Geochemical constraints on kimberite ascent mechanisms revealed by phlogopite in kimberlite and mantle xenoliths

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Kimberlite magmas are of economic and scientific importance because they represent the major host to diamonds and are probably the deepest derived magmas from continental regions. In addition, kimberlite magmas transport abundant mantle and lower crustal xenoliths, thus providing fundamental information on the composition of the sub-continental lithosphere. Despite their importance, the composition and ascent mechanism(s) of kimberlite melts remain poorly constrained. Phlogopite is one of the few minerals that preserves a history of fluid migration and magmatism in the mantle and crust and is therefore an invaluable petrogenetic indicator for kimberlites. Here we present major and trace element compositional data for phlogopite from the Bultfontein kimberlite (Kimberley, South Africa, i.e. the kimberlite type-locality) and from entrained mantle xenoliths. Phlogopite macrocrysts (>0.5 mm) in the Bultfontein kimberlite display concentric compositional zoning patterns. The rims of some grains exhibit compositions analogous to kimberlite groundmass phlogopite (i.e., high Ti-Al-Ba; low-Cr), whereas other rims and intermediate zones (between cores and rims) exhibit higher Cr and lower Al-Ba concentrations. The latter compositions are indistinguishable from matrix phlogopite in polymict breccia xenoliths (considered to represent failed kimberlite intrusions) and from overgrowth rims on phlogopite in other mantle xenoliths. Consequently, it is suggested that these phlogopite grains crystallized from kimberlite melts and that the high Ti-Cr zones originated from early kimberlite melts at mantle depths. It is suggested that successive pulses of ascending kimberlite magma progressively metasomatized the conduit along which later kimberlite pulses ascended, producing progressively decreasing interaction with the surrounding mantle rocks. We postulate that these processes represent the fundamental mechanism of kimberlite magma ascent. Our study also reveals that, in addition to xenoliths/xenocrysts and magmatic phases, kimberlite rocks incorporate material crystallized at mantle depths by previous kimberlite intrusions (‘mantle-derived anteliths’).