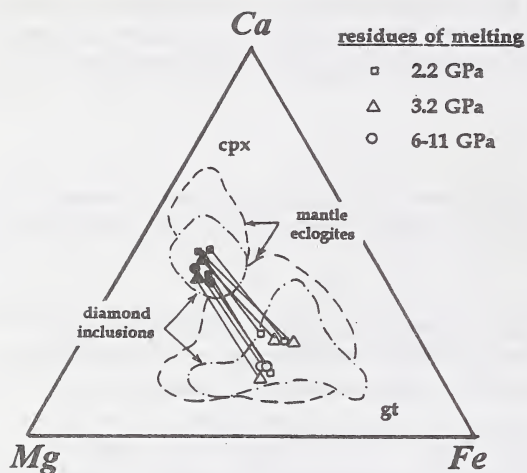


Figure 1. Atomic Ca-Mg-Fe of coexisting garnet-clinopyroxene pairs. Fields for mantle eclogites (dashed) and diamond inclusions (dot-dashed) from Jacob et al. (1994).

pressure, from 2-3wt% at 1.6 GPa to 6-7wt% at 3.2 GPa; above 5 GPa, clinopyroxene contains >8wt% Na₂O, beyond the range observed in eclogite xenoliths. The TiO₂ content of garnet in the residues of melting is in the range 1-2wt% at temperatures between 1000°C and 1150°C, i.e., temperatures at which SiO₂-rich or "granitic" liquids are present, and at pressures of 2-11 GPa. This feature therefore appears to be relatively insensitive to pressure, but strongly dependent on the degree of melting and thus liquid composition and temperature of the experiment. At temperatures of 1200-1250°C, TiO₂ in garnet is 0.3-0.6wt%. Taken together, the systematics of TiO₂ in garnet and Na₂O in clinopyroxene for the experimental residues suggest the following sequence of events: (1) generation of TTG magmas by partial melting of a wet eclogite protolith at 2-4 GPa and 1050-1150°C, (2) sinking of the eclogitic residues of melting to higher temperature and pressure regimes (~1150-1200°C, 5-7 GPa) in the subcontinental mantle (3) sampling of these residues by kimberlites.

A number of geochemical studies of eclogite xenoliths and diamond mineral inclusions in recent years have concluded that the geochemical characteristics of some of these samples are consistent with their having experienced extraction of a low-degree melt component at some point in their history, based on estimates of reconstructed whole rock compositions (e.g., Taylor and Neal, 1989; Jacob et al., 1994). Ireland et al. (1994) describe garnet and clinopyroxene inclusions in diamonds from kimberlites piercing the Siberian craton that are more depleted in incompatible trace elements than the eclogite host minerals. Their interpretation of the sequence of events leading to the observed trace element patterns in the diamond inclusions is

Eclogite xenoliths, diamondiferous eclogites, and eclogite mineral inclusions in diamonds possess a fairly restricted range in terms of the TiO₂ content of garnet (~0.1-0.7 wt%) and the Na₂O content of clinopyroxene (2-7 wt%). Systematics of these components in residual garnet-clinopyroxene pairs from the melting experiments at 2-11 GPa indicate that the distribution observed in the natural samples can be explained by a combination of low-degree partial melting at 2-4 GPa, followed by subsequent equilibration of the dry dense residues at slightly higher temperatures (1150-1250°C) at constant or increasing pressure. This is based upon the fact that the Na₂O content of clinopyroxene in the residues of melting increases progressively with increasing

broadly consistent with the scenario outlined above based on the systematics of TiO_2 in garnet and Na_2O in clinopyroxene for the experimental residues of melting. In order to substantiate these interpretations, the trace element characteristics of the eclogitic residual assemblages, coexisting with TTG partial melts, were determined by ion microprobe (in collaboration with N. Shimizu). The results of these analyses are summarized in Figure 2; the shape of the overall pattern of trace element abundances in residual garnet in the melting experiments is remarkably similar. The higher concentrations of trace elements in the experimentally-equilibrated garnets is attributable to the fact that the starting basalt composition is intermediate between N-type (normal) MORB and E-type (enriched) MORB, a consideration that does not invalidate the correlation in the least. The data presented are therefore broadly consistent with models in which TTG magmas that form the bulk of the early Archean continents are the result of melting of hydrated basalt at lower crustal to upper mantle depths, with the dense eclogite residues of melting foundering and disaggregating in the underlying, juvenile, sub-continental mantle.

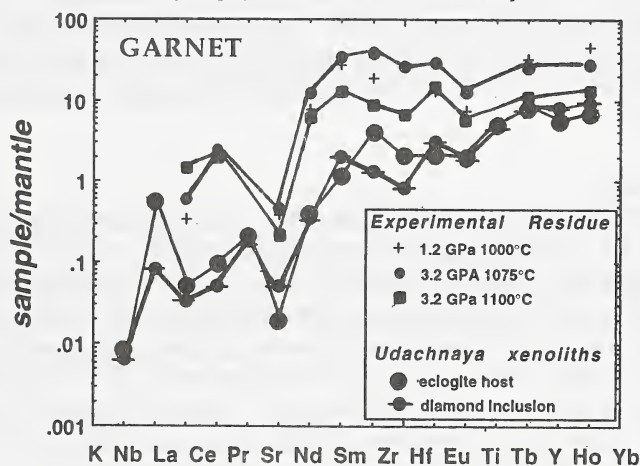


Figure 2. Comparison of trace element compositions of garnet for Udachnaya xenoliths (both eclogite host and inclusions in diamonds), with garnet in the residues of melting experiments at 1-3 GPa, coexisting with TTG liquids. Udachnaya data from Ireland et al., 1994.

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