Re-Os Isotope Systematics of Eclogites from Roberts Victor: Implications for Diamond Growth and Archean Tectonic Processes

Shirey, S.B.[1], Carlson, R.W.[1], Gurney, J.J.[2] and van Heerden, L.[2]

1. Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Rd, NW, Washington, DC 20015, USA
2. Department of Geological Sciences, University of Cape Town, Rondebosch 7700, South Africa

Eclogites are thought to make up perhaps less than 1% by volume of the subcontinental lithospheric mantle (SCLM;Schulze, 1989). At kimberlite pipes where they constitute the bulk of the xenolith population (e.g. Newlands, Orapa, Roberts Victor), they have been proposed to be survivors that have not disaggregated like their formerly coexisting metasomatized peridotitic counterparts (Schulze, 1989). Nonetheless, understanding the petrogenesis of the eclogites is important; they can be strikingly diamondiferous, they are thought to represent basaltic material emplaced at SCLM depths, they often carry surficial geochemical signatures indicative of recycled materials. Recent Re-Os whole rock isochrons on diamondiferous eclogites from Udachnaya, Siberian craton (Pearson et al., 1995) and Newlands, Kaapvaal craton (Menzies et al., 1998) have clearly established these eclogite suites as 2.9±0.4 and 3.6±0.6 Ga old (respectively) and serve as one of the firmer constraints on craton antiquity.

The Roberts Victor kimberlite is a 128±15 Ma old (Smith et al., 1985a) Group II kimberlite (Smith et al., 1985b) situated in the Boshoff district ENE of Kimberley. It is known for its abundant and texturally diverse eclogite suite (Hatton and Gurney, 1987; MacGregor and Carter, 1970). Based largely on work on Roberts Victor eclogites, Kaapvaal craton eclogites have been divided petrographically, mineralogically and geochemically into Group I and Group II types (MacGregor and Carter, 1970; MacGregor and Manton, 1986; McCandless and Gurney, 1989). Group I eclogites have large, subhedral or rounded garnets in a matrix of clinopyroxene, have higher Na_2O (>0.09 wt%) in their garnet, higher K_2O (>0.08 wt%) in their pyroxene, and higher $\delta^{18}O$ compared to the Group II eclogites. Group II eclogites have irregular anhedral garnet and clinopyroxene in an interlocking fabric. Diamondiferous eclogites belong to Group I using the Na_2O_{gt} and K_2O_{cpx} scheme (McCandless and Gurney, 1989).

This Re-Os study of the eclogites at Roberts Victor was undertaken for a number of reasons: to accurately determine the residence time of these eclogites in the SCLM, to see how the Re-Os systematics of nondiamondiferous eclogites compare to more completely studied diamondiferous types, and to see if there are any differences in the Re-Os systematics and ages between texturally and chemically distinct Group I and Group II types. Previous Pb-Pb (Kramers, 1979; Manton and Tatsumoto, 1971) and Sm-Nd (Jacob and Jagoutz, 1994) isotopic work on Roberts Victor eclogites had shown a 2.5-2.7 Ga Archean age that perhaps could be extended back to 3.2 Ga (Manton and Tatsumoto, 1971) but nontheless is younger than the 3.6 Ga age of the Newlands Re-Os eclogite array. There is ample evidence in the U-Pb and Sm-Nd systems for reequilibration between garnet and clinopyroxene up to the time of kimberlite eruption (Jacob and Jagoutz, 1994; McCulloch, 1989). Previous studies (Hatton and Gurney, 1987; MacGregor and Manton, 1986) suggested Roberts Victor Group I eclogites are cumulate oceanic crustal gabbros or remelted oceanic crust whereas Group II eclogites are chilled basaltic liquids with seawater interaction or in-situ melts of SCLM garnet lherzolite that interacted with eclogite magma. A recent Sr, Nd, Pb and O isotopic study of eclogites from the Orapa kimberlite, Botswana suggested Group I eclogites there derive from young subducted oceanic crust + sediment whereas Group II samples derive from an older depleted protolith (Viljoen et al., 1996). Re-Os isotopic work could resolve such petrogenetic models and protolith age indications, yet to date there has been no Re-Os study of non-diamondiferous eclogites and no systematic investigation of the Group I and Group II differences.

Three gram aliquots of 8 eclogites and one diamondiferous websterite, crushed in an alumina jaw-crusher and puck mill, were equilibrated with Re and Os radiotracers and digested in Carius tubes at 240°C for two days (Shirey and Walker, 1995). Os was separated by solvent extraction into CCl_4, back extracted into HBr and purified by microdistillation (Birck et al., 1997)]. Re was isolated and purified by cation exchange chromatography (Morgan and Walker, 1989).

Rhenium contents of Group I eclogites (0.78 to 3.4 ppb) are distinctly higher than Group II eclogites (0.023 to 0.38 ppb) whereas Os contents on both groups are high (0.16 to 0.92 ppb) and overlap completely (Figure 1). $^{187}Os/^{188}Os$ isotopic compositions, age-corrected to the time of kimberlite eruption show quite a range but with one exception are strongly radiogenic (0.1412 to 1.159) in common with other eclogite suites. On a Re-Os isochron diagram, Roberts Victor eclogites scatter considerably but 6 of the 9 analyzed samples generally follow a 3.5 Ga Re-Os array defined by the diamondiferous eclogites from the Newlands kimberlite (Figure 2; Menzies et al., 1998) Three of the 9 samples display severe recent Re gain (3.4 ppb) or loss (0.02 ppb).

Although the Re-Os data set is at present limited, some interesting conclusions may be drawn. We interpret adherence of most of the Roberts Victor eclogites to the 3.5 Ga Newlands array (Figure 2) as showing that the true emplacement age of the eclogite protoliths was in the early Archean. Thus the formation of Kaapvaal eclogites dates from the birth of the craton itself. It is striking that the oldest bona fide ages are obtained on the two diamondiferous samples at Roberts Victor whereas the nondiamondiferous samples have scattered age systematics. The fact that nearly all Roberts Victor, Newlands and Udachnaya diamondiferous eclogites give good mid- to early- Archean Re-Os isochron ages suggests that the Re-Os system in diamondifereous eclogites may be less disturbed than in nondiamondiferous eclogites. Given the scatter in the nondiamondiferous eclogite data (Figure 2), no discernible age difference is yet apparent between Group I and Group II eclogites. The better preservation of early Archean ages in diamondiferous eclogites at Roberts Victor argues strongly that the these diamonds are have early Archean in ages similar to their silicate hosts. They are not likely to be introduced at later times because diamond formation would not necessarily preferentially affect the oldest eclogites. We suggest that the diamond-free Group I eclogites may have been diamond-bearing at one time and had their diamonds destroyed and Re-Os systematics scattered by metamorphic or metasomatic processes after emplacement. We surmise that this process was not as severe in the diamondiferous Group I eclogites and left the diamonds and Re-Os system in these rocks intact.

The Os concentrations of Roberts Victor and Newlands (Menzies et al., 1998) eclogites are strikingly similar and much higher than the Udachnaya eclogites studied by Pearson et al. (1995) which are akin to the low Os concentrations common in basalts (Figure 1). This suggests Siberian and Kaapvaal eclogites may have formed by fundamentally different processes. On a Re vs Os concentration plot, the Roberts Victor eclogites fall near the fields for primitive ocean island basalt (OIB), komatiite and continental flood basalt (CFB) picrite, not typical evolved mid-ocean ridge basalt (MORB) or oceanic gabbros. This rules out most of the previously proposed models for Kaapvaal eclogite formation described above. If the eclogite precursors were formed in an Archean ocean-floor environment and accreted to the SCLM then they must represent primitive portions of oceanic plateaus or ocean islands, or high-temperature, basaltic komatiitic ocean ridge products, not the Archean equivalent of normal MORB. Alternatively they could be deep-seated plume melts such as picrite or basaltic komatiite emplaced into the craton at SCLM depths but in this case explaining the elevated $\delta^{18}O$ would be difficult.

References

Birck, J. L., Roy Barman, M., and Capmas, F., 1997, Re-Os isotopic measurements at the femtomole level in natural samples: Geostandards Newsletter, v. 20, p. 19-27.

Hatton, C. J., and Gurney, J. J., 1987, Roberts Victor eclogites and their relation to the mantle, *in* Nixon, P. H., ed., Mantle Xenoliths: New York, John Wiley and Sons, p. 453-464.

Jacob, D., and Jagoutz, E., 1994, A diamond-graphite bearing eclogitic xenolith from Roberts Victor (South Africa): indication for petrogenesis from Pb, Nd, and Sr isotopes, *in* Meyer, H. A. O., and Leonardos, O. H., eds., Kimberlites, Related Rocks and Mantle Xenoliths, Proceedings of the Fifth International Kimberlite Conference, Brazil, 5: Brasilia, CPRM, p. 304-317.

Kramers, J. D., 1979, Lead, uranium, strontium, potassium and rubidium in inclusion-bearing diamonds and mantle-derived xenoliths from southern Africa: Earth and Planetary Science Letters, v. 42, p. 58-70.

MacGregor, I. D., and Carter, J. L., 1970, The chemistry of clinopyroxenes and garnets of eclogite and peridotite xenoliths from the Roberts Victor Mine, South Africa: Physics of the Earth and Planetary Interiors, v. 3, p. 391-397.

MacGregor, I. D., and Manton, W. I., 1986, Roberts Victor eclogites; ancient oceanic crust: Journal of Geophysical Research, v. 91, p. 14,063-14,079.

Manton, W. I., and Tatsumoto, M., 1971, Some Pb and Sr isotopic measurements on eclogites from the Roberts Victor Mine, South Africa: Earth and Planetary Science Letters, v. 10, p. 217-226.

McCandless, T. E., and Gurney, J. J., 1989, Sodium in garnet and potassium in clinopyroxene: Criteria for classifying mantle eclogites, *in* Ross, J., ed., Kimberlites and Related Rocks, Their Mantle/Crust Setting Diamonds and Diamond

Exploration. Proceedings of the Fourth International Kimberlite Conference: Perth, GSA Special Publication No. 14, p. 827-832.
McCulloch, M. T., 1989, Sm-Nd systematics in eclogite and garnet peridotite nodules from kimberlites: Implication for the early differentiation of the Earth, *in* Ross, J., ed., Kimberlites and Related Rocks, Their Mantle/Crust Setting, Diamonds and Diamond Exploration. Proceedings of the Fourth International Kimberlite Conference: Perth, GSA Special Publication No. 14, p. 864-876.
Menzies, A. H., Shirey, S. B., Carlson, R. W., and Gurney, J. J., 1998, Re-Os isotope systematics of diamond bearing eclogites and peridotites from Newlands kimberlite: this volume.
Morgan, J. W., and Walker, R. J., 1989, Isotopic determinations of rhenium and osmium in meteorites by using fusion, distillation and ion-exchange separations: Analytica Chimica Acta, v. 222, p. 291-300.
Pearson, D. G., Snyder, G. A., Shirey, S. B., Taylor, L. A., Carlson, R. W., and Sobolev, N. V., 1995, Archaean Re-Os age for Siberian eclogites and constraints on Archaean tectonics: Nature, v. 374, p. 711-713.
Schulze, D. J., 1989, Constraints on the abundance of eclogite in the upper mantle: Journal of Geophysical Research, v. 94, p. 4205-4212.
Shirey, S. B., and Walker, R. J., 1995, Carius tube digestions for low-blank Rhenium-osmium analysis: Analytical Chemistry, v. 67, p. 2136-2141.
Smith, C. B., Allsopp, H. L., Kramers, J. D., Hutchinson, G., and Roddick, J. C., 1985a, Emplacement ages of Jurassic-Cretaceous South African kimberlites by the Rb-Sr method on phlogopite and whole-rock samples: Transactions of the Geological Society of South Africa, v. 88, p. 249-266.
Smith, C. B., Gurney, J. J., Skinner, E. M. W., Clement, C. R., and Ebrahim, N., 1985b, Geochemical character of Southern African kimberlites; a new approach based on isotopic constraints: Transactions of the Geological Society of South Africa, v. 88, p. 267-280.
Viljoen, K. S., Smith, C. B., and Sharp, Z. D., 1996, Stable and radiogenic isotope study of eclogite xenoliths from the Orapa kimberlite, Botswana: Chemical Geology, v. 131, p. 235-255.