Re-Os ISOTOPE CONSTRAINTS ON SUBCONTINENTAL LITHOSPHERIC MANTLE EVOLUTION OF SOUTHERN SOUTH AMERICA

Schilling, M.[1]; Carlson, R.W.[2]; Koester, E.[3]; Conceição, R.V.[3]; Bertotto, G.W.[4]; Dantas, C.[5]

1. Departamento de Geología, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Chile. mschilli@cec.uchile.cl
2. Department of Terrestrial Magnetism, Carnegie Institution of Washington, USA. carlson @dtm.ciw.edu
3. Laboratório de Geologia Isotópica, Instituto de Geociencias, Universidad Federal do Rio Grande do Sul, Brasil, koester@ufrgs.br, rommulo.conceicao@ufrgs.br
4. Facultad de Ciencias Exactas y Naturales, Universidad Nacional de la Pampa, Argentina. gwbertotto@yahoo.com.ar
5. CNRS UMR 5562. Dynamique Terrestre et Planétaire. Observatoire Midi Pyrénées, Université Paul Sabatiez, Tuolouos, France. dantas@pontos.cst.cnes.fr

Keywords: Subcontinental lithospheric mantle, South America, Os isotopes, mantle xenoliths

INTRODUCTION

The southern portion of South America is a complex collage of continental terranes accreted to the southwestern proto-margin of Gondwana since late Proterozoic times (Ramos, 1984, 1988). In recent years, many studies have been dedicated to understanding the geotectonic evolution of this region by the location and individualization of amalgamated terranes recognizing the suture zones, the time of the different collisions referred to commonly as orogenic cycles, and the place of origin, the relationship with supercontinents, and the formation ages for the allocthonous terranes.

The formation of these continental terranes and their evolution is directly related to the formation of their respective lithospheric mantle sections, which is essential to the long-term survival of continents because it serves as a stiff buoyant "root". The subcontinental lithospheric mantle consists of a thick section of material left behind after variable partial melt extraction, possibly from the wedge of mantle overlying a subducting oceanic plate. Melt removal causes the continental mantle to be cold and strong but also buoyant compared to oceanic mantle. Studying accidental fragments derived from the subcontinental mantle called mantle xenoliths (e.g. Nixon 1987) carried to the surface by deeply derived magmas provides information about the physical, thermal, compositional and chronological history of the continental lithospheric mantle (Carlson et al., 2005). In particular, the Re-Os isotopic system has been of considerable use in dating mantle melt extraction events (Walker et al., 1989; Shirey and Walker, 1998; Carlson, 2005) that commonly correspond to the time of formation of the lithospheric mantle that is related to the genesis of the overlying continental crust.

Our hypothesis is that the lithospheric mantle sections formed as the roots of southern South America can reflect the history of crust formation and amalgamation at different periods of time and under different geological settings, and so, present different petrogenetic and geochronological characteristics as has been recognized in other continental regions (e.g. Carlson et al., 1999). We present geochronological constraints on the geotectonic evolution of the lithospheric mantle of the southern part of South America, as well as on the mechanisms of formation of young continental crust by studying the Os isotopic characteristics of geographically widely dispersed mantle xenoliths carried to the surface by alkaline magmas of Eocene to recent age in the back arc region of the Andes.

GEOLOGIC BACKGROUND

Just a brief summary of the most important hypotheses that will be discussed in this work are presented here, together with some published geochronologic data for the basement rocks.

The geological province of Precordillera, (Cuyania terrane), has been interpreted as a fragment of Laurentia (e.g. Astini et al., 1995) that accreted to the southwest proto-margin of Gondwana during Ordovician times. Basement xenoliths of this region have been dated with U/Pb zircons of 1102 ± 6 Ma age (Kay et al., 1996).

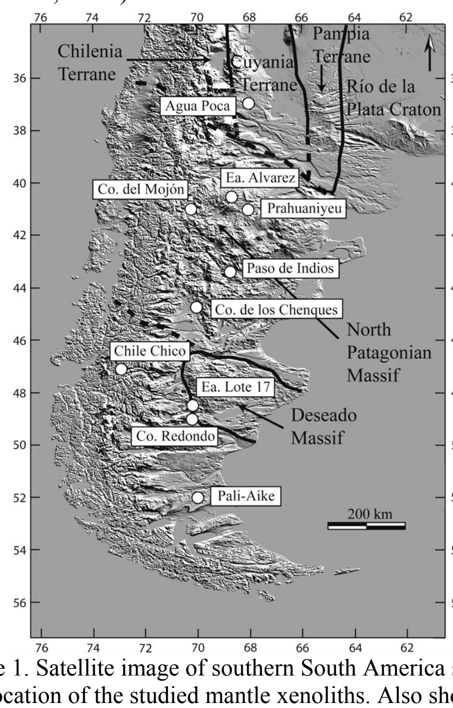

Figure 1. Satellite image of southern South America showing the location of the studied mantle xenoliths. Also shown are the Pampia, Cuyania and Chilenia accreted terranes, the inferred limits of the North Patagonian Massif (also referred as Somuncura Massif) and the Deseado Massif.

In Patagonia, the Deseado Massif has been interpreted as an independent microplate (Ramos and Aguirre-Urreta, 2000) where the Ordovician-Silurian granites and tonalities that outcrop at the northeast region of the Massif reflect the magmatic arc produced by subduction to the southwest of the North Patagonian Massif (Ramos, 2002). Zircons from small outcrops of the basement of the Deseado Massif were dated using the SHRIMP U/Pb method with prominent components at 1000-1100 and 580 ± 6 Ma (Pankhurst et al., 2003). Nd model ages of 1200 Ma were obtained for Jurassic volcanic rocks from the Deseado Massif by Pankhurst et al., (1994). The oldest basement ages obtained for this wide region come from the Malvinas Plateau, where Proterozoic ages (953-1124 Ma) have been obtained for metamorphic rocks from Cabo Belgrano (Cingolani and Varela, 1976; Rex and Tanner, 1982). In the southern edge of South America, in Tierra del Fuego, Pankhurst et al., (2003) obtained a (SHRIMP) U/Pb age of 521 ± 4 Ma for a pre-Jurassic granodiorite from a borehole.

Ramos (1984, 2002) suggests that the Deseado Massif already amalgamated to the North Patagonian Massif in the Ordovician, then accreted to Gondwana during the Permian as evidenced by the metamorphic belt of Sierra de la Ventana. Recently, Pankhurst et al., (2005) conclude that southern Patagonia, including the Deseado Massif, collided in the Carboniferous with an autochthonous Gondwana margin that included the North Patagonian Massif, following a period of northeast-directed subduction. Radiometric ages obtained for the basement of the North Patagonian Massif range mainly from 390 to 860 Ma (Caminos, 1999 and references there in).

Several studies have been dedicated to the mantle xenoliths of this region (Stern et al., 1999; Rivelenti et al., 2004; Conceiçao et al., 2005, Schilling et al., 2005 among many others) but regional study based on Os isotopic composition of mantle samples has not been done before.

RE-OS SYSTEMATICS

The Re-Os isotopic system, based on the decay of ^{187}Re to ^{187}Os can be used to date melting events in peridotites, since Re is moderately incompatible and Os is strongly compatible (Walker et al., 1989; Shirey and Walker, 1998; Carlson, 2005). Melting lowers the Re/Os of the residue and Os isotopic growth will be retarded relative to convecting mantle. Because of the high Os concentrations of peridotites and the low Os concentrations of most melts, the Os isotopic composition of mantle peridotites is less sensitive than other radiometric systems to the metasomatism that commonly affects mantle samples. The time of melt depletion can be determined for individual peridotites by using the observed Re/Os ratio and calculating when the sample had a $^{187}Os/^{188}Os$ matching primitive upper mantle (T_{MA} ages of Walker et al., 1989). These model ages rely on Re immobility, which is often a problem for mantle xenoliths. Another way to provide a minimum estimate of the timing of melt depletion is simply to compare the $^{187}Os/^{188}Os$ of the sample corrected using the measured Re/Os to the time of xenolith host eruption to a mantle evolution model. The time at which the mantle had this $^{187}Os/^{188}Os$ composition is referred to as the T_{RD}, or "Re-depletion" age (Walker et al., 1989). If all of the Re was removed at the time of melting, then the T_{RD} age should equal the T_{MA} age (assuming no Re addition). T_{RD} ages are good approximations to the time of melting for highly refractory peridotites, such as cratonic xenoliths, but in less refractory material, where some Re remains in the residue, T_{RD} ages are minimum ages.

Table 1. Re-Os data, T_{RD} and $T_{MA,}$ and Al_2O_3 content (as weight percent normalized to 100% volatile free) for mantle xenoliths from southern South America

	Sample	Type	Re (ppb)	Os (ppb)	$^{187}Re/^{188}Os$	$^{187}Os/^{188}Os(I)$	error σ	T_{RD} (Ga)	T_{MA} (Ga)	Al_2O_3 (wt%)
Agua Poca	**AP 80**	lherz	0,094	2,619	0,3146	0,12307	0,00016	0,89	3,16	2,83
	AP 91 b	lherz	0,202	2,113	0,6781	0,12723	0,00010	0,33		3,58
	AP 15	lherz	0,028	1,198	0,0940	0,11807	0,00027	1,57	1,99	
	AP78-Z2	py	0,773	0,221	2,5942	0,36341	0,00071			
Co. Del Mojón	**PM4-B2**	harz	0,015	9,943	0,0510	0,12431	0,00019	0,72	0,82	1,18
	PM4-C2	lherz	0,023	0,850	0,0776	0,12369	0,00026	0,81	0,98	1,90
	PM4-B6	harz	0,014	0,256	0,0455	0,12532	0,00019	0,59	0,66	0,82
	PM4-F1	py	0,300	0,058	1,0081	0,92694	0,00080			5,48
Ea. Alvarez	**PM7-B3**	harz	0,009	0,876	0,0300	0,12304	0,00016	0,90	0,96	0,82
	PM7-B7	harz	0,009	2,398	0,0306	0,12513	0,00012	0,61	0,66	0,90
	PM7-B1b	dunite	0,043	0,549	0,1449	0,13583	0,00018			1,12
Prahuaniyeu	**PM8-B1**	harz	0,025	1,615	0,0833	0,11715	0,00010	1,69	2,09	
	PM8-B6	lherz	0,199	3,325	0,6673	0,12647	0,00012	0,43		
Paso de Indios	**PM10-B2**	harz	0,114	4,722	0,3831	0,12439	0,00010	0,71		
	PM10-B3	harz	0,318	0,250	1,0688	0,12937	0,00013	0,03		
Co. Chenques	**PM12-01**	lherz	0,042	2,378	0,1415	0,12271	0,00017	0,94	1,39	1,87
	PM12-17	webst	0,083	2,592	0,2785	0,12271	0,00012	0,94	2,58	2,90
	PM12-26	harz	0,079	2,728	0,2645	0,12123	0,00011	1,14	2,87	1,33
	PM12-15	lherz	0,027	1,146	0,0903	0,12377	0,00022	0,80	1,01	2,59
Chile Chico	**FE01-39b**	lherz	0,329	3,363	1,1060	0,12548	0,00012	0,57		3,61
Co. Redondo	**X-F**	harz	0,180	4,349	0,6027	0,11805	0,00014	1,57		1,99
	X-G	lherz	0,117	3,779	0,3931	0,11979	0,00009	1,34		1,94
	X-D	lherz	0,137	4,021	0,4582	0,11845	0,00021	1,52		2,12
Ea. Lote 17	**L17**	lherz	0,023	2,618	0,0781	0,11679	0,00022	1,74	2,11	
Pali-Aike	**PM18-23**	harz (gte)	0,026	4,092	0,0879	0,12515	0,00012	0,61	0,76	
	PM18-28	lherz (gte)	0,135	1,548	0,4524	0,12772	0,00014	0,26		
	PM18-30	lherz	0,011	2,051	0,0383	0,12425	0,00012	0,73	0,80	
	PM18-33	lherz	0,151	2,822	0,5071	0,12292	0,00014	0,91		
	PM18-1	py (gte, phl)	0,126	6,626	0,4213	0,13422	0,00032			

RESULTS

We analyzed 29 samples that correspond to lherzolites, harzburgites, one websterite, one dunite and three pyroxenites, all in the spinel-facies. Three samples from Pali-Aike contain garnet in their mineral assemblages (one with traces of phlogopite). Petrographic textures vary from protogranular, porfiroblastic to equigranular. The studied samples form a negative trend in Al_2O_3 versus MgO concentration, which is commonly accepted to be the result of variable amounts of melt extraction in a mantle section.

The Re abundances of lherzolites, harburgites and the websterite range between 0.009 to 0.329 ppb (Table 1; Fig. 2). The Os abundances vary from 0.250 to 9.943 ppb and the initial $^{187}Os/^{188}Os$ ratios (calculated to the time of eruption) from 0.1168 to 0.1277. Agua Poca and Prahuaniyeu have variable T_{RD} ages from 0.33 to 1.69 Ga, while their T_{MA} ages range from 1.99 to 3.16 Ga (model ages were calculated using primitive upper mantle (PUM) composition of Meisel et al. (2001); $^{187}Re/^{188}Os = 0.4353$ and $^{187}Os/^{188}Os = 0.1296$). Samples from Cerro del Mojón, Ea. Alvarez, Paso de Indios, Chile Chico and Pali Aike have similar T_{RD} ages with a narrower range from 0.03 to 0.91 Ga, and T_{MA} ages from 0.66 to 0.98 Ga.

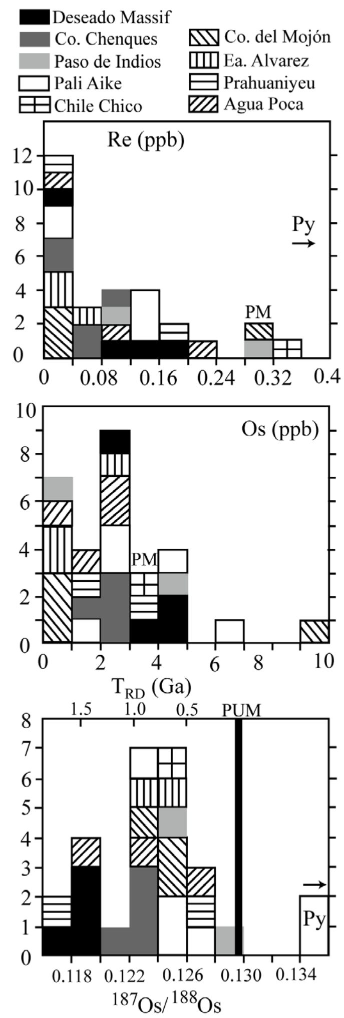

Figure 2. Histograms of Re, Os and $^{187}Os/^{188}Os$ at the time of eruption for the South America mantle xenoliths investigated here. PM is the primitive mantle value from McDonough and Sun (1995) and Py are pyroxenites.

Samples from Cerro de los Chenques also have a narrow but slightly older T_{RD} age range from 0.80 to 1.14 Ga and T_{MA} ages from 1.01 to 2.87 Ga. The three Archean T_{MA} ages (>2.5 Ga) obtained in Agua Poca and Co. de los Chenques are probably consequence of Re addition during metasomatic processes evidenced by petrographic and geochemical characteristics of these samples. The T_{RD} ages calculated for the four samples from the southwest edge of the Deseado Massif (Cerro Redondo and Ea. Lote 17) are Proterozoic ranging from 1.34 to 1.74 Ga (Fig. 2). The samples from Cerro Redondo present evidence of Re enrichment because the most depleted harzburgite has the highest Re/Os ratio. This metasomatic event can be associated with the enhancement of their Sr isotope composition that occurred before the interaction with the host basalt (Schilling et al., 2005; Conceiçao et al., 2005). As a result of the Re introduction, these samples should provide unrealistic T_{MA} ages. On the other hand, the studied sample from Ea. Lote 17 has much lower Re content and can correspond to residue left after the melt extraction process, and so, the T_{MA} age of 2.11 Ga could represent the time of depletion for this sample.

Pyroxenites and dunites have generally higher Re contents ranging from 0.043 to 0.77 ppb, and very low Os contents varying from 0.058 to 0.55 ppb, except for the orthopyroxenite PM18-1 from Pali-Aike with an unusually high 6.63 ppb of Os. All these samples have radiogenic Os isotopic compositions ($^{187}Os/^{188}Os$ from 0.13426 to 0.927) that together with their petrographic and geochemical characteristics resemble those of mantle melts. So, pyroxenites and the dunite sample are interpreted as products of interaction between peridotites and percolating mantle melts.

DISCUSSION

The Re-Os data and the model ages calculated for the studied samples can be related to the lithospheric evolution of southern South America as follows:

1. Samples from Agua Poca with Proterozoic ages may well be relicts from the lithospheric mantle of the Cuyania terrane formed probably as part of the Laurentia continent approximately 1.1 Ga ago. The collision of Chilenia terrane could cause the replacement of part of this old lithospheric mantle by younger mantle represented by xenoliths with Os isotopic composition similar to the modern convective mantle (Brandon et al., 2001 and references there in) and young model depletion ages. A similar process was recognized in the north China craton, inferred to be a consequence of a continental collision (Gao et al., 2002).
2. Mantle samples from Prahuaniyeu with very similar Os isotopic compositions to Agua Poca xenoliths could represent lithospheric fragments of the southern edge of Cuyania terrane or other tectono-stratigraphic terrane (Somuncura Massif?) with similar formation ages, or may simply reflect the heterogeneity that exists in Os isotopic composition within modern convecting mantle (e.g. Esperança et al., 1999).

3. Samples from Cerro del Mojón, Ea. Alvarez, Paso de Indios, Chile Chico and Pali Aike with a wide range in fertility coupled with a range in $^{187}Os/^{188}Os$ similar to modern oceanic peridotites and with T_{RD} and T_{MA} ages from 0.03 to 0.98 Ga, suggest that the lithospheric mantle beneath these regions formed recently from the convecting mantle.
4. The depletion ages obtained for mantle xenoliths from Cerro de los Chenques could mean that the lithospheric mantle under this region effectively formed just before most Patagonian mantle (3).
5. The three samples from Cerro Redondo and the sample studied from Ea. Lote 17, erupted in the southwestern edge of the Deseado Massif present only Proterozoic (1.34 to 2.11 Ga) T_{RD} and T_{MA} ages suggesting this continental block is considerably older than the contiguous continental crust. Thus, it would be possible to relate the Deseado Massif and the Malvinas Plateau, which show similar ages for their basement rocks.

AKNOWLEDGEMENTS

This work is supported by a CONICYT doctoral scholarship to M. Schilling. Special thanks to R.J. Walker for the introduction and training of M. Schilling in the art of Os isotopes and PGEs measurement techniques. We are grateful to C.A. Cingolani for guidance and coordinates of outcrops and to N.Jr. Rieck and G. Mallmann for assistance during field work. Thanks to Y. Orihashi for supply Cerro Redondo samples and to D. Morata and F. Espinoza for supply the sample from Chile Chico.

REFERENCES

Astini, R.A., Benedetto, J.L. and Vaccari, N.E., 1995. The early Paleozoic evolution of the Argentine Precordillera as a Laurentian rifted, drifted and collided terrane. Geol. Soc. Amer., Bull., 107, 253-273.

Brandon, A.D., Snow, J.E., Walker, R.J., Morgan, J.W. and Mock, T.D., 2001. ^{190}Pt-^{186}Os and ^{187}Re-^{187}Os systematics of abyssal peridotites, Earth Planet. Sci. Lett. 177, 319-335.

Caminos, R., 1999. Geología argentina. Instituto de geología y recursos minerales. Anales 29, (5) 107-131.

Carlson, R.W., 2005. Application of the Pt–Re–Os isotopic systems to mantle geochemistry and geochronology. Lithos 82, 249-272.

Carlson, R.W., Pearson, D.G., Boyd, F.R., Shirey, S.B., Irvine, G., Menzies, A.H. and Gurney, J.J., 1999. Re-Os systematics of lithospheric peridotites: implications for lithospheric formation and preservation. In Gurney J.J., Gurney, J.L., Pascoe, M.D. and Richardson, S.H., (eds.) Proc. 7th Int. Kimberlite conf., volume 1: Cape Town, Red Roof Design, 99-108.

Carlson, R.W., Pearson, D.G. and James, D.E., 2005. Physical, chemical, and chronological characteristics of continental mantle. Rev. Geophys., 43, RG1001. doi: 10.029/2004RG000156. (G3 1-24).

Cingolani, C. and Varela, R., 1976. Investigaciones geológicas y geocronológicas en el extreme sur de la Isla Gran Malvina, sector cabo Belgrano (Cabo Meredith), Islas Malvinas. 6º Cong. Geol. Argentino, Actas I, 457-474.

Conceição R.V., Mallmann G., Koester E., Schilling M., Bertotto G.W., Rodriguez-Vargas A. 2004. Andean subduction-related mantle xenoliths: isotopic evidence of Sr-Nd decoupling during metasomatism. Lithos 82, 273-287.

Esperança, S., Sichel, S.E., Horan, M.F., Walker, R.J., Juteau, R. and Hekinian, R., 1999. Some abyssal peridotites are old! In Ninth annual Goldshmidt conference, abstracts #7389, LPI contribution No. 971, Houston, TX (CD-ROM).

Gao, S., Rudnick, R.L., Carlson, R.W., McDonough, W.F. and Liu, Y.S., 2002. Re-Os evidence for replacement of ancient mantle lithosphere beneath the North China craton. Earth Planet. Sci. Lett. 198, 307-322.

Kay, S.M., Orrel, S. and Abbruzzi, J.M., 1996. Zircon and whole rock Nd-Pd isotopic evidence for a Grenville age and a Laurentian origin for the Precordillera terrane in Argentina. J. Geol. 104, 637-648.

McDonough W. F. and Sun S.-S. 1995. Composition of the Earth. Chem. Geol. 120, 223–253.

Nixon, P.H. 1987. Mantle xenoliths, Jhon Wiley, Hoboken, N.J.

Pankhurst, R.J., Hervé, F. and Rapela, C.W., 1994. Sm-Nd evidence for the Grenvillian provenance of the metasedimentary basement of Southern Chile and West Antartica. 7º Cong. Geol. Chileno, Actas II, 1414-1418, Concepción.

Pankhurst, R.J., Rapela, C.W., Loske, W.P., Márquez, M. and Fanning, C.M., 2003. Chronological study of the pre-Permian basement rocks of southern Patagonia. J. South Am. Earth Sci. 16, 27-44.

Pankhurst, R.J., Rapela, C.W., Fanning, C.M. and Márquez, M., 2005. Gondwanide continental collision and the origin of Patagonia. Gondwana 12, Mendoza, Abstracts.

Ramos, V.A., 1984. Patagonia, Un continente a la deriva?. 10º Congr. Geol. Argentino, Actas, 2, 311-325.

Ramos, V.A., 1988. Tectonics of the Late Proterozoic-early Paleozoic: a collisional history of Southern South America. Episodes, 11, 168-174.

Ramos, V.A., 2002. Evolución Tectónica. In Haller, M.J. (ed.) Geología y Recursos Naturales de Santa Cruz. Relatorio del XV Congreso Geológico Argentino. El Calafate, I-23:365-387. Buenos Aires.

Ramos, V.A. and Aguirre-Urreta, M.B., 2000. Patagonia. In Cordani, U.J., Milani, E.J., Thomaz Filho, A. and Campos, D.A. (eds.) Tectonic evolution of South America, 31º International Geological Congres, 369-380, Río de Janeiro.

Rex, D.C. and Tanner, P.W.G., 1982. Precambrian age for the gneisses at Cape Meredith in the Folkland islands. In Antartic Geoscience, Campbell Craddock (ed.) Symposium on Antartic geology and geophysiscs, 107-108. The University of Wisconsin press.

Rivalenti G., Mazzucchelli, M., Laurora, A., Ciuffi, S.I.A., Zanetti, A., Vannucci, R. and Cingolani, C.A., 2004. The back arc mantle lithosphere in Patagonia. J. South. Am. Earth Sci. 17, 121-152.

Schilling, M., Conceição, R.V., Mallmann, G., Koester, E., Kawashita, K., Hervé, F., Morata, D. and Motoki, A., 2005. Spinel-facies mantle xenoliths from Cerro Redondo, Argentine Patagonia: Petrographic, geochemical and isotopic evidence of interaction between xenoliths and host basalt. Lithos 82, 485-502.

Shirey, S.B. and Walker, R.J., 1998. Re-Os isotopes in cosmochemistry and high-temperature geochemistry. Ann. Rev: Earth and Planet. Sci. 26, 423-500.

Stern, C.R., Killian, R., Olker, B., Hauri, E.H. and Kyser, T.K., 1999. Evidence from mantle evolution for relatively thin (<100 km) continental lithosphere below the

Phanerozoic crust of southernmost South America. Lithos 48, 217-235.
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. Geochim. Cosmochim. Acta 53, 1583– 1595.

RESUMEN

Presentamos datos isotópicos de Re-Os de xenolitos mantélicos provenientes del sur de Sudamérica (36º-52ºS) transportados a superficie por magmatismo alcalino Eoceno a reciente. Nuestra hipótesis es que el manto litosférico formado como raíz del extremo sur del continente Sudamericano refleja la historia de formación de corteza y su amalgamación en diferentes momentos, bajo diferentes regimenes tectónicos, y por lo tanto presenta características petrogenéticas y geocronológicas diferentes. El sistema isotópico Re-Os entrega información geocronológica única sobre el tiempo de fusión en el manto, proceso asociado a la formación del manto litosférico. Nuestros datos muestran edades modelo coherentes para el manto litosférico, correlacionables con algunas hipótesis sobre la evolución cortical de esta región. La mayoría de las muestras tienen valores de Os isotópico similares al manto convectivo, con edades modelo relativamente jóvenes desde 0.03 a 0.91 Ga, lo que sugiere una formación relativamente reciente del manto litosférico. Xenolitos de Agua Poca y probablemente Prahuaniyeu representan la raíz del terreno Cuyania de edad Grenviliana, interpretado como un fragmento derivado de Laurentia, donde muestras con edades modelo antiguas representarían relictos del manto litosférico original (~1.1 Ga), que pudo ser parcialmente reemplazado por manto convectivo más joven durante la acreción del terreno Chilenia, como sugieren edades modelo jóvenes. Muestras erupcionadas en la esquina suroeste del Macizo del Deseado muestran únicamente edades Proterozoicas, sugiriendo que esta microplaca se habría formado durante este periodo y por lo tanto podría ser correlacionada con las Islas Malvinas que presentan edades similares en rocas de su basamento.