Comunicaciones, N° 35 (1985): 227 - 231
Departamento de Geología – Universidad de Chile – Santiago

EVOLUCION DE LA LITOSFERA MANTELICA SUBCONTINENTAL BAJO LA PARTE MAS MERIDIONAL DE SUDAMERICA

EVOLUTION OF THE SUBCONTINENTAL MANTLE LITHOSPHERE BELOW SOUTHERNMOST SOUTH AMERICA

CHARLES STERN, KIYOTO FUTA, SANDRA SAUL, AND MILKA A. SKEWES
Department of Geological Sciences, University of Colorado, Boulder, Colorado, U.S.A. 80309.

Major magmatic and tectonic events affecting the earth's crust are expressions of processes occurring in the upper mantle. Samples of the subcontinental mantle brought to the surface as ultramafic inclusions in kimberlites and alkali basalts have been shown to preserve a record of events that in some cases may be correlated with the geologic evolution of the crust through which they have been transported. Ultramafic xenoliths found within the Pali-Aike volcanic field (Skewes and Stern, 1979), the southernmost outcropping of the Patagonian basalts, preserve evidence of a sequence dating from earliest earth history to recent times, of mantle processes relevant to the continental lithosphere of southern South America.

The xenoliths found in the Pali-Aike basalts are lithologically very heterogeneous (Stern et al,1985). They include garnet-bearing and garnet-free lherzolites, harzburgites, and pyroxenites. Phlogopite veins are observed cutting these various lithologies. Some of the garnet-bearing lherzolites are similar in composition, at least with respect to major elements, to estimates of primitive undifferentiated mantle material. In general, the garnet-bearing xenoliths are more "fertile" than the garnet-free xenoliths; i.e. they are richer in Al_2O_3, CaO, Na_2O, and TiO_2 and thus potentially capable of yielding a grater amount of basaltic melt.

Mineral geothermometry and geobarametry indicate that all the xenoliths encountered in the Pali-Aike basalts equilibred in the lithosphere; i.e., within 100 kilometers of the surface and at temperatures well below the dry solidus of peridotite. Fertile garnet-bearing and infertile garnet-free lithologies are apparently intermixed throughout the deeper part of the cross-section of the subcontinental lithosphere represented by the xenoliths.

The more fertile garnet-lherzolites have Sr and Nd isotopic compositions similar to the mantle source of mid-ocean ridge basalts. All the xenoliths have Sr and Nd isotopic compositions similar to the suboceanic mantle; i.e. within the mantle array determined by the isotopic composition of basalts erupted in oceanic regions(Fig.1A). The isotopic composition of the xenoliths thus reflects time intergrated depletion, compared to the undifferentiated Bulk Earth, of Rb relative to Sr and Nd relative to Sr and Nd relative to Sm. However the current Sm/Nd ratios of the xenoliths are less than Bulk Earth (Fig.1B). Phlogopite in veins has low $^{87}Sr/^{86}Sr$ = 0.7035 (Fig.1A) despite having a very high Rb/Sr = 3.1.

As a group the xenoliths do not define an isochron, suggesting that the lithologic and isotopic heterogeneities of the mantle material forming the subcontinental lithosphe-

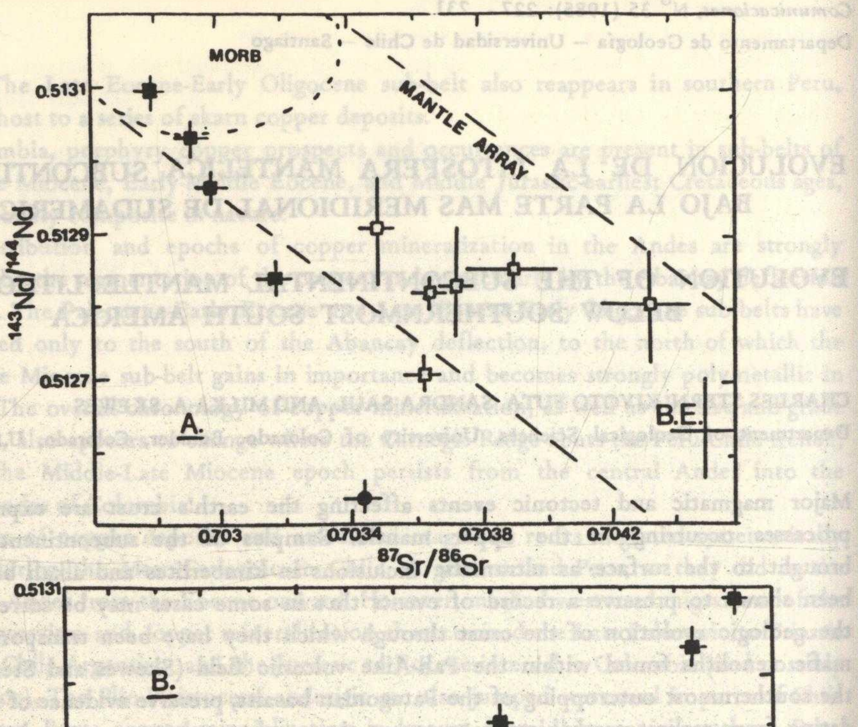

Fig.1. Plots of $^{143}Nd/^{144}Nd$ versus $^{87}Sr/^{86}Sr$ (A) and $^{143}Nd/^{144}Nd$ versus $^{147}Sm/^{144}Nd$ (B) for garnet-bearing (solid squares) and garnet-free (empty squares) peridotites and phlogopite (solid circle) from a vein cutting a peridotite xenolith. The lines emanating from the symbols represent the analytical uncertainty. Both figures show the composition of primitive undifferentiated Bulk Earth (B.E.), and the fields for mid-ocean ridge basalts (MORB) and the mantle array, which is the isotopic composition of the suboceanic mantle as indicated by analysis of basalts erupted in oceanic regions, are indicated in A.

Fig.1. Diagramas $^{143}Nd/^{144}Nd$ versus $^{87}Sr/^{86}Sr$ (A) y $^{143}Nd/^{144}Nd$ versus $^{147}Sm/^{144}Nd$ (B) para peridotitas con granate (cuadrados llenos),sin granate (cuadros vacios) y flogopita (círculo lleno) de una venilla en un xenolito de peridotita. Las lineas que emanan de los símbolos, representan la incerteza analítica. Ambas figuras muestran la composición de la Tierra primitiva indiferenciada (B.E.), y en (A) se indica ademas el campo de los basaltos de las cadenas hemioceanicas (MORB) y de la composicion isotópica del manto suboceánico indicado por los análisis de basaltos eruptados en regiones oceánicas.

re below southernmost South America have developed by a sequence of processes. These processes can be broadly subdivided into a pre-accretionary stage prior to the time that the mantle material currently forming the subcontinental lithosphere was stabilized below the continental crust and thus removed from large scale convective overturn, an accretionary event which stabilized the current subcontinental mantle lithosphere below southern South America, and a post-accretionary stage.

Prior to being stabilized below the continental crust, the material now forming the subcontinental lithosphere below southern South America must have been involved in large scale convective overtun in the mantle and thus been evolving along with the current suboceanic mantle system. This is confirmed by the isotopic similarity between the xenoliths found in the Pali-Aike basalts and the suboceanic mantle. To allow the development of the Sr and Nd isotopic compositions observed in the garnet-lherzolite xenoliths from Pali-Aike and inferred for the mantle source of mid-ocean ridge basalts, these materials must have experienced an event, at least 2-3 billion years ago, that depleted them in Rb relative to Sr and Nd relative to Sm. Extraction from the primitive undifferentiated mantle of a liquid resembling kimberlite, formed by a small degree of partial melting, could produce this effect (Wood, 1979), Alternatively, settling to the base of the upper mantle at the 670 kilometer seismic discontinuity, of garnet –and clinopyroxene– rich cumulates from a magma Ocean formed by 15-20 percent partial melting of the whole mantle associated with the accretion of the earth, could have formed a large reservoir of fertile but large-ion lithophile element depleted mantle (Anderson, 1981). This material would be, in a sense, the terrestrial equivalent of the plagioclase-rich lunar highlands which are believed to have formed by floatation on an accretionary related magma ocean on the moon. On the earth, pressure effects stabilized garnet and Al-rich pyroxenes which sank rather than floated. Upper mantle convection continues to bring this material from the bottom of the upper mantle to below mid-ocean ridges where it melts to yield modern-ocean ridge basalts.

The main lithological variations observed in the Pali-Aike xenoliths probably formed by heterogeneous removal of magma resulting in infertile mixed with fertile lithologies as well as iron-rich garnet-harzburgites and garnet-orthopyroxene veins which represent cummulate phases left behind as the magma was removed. This event most likely occurred below an oceanic spreading center when the mantle now stablized below southern South America was still involved in large scale upper mantle convective overturn, since the high temperature required to produce the large percentage of melt extracted as indicated by residual harzburgites and dunites, is unlikely to have been achieved within the subcontinental lithosphere.

The lack of any phases with Sr and Nd isotopic compositions suggesting ancient enrichment events, such as have been reported in ultramatic xenoliths derived from the subcontinental lithosphere below the Precambrian craton of Africa (Cohen et al., 1984), indicates that the accretion of the continental lithosphere below southern South America was a relatively recent event. This is consistent with the Phanerozoic age of the crustal rocks in this region, which have been interpreted to have formed as arc-trench gap materials accreted to the western margin of Gondwanaland during the Paleozoic (de Wit, 1977). The removal of the subcontinental mantle lithosphere from large scale convective overturn in the upper mantle and its stabilization below the continental crust may have occurred in association with crustal accretion. Alternatively stabilization of the subcontinental lithosphere may have occurred at a later date, either in the Mesozoic when rifting of South America and Africa was associated with widespread bimodal basaltic and silicic volcanism in southern South America suggesting extensive thinning and possibly replacement of the pre-Mesozoic subcontinental lithosphere (Bruhn et al., 1978), or in the Cenozoic when subduction of the Chile Rise spreading ridge may have significantly modified subcontinental mantle structure. Isotopic studies of the Patagonian plateau basalts have yielded pseudoisochrons of 500-600 million years favoring the Paleozoic as the age of isotopic equilibration of the mantle source regions of these basalts which may be the deeper parts of the subcontinental lithosphere (Stern et al., 1983). However such pseudoisochrons may have little significance.

A feature of the xenoliths that developed after this material had been stabilized below the continental crust is the observed decoupling of trace element compositions and isotope ratios such that the xenoliths have Sm/Nd similar to or less than Bulk Earth (Figure lB) but isotopic ratios implying time integrated depletion of Nd relative to Sm (Figure 1A). This effect may be explained by"mantle metasomatism" which introduces large-ion-lithophile element enriched fluids into the mantle without modifying its mineralogy (Menzies, 1983). This non-modal enrichment of the subcontinental mantle below southern South America may or may not have been contemporaneous with the modal metasomatism responsible for the emplacement of the phlogopite veins observed cutting many of the xenoliths. This latter event clearly occurred relatively shortly before the xenoliths were transported to the surface in the Pali-Aike basalts as indicated by the high Rb/Sr but low $^{87}Sr/^{86}Sr$ of the phlogopite. The materials responsible for the non-modal and modal metasomatism observed in the xenoliths from the Pali-Aike basalts may have been ultimately derived from subducted oceanic lithosphere.

In the late Pleistocene, alkali basalt generated in the subjacent mantle passed through the subcontinental lithosphere incorporating fragments of wall rock which have served as the basis for the outline of the chronology of mantle evolution discussed above.

This work has been supported by National Science Foundation grants EAR75-04076 EAR76-82456, EAR79-11204, and EAR83-13884.

REFERENCES

Anderson, D.L. (1981). Hotspots, basalts, and the evolution of the mantle. Science, volume 213, pages 82-89.

Bruhn, R.L., Stern, C.R., and DeWit, M.J. (1978). Field and geochemical data bearing on the development of a Mesozoic volcano-tectonic rift zone and back-arc basin in southernmost South America. Earth and Planetary Science Letters, volume 41, pages 32-46.

Cohen, R.S., O'Nions, R.K., and Dawson, J.B. (1984). Isotope geochemistry of xenoliths from East Africa: implications for the development of mantle reservoirs and their interaction. Earth and Planetary Science Letters, volume 68, pages 209-220.

De Wit, M.J. (1977). The evolution of the Scotia arc as a key to the reconstruction of Gondwanaland. Tectonophysics, volume 37, pages 53-81.

Menzies, M. (1983). Mantle ultramafic xenoliths in alkaline magmas: evidence for mantle heterogeneity modified by magmatic activity. In Continental Basalts and Mantle Xenoliths, C.J Hawkesworth and M.J. Norry editors, Shiva Geology Series, Shiva Publishing, Chesire, England. pages 92-110.

Skewes, M.A., and Stern, C.R. (1979). Petrology and geochemistry of alkali basalts and ultramafic inclusions from the Pali-Aike basalts in southern South America and the origin of the patagonian plateau lavas. Journal of Volcanologic and Geothermal Research, volume 6, pages 3-25.

Stern, C.R., Futa, K., Saul, S., and Skewes, M.A. (1985). Ultramafic xenoliths found in the Pali-Aike basalts: their implications for the nature of the mantle below southern South America. Proceedings of the Fourth Congreso Geologico Chileno, Antofagasta, Chile, August 1985, volume , pages

Stern, C.R., Futa, K., and Ziching, P. (1983). Pb, Sr, and Nd isotopic composition of alkali basalts of the Patagonian plateau lavas, South America. Geological Society of America Abstracts with Programs, 1983 Annual Meeting, Indianapolis, Indiana, volume 61, page 465.

Wood, D.A. (1979). A variably veined suboceanic upper mantle-genetic significance for mid-ocean ridge basalts from geochemical evidence. Geology, volume 7, pages 499-503.