Low $^{87}Sr/^{86}Sr$ in Kimberlitic Perovskite – Further Evidence for Recycled Oceanic Crust as a Possible Source of Kimberlites

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The discovery of a low $^{176}Hf/^{177}Hf$ signature by Nowell et al., (2004) in some kimberlites has sparked renewed interest in the idea that kimberlites may be sourced in old, recycled oceanic crust, an idea introduced by Sharp (1974) and Ringwood (1989). The peculiar Hf-Nd isotope signature of these kimberlites, extending from the modern Hf-Nd mantle array to well below it (to large negative $\Delta\varepsilon_{Hf}$) appears to require a source with long-term low Lu/Hf and sub-chondritic Sm/Nd. Isotopic modelling shows that old oceanic crust (in particular old E-MORB), once converted to eclogite and stored deep in the mantle for long periods of time, can develop such signatures. Remobilization of old oceanic crust in deep plumes (Nowell et al., 2004), or transfer of such Hf-Nd isotope signatures to the mantle via mobile mantle fluids or low-degree partial melts (Gaffney et al., 2007), have been suggested as possible physical links with kimberlite source regions. This model is broadly related to longstanding observations that many group-1 kimberlites are isotopically similar to some OIB, for which sources in old, subducted oceanic crust have often been proposed.

Two key aspects of oceanic crust are its low Rb/Sr and $^{87}Sr/^{86}Sr$ (modern MORB: Rb/Sr ≈ 0.018, mostly 0.7025-0.7035), inherited from long-term incompatible-element depleted mantle. If recycled old oceanic crust does play a role in generating kimberlitic magmas, kimberlites should have low, MORB-like initial $^{87}Sr/^{86}Sr$. Although existing data for Group 1 kimberlites do include examples with $^{87}Sr/^{86}Sr_i$ as low as ca. 0.703, many more appear to cluster near 0.704 and higher, apparently ruling out recycled low-$^{87}Sr/^{86}Sr$ oceanic crust as an important source component. However, given that most kimberlites are altered, original Rb-Sr systems may be disturbed by alteration of kimberlite groundmass (and perhaps by contamination with xenocrystic material). We suggest that most kimberlite whole rock $^{87}Sr/^{86}Sr_i$ ratios may be compromised, making whole rock Sr isotope data unsuitable for testing the recycled oceanic crust model.

By contrast, $^{87}Sr/^{86}Sr_i$ data obtained from kimberlitic perovskite appear to be much more robust (Heaman, 1989; Paton et al., 2007). Perovskite ($CaTiO_3$, often >1000 ppm Sr, Rb/Sr≈0) is a common groundmass mineral in kimberlites (Chakhmouradian and Mitchell, 2000) and should record the $^{87}Sr/^{86}Sr$ of the kimberlite melt at the time of perovskite formation. High Sr concentrations and near-zero Rb/Sr in many kimberlitic perovskites allow for easy isotopic analysis by both conventional and in situ (LA-MCICPMS, Paton et al., 2007) methods, with minimal age corrections even in very old perovskites.

In an effort to test the claim that kimberlite bulk rock Rb-Sr systems are disturbed, and to search for evidence of MORB-like low $^{87}Sr/^{86}Sr_i$ in a well-studied kimberlite, we obtained Hf-Nd-Sr isotopic data for whole rocks and melt-derived perovskite from the ultrafresh Udachnaya-East pipe, Yakutia. Although perovskite is present in the host kimberlite, the perovskites studied here were extracted from a small autolith with unusually abundant (10%) perovskite (Fig.1). Mineral compositions in the autolith (31% MgO, fresh olivine, phlogopite, perovskite, alkali carbonates and chlorides) are identical to those in the host kimberlite groundmass, implying a petrogenetic link. A pooled 363±3 Ma age from 7 small (<1 mg) phlogopite Rb-Sr ages (anchored to $^{87}Sr/^{86}Sr$ from associated perovskite) as well as identical Ar-Ar ages (D.Phillips, unpubl. data) further support this link: the autolith phlogopite age of ≈363±3 Ma is the same within errors as a 367±5 Ma SHRIMP U-Pb age for perovskite from Udachnaya-East (Kinny et al., 1997).

Initial Nd-Sr isotope ratios for the host kimberlite (groundmass after removal of xenocrystic material, ε_{Nd} +4, 0.7036-0.7049) are typical of Group-1 kimberlites. Initial ε_{Hf} in the same samples is ≈+5. This places Udachnaya-East near the radiogenic end of the global Group-1 kimberlite Hf-Nd isotope field, with modestly negative $\Delta\varepsilon_{Hf}$ (≈-3.7). Autolith perovskite yields similar ε_{Nd} (+3.9,+4.7,+4.8) and ε_{Hf} (+5.4,+5.6, Hf isotopes measured in ≈100 mg samples of mixed perovskite, olivine and phlogopite). However, $^{87}Sr/^{86}Sr_i$ derived from three samples of pure, handpicked perovskite is 0.70303, 0.70303 and 0.70308, considerably lower than in the host kimberlite. Very similar perovskite $^{87}Sr/^{86}Sr_i$ results were obtained by in situ laser ablation MC-ICPMS (≈0.7031, Fig.2).

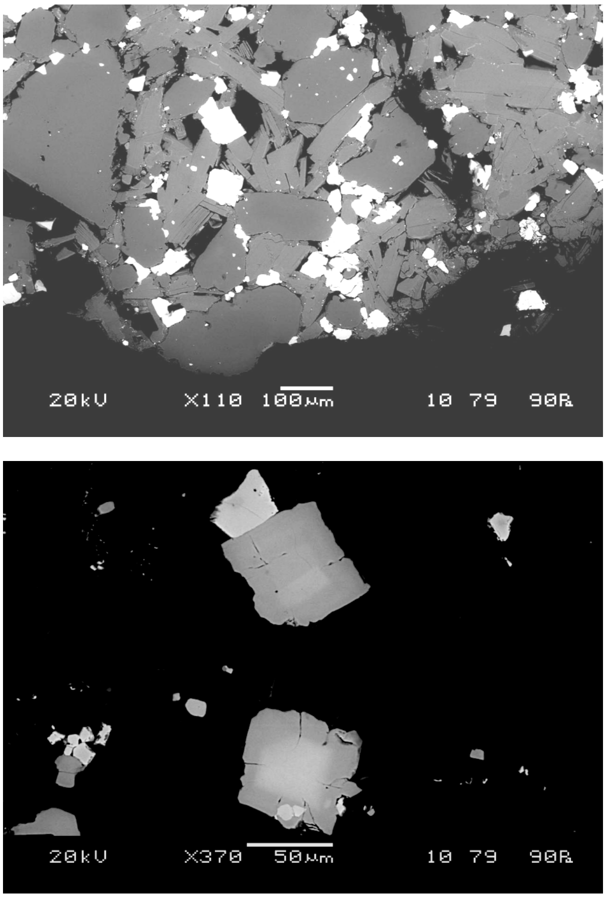

Fig.1 BSE image of autolith UV-31K-05, showing abundant perovskite (bright) in matrix of fresh olivine and phlogopite laths. Close-up in bottom panel shows spinel (bright) and zoned perovskite (grey).

Given their similar mineral chemical and Nd-Hf isotopic compositions, such a pronounced Sr isotopic contrast (0.7031 vs ≈0.7036-0.7049) between autolith perovskite and kimberlite groundmass is unexpected. Higher $^{87}Sr/^{86}Sr_i$ in host kimberlite may reflect inaccurate age corrections due to complex Rb redistribution between leachate and residues (Maas et al., 2005). By contrast, perovskite, with Rb/Sr near 0, is a much simpler matrix and is thus likely to preserve a more straightforward and robust Sr isotopic record of the kimberlite melt. The obervation that even acid-leached samples from an ultrafresh kimberlite such as Udachnaya-East do not preserve original $^{87}Sr/^{86}Sr_i$ is sobering. Clearly, initial Sr isotope ratios obtained from kimberlite (or groundmass) whole rock powders need to be interpreted with considerable caution.

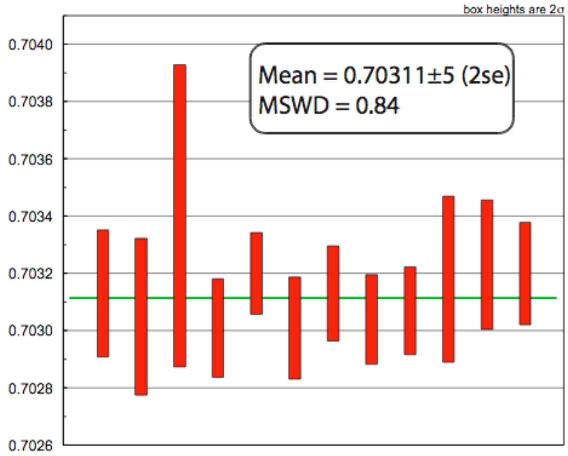

Fig.2 Initial Sr isotope ratios of 12 autolith perovskite grains, measured by LA-MCICPMS. $^{87}Rb/^{87}Sr \leq 0.0005$ Eight further grains (higher Rb/Sr) yield similar pooled initial $^{87}Sr/^{86}Sr \approx 0.70314\pm9$. Analytical techniques described in Paton et al., (2007).

More importantly though, a melt $^{87}Sr/^{86}Sr \approx 0.7031$ in a Devonian kimberlite supports a major role of recycled oceanic crust in Group-1 kimberlite petrogenesis, as inferred from Hf-Nd isotope data. In this model, the relatively low ε_{Nd} in Udachnaya-East and other Group-1 kimberlites relative to modern MORB requires derivation of the recycled oceanic crust from ancient (1 Ga and older) MORB mantle, followed by substantial storage and ageing of this crust with a broadly chondritic to substantially sub-chondritic Sm/Nd, as discussed in Nowell et al. (2004). Many parallels appear to exist with isotopically similar OIB for which a recycled coeanic crust source has also been considered. Clearly, further development of this model requires acquisition of perovskite Sr isotope data from other kimberlites, in particular those with Δe_{Hf} more negative than those in Udachnaya-East. Reliable perovskite-based Sr isotope data would also help constrain the role, if any, in Group-1 kimberlite petrogenesis of other low-ε_{Hf}-ε_{Nd} sources, such as old continental crust, or parts of the subcontinental lithosphere.

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