A model for eclogite-peridotite interactions: activity-driven metasomatism, with evidence from the Zero eclogite suite, South Africa

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It is well known that the dehydration and melting of basaltic oceanic crust in subduction zones is of crucial importance for the geochemical signature of magmatic-arc. At the same time, deep-seated kimberlite-borne eclogite xenolith suites both of South Africa and Siberia are being interpreted as remnants of such subducted slabs (e.g. Jacob et al., 1994; Snyder et al., 1997), and much speculation is concerned with the possible role of slab-mantle or, more generally, eclogite-peridotite interactions for the compositions of subcratonic lithosphere or in the genesis of some basalts (e.g. Yaxley and Green, 1998). Here, we want to systematize eclogite-peridotite relationships using an analysis of component activities imposed by their differing bulk compositions and arrive at a reaction sequence which must be satisfied by any of the geochemically based models.

Whereas it is generally appreciated that 4-phase garnet lherzolite in the upper mantle constitutes a buffer for the silica activity through the equilibrium $Ol + SiO_2 = Opx$ (reaction [Gt] in Fig. 1), it is less known that in the system CMAS, the reaction $Opx + Cpx + Al_2O_3 = Garnet$ ([Ol] in Fig. 1) also fixes the activity of Al_2O_3 at a given P, T, and bulk composition. Thus, mantle peridotite has to reside at an invariant point in $a(Al_2O_3)$-$a(SiO_2)$ space as shown in Fig. 1, the exact numerical value of which varies with P, T along a geotherm for any bulk composition. Eclogite, in contrast, generally lacks olivine and orthopyroxene and therefore must be associated with $a(Al_2O_3)$-$a(SiO_2)$ to the right of the lherzolite invariant point in Fig. 1. The activity of Al_2O_3 in a bimineralic Garnet + Cpx eclogite is defined by the reaction $Cpx + Al_2O_3 = Garnet$ and depends on the aluminum (Ca-tschermakite) content of Cpx and the X_{Ca} (grossular content) of garnet. Thus a field for bimineralic eclogites is generated in activity space which nonetheless cannot be in

equilibrium with peridotite activities. More specifically, kyanite-bearing eclogites must be located at high $a(SiO_2)$ to stabilize kyanite, and quartz/coesite-bearing kyanite eclogites at still higher $a(SiO_2)$, both grossly out of equilibrium with peridotitic compositions at ambient P and T. This is also shown in Fig. 1. The consequence of these relationships is that eclogites e. g. in subducted slabs constitute a disequilibrium couple with surrounding peridotite at mantle depths, and the resulting activity gradients across the slab-mantle interface must drive metasomatic exchange. In other words, the eclogites must lose silica and aluminum to the surrounding mantle peridotites. The resulting metasomatic sequence is first, elimination of any quarz/kyanite in the eclogite, rendering it bimineralic; then, at progressed metasomatism, production of orthopyroxene. We suggest that this is the ultimate reason for the comparative scarcity of coesite/kyanite in kimberlite-borne eclogites vs. orogenic eclogites within the continental crust (both originating from similar oceanic crust). Conversely, orthopyroxene must be produced in peridotites as well below as above a subducted slab, by metasomatic exchange with its eclogites. This may help to explain the high-Si, Opx-rich character of old Archaean lithospheric roots, given that more frequent subduction and a hotter geotherm in the Archaean promote the proposed metasomatic exchange. Both direct slab melts and hydrous fluids from slab dehydration must reflect $a(Al_2O_3)$-$a(SiO_2)$ of their source and react with the peridotite they encounter. Still, with both metasomatic agents the nature of the metasomatic reactions is essentially determined by the activity gradients between eclogite and peridotite.

We are presently investigating a suite of eclogite xenoliths from the Zero kimberlite, South Africa, which apparently shows evidence for the proposed metasomatic exchange. This suite consists of kyanite
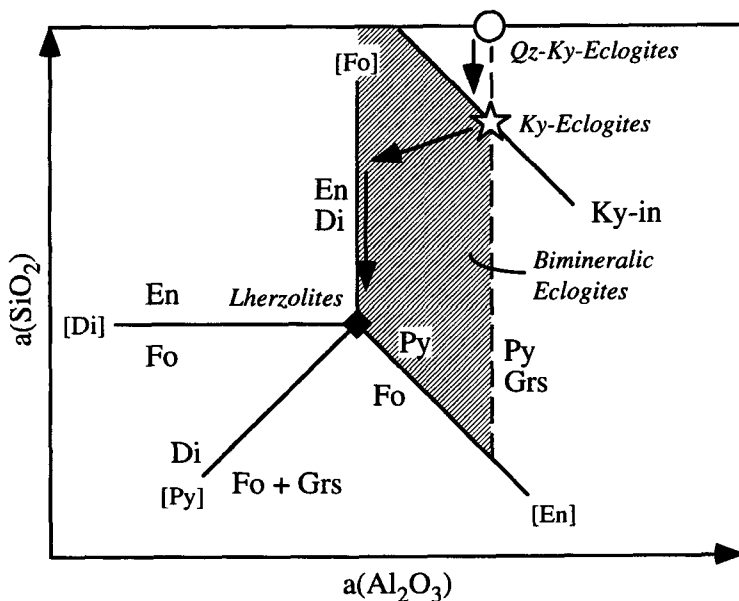
FIG. 1. Silica-aluminum activity relationships between peridotite and eclogite in the system CMAS at pressures above the spinel-out reaction. The activity values are not quantified, as numerical values shift with P and T; the relative disposition of reactions does not. Typical 4-phase lherzolitic compositions are stable at an invariant point marked by the black diamond. Radiating reactions are labeled by the missing phase (Fo: Forsterite, Di: Diopside, Py: Pyrope, En: Enstatite). Dashed vertical line gives $a(Al_2O_3)$ of the garnet-clinopyroxene equilibrium in eclogites. This varies with composition (shaded field). Buffered activities of kyanite- and kyanite/quartz-eclogites are indicated by white star and circle, respectively. The arrows show the development of activities in a starting quartz-kyanite eclogite during progressive metasomatic exchange with peridotite.

eclogites (rare), bimineralic eclogites and many 'eclogite' xenoliths rich in orthopyroxene. Mineral compositions show a strong decrease of X_{Ca} in garnet, from about 0.5 to 0.15, in the given order, which is consistent with a compositional development along the trend outlined in Fig. 1. Most striking is the presence of sanidine in the orthopyroxene-bearing samples, along with numerous sanidine and quartz inclusions exclusively in the cores of their garnets. This demonstrates that these xenoliths a) are of subduction origin; b) cannot have lost a large melt fraction because they have retained their K; c) nonetheless have experienced a reduction in $a(SiO_2)$ eliminating quartz anywhere save as relics in not fully-equilibrated garnet cores. We suspect that the

compositional trends of many other now bimineralic eclogite suites bear information about similar eclogite-peridotite exchange metasomatism.

References

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