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Re–Os isotope constraints on subcontinental lithospheric mantle evolution of southern South America

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Abstract

We present Re–Os isotopic data for widely dispersed mantle xenoliths carried to the surface of southern South America (36°–52° S) by Eocene to recent alkaline magmatism. Our hypothesis is that the lithospheric mantle sections formed as the roots of southern South America reflect the history of crust formation and amalgamation at different periods of time and so present a complimentary picture of continent growth in South America by sampling deeper sections of continental lithosphere than provided by crustal rocks from the area. The Re–Os isotopic system gives unique chronological information about the time of mantle depletion that is associated with lithosphere formation. Our data show coherent model ages for the lithospheric mantle that can be correlated with some hypotheses for crustal evolution of this region. Most samples show Os isotopic values similar to the present suboceanic mantle, suggesting a relatively recent lithospheric mantle formation from the convecting mantle. Xenoliths from Agua Poca and Prahuaniyeu represent fragments of an ancient depleted lithosphere, probably corresponding to the roots of the Cuyania terrane inferred to be a fragment derived from Laurentia and formed during the Mesoproterozoic. Alternatively, all or parts of the recognized ancient lithosphere are relicts of other known ancient continental blocks, such as the Pampia terrane or the Río de la Plata craton. Samples erupted in the southwest corner of the Deseado Massif give Proterozoic depletion ages (1.34 to 2.11 Ga) that are considerably older than previous radiogenic formation ages obtained for the very few basements rocks of this continental block. We propose that Deseado Massif is Proterozoic in age, probably related to the Malvinas/Falkland Islands and plateau and so should be considered for the reconstruction of the supercontinent of Rodinia.

Keywords: subcontinental lithospheric mantle; South America; mantle xenoliths; Os isotopes

1. 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 through distinction of amalgamated terranes, recognizing the suture zones, the time of the different collisions, the place of

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origin, the relationship with supercontinents, and the formation ages for the allocthonous terranes.

The formation of these continental terranes and their evolution is possibly directly related to the formation of their respective lithospheric mantle sections. Several studies, mostly of cratonic regions, have shown that 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 (e.g. Boyd, 1987). Melt removal causes the continental mantle to be cold and strong, but also buoyant compared to oceanic mantle (e.g. Jordan, 1975). Studying accidental fragments derived from the subcontinental lithospheric 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 subcontinental mantle (Carlson et al., 2005). In particular, the Re–Os isotopic system ($^{187}\mathrm{Re}\rightarrow{}^{187}\mathrm{Os}+\beta^{-}$; $\lambda=1.666\times10^{-11}$ yr^{-1}, Smoliar et al., 1996) has been of considerable use in dating mantle melt extraction events (Walker et al., 1989; Shirey and Walker, 1998; Carlson, 2005) that are generally related to the genesis of the overlying continental crust. This application is possible because Re is moderately incompatible while Os is strongly compatible in the mantle, and consequently, melting lowers the Re/Os ratio of the residue causing Os isotopic growth to be retarded relative to fertile mantle. Because of the high Os concentration of peridotites and the low Os concentration of most mantle melts, the Os isotopic composition of mantle peridotite 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 measured Re/Os ratio and calculating when the sample had an $^{187}\mathrm{Os}/^{188}\mathrm{Os}$ matching that of an undifferentiated model mantle (see Walker et al., 1989, Fig. 1). This model age, referred as

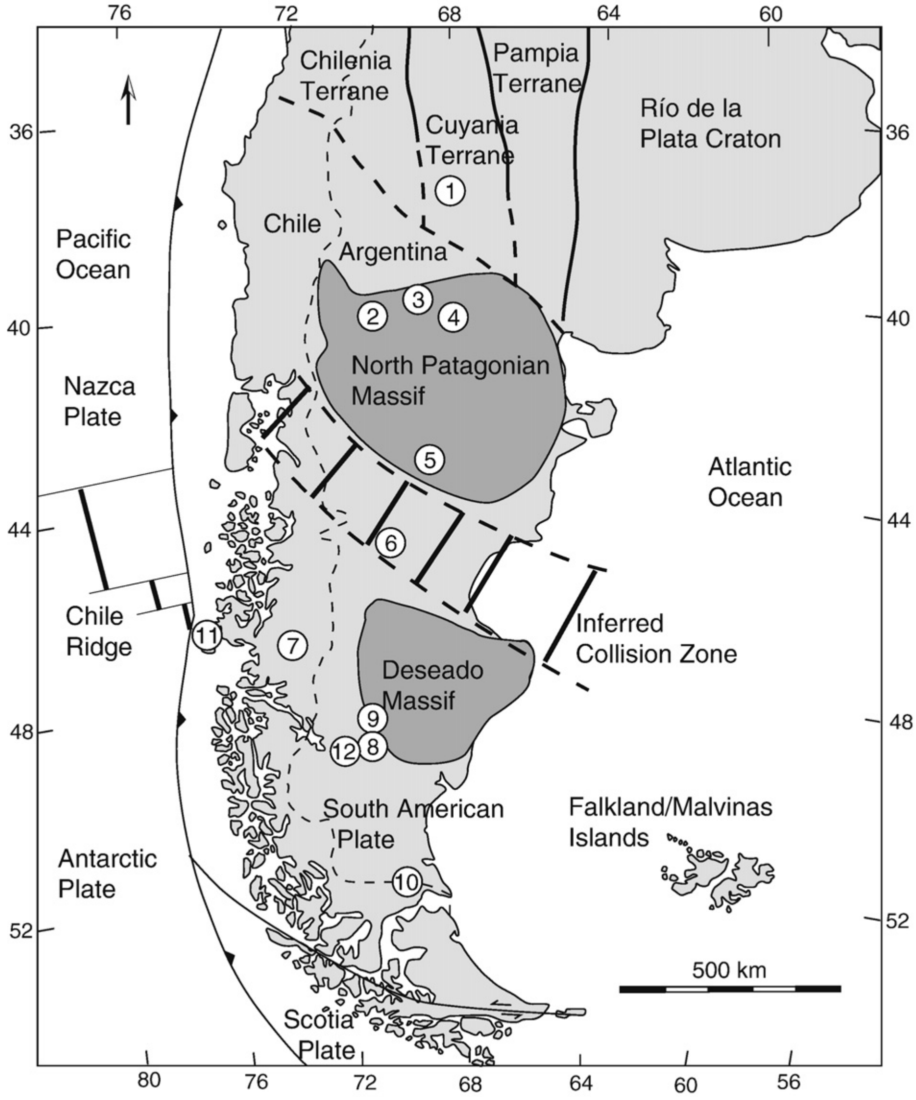

Fig. 1. Map of southern South America showing the present geological setting and the location of the studied mantle xenoliths, modified from Pankhurst et al. (2006). Studied localities are: 1, Agua Poca; 2, Cerro del Mojón; 3, Estancia Alvarez; 4, Prahuaniyeu; 5, Paso de Indios; 6, Cerro de los Chenques; 7; Chile Chico; 8, Cerro Redondo; 9, Estancia Lote 17; and 10, Pali-Aike. Also shown are the Río de la Plata Craton, the Pampia, Cuyania, and Chilenia accreted terranes, the inferred limits of the North Patagonian Massif and the Deseado Massif, the Malvinas/Falkland Islands, the Taitao ophiolite (11), and the Tres Lagos xenolith locality (12).

T_{MA}, was defined by Luck and Allègre (1984) and is completely analogous to the Sm–Nd model age of DePaolo and Wasserburg (1976) but relies on the immobility of Re subsequent to the melting event, which can be a problem, e.g. for those mantle xenoliths that have suffered melt infiltration. A minimum estimate of the timing of melt depletion can be obtained by calculating the $^{187}Os/^{188}Os$ of the sample, using the measured Re/Os ratio, but only to the time of its host basalt eruption, and comparing this to the 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): thus 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, or in cases where secondary Re has been added long before the time of eruption, T_{RD} ages are minimum depletion ages. In very exceptional cases, where mantle peridotites that come from the same mantle source (isotopically homogeneous) suffered a single melting event and no Re or Os mobility has occurred subsequent to melting, an isochron can be obtained. Rhenium mobility and multiple sources and melting events in mantle sections are responsible for the rareness of Re–Os isochrons in peridotite xenolith suites.

Our hypothesis is that the lithospheric mantle sections formed as the roots of southern South America reflect the history of crust formation at different periods of time and so provide information on the record of lithosphere formation that complement studies carried out on shallow crustal samples. The application of the Re–Os isotopic system to the widely distributed suite of mantle xenoliths available from southern South America allows the recognition of regional variations of geochronological characteristics of the lithospheric mantle. These distinct age provinces can then be related to the assembly history of the overlying crust.

2. Geological background

A brief summary of some published geochronologic data for basement rocks and important hypotheses about the geological evolution of southern South America are presented here. In Fig. 1 we show a map with the present tectonic setting, the location of the studied samples and the continental blocks recognized to participate in the construction of the southern edge of South America by successive collisions based on the work of Ramos (1988, 1996), Kraemer et al. (1994), Bahlburg and Hervé (1997), Chernicoff and Zappettini (2003), and Pankhurst et al. (2003, 2006). At present, not all the terrane boundaries are well constrained, and some of them are simply inferred.

Three large terranes, Pampia, Cuyania (also referred to as Precordillera in the literature), and Chilenia accreted to the western proto-margin of Gondwana, represented by the 2000–2200 Ma Río de la Plata craton (Santos et al., 2003; Rapela et al., 2007), during the Early Cambrian, Middle Ordovician, and late Devonian times, respectively (e.g. Vujovich et al., 2004). Several lines of evidence support the hypothesis that Cuyania rifted from the Ouachita embayment of Laurentia (Astini et al., 1995; Thomas and Astini, 1999; Thomas and Astini, 2003), however an origin from the southern margin of west Gondwana is still not eliminated (e.g. Finney et al., 2005). The relatively long Grenvillian history of the Cuyania terrane has been documented by several isotopic ages obtained for its basement rocks, with middle Proterozoic ages, ranging from 1000 Ma to 1250 Ma (Abruzzi et al., 1993; Kay et al., 1996; Sato et al., 2000, 2004; Vujovich et al., 2004). All areas of Cuyania basement also share common Mesoproterozoic Sm–Nd T_{DM} ages for basement rocks (Kay et al., 1996; Sato et al., 2000; Varela et al., 2003). To the east, the basement rocks of the Pampia terrane also record Grenvillian ages (e.g. Varela et al., 2003; Casquet et al., 2006). The continuity of the Cuyania terrane further south into Patagonia has not been confirmed (Sato et al., 2000) and high-resolution aeromagnetic data suggest this terrane is truncated south of 39° S (Chernicoff and Zappettini, 2003). However, there is evidence that the Ordovician Famantinian orogen, related to the collision of Cuyania terrane with the western proto-margin of Gondwana, continues to the south at scattered locations within the North-Patagonian Massif (e.g. Pankhurst et al., 2006).

The oldest basement rocks of the North Patagonian Massif have been found mainly at the east and northeast area of the massif, and correspond to the fine-grained meta-sandstones of El Jagüelito and Nahuel Niyeu Formations. Detrital zircons from these formations were dated using the U–Pb SHRIMP method, showing the youngest age peaks at 535 Ma and 515 Ma, respectively, which were interpreted to be close to their ages of deposition (Pankhurst et al., 2006). The older provenance of the studied samples is typically Gondwanan with ages of 550–750 Ma (Pampean and Brasiliano) and 1000–1200 Ma (Grenvillian), as well as a small component of older ages, including some at 2200 Ma. To the south, Pankhurst et al. (2003) dated small outcrops of the basement of the Deseado Massif, consisting of weathered, altered granitoids and their metasedimentary host rocks by the U–Pb zircon method using a SHRIMP, and obtained prominent components at 1000–1100 and 580±6 Ma, the latter probably approximating the age of sedimentation. Neodymium model ages of 1200 Ma were obtained for Jurassic volcanic rocks from the Deseado Massif by Pankhurst et al. (1994). Similar old basement ages have been reported on the Malvinas/Falkland Plateau (953–1124 Ma) for metamorphic rocks from Cabo Belgrano (Cingolani and Varela, 1976; Rex and Tanner, 1982). On the southern edge of South America, in Tierra del Fuego, Söllner et al. (2000) and Pankhurst et al. (2003) obtained U/Pb ages on zircons of 529±7.5 Ma, and 521±4 Ma, respectively, for a pre-Jurassic granodiorite from a borehole.

In regard to the tectonic evolution of Patagonia, the Deseado Massif has been interpreted as an independent microplate (Ramos and Aguirre-Urreta, 2000) where the Ordovician–Silurian tonalities that outcrop at the northeast region of the massif reflect the magmatic arc produced by the subduction to the southwest of the North Patagonian Massif (Ramos, 2002). Ramos (2002) suggests that the Deseado Massif already amalgamated to the North Patagonian Massif in the Ordovician, accreted to Gondwana during the Permian as evidenced by the metamorphic belt of Sierra de la Ventana. Recently, Pankhurst et al. (2006) proposed a different hypothesis where 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. The inferred collision zone is shown in Fig. 1.

Several studies based on mineral and whole rock chemistry, and isotopic analysis of mantle xenoliths from Southern South America have been performed with the aim of characterizing the subcontinental lithospheric mantle of this region, placing constraints on the processes involved on its evolution (Stern et al., 1999; Gorring and Kay, 2000; Laurora et al., 2001; Rivalenti et al., 2004, 2007; Conceição et al., 2005; Schilling et al., 2005; Bjerg et al., 2005; Ntaflos et al., 2007, among many others). However, this is the first study involving measurements of Os isotopes of mantle-derived rocks on a regional scale in southern South America.

3. Analytical techniques

Major element composition of samples AP80 and AP91 from Agua Poca were analyzed by Fusion-ICP at Activation Laboratories Ltd. (ActLabs), Canada. Major element compositions of samples AP15 and AP78-Z2 from Agua Poca, and samples from Cerro del Mojón, Estancia Alvarez, Prahuaniyeu, Paso de Indios, Cerro de los Chenques, Estancia Lote 17, and Pali Aike were obtained in a Rigaku RIX 2000 X-Ray Fluorescence Spectrometer at CPGq-UFRGS, Brazil. Major element compositions of Cerro Redondo and Chile Chico xenoliths were measured by ICP-AES at the Universidad de Chile. The MgO and Al_2O_3 analyses are considered accurate to within 2%. Mineral major-element compositions of Agua Poca xenoliths were carried out at the Dipartimento di Scienze della Terra dell' Università degli Studi di Modena e Reggio Emilia, Italy, with an ARL-SEMQ electron microprobe in wavelength dispersive mode, with an accelerating potential of 15 kV and a beam current of 20 nA. Mineral major-element compositions of samples X-F and X-D from Cerro Redondo were determined by electron microprobe at the University Pierre et Marie Courie, Paris, on a Camebax SX-50, using an accelerating voltage of 15 kV, a beam current of 40 nA and a count time of 20 s. Samples X-G (Cerro Redondo), FE01-39b (Chile Chico) and L-17 (Estancia Lote 17) were analyzed by electron microprobe at the Universidad de Chile on a SEM-probe Camebax SU-30 using an accelerating voltage of 15 kV, a beam current of 10 nA, and a count time of 10 s. Mineral major-element chemistry for samples from Cerro del Mojón and Estancia Alvarez was determined at Centro de Estudos em Petrologia e Geoquímica (CPGq) of Universidade Federal de Rio Grande do Sul (UFRGS), Brazil, using a Cameca SX50 electron microprobe in WDS mode employing 15 kV acceleration voltage, 10 nA beam current, and counting times of 30 s. The mineral major-element chemistry of mantle xenoliths from Prahuaniyeu, Cerro de los Chenques, Paso de Indios, and Pali Aike were determined with a CAMECA SX50 electron microprobe with SAMx automation at the Paul Sabatier University, Toulouse, France, using wavelength-dispersive spectrometry (WDS). Analyses were performed with an accelerating voltage of 15 kV and a beam current 20 nA. Equilibration temperatures were estimated using the mineral chemistry and the geothermometer of Brey and Köhler (1990). The mineral modes of the studied mantle xenoliths were obtained by point counting and chemical balance between whole rock and mineral chemistry.

Rhenium–Osmium procedures followed those detailed in Carlson et al. (1999), which includes Carius tube digestions of approximately 1 g of sample powder for peridotites and 2 g for pyroxenites, using a mixed Re–Os spike, followed by Os extraction into CCl_4 and Re purification on anion exchange columns. Re and Os were loaded onto Pt filaments with $Ba(NO_3)_2$ as an activator and analyzed as negative ions, peak-hopping in a single secondary electron multiplier on the DTM 15-inch mass spectrometer (see Carlson and Irving, 1994 for details). Os isotopic compositions are corrected for oxygen based on the oxygen isotopic composition reported by Nier (1950), fractionation corrected to $^{192}Os/^{188}Os = 3.082614$, and reported relative to a value of $^{187}Os/^{188}Os = 0.1740$ for the DTM Os standard. Total procedural blanks did not exceed 2.0 pg for either Os and Re. These blanks are inconsequential for Os, but are significant for the samples with lower Re contents, consequently blank corrections were made to all samples using an average Re blank of 1 ± 0.5 pg. Re–Os model ages are calculated relative to the modern-day primitive mantle parameters of Meisel et al. (2001); $^{187}Re/^{188}Os = 0.4353$ and $^{187}Os/^{188}Os = 0.1296$.

4. Samples and localities

The petrography, mineral phases, whole rock chemistry, and Sr, Nd and Pb isotopic analysis of some of the samples studied here have been the focus of previous studies (Bertotto, 2000, 2003; Espinoza and Morata, 2003; Mallmann, 2004; Conceição et al., 2005; Rieck, 2005; Schilling et al., 2005; Dantas, 2007) . Table 1 lists the coordinates of the ten localities sampled, the

Table 1
Geographic location of sampled localities during this work, the respective host basalt ages, and previous studies of xenoliths from these localities

Locality	Latitude (S)	Longitude (W)	Host basalt age	Previous studies
Agua Poca	37°01′	68°07′	Pleistocene	1*, 2*, 3*
Cerro del Mojón	41°06′	70°13′	Miocene	4*, 5,
Estancia Alvarez	40°46′	68°46′	Miocene	4*, 5, 6
Prahuaniyeu	41°20′	67°54′	Miocene	7, 8, 9*
Paso de Indios	43°38′	68°56′	Eocene	–
Cerro de los Chenques	44°52′	70°03′	Pleistocene–Holocene	5, 10, 11*
Chile Chico	46°35′	71°51′	Eocene	12*
Cerro Redondo	49°07′	70°08′	Pliocene–Pleistocene	3*, 13*
Estancia Lote 17	48°34′	70°10′	Miocene	3*, 8, 14, 15
Pali Aike	52°01′	70°12′	Pliocene–Pleistocene	3*, 16, 17, 18

*References including some samples analyzed in the present study.
Previous studies include: 1*, Bertotto, 2000; 2*, Bertotto, 2003; 3*, Conceição et al., 2005; 4*, Mallmann, 2004; 5, Rivalenti et al., 2004; 6, Varela et al., 1998; 7, Ntaflos et al., 2001; 8, Bjerg et al., 2005; 9*, Dantas, 2007; 10, Rivalenti et al., 2007; 11*, Rieck, 2005; 12, Espinoza and Morata, 2003; 13*, Schilling et al., 2005; 14, Gorring and Kay, 2000; 15, Laurora et al., 2001;16, Stern et al., 1999; 17, Kempton et al., 1999a; and 18, Kempton et al., 1999b.

estimated ages for the respective host basalts that range from the Eocene to Holocene, and references to previous studies carried out on some of the same samples analyzed here, as well as some studies on mantle xenoliths derived from the same localities performed by other authors. A summary of the type of rocks, petrographic textures, mineral modes, and the temperature of equilibration of the analyzed xenoliths is presented in Table 2. The Re–Os isotopic data, together with the MgO and Al_2O_3 whole rock contents, the whole rock Mg# (Mg# = Mg/(Mg + Fe) as cations), the olivine forsterite content, and the spinel Cr# (Cr# = Cr/(Cr + Al) as cations) are shown in Table 3.

The 29 samples analyzed in this study include fifteen lherzolites, nine harzburgites, one websterite, one dunite and three pyroxenites, all in the spinel-facies. Three samples from Pali-Aike also contain garnet in their mineral assemblages. Petrographic textures of the studied samples vary from coarse-granular, porphyroclastic to equigranular (Table 2). The temperatures of equilibration range widely from 726 °C to 1202 °C, but most of them range from 900 °C to 1100 °C, with an average of 972 °C. Fig. 2 plots the MgO versus Al_2O_3 contents (anhydrous wt.%) where the whole set of samples form a negative trend; a pattern commonly inferred to be the result of variable amounts of melt extraction in a mantle section (e.g. McDonough, 1990).

We studied three lherzolites and one pyroxenite from Agua Poca. Samples AP80 and AP91 have veins of glass less than 10 microns thick, and the pyroxenite is characterized by the intercalation of clinopyroxene and orthopyroxene bands. Prahuaniyeu and Paso de Indios peridotites are less than 5 centimeters in size (Dantas, 2007). All studied samples from Estancia Alvarez contained serpentine veins. One of these (PM7-B1) corresponds to

Table 2

Summary of petrographic characteristics of southern South America mantle xenoliths including the type and petrographic texture of rocks, the percentage of mineral modes and the temperatures of equilibration estimated using the geothermometer of Brey and Köhler (1990)

Sample	Type	Texture	Ol	Opx	Cpx	Sp	Others	T (°C)
Agua Poca								
AP 80	lherz	porph	73.4	17.4	8.0	1.2		1049
AP 91	lherz	porph-equi	57.6	19.7	18.0	4.7		1036
AP 15	lherz	prot-porph	61.6	24.8	11.5	2.1		1139
AP78-Z2	py	equi	0.0	33.3	55.9	10.0	plagioclase (0.8%)	966
Cerro del Mojón								
PM4-B2	harz	coarse-porph	66.8	27.4	4.6	1.2	melt pockets (0.2%)	927
PM4-C2	lherz	porph	57.9	9.4	13.5	0.7	amphibole (0.4%) and melt pockets (18%)	910
PM4-B6	harz	coarse-porph	82.2	14.3	0.9	2.5		898
PM4-F1	py	prot	5.6	4.5	86.1	3.8		979
Estancia Alvarez								
PM7-B3	harz	coarse-porph	88.7	8.9	1.3	4.0	serpentine veins	
PM7-B7	harz	coarse-porph	80.6	14.5	1.7	3.1	serpentine veins	838
PM7-B1	dunite	coarse	95.6	–	1.9	2.6	serpentine veins	
Prahuaniyeu								
PM8-B1[a]	harz	equi-tabular	73.4	14.1	9.7	2.8		1202
PM8-B6	lherz	porph-equi						950
Paso de Indios								
PM10-B2[a]	lherz	equi	77.2	13.8	6.7	2.3		976
PM10-B3[a]	harz	porph	75.9	17.6	4.1	2.4		1026
Cerro de los Chenques								
PM12-01	lherz	equi	41.1	44.6	12.3	1.4	melt pockets	
PM12-15	lherz	porph-equi	63.5	25.3	7.9	3.3	melt pockets	928
PM12-17	webst	equi	30.9	42.2	20.7	6.2	melt pockets	1017
PM12-26	harz	equi	75.9	18.8	3.8	1.5	melt pockets	814
Chile Chico								
FE01-39b[a]	lherz		44.3	36.5	15.3	3.8		812
Cerro Redondo								
X-F	harz	coarse	57.1	38.4	3.0	1.5		1033
X-G	lherz	coarse	60.6	27.8	10.9	0.7		847
X-D	lherz	coarse	71.6	15.7	11.4	1.3		1002
Estancia Lote 17								
L17[a]	lherz	coarse	75.8	15.6	7.5	1.1		1038
Pali-Aike								
PM18-23	harz	equi-tabular	74.5	20.3	Trace	0.4	garnet (4.8%)	1080
PM18-28	lherz	equi	61.0	14.7	13.6	0.8	garnet (9.9%)	1088
PM18-30	lherz	porph-equi	79.0	11.0	8.7	1.3		1009
PM18-33	lherz	coarse	69.0	18.8	10.3	1.9		726
PM18-1	py		5.0	75.0	1.0	9.0	garnet (10%) and traces of phlogopite	

The utilized abbreviations are; lherz: lherzolite; webst: websterite; harz: harzburgite; py: pyroxenite; prot: protogranular; porph: porphiroclastic; equi: equigranular; Ol: olivine; Opx: orthopyroxene; Cpx: clinopyroxene; and Sp: spinel.

[a] Modal proportion calculated by chemical balance between mineral and whole rock compositions.

Table 3
Rhenium–Osmium data, T_{RD} and T_{MA} model ages, and other representative geochemical data for mantle xenoliths from southern South America, including MgO and Al_2O_3 contents, whole rock Mg# (Mg#=Mg/(Mg+Fe) as cations), forsterite content of olivines (Fo Ol), and Cr # of spinels (Cr#=Cr/(Cr+Al) as cations)

Sample	Re (ppb)	Os (ppb)	$^{187}Re/^{188}Os$	$^{187}Os/^{188}Os$ (I)	Error σ	T_{RD} (Ga)	T_{MA} (Ga)	MgO [a] (wt.%)	Al_2O_3 [a] (wt.%)	Mg #	Fo Ol	Cr# sp
Agua Poca												
AP 80	0.094	2.619	0.3146	0.12307	0.00016	0.89	3.16	44.16	2.83	91.9	90.4	10.2
AP 91 b	0.202	2.113	0.6781	0.12723	0.00010	0.33	future	40.74	3.58	89.9	89.5	7.8
AP 15	0.028	1.198	0.0940	0.11807	0.00027	1.57	1.99	43.15	1.82	89.5	90.6	24.7
AP78-Z2	0.773	0.221	2.5942	0.36341	0.00071	future	6.16	21.46	13.96	87.7	–	3.6
Cerro del Del Mojón												
PM4-B2	0.015	9.943	0.0510	0.12431	0.00019	0.72	0.82	45.83	1.18	90.7	91.5	37.9
PM4-C2	0.023	0.850	0.0776	0.12369	0.00026	0.81	0.98	44.41	1.90	89.9	91.0	26.4
PM4-B6	0.014	0.256	0.0455	0.12532	0.00019	0.59	0.66	46.80	0.82	90.6	91.3	41.5
PM4-F1	0.300	0.058	1.0081	0.92694	0.00080		52.25	21.23	5.48	84.1	83.9	5.0
Estancia Alvarez												
PM7-B3	0.009	0.876	0.0300	0.12304	0.00016	0.90	0.96	46.38	0.82	90.4		
PM7-B7	0.009	2.398	0.0306	0.12513	0.00012	0.61	0.66	46.16	0.90	90.5	91.2	41.3
PM7-B1	0.043	0.549	0.1449	0.13583	0.00018	future	future	45.07	1.12	84.1	85.1	18.9
Prahuaniyeu												
PM8-B1	0.025	1.615	0.0833	0.11715	0.00010	1.69	2.09	43.46	2.09	90.7	91.4	–
PM8-B6	0.199	3.325	0.6673	0.12647	0.00012	0.43	future	43.63	1.06	83.6	90.2	19.3
Paso de Indios												
PM10-B2	0.114	4.722	0.3831	0.12439	0.00010	0.71	5.78	44.05	1.53	89.7	90.3	26.1
PM10-B3	0.318	0.250	1.0688	0.12937	0.00013	0.03	future	44.70	1.51	90.0	91.1	25.5
Cerro de los Chenques												
PM12-01	0.042	2.378	0.1415	0.12271	0.00017	0.94	1.39	43.40	1.87	88.3	–	–
PM12-15	0.027	1.146	0.0903	0.12377	0.00022	0.80	1.01	41.19	2.59	88.9	90.1	16.9
PM12-17	0.083	2.592	0.2785	0.12271	0.00012	0.94	2.59	41.16	2.90	88.1	88.9	9.2
PM12-26	0.079	2.728	0.2645	0.12123	0.00011	1.14	2.88	44.70	1.33	90.3	90.6	29.3
Chile Chico												
FE01-39[a]	0.329	3.363	1.1060	0.12548	0.00012	0.57	future	37.27	3.61	89.22	89.5	11.2
Cerro Redondo												
X-F	0.180	4.349	0.6027	0.11805	0.00014	1.57	future	43.59	1.99	91.1	91.5	19.3
X-G	0.117	3.779	0.3931	0.11979	0.00009	1.34	12.71	43.38	1.94	91.0	91.2	20.3
X-D	0.137	4.021	0.4582	0.11845	0.00021	1.52	future	44.10	2.12	90.7	91.1	18.2
Estancia Lote 17												
L17	0.023	2.618	0.0781	0.11679	0.00022	1.74	2.11	45.64	1.16	91.2	91.3	31.3
Pali-Aike												
PM18-23	0.026	4.092	0.0879	0.12515	0.00012	0.61	0.76	41.66	2.78	88.5	89.3	31.9
PM18-28	0.135	1.548	0.4524	0.12772	0.00014	0.26	future	38.51	3.97	88.6	89.6	29.7
PM18-30	0.011	2.051	0.0383	0.12425	0.00012	0.73	0.80	43.00	2.36	89.1	90.1	14.7
PM18-33	0.151	2.822	0.5071	0.12292	0.00014	0.91	future	41.98	2.65	90.1	90.6	18.5
PM18-1	0.126	6.626	0.4213	0.13422	0.00032	future	future	35.92	6.82	86.5	–	–

[a] Presented as weight percent (wt.%) normalized to 100% volatile free.

a dunite where basaltic material is observed between olivine crystals implying significant interaction with basaltic melts. Two samples from Cerro del Mojón, have melt pockets that were ascribed to the interaction with metasomatic fluids derived from the subducting oceanic crust by Mallmann (2004). In sample PM4-C2, the melt pockets reach 18% of the volume, and there is also amphibole in its mineral assemblage. Sample PM4-F1 from this locality is a pyroxenite inferred to have formed as the crystallization product of basaltic melts percolating through the mantle column (Mallmann, 2004). Cerro de los Chenques xenoliths include two lherzolites, one harzburgite and one websterite, with sizes ranging from 4 to 10 cm in diameter. All studied samples from this locality show silicate-melt pockets that are related to the formation of secondary olivine, clinopyroxene, and spinel crystals. Harzburgite PM12-26 has U-shaped whole rock and clinopyroxene normalized incompatible-trace element patterns with low HREE abundances, suggesting a relatively strong melt-depletion event followed by an enrichment event (Dantas, 2007). The selected Cerro Redondo xenoliths were those recognized to be the less affected by the host basalt infiltration identified by the work of Schilling et al. (2005). However, even those samples free from host basalt contamination show Sr isotopic enrichment without significant Nd isotopic variation, suggestive of slight metasomatic enrichment prior to capture. Sample PM18-1 from Pali-Aike contains spinel and garnet, and is an orthopyroxenite vein cross-cutting a harzburguite, supposedly formed during a first metasomatic event by the interaction of a Si-rich magma with peridotitic whole rock. Phlogopite and clinopyroxene in this sample were formed during a second metasomatic event (Dantas, 2007).

5. Re–Os isotopic results

Osmium isotopic data are reported in Table 3 and Fig. 3 for the studied mantle xenoliths. The Re abundances of lherzolites,

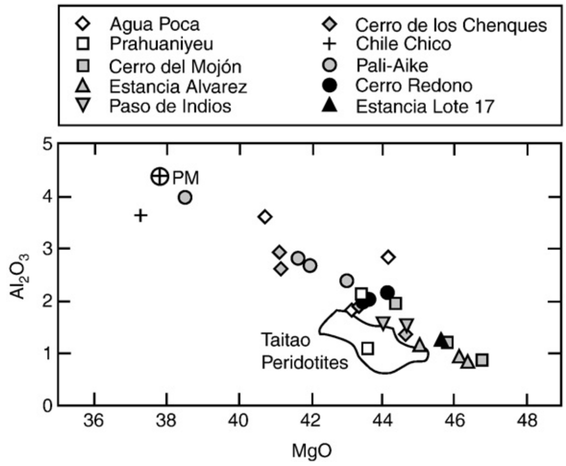

Fig. 2. Diagram plotting MgO versus Al_2O_3 contents (as weight percent and water free) of the studied mantle xenoliths showing a negative correlation that is commonly inferred to be the consequence of variable amounts of melt extraction during partial melting events (e.g. McDonough, 1990). The primitive mantle (PM) value of McDonough and Sun (1995) and the range of Taitao samples are also shown for comparison (see Section 6.3).

harburgites and the websterite range between 0.009 to 0.33 ppb (Table 3; Fig. 3a). The Os abundances of these samples vary from 0.25 to 9.94 ppb and the initial $^{187}Os/^{188}Os$ ratios (calculated to the time of eruption) from 0.1168 to 0.1294. With the exception of samples FE01-39b from Chile Chico, and PM10-B3 from Paso de Indios, the studied samples have relatively low Re contents compared to the primitive mantle reference (Fig. 3a); consistent with these samples being residues of variable amounts of mantle melting. However, several samples show higher $^{187}Re/^{188}Os$ than the estimated ratio for the Primitive Mantle (0.4353; Meisel et al., 2001), which is indicative of secondary Re enrichment after a first melting event, including the possibility of infiltration of the xenolith by the host lava (Table 3). The high Re/Os coupled with unradiogenic Os leads to unrealistically old T_{MA} model ages for these samples. Similarly, unexpectedly old T_{MA} ages obtained in some samples (PM10-B2, PM12-17, PM12-26, and X-G) could be explained by the same reason, because Re addition increases the steepening of the growth curve for the sample and hence pushes back the intersection with the mantle evolution curve. Thus, we consider as geologically meaningful only T_{MA} model ages calculated for samples with very low $^{187}Re/^{188}Os$ ratios, arbitrarily lower than 0.1. The T_{RD} model ages provide estimations of minimum depletion ages. With these criteria, the best estimation for the time of melting events recorded by the Agua Poca and Prahuaniyeu mantle xenoliths range from 0.33 to 2.09 Ga. Samples from Cerro del Mojón, Estancia Alvarez, Paso de Indios, Chile Chico and Pali-Aike have T_{RD} and T_{MA} ages varying from 0.03 to 0.98 Ga. Samples from Cerro de los Chenques have a narrower and slightly older T_{RD} age range from 0.80 to 1.14 Ga. The T_{RD} ages calculated for the four samples from the southwest edge of the Deseado Massif (Cerro Redondo and Estancia Lote 17) are Proterozoic, ranging from 1.34 to 1.74 Ga (Fig. 3c). The sample X-F from Cerro Redondo, which is the most depleted harzburgite from this locality, has the highest $^{187}Re/^{188}Os$ ratio. This is indicative of secondary Re addition even though this sample does not show obvious signs of host basalt (Schilling et al., 2005). The high Re/Os coupled with the quite unradiogenic Os isotopic composition of X-F indicates that the Re-addition did not occur long before the host basalt eruption, but this severely compromises the T_{MA}, but not necessarily the T_{RD}, age of this sample. On the other hand, the sample L17 from Estancia Lote 17, has much lower Re content and low Re/Os ratio and probably corresponds to a residue left after melt extraction. For this sample, the T_{MA} age of 2.11 Ga could represent a close estimation of the time of melt depletion.

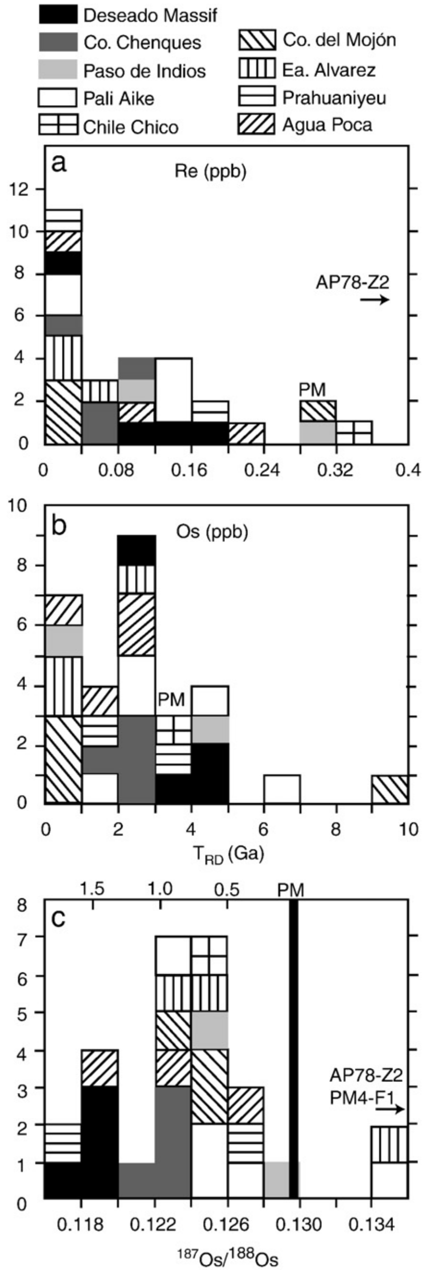

Fig. 3. Histograms of Re and Os concentration (in parts per billion) and $^{187}Os/^{188}Os$ at the time of eruption for the South America mantle xenoliths investigated here, with their calculated T_{RD} ages. PM show the primitive mantle values estimated for Re and Os (McDonough and Sun, 1995), and for $^{187}Os/^{188}Os$ ratio (Meisel et al., 2001).

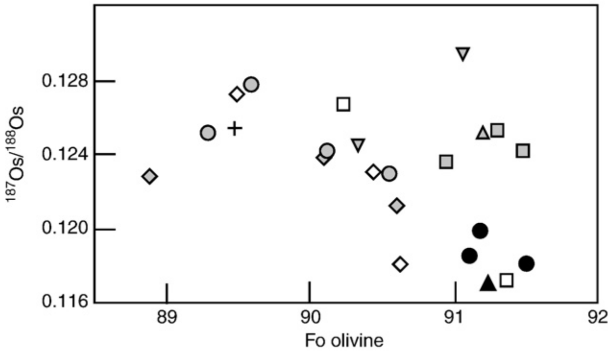

Fig. 4. Forsterite content of olivines versus $^{187}Os/^{188}Os$ ratios of studied mantle xenoliths (symbol captions in Fig. 2). Most samples show a scattered pattern, suggesting relatively recent depletion events. Only samples from Agua Poca (open diamonds) and Prahuaniyeu (open squares) have a negative correlation that could be the result of ancient partial melting events.

Pyroxenites and dunite have generally higher Re contents than peridotites, ranging from 0.043 to 0.773 ppb, and very low Os contents varying from 0.058 to 0.549 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 0.1342 to 0.9269) that together with their geochemical characteristics suggest formation from, or extensive interaction with, mantle melts (Mallman, 2004; Dantas, 2007). In all cases, the pyroxenites have Re/Os ratios too low to explain their measured Os isotopic compositions, which indicates either that the pyroxenites experienced recent Re loss, that they are relatively young crystallization products from magmas with high $^{187}Os/^{188}Os$, or that they are products of interaction between peridotites and percolating mantle melts.

6. Discussion

6.1. Proterozoic lithospheric mantle under the Cuyania terrane?

Given the location of the Agua Poca xenoliths, we expect them to represent fragments derived from the mantle "root" of the Cuyania terrane (Fig. 1) where crustal basement rocks have Mesoproterozoic ages (Abruzzi et al., 1993; Kay et al., 1996; Sato et al., 2000, 2004; Vujovich et al., 2004). Meaningful model ages obtained for Agua Poca peridotites range from 0.33 to 1.99 Ga. The negative correlation between forsterite olivine contents with the $^{187}Os/^{188}Os$ ratios of Agua Poca xenoliths (Fig. 4) is consistent with different degrees of depletion during an ancient partial melting event. Moreover, the Agua Poca xenoliths show a remarkably good correlation in the Al_2O_3 versus $^{187}Os/^{188}Os$ diagram (Fig. 5a) as has also been reported for other xenolith suites (Handler et al., 1997; Peslier et al., 2000, Meisel et al., 2001) as well as for orogenic peridotite massifs (Reisberg et al., 1991; Reisberg and Lorand, 1995; Meisel et al., 1997). Reisberg and Lorand (1995) interpreted for the first time those trends as pseudo-isochrons, considering that aluminum is an immobile element that exhibits a similar degree of incompatibility as Re during mantle melting. If the data form a positive trend, then the $^{187}Os/^{188}Os$ of the intercept or the $^{187}Os/^{188}Os$ present at the lowest likely Al_2O_3 concentration for a melt-residue (e.g., 1 wt.% Al_2O_3), can be used as the initial ratio, and this ratio compared to a model mantle evolution trend to determine the time of melting. Extrapolating the trend to an Al_2O_3 concentration of 1% for the Agua Poca xenoliths, where the Re/Os ratios of the studied samples are close to zero (Fig. 5b), the initial $^{187}Os/^{188}Os$ is 0.1138, corresponding to a depletion age of 2.14 Ga.

Prahuaniyeu peridotites were carried to the surface approximately 200 km south of the Agua Poca locality (Fig. 1) and present similar petrographic and geochemical characteristics to Agua Poca xenoliths in terms of the degree of depletion reflected in their mineral and major element compositions (Tables 2 and 3). The Re and Os concentrations and the Os isotopic composition variation are also similar, with model ages varying from 0.43 to 2.09 Ga. The two analyzed samples also show a negative correlation between the forsterite content of olivines and the $^{187}Os/^{188}Os$ ratios, suggesting that the older age better approximates the melt-depletion age of this mantle section, but the samples do not show a positive correlation in the Al_2O_3 versus $^{187}Os/^{188}Os$ diagram (Fig. 5a).

Our preferred hypothesis is that Agua Poca and probably Prahuaniyeu mantle xenoliths are derived from the Proterozoic lithospheric mantle remnant of the Cuyania terrane. However, the poor definition of the exact location of terrane boundaries and their structural relations at depth, allow the possibility that

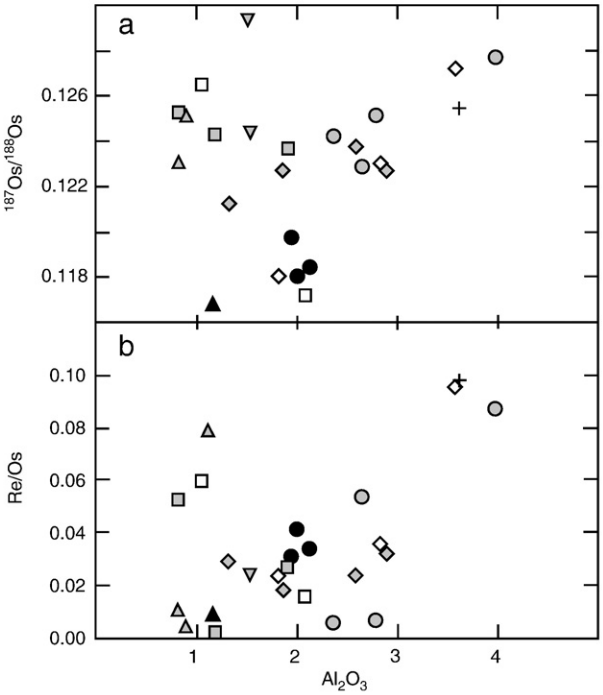

Fig. 5. (a) Diagram plotting the Al_2O_3 contents (as weight percent and water free) versus the $^{187}Os/^{188}Os$ ratios (symbol captions in Fig. 2). Most samples show a scattered distribution suggesting relatively recent formation from a young and heterogeneous convecting mantle. Only samples from Agua Poca (open diamonds) form a good liner trend that can be interpreted as a pseudo-isochron (see section 6.1). (b) Al_2O_3 versus Re/Os diagram showing that the Re/Os ratios of some of the studied samples go to zero when the Al_2O_3 content is near 1%.

all or part of the mantle xenoliths from these localities come from the lithospheric mantle sections of other continental blocks, such as the Pampia terrane or even the Río de la Plata craton. This hypothesis is supported by the fact that the oldest depletion model ages obtained in the Agua Poca and Prahuaniyeu mantle xenoliths (~2.1 Ga) are significantly older than the ages determined for the basement rocks of the Cuyania terrane (1.0–1.2 Ga), and are more similar to the age of the Río de la Plata craton (2.0–2.2 Ga). Another possible explanation of the age difference between mantle and crustal basement in this terrane is that there is an older (Paleoproterozoic) crustal basement under the Cuyania terrane that has not been recognized yet. Seismic data also support the existence of a depleted cold lithospheric mantle root under the Cuyania and Sierras Pampeanas terranes around 31° S (Wagner et al., 2006). Wagner et al. (2006) propose that their results reflect the presence of a fragment of ancient Laurentian lithosphere. However, they do not recognize significant east–west changes in the velocity anomalies, which may indicate that the terrane boundaries at the surface do not accurately represent the terrane boundaries at depth, or that the Cuyania and the Pampia terranes are underlain by similar depleted and cold lithosphere (Wagner et al., 2006).

6.2. Proterozoic lithospheric mantle under the Deseado Massif

Several authors have recognized the Deseado Massif as an independent plate (e.g. Ramos and Aguirre-Urreta, 2000; Ramos, 2002; Pankhurst et al., 2006). The very scarce outcrops of continental basement of the Deseado Massif have yielded isotopic ages from 340 to 586 Ma, while some inherited zircons have prominent age peaks between 1.0 and 1.1 Ga with some ages as old as 1430 Ma (Pankhurst et al., 2003). Some of those samples yield reasonably consistent Nd model ages of 1400–1600 Ma for the initial mantle extraction to form the continental source material (Pankhurst et al., 2003). The limited Re–Os data for all spinel peridotites derived from the southwest corner of the Deseado Massif (Cerro Redondo and Estancia Lote 17) show only Proterozoic T_{RD} ages, ranging from 1.34 to 1.74 Ga. The T_{MA} model age of 2.1 Ga of sample L17 seems to be a good approximation to the time of melt depletion, if its low Re/Os ratio was acquired during a single melting event of a mantle source with primitive characteristics.

The Os isotopic data thus suggest that the Deseado Massif is probably Proterozoic in age, and that the few outcrops recognized until now have not shown the oldest basement rocks, which must be hidden under younger rocks or the sedimentary cover. These hidden ancient rocks could be the source of significant populations of old zircons (1.0 to 1.2 Ga) analyzed by SHRIMP on rocks derived from the Deseado Massif (Pankhurst et al., 2003) and from the low grade metamorphic complexes of the Patagonian Andes, located to the east and south east of the Deseado Massif, at the western edge of the South American plate (Hervé et al., 2003).

Recently, Ntaflos et al. (2007) concluded that the mantle samples from Tres Lagos, located approximately 110 km southwest of Cerro Redondo (Fig. 1), represent an isolated piece of depleted Proterozoic lithospheric mantle, in which metasomatism was not a significant process, based on the mineral and modal composition of peridotite xenoliths. To reach this conclusion, those authors utilized a diagram that plots the modal olivine content versus the forsterite content of olivines, in which Griffin et al. (2003) defined fields for Archean, Proterozoic and Phanerozoic mantle peridotite xenoliths. In Fig. 6 we plot the samples of the preset study in the mentioned diagram, where the fields defined by Griffin et al. (2003) and for Tres Lagos xenoliths studied by Ntaflos et al. (2007) are shown. Cerro Redondo and Estancia Lote 17 samples plot into the field of Proterozoic mantle peridotites, together with samples with the oldest depletion ages from Agua Poca and Prahuaniyeu. Only two samples from Cerro del Mojón that do not have Proterozoic model ages, plot in the field of Proterozoic peridotites, and this could be a consequence of the percolating melts that formed the melt pockets observed in those xenoliths, and produced the modification of mineral modes. Most of the other samples studied here that are characterized by younger Re-depletion ages, plot into the field of Phanerozoic lherzolites (see Section 6.3).

The most depleted compositions are apparently found under the ancient continental block (compare the Deseado Massif and Pali-Aike xenoliths discussed in Section 6.3; Table 2), consistent with a more buoyant and stable lithospheric mantle in these regions. This could help to explain the positive relief of the Deseado Massif compared to the surrounding areas.

The absence of exposed basement rocks of this age impedes a better constraint on the temporal and spatial relationship between the Deseado Massif and other Proterozoic continents using paleomagnetic techniques. Nevertheless, the geochronologic implications of the Os isotope data, and the geographical proximity of the Deseado Massif and the Malvinas/Falkland Islands and plateau (Fig. 1), where basement rocks also have shown Proterozoic ages of approximately 1.1 Ga (Cingolani and Varela, 1976; Rex and Tanner, 1982), suggest that both microplates could be derived from the same continental block. This hypothesis is also supported by the reconstruction of

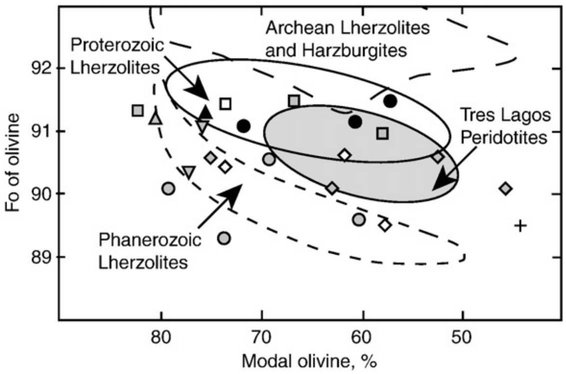

Fig. 6. Diagram of modal olivine content versus forsterite content of olivines for mantle xenoliths of the present study (symbol captions in Fig. 2). In the diagram are shown the fields of Archean lherzolites and harzburgites, Proterozoic peridotites, and Phanerozoic peridotites defined by Griffin et al. (2003). The field defined by Tres Lagos peridotites is based on the work of Ntaflos et al. (2007).

Gondwana prior to the opening of the Atlantic Ocean, which suggests that Patagonia was close to the Malvinas/Falkland Islands, and both close to South Africa (e.g. Marshall, 1994). In this case, the Deseado Massif will need to be included in the reconstruction of Rodinia supercontinent, in which Southern Africa, East Antarctica, and the Malvinas/Falkland Islands and plateau, which includes the Maurice Ewing Massif to the east, were adjacent (Wareham et al., 1998).

6.3. Young lithospheric mantle formation under the North Patagonian Massif and other Patagonian regions: implications for young continental crust formation

The origin and evolution of the North Patagonian Massif is not yet well understood (Ramos, 2002; Pankhurst et al., 2006). The oldest basement rocks of the North Patagonian Massif correspond to metasedimentary rocks located at the east and north east of the massif, with estimated deposition ages between 515 Ma and 535 Ma, based on the age of the youngest zircon population (Pankhurst et al., 2006). Coincidentally, all mantle samples derived from the North Patagonian Massif (Cerro del Mojón, Estancia Alvarez, Paso de Indios, and Cerro de los Chenques), excepting Prahuaniyeu that could be part of the Grenvillian Cuyania terrane (Section 6.1), have a range in ^{187}Os/^{188}Os similar to modern oceanic peridotites (Snow and Reisberg 1995; Brandon et al., 2000; Schulte, 2007) with T_{RD} and T_{MA} ages varying from 0.03 to 0.98 Ga. These results, together with the scattered distribution of these samples in the diagrams of olivine forsterite (Fig. 4) and Al_2O_3 (Fig 5a) contents versus ^{187}Os/^{188}Os ratios, suggest that the lithospheric mantle beneath this region formed recently from a heterogeneous convecting mantle. The samples found at the Cerro de los Chenques, erupted right over the “Inferred Collision Zone” between the Deseado Massif and the North Patagonian Massif (Pankhurst et al., 2006; Fig. 1), are slightly less radiogenic than other peridotites of the North Patagonian Massif, which could mean that the lithospheric mantle under this region formed just before most of the massif lithosphere. The samples derived from the Chile Chico and Pali-Aike localities, which are located approximately 150 km east and 200 km south of the Deseado Massif margin respectively, have similar ^{187}Os/^{188}Os ratios to the analyzed North Patagonian Massif peridotites ranging from 0.1229 to 0.1277, suggesting also a similar origin and Os isotopic evolution. Similar Os isotopic ratios were obtained by Stern et al. (1999) for Pali-Aike mantle xenoliths. Most samples from the Patagonian Massif, Pali-Aike, and Chile-Chico plot inside or near the field of Phanerozoic lherzolites (Fig. 6) defined by Griffin et al. (2003).

Several studies of abyssal and ophiolite peridotites have defined the Os isotopic variability of the convecting upper mantle (Brandon et al., 2000; Snow and Reisberg, 1995; Walker et al., 1996, 2002; Tsuru et al., 2000; among many others). Recently, Schulte (2007) present a complete characterization of the Os isotopic range found in peridotites derived from the ultramafic section of the Taitao ophiolite, which was emplaced only 3–6 Ma ago along the west coast of Chile at approximately 46° S. The Taitao is the youngest known ophiolite. This ophiolite represents an oceanic lithosphere fragment derived from the Chile ridge (Forsythe et al., 1986; Nelson et al., 1993; Veloso et al., 2005). Considering its geographical location, together with its age of emplacement that implies a relatively short interval of time for post-emplacement alteration, makes it the best candidate to represent the original composition of the convecting mantle from which the relatively young subcontinental lithospheric mantle under southern South America was formed. The Taitao peridotites tend toward more depleted compositions based on major element compositions (Fig. 2) and the forsterite content of olivines, but have similar Os isotopic compositions to subcontinental peridotites derived from the North Patagonian Massif, Chile Chico and Pali-Aike (Fig. 7). Some differences observed between the Os isotopic composition of suboceanic and subcontinental samples are the presence of samples with more unradiogenic Os isotopic values among the former, recording relatively ancient partial melting events in the convecting mantle, and the presence of more radiogenic samples, closer to the present composition estimated for the primitive mantle (Meisel et al., 2001), among the subcontinental mantle samples. These results make it difficult to support the idea that the subcontinental lithospheric mantle of this region was formed only by partial melting events of the convecting mantle, which would leave residues even more depleted. In order to explain the observed geochemical and isotopic characteristics of southern South American xenoliths, we propose that the young subcontinental lithospheric mantle is formed by any or all of: (1) small degrees of partial melting of the convecting mantle in the mantle wedge over the subducting slab, (2) the direct addition of convecting mantle material to the young subcontinental lithospheric mantle by thermal cooling, in a process similar to the formation of the suboceanic lithospheric mantle, and (3) secondary metasomatic processes caused by the percolation of slab-derived fluids and melts through the subcontinental lithospheric mantle. In this model, the young subcontinental lithospheric mantle formation process can be described as follows. Small degree partial melting events in the mantle wedge produce mantle residues slightly less dense than the original mantle source, which tend to be added to the subcontinental lithospheric mantle. At the same time, the

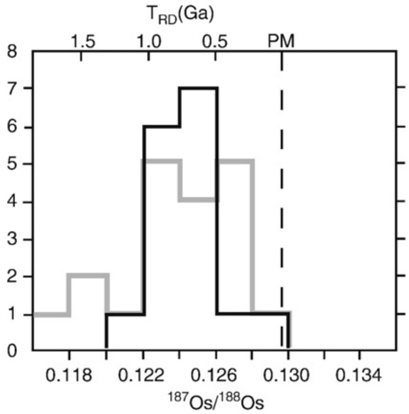

Fig. 7. Comparison of the histograms of ^{187}Os/^{188}Os for the North Patagonian Massif (excepting Prahuaniyeu samples), Chile Chico, and Pali-Aike mantle xenoliths investigated here (black line), with peridotites from Taitao ophiolite (grey line) studied by Schulte (2007), at the time of eruption and emplacement, respectively. PM is the primitive mantle value from Meisel et al. (2001).

cooling of the convecting mantle in contact with the subcontinental lithospheric mantle adds more material to the subcontinental lithospheric mantle. Finally, the subcontinental lithospheric mantle can be refertilized by infiltrating fluids and melts, probably derived from the subducting slab or the asthenosphere, which could be responsible for the metasomatic processes registered in the mantle xenoliths (Gorring and Kay, 2000; Kilian and Stern 2002; Conceição et al., 2005), the more fertile compositions and lithologies found in the subcontinental lithospheric mantle than in the sub-oceanic mantle, and the presence of samples with Os isotopic compositions slightly more radiogenic in the subcontinental lithospheric mantle than in the oceanic mantle (Brandon et al., 1996). Also the presence of pyroxenite xenoliths found in these localities, with petrographic, geochemical, and isotopic characteristics resembling the characteristics of mantle melts, but with isotopic compositions more like crust (e.g. very radiogenic Os), can be ascribed to the same interaction between a mantle peridotite column of the subcontinental lithospheric mantle and ascending basaltic melts that involve a contribution from sediments on the downgoing plate. It is worthy of note that the young subcontinental lithospheric mantle as sampled by the xenoliths from the younger southern South American terranes, ranges to more fertile compositions than seen in young convecting mantle, for example, the Taitao ophiolite. The increased density of more fertile mantle could lead to delamination of the subcontinental lithospheric mantle, along with a dense portion of the lower crust; a process that recently has received much attention as a mechanism to explain the bulk composition of continental crust (e.g. Behn and Kelemen, 2006). This leads to the interesting possibility that the western and southernmost sections of South America sample a stage of continental lithosphere evolution between its initial formation and its geodynamic modification that results in the long-term stability similar to that observed for cratonic lithosphere.

7. Conclusions

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. Mantle xenoliths from Agua Poca and probably Prahuaniyeu with Proterozoic ages may well be relicts from the lithospheric mantle of the Cuyania terrane formed probably as part of the Laurentia continent during the Proterozoic. However, it is not possible to discard an origin from other known ancient continental blocks, such the Pampia terrane or the Río de la Plata craton.
2. Samples from the North Patagonian Massif (Cerro del Mojón, Estancia Alvarez, and Paso de Indios), Chile Chico and Pali Aike, have a wide range in fertility and a range in $^{187}Os/^{188}Os$ similar to modern oceanic peridotites, which suggests that the lithospheric mantle beneath these regions formed recently from the heterogeneous convecting mantle.
3. The three peridotites from Cerro Redondo and the lherzolite studied from Estancia Lote 17, carried to the surface at the southwestern edge of the Deseado Massif provide Proterozoic (1.34 to 2.11 Ga) T_{RD} and T_{MA} ages suggesting that this continental block is considerably older than previously thought. Thus, it would be possible to relate the Deseado Massif and the Malvinas/Falkland Plateau, which also show Proterozoic ages (0.95 – 1.1 Ga) for their basement rocks. This association should be considered in the reconstruction of the continents during that time.

More work on the Os isotopic composition of mantle peridotites derived from southern South America and other Gondwanian regions would be a useful tool to identify lithospheric mantle heterogeneities and the assembly history of the continents, particularly when crustal basement is poorly exposed. Particularly valuable is the possibility to determine the location and extent of ancient lithospheric mantle “roots” under continental blocks, such as were discovered here for the Cuyania terrane and the Deseado Massif.

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