Peridotite Xenoliths from the Williams Kimberlite, Montana: Implications for Delamination of the Wyoming Craton Lithosphere

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Introduction

Many Archean cratons include >200 km thick lithospheric mantle "keels" distinguished by unusually fast and anisotropic seismic velocities (e.g. Silver and Chan, 1988; Polet and Anderson, 1995). Xenoliths from these keels are dominated by peridotites that are depleted in Ca, Al and Fe compared to any estimate of fertile mantle (Boyd and Mertzman, 1987). For the Kaapvaal and Siberian cratons, Re-Os isotope systematics show this depletion to have occurred in the Archean (Pearson et al., 1995a,b). Some cratons, however, such as the Sino-Korean craton in China and the Wyoming craton in western North America (Van der Lee and Nolet, 1997), do not have thick, seismically fast, lithospheric mantle. The lack of a seismically defined keel implies either delamination of a previously present keel or that the mantle beneath these cratons is compositionally, or thermally, distinct from that underlying other Archean cratons.

To investigate the characteristics of the mantle beneath the Wyoming craton, we have examined the chemical and isotopic characteristics of peridotite xenoliths from the Williams kimberlite. The Williams kimberlite is part of a large swarm of middle Eocene mafic-alkalic magmas occurring in north-central Montana (Hearn, 1989; O'Brien et al., 1991; Scambos, 1991). This magmatic activity is believed to be related to steepening subduction of the Farallon plate beneath North America and to an influx of hot asthenospheric mantle into the region formerly occupied by the shallow subducting slab (Lipman et al., 1972; O'Brien et al., 1995). The Williams kimberlite contains a variety of crustal and mantle xenoliths and xenocrysts (Hearn and McGee, 1984; Hearn, 1993). Six peridotites and one garnet-clinopyroxene composite megacryst (W210, T = 1264°C, P = 4.5 GPa) were selected for analysis. Peridotite samples are one spinel peridotite (H67-28I, T = 980°C), two "low-temperature" granular garnet peridotites (H68-16B, T=959°C, P = 3.8 GPa; T3-4, T = 1006°C, P = 4.2 GPa) that lie on a typical 44mW/m^2 shield geotherm and 3 "high-temperature" garnet peridotites (WP28-3-1, T = 1327°C, P = 4.8 GPa; H81-21, T = 1344°C, P = 5.4 GPa; H69-15F, T = 1320°C, P = 4.6 GPa) that lie distinctly above a typical shield geotherm (Hearn and Boyd, 1975; Hearn and McGee, 1984).

Major element determinations show all samples to have similar compositions with no clear compositional difference between low-T and high-T samples. For the Williams peridotites, SiO_2 ranges from 43.4 to 44.6 wt%, MgO from 43.3 to 44.2 wt %, FeO from 6.8 to 7.6%, CaO from 0.56 to 1.11 wt%, Al_2O_3 from 0.52 to 1.09 wt% with Mg/(Mg+Fe) ranging from 0.911 to 0.920, all values within the range of typical depleted lithospheric peridotites from the Kaapvaal (Boyd and Mertzman, 1987) and Siberian (Boyd et al., 1997) cratons.

Sr, Nd and Pb isotope measurements were performed on acid-washed, hand-picked, clinopyroxene separates. Low-T samples have $^{87}Sr/^{86}Sr$, ε_{Nd} and $^{206}Pb/^{204}Pb$ ranging from 0.7042 to 0.7065, +0.5 to -7.9, and 17.39 to 18.49, respectively, which overlap the ranges (0.7032 to 0.7046; +2.1 to -6.8; 18.19 to 19.18) for the high-T samples. Garnet-clinopyroxene pairs from the composite megacryst and one high-T sample define Sm-Nd ages (66.9 +/- 11 Ma and 55.6 +/- 13 Ma, respectively) approaching the 48 Ma eruption age of the Williams kimberlite. Garnet-clinopyroxene pairs from the remaining high-T samples and one low T sample give negative slopes on a Sm-Nd isochron diagram because the garnets have lower $^{143}Nd/^{144}Nd$ than the clinopyroxenes. A similar situation was found by Gunther and Jagoutz (1995) in low-T Kimberley peridotites. These authors suggested that this isotopic pattern results from the formation of garnet during decomposition of amphibole and spinel to orthopyroxene and garnet during changing P-T conditions shortly before capture of the xenolith by the host kimberlite. Hearn and McGee (1984) suggested that phlogopite-rimmed clots of moderate-Cr garnet, Cr-spinel, Cr-diopside and enstatite in two Williams low-T peridotites formed by the breakdown of high-pressure, high-Cr garnet brought into the garnet-spinel stability field. These textural/mineralogical features, the observed isotopic disequilibrium and the irregular Cr/Al zoning observed in the low-T peridotite garnets indicates that these samples experienced significant changes in pressure and temperature just prior to their capture by the host kimberlite.

Whole rock Re-Os isotope systematics of the Williams peridotites provide the most compelling chronological story for the history of the cratonic keel of the Wyoming craton. The 3 low-T samples have the unradiogenic Os typical of Re-depleted cratonic peridotites. These samples have Re-depletion model ages ranging from 1.7 to 2.5 Ga, similar to those of shallow spinel peridotites contained in the nearby Highwood Mountains and Eagle Buttes minettes (Carlson and Irving, 1994). The high-T peridotites from Williams, however, have Os isotopic compositions ($^{187}Os/^{188}Os$ from 0.1229 to 0.1250) only slightly lower than expected for modern "fertile" mantle. The high-T peridotites define a Re-Os isochron of 66 +/- 209 Ma (large uncertainty caused by the small range in $^{187}Os/^{188}Os$) consistent with their separation from the convecting, sublithospheric, mantle in the late Mesozoic - early Cenozoic. Thus, the lower portions of the lithospheric keel sampled by the Williams xenoliths may be the source residues of the extensive volcanism occurring in Montana/Wyoming during the Mesozoic/Cenozoic.

The chemical composition of the Williams peridotites indicates that this area of the Wyoming craton is underlain by peridotite displaying the typical Ca, Al, Fe, Re depletion observed in other Archean craton lithospheric peridotites. On the other hand, the Re-Os systematics of the Williams peridotites show that the Proterozoic - late-Archean keel to the craton is truncated at relatively shallow depth (< 150 km) and is underlain by depleted peridotite that was recently underplated to its base. Presumably, because of its relatively young age, the temperature structure of this underplated addition to the craton may more closely resemble that of the surrounding asthenospheric mantle thus disguising the seismic signature of its presence. If the Wyoming craton ever had an old, thick, lithospheric mantle keel, the relatively young Os model ages for the high-T Williams peridotites are consistent with suggestions (Eggler et al., 1988) that the thick keel was removed prior to the Cenozoic volcanism that produced the Williams kimberlite.

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