Evolution of the Earth's mantle: perspective from the Re-Os isotopic system

S.B. Shirey

Department of Terrestial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road, NW, Washington, DC 20015 USA (shirey@dtm.ciw.edu)

Introduction

The Re-Os isotopic system (Allegre and Luck, 1980; Faure, 1986; Shirey, 1991) has seen increasing use as a unique tracer, complementry to other radioisotope systems because of its chalcophile/siderophile behavior. Increased use has followed improvements in measurement sensitivity (Creaser *et al.*, 1991; Vlkening *et al.*, 1991), analytical accuracy (Walczyk *et al.*, 1991; Yin *et al.*, 1993) and chemical separation and spike sample equilibration (Morgan and Walker, 1989; Morgan *et al.*, 1991) at picogram levels (Walker, 1988; Shirey and Walker, 1994).

Meteorites

The Re-Os system has provided the first direct radiogenic isotopic ages on iron meteorites (Luck *et al.*, 1980; Luck *et al.*, 1983; Walker *et al.*, 1989; Horan *et al.*, 1992; Morgan *et al.*, 1992). With all uncertainties, these ages are within errors of the age of the solar system. Slight initial Os isotopic differences exist between chondrites and irons (Luck and Allegre, 1983; Walker *et al.*, 1989) and between different groups of irons (Horan *et al.*, 1992; Morgan *et al.*, 1992). Addition of chondritic material late in Earth's accretion may have determined the Re-Os systematics of the mantle (Morgan, 1985; Morgan, 1986).

Lithospheric studies

Xenoliths of spinel and garnet peridotite in kimberlite and minette from the Siberian, Kaapvaal and Wyoming cratons show the lowest ^{187}Os/^{188}Os (0.106 to 0.125) yet reported (Walker *et al.*, 1989; Carlson and Irving, in press; Pearson *et al.*, in press). These low ^{187}Os/^{188}Os have mid-Proterozoic to mid-Archean minimum model ages relative to a convecting mantle, only possible if the xenoliths have been part of the subcontinental lithospheric mantle since the mid-Archean. The low Re/Os could have been produced by high-temperature melt depletion (Walker *et al.*, 1989; Carlson and Irving, in press; Pearson *et al.*, in press) or high pressure crystal accumulation (Pearson *et al.*, submitted) as a result of cratonic lithosphere stabilization processes.

Oceanic Mantle Reservoirs and Convecting Mantle Evolution: Re-Os isotopic study of MORB has been difficult because of the low Os concentrations (<10 ppt; Hertogen *et al.*, 1980; Martin, 1991) and the incorporation of seawater Os (Martin, 1991). Analyses of the Zambales ophiolite and abyssal peridotites have established the ^{187}Os/^{188}Os of MORB at 0.120 to 0.132 (Martin, 1991). Ridge-centered MORB may be best analyzed using Fe-sulfides (Martin *et al.*, 1993).

OIB have proven amenable to Os isotopic study because their concentrations are greater than 100 ppt. The highest Os isotopic compositions measured in OIBs (^{187}Os/^{188}Os of 0.144 to 0.150) representative of OIB plume sources are for HIMU ocean islands (Hauri and Hart, 1993; Reisberg *et al.*, 1994). Correlation of the radiogenic Os isotopic signature with other HIMU isotopic characteristics provides further confirmation that HIMU OIB sources are dominated by recycled oceanic lithosphere (Hauri and Hart, 1993; Reisberg *et al.*, 1994). EMII-like OIBs have ^{187}Os/^{188}Os compositions of 0.123 to 0.136 that overlap abyssal peridotites, consistent with the incorporation of small amounts of Os-poor, but Os-isotopically-enriched sediment in their sources (Hauri and Hart, 1993; Reisberg *et al.*, 1994). Hawaii and Iceland have ^{187}Os/^{188}Os ranging from 0.131 to 0.140 (Martin, 1991; Pegram and Allegre, 1992), midway between the depleted MORB mantle source and the HIMU mantle source. The ^{187}Os/^{188}Os of Hawaiian and Icelandic basalts with primitive ^{3}He/^{4}He converges on a value of 0.132 indicative of a plume source compositions free from interaction with ambient mantle or subvolcanic oceanic lithosphere (Martin, 1991).

Ophiolite complexes (Luck and Allegre, 1991; Martin, 1991), orogenic lherzolites (Reisberg *et al.*, 1991), and other ultramafic intrusions (Hattori and Hart, 1991) have been used to examine the depleted mantle through the Phanerozoic.

Peridotites from ophiolites show a range of initial Os isotopic compositions some of which are as radiogenic as enriched mantle. Noble metal phases in ophiolites and ultramafic intrusions have lower Os isotopic compositions (Hattori and Hart, 1991; Luck and Allegre, 1991) but they display significant isotopic heterogeneity. Variations in the Os isotopic composition of the Precambrian mantle are poorly known because the number of published Os isochron initial ratios on volcanic rocks is sparse (Walker *et al.*, 1988) and their accuracy is plagued by uncertainties about open system behavior (Walker *et al.*, 1989) and spike-sample equilibration (Shirey and Walker, 1994).

Layered intrusions, ore deposits, lithosphere-asthenosphere interactions

The Re-Os system can be used to constrain the role of subcontinental lithosphere in the genesis of flood basalts. Combined Nd and Os isotopic systematics of picrites from the Karoo flood basalt province of South Africa and the Keweenawan midcontinent rift of North America have been explained by mixing of plume-derived and lithospheric mantle sources (Ellam *et al.*, 1992; Shirey, 1991).

In mafic layered intrusions, the Re-Os system has proved a useful tracer of the effect of crustal assimilation versus mantle source composition on the composition of platinum group element ores. The late Archean Stillwater Complex, Montana displays initial Os isotopic compositions in silicate rocks and chromitites that range from subchondritic to enriched due to melting of lithospheric mantle (Lambert *et al.*, in press; Lambert *et al.*, 1989) and contamination of mantle-derived melt with Archean crust (Lambert *et al.*, in press; Martin, 1989). Assimilation clearly has elevated the Os isotopic compositions of platinum group metals in the early Proterozoic Bushveld Complex, South Africa (Hart and Kinloch, 1989; McCandless and Ruiz, 1991) and has affected other layered gabbros too (Hattori *et al.* 1991). The maximum extent of this process probably is seen in the mid-Proterozoic Sudbury Complex, Ontario where the initial Os isotopic compositions are so radiogenic that Archean crust has been the chief source of the Os (Walker *et al.*, 1991).

References

Allegre, C.J. and Luck, J.M. (1980) *Earth Planet. Sci. Lett.*, **48**, 148–54.

Carlson, R.W. and Irving, A.J. (in press) *Earth Planet. Sci. Lett.*,

Creaser, R.A., Papanastassiou, D.A. and Wasserburg, G.J. (1991) *Geochim. Cosmochim. Acta*, **55**, 397–401.

Ellam, R.M., Carlson, R.W. and Shirey, S.B. (1992) *Nature*, **359**, 718–21.

Faure, G. (1986) Principles of Isotope Geology. Wiley, New York. Hart, S.R. and Kinloch, E.D. (1989) *Econ. Geol.* **84**, 1651–55.

Hattori, K., Cabri, L.J. and Hart, S.R. (1991) *Contrib. Mineral. Petrol.* **109**, 10–8.

Hattori, K. and Hart, S.R. (1991) *Earth Planet. Sci. Lett.*, **107**, 499–514.

Hauri, E.H. and Hart, S.R. (1993) *Earth Planet. Sci. Lett.*, **114**, 353–71.

Hertogen, J., Janssens, M.J. and Palme, H. (1980) *Geochim. Cosmichim. Acta*, **44**, 2125–43.

Horan, M.F., Morgan, J.W., Walker, R.J. and Grossman, J.N. (1992) *Science*, **255**, 1118–21.

Lambert, D.D., Morgan, J.W., Walker, R.J., Shirey, S.B., Carlson, R.W., Zientek, M.L. and Koski, M.S. (1989) *Science*, **244**, 1169–74.

Lambert, D.D., Walker, R.J., Morgan, J.W., Shirey, S.B., Carlson, R.W., Zientek, M.L., Lipin, B.R. and Koski, M.S. (in press). *J. Petrol.*

Luck, J. and Allegre, C. J. (1983) *Nature*, **302**, 130–2.

Luck, J. M. and Allegre, C.J. (1991) *Earth Planet. Sci. Lett.*, **107**, 406–15.

Luck, J.M., Birck, J.L. and Allegre, C.J. (1980). *Nature*, **283**, 256–9.

Martin, C. E. (1989) *Earth Planet. Sci. Lett.*, **93**, 336–44.

Martin, C.E. (1991). *Geochim. Cosmochim. Acta*, **55**, 1421–34.

Martin, C.E., Wasserburg, G.J., Papanastassiou, D.A. and Peach, C.L. (1993) *EOS*.

McCandless, T. E. and Ruiz, J. (1991) *Geology*, **19**, 1225–8.

Morgan, J. W. (1985). *Nature*, **317**, 703–5.

Morgan, J. W. (1986) *J. Geophys. Res.*, **91**, 12,375–87.

Morgan, J. W., Golightly, D. W. and Dorrzapf, A. F., Jr. (1991) *Talanta*, **38**, 259–65.

Morgan, J. W. and Walker, R. J. (1989) *Anal. Chim. Acta*, **222**, 291–300.

Pearson, D.G., Carlson, R.W., Shirey, S.B., Boyd, F.R. and Nixon, P.H. (subm). *Earth Planet. Sci. Lett.*

Pearson, D.G., Shirey, S.B., Carlson, R.W., Boyd, F.R., Pokhilenko, N.P. and Shimizu, N. (in press) *Geochim Cosmochim. Acta* .

Pegram, W.J. and Allegre, C.J. (1992). *Earth Planet. Sci. Lett.*, **111**, 59–68.

Reisberg, L., Zindler, A., Marcantonio, F., Sachi, K.A., Wyman, D., Salters, V., White, W. and Weaver, B. (1994). *Earth Planet. Sci. Lett.*

Reisberg, L. C., Allegre, C. J. and Luck, J. M. (1991). *Earth Planet. Sci. Lett.*, **105**, 196–13.