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Origins and timing of amphibole and phlogopite formation in kimberlite-borne eclogite and pyroxenite xenoliths

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Introduction

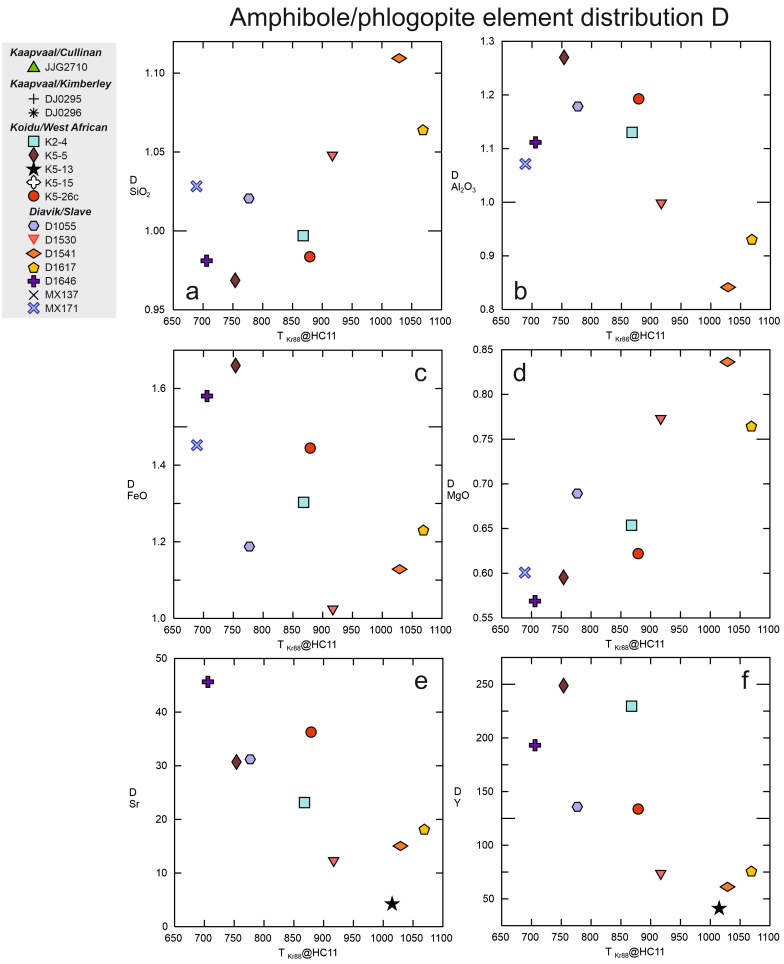
The presence of phlogopite and amphibole in cratonic mantle xenoliths is an expression of modal metasomatism at high H_2O activity that may weaken the lithosphere and may also be detrimental to its diamond inventory. Melts from the kimberlite-carbonatite spectrum are typically invoked to explain the presence of these hydrous minerals in cratonic mantle xenoliths. In particular, precursory deep lithospheric proto-kimberlite activity is known to pervasively affect and "condition" the mantle prior to successful kimberlite eruption. Previous work mostly focused on metasomatised peridotite or "exotic" (MARID, PIC) xenoliths. Eclogite and pyroxenite xenoliths containing phlogopite and amphibole (from the edenite-pargasite series) are more rarely reported, and hydrous mineral-bearing, finer-grained and texturally unequilibrated assemblages in cracks, veins or interstices are seldomly investigated. We studied a selection of eclogite and pyroxenite xenoliths from Diavik (Slave craton), Koidu (West African craton), Cullinan and Kimberley (both Kaapvaal craton), containing texturally diverse phlogopite and/or amphibole, with the aim of narrowing down the origin and timing of hydrous mineral addition to the cratonic lithosphere.

Samples and methods

Phlogopite ± amphibole occur in various textural settings ranging from equilibrated, to platy or fine-grained and restricted to veins and altered cracks in garnet or clinopyroxene. Prior work indicates that garnet and clinopyroxene in these samples have a variety of protoliths, ranging from basaltic or picritic, with high total REE contents and no or negative Eu anomalies, to gabbroic with low total REE contents and positive Eu anomalies. Geochemical compositions indicate that some of these samples remained relatively pristine whereas others were variably strongly metasomatised. Major and trace element compositions of phlogopite and amphibole were determined at Goethe University Frankfurt by electron probe microanalyser and laser ablation microprobe inductively-coupled plasma mass spectrometry respectively, while phlogopite Ar-Ar dating was carried out by Noble Gas Mass Spectrometry ($^{40}Ar/^{39}Ar$) at Vrije Universiteit Amsterdam.

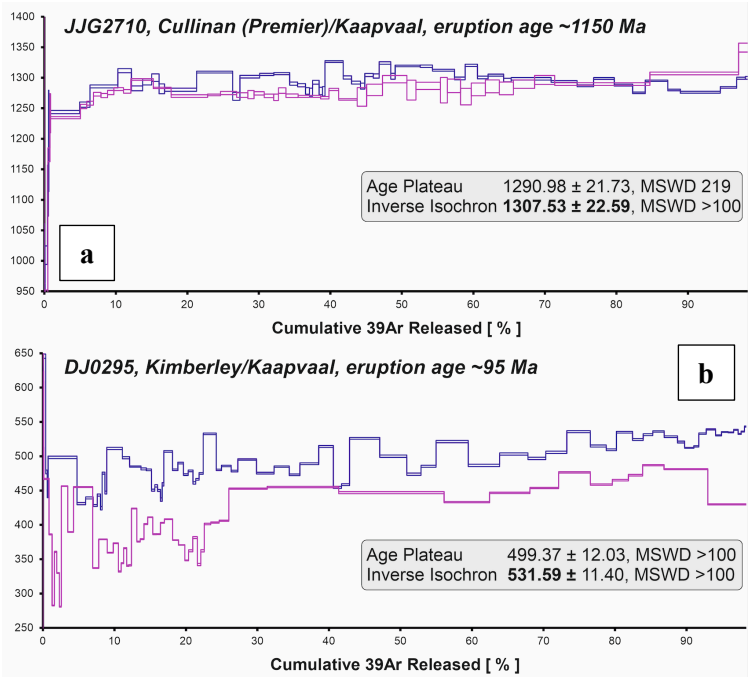
Results and discussion

Eclogitic phlogopite and amphibole have high concentrations in LILE. Eclogitic phlogopites exhibit similar LILE contents to those of kimberlite phenocrysts, suggesting precipitation from a kimberlite-like melt, while significant intra-sample chemical heterogeneity likely reflects evolution of the kimberlite melt during percolation. Although texturally unequilibrated, major element compositions of amphibole, averaged per sample, show correlations with those of both garnet and clinopyroxene, suggesting amphibole replaces both minerals, whereas phlogopite compositions only correlate with those of garnet. Nevertheless, phlogopite and amphibole appear to approach chemical equilibrium as the distribution of some elements, averaged per sample (n = 9), correlates with temperature of last equilibration (e.g., MgO: $r^2 = 0.73$; Y: $r^2 = 0.63$) (Fig. 1). Taken together, this also suggests formation of texturally unequilibrated phlogopite and amphibole at mantle depths rather than precipitation upon ascent. As eclogite may constitute up to 20% of the cratonic lithosphere, this has implications for the mantle's H_2O and halogen storage capacity, as well as for the solidus temperature and seismic velocity of hydrous mineral-bearing eclogite sources, which may contribute to seismic mid-lithospheric discontinuities.



Distribution D between amphibole and phlogopite of a.-d. major element oxides and e.-f. trace element concentrations as a function of clinopyroxene-garnet Fe-Mg exchange temperatures (formulation of Krogh 1988) solved iteratively with peridotite-derived regional steady-state conductive geotherms (geotherm family of Hasterok and Chapman 2011).

While we could not define plateau or isochron ages for any of the samples, ^{40}Ar-^{39}Ar dating yielded age ranges of ~300-500 Ma for phlogopite from the two Kimberley eclogites (kimberlite emplacement ~90 Ma, temperature of last residence 920 and 1030 °C), suggesting formation or cooling below closure temperature within a few 100 Ma of entrainment to the surface. Of note, ~1260-1320 Ma for phlogopite from the Cullinan eclogite (emplacement ~1.15 Ga, 910 °C) implies that precursory metasomatism similarly preceded Mesoproterozoic kimberlite activity (Fig. 1). In contrast, phlogopite from a low-temperature Diavik eclogite (emplacement 54 Ma, 710 °C) yielded ~1400-1700 Ma, a time span previously linked to strong HFSE metasomatism. The broad consistency observed in our phlogopite Ar age data with protolith evolution may indicate that phlogopite can retain Ar over long time spans at mantle conditions in the range documented by our samples.



^{40}Ar/^{39}Ar step heating spectra for phlogopite – y-axis shows apparent ^{40}Ar/^{39}Ar age in Ma (see Kuiper et al. 2008). Two experiments were performed on phlogopite separated from five samples (two examples shown here). No true plateau or isochron ages were obtained, as indicated by the high MSWDs. The eruption ages for the host magmas are given to illustrate that the ^{40}Ar-^{39}Ar ages are distinct.

References

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