ULTRAMAFIC XENOLITHS FROM THE PALI-AIKE BASALTS: IMPLICATIONS FOR THE NATURE AND EVOLUTION OF THE SUBCONTINENTAL LITHOSPHERE BELOW SOUTHERN SOUTH AMERICA

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Type-I Cr-diopside ultramafic xenoliths found in the Pleistocene Pali-Aike alkali basalts, the southernmost units of the Patagonian plateau lavas of southern South America, include both garnet-free and garnet-bearing peridotites, the latter uncommon in alkali basalts (Skewes and Stern, 1979). Spinels occur in both the garnet-free and the garnet-bearing xenoliths so that a division between spinel- and garnet-peridotite is not suitable for the Pali-Aike xenoliths. The xenoliths are lithologically diverse, consisting dominantly of lherzolites and harzburgites, but also including dunites and orthopyroxenites. All the Pali-Aike peridotites have coarse granular textures.

Olivine and orthopyroxene compositions in both garnet-free and garnet-bearing lherzolites are similar and range from between Fo_{90-87} and En_{87-85}. These minerals are more Mg-rich in garnet-free harzburgites, with olivine composition ranging between Fo_{92-90} and orthopyroxene compositions between En_{90-87}. In contrast, garnet-bearing harzburgites have more Fe-rich olivines, with compositions between Fo_{88-85}, and orthopyroxenes, with compositions between En_{85-83}. Garnet-orthopyroxenites, which typically occur as segregations within garnet-harzburgites, have even more Fe-rich orthopyroxenes, with compositions between En_{84-82}. Clinopyroxenes are Cr-diopsides. Garnets, which vary from 0-25 modal percent in lherzolites and harzburgites, and from 0-60 modal percent in orthpyroxenites, are Cr-pyropes with Cr_2O_3=0.8-2.2 weight percent. Cr contents are higher in garnets in lherzolites compared to either harzburgites or orthopyroxenites. Spinel compositions range from low Cr/high Al types to high Cr/low Al chromites. Garnet-bearing xenoliths contain only the latter type, but garnet-free xenoliths may contain either type but not both together. Mineral geothermometry indicates that the low Cr/high Al spinels occur in lower temperature xenoliths and the high Cr/low Al chromites occur in higher temperature xenoliths.

Pargasitic amphibole, with K_2O=0.9-1.4, TiO_2=1.8-2.4, and Cr_2O_3=1.4-1.7 weight percent, occurs as between 0-5 modal percent of unzoned grains equidimensional to other mineral grains in garnet-lherzolites. Phlogopite occurs as both disseminated grains and in veins. Disseminated phlogopite is pale in color and contains significant Cr_2O_3=2.2 weight percent, but little TiO_2=0.6 weight percent. Phlogopite in veins, occasionally with ilmenite, is dark orange due to high TiO_2=5.3-7.0 weight percent.

Bulk-rock chemistry of the xenoliths reflects mineral compositions. The garnet-lherzolites are fertile, having SiO_2, TiO_2, Al_2O_3, FeO, MgO, and CaO similar to estimates of 'pyrolite'. However, K_2O is very low in all xenoliths except those cut by phlogopite veins. Harzburgites are infertile, with very low TiO_2 and Na_2O as well as K_2O, but garnet-bearing harzburgites have higher FeO, Al_2O_3, and CaO than garnet-free harzburgites.

Temperatures of equilibration, determined using the two-pyroxene geothermometer of Wells (1977), range from 830-1080°C for garnet-free peridotites and from 1000-1150°C for garnet-bearing peridotites. With these temperatures, pressures of equilibration of garnet-bearing xenoliths determined with the geobarometer of Nickel and Green (1985) range from 18-24 kilobars, consistent with the stability of amphibole in some of these xenoliths. The coarse granular textures of the xenoliths, combined with these estimates of their pressure and temperature of equilibration, indicate that they were all derived from the continental lithosphere above the zone of generation of their alkali basalt host. The calculated temperature of 1150°C at a depth of 75 kilometers and the calculated geotherm of 10°C/km between 60-80 kilometers depth are higher than those determined from xenoliths suites found in cratonic regions of low heat flow, which is considered appropriate for the tectonically active area of back-arc magmatic activity inwhich the Pali-Aike basalts occur. Recrystallized-grain-size paleopiezometry has been used to estimate the differential stress levels for the mantle source of these xenoliths and this stress profile is similar in character to that determined for other continental extension zones (Douglas et al., 1985).

The data indicate that the upper part of the subcontinental lithosphere below southernmost South America consists dominantly of infertile garnet-free harzburgites at depths shallower than about 50 kilometers. At greater depths, between 50-70 km, fertile garnet-lherzolites occur along with infertile Mg-rich garnet-free harzburgites. The coexistance of these two lithologies is confirmed by their occurrance as compound xenoliths. Garnet-lherzolites dominate, and Mg-rich garnet-free harzburgites are absent from the deepest portion of the subcontinental lithosphere represented by the Pali-Aike xenoliths, at depths greater than 70 km. Infertile but Fe-rich garnet-harzburgites and orthopyroxenites also occur within the deeper portions of the lithosphere, at depths greater than 50 kilometers, and this part of the subcontinental lithosphere has been affected by modal metasomatism responsible for the emplacement of disseminated and vein phlogopite.

The Sr and Nd isotopic compositions of the fertile garnet-lherzolites range from $^{87}Sr/^{86}Sr$=0.7027-0.7032 and $^{143}Nd/^{144}Nd$=0.5131-0.5128, the lower Sr and higher Nd isotopic values being similar to mid-ocean ridge basalts. The isotopic compositions of the infertile garnet-free harzburgites range from $^{87}Sr/^{86}Sr$=0.7034-0.7043 and $^{143}Nd/^{144}Nd$=o.5129-0.5127 and these values are similar to ocean island basalts. Although all the xenoliths have isotopic compositions indicating time intergrated depletion, compared to undifferentiated Bulk Earth, of Rb relative to Sr and Nd relative to Sm, their current $^{147}Sm/^{144}Nd$ ratios are similar to or less than Bulk Earth and range from 0.23-0.19 for the garnet-lherzolites and 0.16-0.13 for the garnet-free harzburgites. Vein phlogopite has $^{147}Sm/^{144}Nd$=0.125 and $^{143}Nd/^{144}Nd$=0.51255, but plots on the low $^{87}Sr/^{86}Sr$ side of the mantle array. with $^{87}Sr/^{86}Sr$=0.7035 despite having a very high Rb/Sr=3.

The lack of any phases with Sr and Nd isotopic compositions suggesting ancient enrichment events, such as have been reported from xenoliths derived from the Precambrian cratonic regions of Africa (Cohen et al., 1984), suggests that the accretion of the lithosphere below southern South America was a relatively recent event, consistent with the Phanerazoic age of the crustal rocks in this region (de Wit, 1977). The isotopic similarity of the Pali-Aike peridotites with oceanic basalts suggests that prior to being removed from large scale convective overturn and stablized below the continental crust during the Phanerozoic this material was evolving along with the current suboceanic mantle system. It is probable that the formation of the main lithologic diversity observed in the Pali-Aike xenoliths took place during this pre-accretionary phase by heterogeneous removal of magma below an oceanic spreading center resulting in fertile unmelted garnet-lherzolites being mixed with infertile Mg-rich crystal residues. Fe-rich garnet-harzburgites and orthopyroxenites may be recrystallized crystal cumulates formed in magma conduits during this event.

A feature of the xenoliths that developed after this material had been stablized below the continental crust is the observed decoupling of trace element composition and isotopic ratios. In those xenoliths in which no amphibole or phlogopite is observed, this effect may be explained by 'mantle metasomatism' which introduces large-ion-lithophile element enriched fluids into the mantle without modifying its mineralogy. This non-modal enrichment of the subcontinental mantle may be related to the modal metasomatism responsible for the emplacement of phlogopite veins, with disseminated phlogopite representing an intermediate stage of recrystallization and dispersial of such veins.

The emplacement of phlogopite veins apparently occurred only shortly before the xenoliths were transported to the surface in the Pali-Aike basalts, as indicated by their high Rb/Sr ratios and low $^{87}Sr/^{86}Sr$. These phlogopites are isotopically very distinct from the Pali-Aike basalts, but the isotopic composition of the basalts lie along a mixing curve for phlogopite + garnet-lherzolite. Modal metasomatism of the subjacent mantle may have been a precursor for the generation of the alkali basalts themselves. The isotopic composition of the phlogopites is similar to mixtures of oceanic basalts and sediments and the material responsible for the emplacement of these veins may have been derived by dehydration of subducted oceanic lithosphere. A great deal of ocean lithosphere has been subducted beneath the western margin of South America during the Phanerozoic and fluids derived by dehydration of this subducted material may rise continually through the asthenosphere into the overlying subcontinental lithosphere or be emplaced only during episodes of low angle subduction such as may have occurred below southern South America just after the subduction of the Chile Rise in the Miocene.

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