

MANTLE XENOLITHS IN POTASSIC MAGMAS FROM MONTANA: Sr, Nd AND Os ISOTOPIC CONSTRAINTS ON THE EVOLUTION OF THE WYOMING CRATON LITHOSPHERE.

Irving, ⁽¹⁾A.J. and Carlson, ⁽²⁾R.W.

(1) Dept. Geol. Sciences, Univ. of Washington, Seattle, WA 98195 USA; (2) Dept. Terrestrial Magnetism, Carnegie Inst. Washington, Washington, DC 20015 USA.

A variety of ultramafic xenoliths occur at several localities within the late Cretaceous to Oligocene volcanics and dikes of the alkalic igneous province of central Montana, U.S.A. In concert with geochemical and isotopic studies of the magmatic rocks (Irving and O'Brien, this volume), similar detailed analysis of the ultramafic xenoliths has been undertaken in an attempt to understand the evolution of the Archean lithosphere and to evaluate its effects on the magmas that percolated through it. Previous work on the magmatic rocks in the Highwood Mountains subprovince (O'Brien et al., 1991) has suggested an important role for Archean lithospheric mantle in providing a small volume component of extreme composition that controlled most of the isotopic and certain trace element features of the erupted magmas.

Two quite distinct suites of ultramafic xenoliths have been studied from Eocene primitive olivine minette dikes from the Highwood Mountains (located near Great Falls) and Eagle Buttes (located 40 km to the northeast). Lithologies at the first locality include peridotites (Cr-spinel harzburgite and spinel lherzolite, with or without mica and amphibole), websterite (one as a band or dike in harzburgite), several types of mica dunite (containing accessory Cr-spinel and clinopyroxene), and glimmerite (as veins cutting harzburgite). The Eagle Buttes suite contains anhydrous, Cr-diopside spinel lherzolites and harzburgites that resemble those found typically in alkalic basalts worldwide. Application of the most reliable thermobarometers for spinel peridotites (Wells, 1977 2-pyroxene solvus; Sack and Ghiorso, 1991 olivine-spinel; Kohler and Brey, 1990 Ca in olivine) is hampered by the very high Ca content of clinopyroxenes and the very low Ca content of olivine (50-160 ppm, using microprobe counting times of 500 sec). Nevertheless, it is evident that the majority of peridotites and dunites from both localities equilibrated at unusually low temperatures (600-700°C). Calculated pressures are 14-20 kbar for the Highwood samples and 12 kbar for those from Eagle Buttes. Two of the mica dunites equilibrated at much higher temperatures (980°C) and apparently at higher pressures than the other Highwood samples. Garnet peridotite xenoliths from the kimberlitic Williams diatreme located about 100 km east of these localities (Hearn and McGee, 1984) must be samples of even deeper lithosphere.

The unique glimmerite vein consists mostly of Ti-rich phlogopitic mica with subordinate orthopyroxene and minor clinopyroxene, plagioclase (An_{72}), celsian, zircon and rutile. The pyroxenes give an equilibration temperature of 1020°C, and the presence of calcic plagioclase in this mineral assemblage is not inconsistent with the pressure estimates obtained from other Highwood ultramafic and granulite xenoliths. The presence of zircon and the bulk rock U abundance of 0.8 ppm offer the possibility of precisely dating this vein, particularly if this large xenolith has experienced only transient heating during entrainment and ascent. The vein has a selvage of mica orthopyroxenite adjacent to the surrounding harzburgite.

A striking and unexpected feature of all the Highwood xenoliths is the presence of large negative Eu anomalies ($Eu/Eu^* = 0.2-0.4$), accompanied by relatively high abundances of trivalent REE (Fig. 1). In contrast, one spinel harzburgite from Eagle Buttes has lower REE abundances with no significant Eu anomaly, yet is relatively light-REE enriched ($La_N/Yb_N = 16$). The peridotites have bulk $Mg/(Mg + \Sigma Fe)$ of 0.87-0.89 with bulk CaO contents of 1.1-2.8 wt.%, whereas the mica dunites are both more and less magnesian ($Mg/(Mg + \Sigma Fe) = 0.83-0.91$), and have higher Sm/Nd, K, Rb and Ba. The glimmerite is relatively enriched in Ba (1880 ppm), Zr (350 ppm), Th (3 ppm), Cr (930 ppm) and Ni (1280 ppm).

Bulk rock isotopic ratios for several of the Highwood xenoliths range to extreme values ($^{87}\text{Sr}/^{86}\text{Sr} = 0.715$ to 0.769 , $\epsilon_{\text{Nd}} = -16$ to -40 , $^{187}\text{Os}/^{186}\text{Os} = 0.90$ to 1.04). Nd model ages relative to depleted mantle range from 2.6 Ga to greater than 4 Ga, and Os model ages (T_{RD}, Walker et al., 1989) range from 0.4 to 3.0 Ga (with 3 out of 4 greater than 2.7 Ga). The Os model ages are calculated assuming Re/Os = 0 and give the absolute minimum age of Re loss. The samples analyzed so far show an inverse correlation between $^{187}\text{Os}/^{186}\text{Os}$ and Fo content of olivine, suggesting that Re loss accompanied partial melt removal during formation of the lithosphere in the early Archean (as noted previously by Walker et al. (1989) for xenoliths from southern Africa). In contrast, a 2.5 Ga Sr model age for a mica dunite may imply late Archean/Proterozoic enrichment in Rb by metasomatic addition of mica. The glimmerite vein ($\epsilon_{\text{Nd}} = -33$) is interpreted as an ancient metasome that is probably one example of the material contributing to the wide range of isotopic compositions measured in the younger magmatic rocks.

Ultramafic rocks displaying some similar geochemical features to the Montana xenoliths, including negative Eu anomalies, occur as tectonic inclusions within 3.7 Ga gneisses from Labrador (Collerson et al., 1991). They differ, however, in their isotopic characteristics, and appear to be ancient partial melting residues, without the presumably subsequent but still ancient enrichment signature.

Prior to the metasomatic addition of mica, the olivine-rich rocks from Montana may have been cumulates complementary to ancient feldspathic crust, or possibly residues from partial melting of less ancient asthenospheric mantle. The negative Eu anomalies may be a consequence feldspar removal or perhaps the partitioning behavior of orthopyroxene under highly reducing conditions (McKay et al., 1990). In either case the compositional differences among mantle lithospheric samples throughout central Montana suggest that there is considerable regional variability in equilibration temperature, trace element composition and age (and possibly intrinsic $f\text{O}_2$) as a function of both depth and geographic location. Given this, it is not surprising that there is also wide variation in the isotopic and trace element composition of erupted magmas within this province.

References

- Collerson, K. D., Campbell, L. M., Weaver, B. L. and Palacz, Z. A. (1991) Evidence for extreme mantle fractionation in early Archean ultramafic rocks from northern Labrador. *Nature*, 349, 209-214.
- Hearn, B. C., Jr. and McGee, E. S. (1984) Garnet peridotites from Williams kimberlites, north-central Montana, U.S.A. In J. Kornprobst, Ed., *Kimberlites II: The mantle and crust relationships*, p. 57-70. Elsevier, Amsterdam.
- Irving, A. J. and O'Brien, H. E. (1991) Isotopic and trace element remote sensing of Montana continental lithosphere from erupted magmas. This volume.
- Kohler, T. P. and Brey, G. P. (1990) Calcium exchange between olivine and clinopyroxene calibrated as a geothermobarometer for natural peridotites from 2 to 60 kb with applications. *Geochimica et Cosmochimica Acta*, 54, 2375-2388.
- McKay, G., Wagstaff, J., and Le, L. (1990) REE distribution coefficients for pigeonite: Constraints on the origin of the mare basalt europium anomaly. In *Lunar and Planetary Science XXI*, 773-774. Lunar and Planetary Institute, Houston.
- O'Brien, H. E., Irving, A. J. and McCallum, I. S. (1991) Eocene potassic magmatism in the Highwood Mountains, Montana: Petrology, geochemistry and tectonic implications. *Journal of Geophysical Research*, in press.
- Sack, R. O. and Ghiorso, M. S. (1991) Chromian spinels as petrogenetic indicators: Thermodynamics and petrological applications. *American Mineralogist*, in press.

Walker, R. J., Carlson, R. W., Shirey, S. B., and Boyd, F. R. (1989) Os, Sr, Nd, and Pb isotope systematics of southern African peridotite xenoliths: Implications for the chemical evolution of subcontinental mantle. *Geochimica et Cosmochimica Acta*, 53, 1583-1595.

Wells, P. R. A. (1977) Pyroxene thermometry in simple and complex systems. *Contributions to Mineralogy and Petrology*, 62, 129-139.

