Lithospheric evolution in circum-cratonic settings: a Re-Os isotope study of peridotite xenoliths from the Vitim region, Siberia

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The lithospheric mantle beneath most cratonic regions appears to be of comparable age to the overlying crust and is tectonically robust. Less clear is the age and robustness of the lithospheric mantle beneath circum-cratonic regions. Questions of particular interest are (1) whether the cratonic mantle extends beyond the craton cover for significant distances, (2) the nature of circum-cratonic lithospheric mantle and its relationship to the age and geologic history of the overlying crust, and (3) the relationship of the lithospheric mantle to the modern tectonic setting, particularly continental rifting. One of the regions that these questions can be addressed is Siberia. The Siberian craton is intruded by numerous kimberlites that carry mantle peridotite xenoliths of Archaean age (Pearson *et al.*, 1995), which are petrologically similar to Archaean lithospheric mantle elsewhere (Boyd *et al.*, 1997).

The poly-stage Sayan-Baikal fold belt originated in the Early Palaeozoic from closure of the palaeo-Asian ocean and collision of several Precambrian micro-continents with the Siberian craton to the north. It experienced repeated orogenic and intra-continental magmatic episodes; the last of them producing the Cenozoic Vitim volcanic field, in which Miocene and younger alkali basalts and tuffs contain xenoliths of spinel- and garnet-bearing peridotites that provide a valuable insight of the lithospheric mantle (Ionov *et al.*, 1993). The Vitim Highland region that the xenoliths are erupted through is not thought to have undergone significant modification of lithospheric mantle due to recent rifting in the Baikal rift zone, some 100–200 km to the west, and so the xenoliths should provide a record of pre-rift lithospheric evolution (Ionov *et al.*, 1993). We have analysed a suite of these xenoliths, described by Ionov *et al.* (1993), plus new samples, for Re-Os isotopic composition, with the aim of constraining the age and evolution of the lithospheric mantle beneath the region.

Whole rocks

The sample suite ranges from spinel lherzolites and harzburgites, through garnet-spinel lherzolites, to garnet lherzolites and spans a large range of bulk composition, with Al_2O_3 varying from 1.5 to 4.7 wt.%. In general, the Vitim peridotites are substantially more fertile than cratonic xenoliths from either Siberia or southern Africa, with olivine mg-numbers not exceeding 0.91 (Ionov *et al.*, 1993). The Vitim peridotite suite is characterized by very low S contents (Ionov *et al*, 1992). Re and Os may exhibit both siderophile and chalcophile behaviour making these rocks of interest in constraining mantle Re-Os systematics.

Samples were digested in Carius Tubes and Os extracted via solvent extraction and run by N-TIMS. Os abundances in the Vitim peridotites appear anomalously low (0.6 to 1.25 ppb), well below 'average' mantle peridotite (~3 ppb). These values replicate well and have been confirmed by fire-assay on some samples. Comparable, low Os concentrations have been observed in some other spinel-peridotite xenoliths from several Proterozoic crustal sections in S.E. Australia (Handler *et al*, 1997).

$^{187}Os/^{188}Os$ for 8 samples varies from 0.1174 to 0.1301 and correlates positively with Al_2O_3 content ($r^2 = 0.985$). We have not yet analysed the lowest Al_2O_3 samples. The Re depletion model age (T_{Rd}) for the lowest $^{187}Os/^{188}Os$ sample is 1.5 Ga, this value could increase further once the low Al_2O_3 samples are analysed, but is in general agreement with the Proterozoic Nd model ages obtained by Ionov and Jagoutz (1989). The validity of extrapolating Al_2O_3 *vs*. Os isotope trends for mantle peridotites is not clear. Because of the significant Al content of enstatite, especially in spinel facies peridotites, and the likely control of Re by sulphide in spinel peridotites, it is likely that Re will be depleted well before Al is exhausted from a melting residue in most situations. Extrapolation of Al_2O_3 *vs* $^{187}Os/^{188}Os$ correlations to zero Al_2O_3 may thus lead to serious overestimates of formation ages and hence we have not performed this calculation.

Whole rock sulphur contents are low (<25 ppm) and the present data shows no direct correlation between bulk S and either Os content or isotopic ratio. The general observation that these peridotites contain low Os and have low S is evidence for Os control by sulphide in residues. Re analyses are currently being performed.

Spinels

In an effort to address the low Os contents of the whole rocks further, 2 spinel separates were analysed from spinel peridotites. Digestions were made by Carius Tubes using concentrated sulphuric acid at 300°C and subsequent distillation from chromic acid after further Carius Tube spike-sample equilibration. Total dissolution of spinel and its inclusions is obtained by this method. Spinel from 314–56 contained 0.106 ppb Os, compared to 0.923 ppb in the whole rock. Spinel from 314–59 contained 0.735 ppb Os compared to 1.25 ppb in the whole rock. Considering the low modal abundance of spinel in these rocks (3 and 2.2% respectively), and its low Os concentration, it is inconceivable that the low whole rock concentrations are due to lack of spinel dissolution.

Interestingly, in both cases, Os in the spinels was substantially more radiogenic than in the whole rocks, possibly reflecting preferential, or more rapid interaction/equilibration with metasomatic components. These questions are being addressed by Re and PGE analysis of the spinel.

Discussion

The mostly fertile compositions of the Vitim peridotites, combined with their Os isotope compositions, the lowest of which is considerably above average cratonic peridotite, strongly suggest the absence of Archaean mantle beneath the Vitim Highland.

The low Os abundances of the Vitim peridotites are not presently understood but are unlikely to reflect an analytical artifact. Clinopyroxene in all but one Vitim peridotite we studied shows depletion in light relative to intermediate *REE* reflecting partial melting and melt extraction. The clinopyroxenes are also depleted in highly incompatible trace elements (Nb, Ta, Th, U) and show no geochemical evidence for significant interaction with melt or metasomatic enrichment following the initial depletion event/s. Interstitial sulphide grains in the xenoliths show variable degrees of secondary alteration that could have been responsible for partial loss of sulphur and relatively low bulk rock S contents (Ionov *et al.*, 1992). However, the S contents are not related to degree of secondary alteration, and it is not likely that alteration has significantly lowered whole rock Os contents.

The major and trace element composition of the xenoliths and their minerals, and evidence for long-term depletion in incompatible elements provided by Sr-Nd isotope data indicates that the Al_2O_3 *vs* $^{187}Os/^{188}Os$ correlation reflects progressive melt removal from a single protolith, or a series of coeval ancient melt removal episodes. The linear nature of the Al-Os isotope trend may argue, in addition to trace element evidence, against significant melt re-enrichment effects. The lowest $^{187}Os/^{188}Os$ obtained so far on a Vitim sample is indicative of melt depletion in the Proterozoic (at least 1.5 Ga ago) and thus the mantle lithosphere in the Vitim region may be of broadly similar age to the age of formation of mature crust and robust continental lithosphere in the region (Ionov *et al.*, 1993). Hence, the lateral age variation across the craton to circum-craton margin in southern Siberia broadly matches that observed in the crustal basement rocks and suggests that the crust and mantle in the lithosphere have been coupled over very long time periods beneath, and circumferential to the Siberian craton.

References

Boyd, F.R., Pokhilenko, N.P., Pearson, D.G., Mertzman, S.A., Sobolev, N.V. and Finger, L.W. (1997) *Contrib. Mineral. Petrol.*, **128**, 228–46.

Handler, M., Bennet, V.C. and Esat, T. (1997) *Earth Planet. Sci. Lett.*, **151**, 61–75.

Ionov, D.A., Ashchepkov, I.V., Stosch, H.-G., Witt-Eickschen, G. and Seck, H.A. (1993) *J. Petrol.*, **34**, 1141–75.

Ionov, D.A., Hoefs, J., Wedepohl, K.H. and Wiechert, U. (1992) *Earth Planet. Sci. Lett.*, **111**, 269–86.

Ionov, D.A. and Jagoutz, E. (1989) *Doklady USSR Acad. Sci: Earth Sci. Sect.*, **301**, 232–6.