Revista de la Asociación Geológica Argentina, 59 (4): 556-568 (2004)

Magmatic sources, setting and causes of Eocene to Recent Patagonian plateau magmatism (36°S to 52°S latitude)

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RESUMEN. *Fuentes magmáticas, ambientes y causas del magmatismo de plateau Eoceno a Reciente en la Patagonia (36°S a 52°S latitud).* Las provincias volcánicas basálticas de retroarco continentales y de intraplaca proveen información sobre la evolución del manto por debajo de los continentes y del flujo de material que ha sido subducido, pero no extraido por el volcanismo de arco. Una de las más grandes regiones magmáticas máficas continentales es la Provincia Patagónica donde grandes eventos volcánicos máficos de plateau se han desarrollado desde el Paleoceno al Reciente en ausencia de una importante extensión. Los eventos más grandes produjeron el Basalto Posadas en el Eoceno (~ 46°S a 50°S); la provincia magmática Somuncura en el Oligoceno Superior a Mioceno Inferior (41°S a 43°S, además de los magmas de similar edad hasta los 46°S); las lavas miocenas superiores a pliocenas al este del punto triple de Chile (~46°S a 49°S), y la provincia magmática de Payunia (36°S a 38,5°S). Las provincias del Basalto Posadas y la del punto triple de Chile han sido asociadas respectivamente, del punto de vista tectónico, con colisiones de las dorsales oceánicas de Farallón-Aluk y de Nazca-Antárctica con la trinchera de Chile durante el Eoceno y el Mioceno-Reciente; la provincia de Somuncura con una anomalía termal en el manto vinculada a cambios en los vectores de convergencia durante el Oligoceno a Mioceno Inferior; y las lavas de Payunia con el empinamiento de una zona de subducción anteriormente horizontal. Entre los 45°S-50°S donde el volcanismo de arco está mayormente ausente, los magmas de plateau no muestran afinidad en sus elementos con rocas de arco, como lo indican las relaciones Ba/La ratios < 20 (arcos > 20) y las relaciones La/Ta <18 (arcos > 25). Lo mismo se comprueba en los magmas pre-29 Ma en el Somuncura y en los magmas pre-20 Ma en la región de Payunia. Los magmas asociados eruptados cerca del arco pueden tener relaciones más altas. Esta situación contrasta con los magmas post-29 Ma del Somuncura y los magmas post-20 Ma de Payunia al norte de los 45°S, en los cuales las relaciones Ba/La superiores a 30 y las relaciones La/Ta < 20 se extienden mucho más hacia el este, mientras que lavas con relaciones La/Ta > 20 ocurren hacia el oeste. Estas relaciones más altas coinciden con la introducción de componentes de arco en las fuentes magmáticas del manto como resultado de una interacción con la losa subducida paleógena en la región de Somuncura y con la deshidratación de una losa subhorizontal en la región de Payunia. Al mismo tiempo las relaciones isotópicas de Nd y Sr de la mayoría de las lavas de plateau se agrupan en el campo de los OIB (en su mayoría con un ΣNd = +5 a -1 y ^{87}Sr/^{86}Sr = 0,7035 a 0,7048), con los magmas del Basalto Posadas como los más empobrecidos, y los del Somuncura y algunos magmas del punto triple de Chile, como los más enriquecidos. A través de la región los datos tectónicos, geoquímicos, e isotópicos son consistentes con el gran volumen de los magmas de plateau debido a perturbaciones tectónicas que provocan la fusión en un manto caliente que ha estado al borde de la fusión desde la fragmentación mesozoica del Gondwana.

Palabras clave: *Basaltos patagónicos, Hotspots, Isótopos, Elementos traza, Colisión dorsal-trinchera*

ABSTRACT. Continental back-arc and within-plate basaltic volcanic provinces provide a view into the evolution of the mantle beneath continents and the mass flux of materials that are subducted, but not extracted by arc volcanism. One of the largest continental mafic provinces is the Patagonian province where large mafic plateau volcanic events ranging in age from late Paleocene to Recent have occurred in the absence of major extension. The largest events produced the Eocene Posadas Formation (~ 46°S to 50°S), the late Oligocene to early Miocene Somuncura magmatic province (41°S to 43°S plus similar age magmas up to 46°S), the late Miocene to Pliocene lavas east of the Chile Triple Junction (~46°S to 49°S), and the Payunia magmatic province (36°S to 38.5°S). Tectonically, the Posadas and Triple Junction provinces have been respectively associated with Eocene and Miocene-Recent collisions of the Farallón-Aluk and the Nazca-Antarctic spreading ridges with the Chile trench, the Somuncura province with a mantle thermal anomaly linked to late Oligocene/early Miocene changes in plate convergence vectors, and the Payunia lavas with steepening of a formally shallow subduction zone. Between 45°S-50°S where Tertiary arc volcanism was largely absent, the plateau magmas show almost no trace element affinity with arc rocks as indicated by Ba/La ratios < 20 (arcs > 20) and La/Ta ratios <18 (arcs > 25). The same is true for pre-29 Ma magmas in the Somuncura and pre-20 Ma magmas in the Payunia regions. Associated magmas erupted near the arc can have higher ratios. This situation contrasts with post-29 Ma Somuncura and post-20 Ma Payunia magmas north of 45°S in which Ba/La ratios over 30 and La/Ta ratios < 20 extend far to the east, and lavas with La/Ta ratios > 20 occur to the west. These higher ratios fit with the introduction of arc components into the mantle magma sources as a result of interaction with a Paleogene subducting slab in the Somuncura region and dehydration of a shallowly subducting slab in the Payunia region. At the same time, Nd and Sr isotopic ratios of most of the plateau lavas plot in the OIB field (most ΣNd = +5 to -1; ^{87}Sr/^{86}Sr = 0.7035 to 0.7048) with Posadas magmas being the most depleted, and Somuncura and some Triple Junction magmas being the most enriched. Across the plateau, these tectonic, chemical, and isotopic data are consistent with the large volume plateau magmas being due to tectonic perturbations that provoke melting in a hot mantle that has been on the verge of melting since the Mesozoic breakup of Gondwana.

Key words: *Patagonian basalts, Hotspots, Isotope, Trace element, Ridge-trench collision*

Introduction

One of the largest Cenozoic retroarc continental basaltic provinces is in Patagonia where mafic plateau volcanism has occurred throughout Tertiary to Recent times (Fig. 1). Major questions exist as to why these Patagonian plateau magmatic events, which are not tied to major times of retroarc extension, occurred when and where they did (Kay 2002a). Part of the explanation seems to lie in the fact that oceanic ridges and young oceanic crust have been subducting at the Chilean trench to the west throughout much of this time. As a result, the spatial and temporal pattern of some major events has been associated with slab-windows formed in conjunction with collisions of spreading ridges with the Chile trench (Ramos and Kay 1992; Gorring *et al*. 1997, D'Orazio *et al*. (2001). A long recognized problem with these simple models is that not all spreading ridge collisions are associated with large plateau eruptions (Ramos and Kay 1992). Further north in Patagonia, plateau events have been associated with thermal anomalies associated with a major late Oligocene/early Miocene change in plate convergence vectors (Kay *et al*. 1993b; Muñoz *et al.* 2000; de Ignacio *et al*. 2001) and the aftermath of shallow subduction events (Kay 2001, 2002b). A common problem with all of these explanations is that the volume of magma erupted in plateau events is greater than expected as a thermal consequence of these events (Gorring *et al*. 1997; Kay 2001).

Within this framework, the purpose of this paper is to present a brief summary of the major Eocene to Recent Patagonian plateau magmatic events, compare and contrast distinctive features of their chemical and isotopic signatures, discuss their tectonic setting, and speculate on the cause of mantle melting. A map showing the distribution of the major plateau magmas in space and time is presented in Figure 1, and summary plots of published and unpublished Ba/Ta versus La/Ta ratios and $^{87}Sr/^{86}Sr$ versus ΣNd ($^{143}Nd/^{144}Nd$) ratios are shown in Figures 2 and 3. Largely new chemical and isotopic analyses and ages of selected large and small plateau flows from across the region are listed in Tables 1 to 4. Overall, the Ba/la versus La/Ta plot (Fig. 2) provides a comparison of the relative OIB/MORB versus arc-like character of lavas from across the regions as OIB/MORB magmas have La/Ta ratios < 25 and Ba/La < 20 whereas arc magmas have higher ratios. Plot of $^{87}Sr/^{86}Sr$ versus ΣNd (Fig. 3) compare relative amounts of isotopic enrichment (higher $^{87}Sr/^{86}Sr$ ratios and lower ΣNd values) and depletion in the plateau magmas. In situ crustal contamination is not considered to be a major factor in creating either the trace element or isotopic differences among the plateau lavas (Kay *et al*. 1993a; Gorring and Kay 2001; Kay 2001. As such, arc-type trace element ratios are generally attributed to crust added to the mantle wedge in the subduction process (subducted sediment and crust removed by forearc subduction erosion) or to fluids derived from dehydration of altered oceanic crusts. Isotopic differences reflect differences in mantle source regions as well as contributions from arc processes.

Overview of chemistry and tectonic setting of Cenozoic Patagonian plateau volcanic sequences

Paleocene to Eocene Plateau lavas: Ridge-trench Collision

The most voluminous Paleocene to Eocene mafic plateau magmas (Fig. 1) erupted between 46°S and 51°S where they are mapped in the Posadas Formation to the west and formations like the Basalto del Doce to the east (see Ardolino et al. 1999). Most have K/Ar ages between ~57 to ~ 52 Ma and ~ 47 to ~ 39 Ma (see Ramos and Kay, 1992; Kay et al. 2002). These are the magmas that Ramos and Kay (1992) and Kay et al. (2002) attributed to asthenospheric mantle sources that had been modified by slab-window processes linked to the near-normal trench collision of the Aluk-Farallón spreading ridge with the Chile trench (Cande and Leslie 1986). In accord with this setting, the chemical signatures of the Eocene Basalto Posadas flows have strong OIB/MORB like chemical affinities (Fig. 2; La/Ta <12; Ba/La < 11) and relatively depleted isotopically signatures ($^{87}Sr/^{86}Sr < 0.7038$; eNd > 4.5). More isotopically enriched magmas with somewhat higher La/Ta ratios in this region are either of Paleocene age or are smaller volume flows that erupted over older lithosphere in eastern Patagonia (Basalto del Doce: Figs. 2 and 3).

Further north, lesser volumes of Eocene alkali basaltic plateau lavas occur in the Sarmiento and Somuncura regions between 46°S to 41°S (Fig. 1, review in Ardolino *et al.* 1999; Lema and Cortés 1987; Kay et al. 1993b). These magmas (Table 3; Kay et al. 1993a,b) are like the Posadas flows in being typified by intraplate Ba/La (<16) and La/Ta (<13) ratios (Fig. 2) and depleted isotopic signatures ($^{87}Sr/^{86}Sr < 0.7036$; ΣNd > 4.2: Fig. 3). Their eruption (56 to 40 Ma, Lema and Cortez 1987) is generally contemporaneous with that of Huitrera Formation mafic and silicic magmas in the western part and west of the Meseta de Somuncura (Rapela *et al.* 1988; Kay and Rapela 1987). Further north near 38°S to 36°, plateau magmas are absent east of the Eocene andesitic arc (56 to 52 Ma) and Collipilli near retroarc magmas (Llambías and Rapela 1989; Jordan *et al*. 2001).

Late Oligocene/Early Miocene Sequences in Central Patagonia: "Hotspot-like" Intraplate Magmas

The next major plateau magmatic episode produced the voluminous late Oligocene/early Miocene Somuncura magmatic province between 41ºS and 43ºS (Fig. 1; Corbella 1984; Ardolino and Franchi 1993; Ardolino *et al.* 1999; Kay et al. 1993b). These mafic flows form the largest plateau magmatic province in Patagonia. The 29 to 26 Ma ($^{40}Ar/^{39}Ar$ in Table 2, K/Ar ages in Ardolino and Franchi 1993) tholeiitic to mildly alkaline mafic flows that built most of the plateau have an intraplate-like chemistry (Table 2; Figs. 2 and 3; plateau fields 1 to 3) with a number

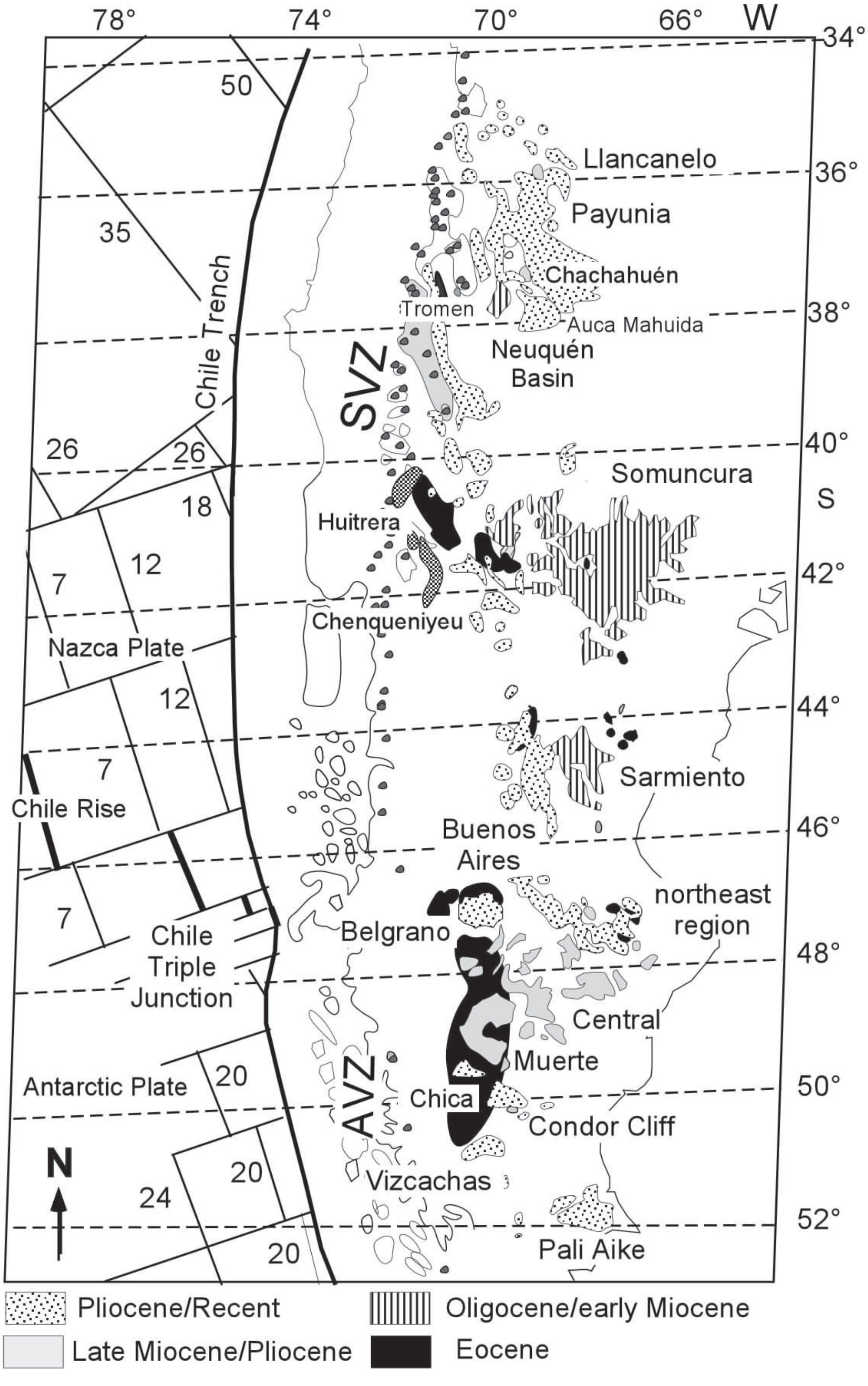

Figure 1: Map of Patagonia showing locations of plateau flows discussed in the text (after Kay 2002a). AVZ and SVZ indicate the Austral and Southern Volcanic Zones which are separated by a modern gap in arc volcanism east of the Chile Triple Junction. Map is largely based on the 1997 1: 2,500,000 scale geologic map of Argentina (Servicio Geológico Minero Argentino, Buenos Aires) and the 1980 1:1,000,000 scale geologic map of Chile (SERNAGEOMIN, Santiago)

Table 1: Major and Trace Element Chemistry of Patagonia Plateau Lavas - Neuquen Basin.

	Early Miocene				Latest Miocene		Latest Pliocene to Recent							
	La Matancilla region					Pliocene								
		Huantriaico		Desfiladero	Chachahuén		Rio Colorado Region			Auca Mahuida Complex			Tromen Region	
				dike		Parva Negra	Tanque	Cerro Mendez						
	DRC21	HDR18	HDR20	HDR25	DRC13	HDR12	DR38	DRC2	DRC14A	RD3	RD1	RD8	TDR19	TDR31
SiO_2	47,75	47,58	47,17	48,63	53,82	47,71	50,66	48,61	48,29	48,88	48,89	51,04	50,11	52,25
TiO_2	2,27	2,42	1,69	1,50	1,35	2,32	1,88	1,77	2,08	2,06	2,03	2,01	1,84	1,47
Al_2O_3	14,37	14,89	19,22	17,98	17,53	18,49	18,11	15,86	15,00	16,58	18,44	17,72	18,00	19,77
FeO	10,99	11,41	11,17	10,92	8,67	11,28	9,38	10,72	10,66	10,00	9,73	10,39	10,42	8,14
MnO	0,16	0,02	0,19	0,18	0,17	0,20	0,17	0,16	0,16	0,20	0,15	0,20	0,19	0,15
MgO	8,31	8,75	4,83	5,38	3,85	4,75	4,50	7,34	8,14	5,88	4,30	4,51	4,43	4,05
CaO	8,46	8,50	11,57	10,81	8,06	8,69	7,12	10,16	9,08	9,39	9,03	8,28	9,35	8,50
Na_2O	3,82	3,58	3,01	3,34	4,10	4,26	4,67	3,52	3,69	3,83	3,86	4,53	3,51	3,85
K_2O	1,39	1,59	0,77	1,23	2,05	1,58	2,25	0,73	1,19	1,46	1,43	1,82	1,20	1,48
P_2O_5	0,53	0,71	0,27	0,32	0,49	0,49	0,54	0,26	0,41	0,42	0,48	0,36	0,42	0,40
Total	98,27	99,45	99,90	100,28	100,10	99,77	99,29	99,10	98,69	98,70	98,33	100,86	99,47	100,07
La	23,1	35,1	11,7	15,5	24,1	21,2	28,9	11,6	18,1	17,8	22,1	22,0	21,8	23,5
Ce	48,5	73,0	27,3	32,4	53,8	46,0	59,2	27,9	40,7	38,1	47,5	47,1	45,3	52,8
Nd	24,5	40,0	14,5	20,5	22,4	26,4	31,0	15,0	22,4	20,2	23,4	24,2	26,8	22,9
Sm	5,88	7,74	4,54	4,90	6,40	5,82	6,38	4,49	5,46	5,33	5,61	5,74	6,20	5,91
Eu	1,727	2,195	1,435	1,514	1,75	1,852	1,77	1,42	1,76	1,706	1,738	1,764	1,620	1,443
Tb	0,862	0,967	0,818	0,731	0,896	0,951	0,932	0,755	0,821	0,798	0,786	0,850	0,926	0,885
Yb	1,39	1,70	2,30	2,13	2,25	2,80	2,23	1,63	1,72	1,81	1,95	1,99	3,00	2,31
Lu	0,164	0,237	0,298	0,284	0,298	0,399	0,349	0,213	0,227	0,235	0,256	0,264	0,407	0,318
Sr	824	855	678	654	900	730	851	524	596	674	790	573	452	654
Ba	283	346	128	242	745	292	519	286	445	405	346	360	530	406
Cs	0,3	0,6	0,9	0,7	3,2	0,5	1,6	0,1	0,4	0,9	0,8	0,3	0,8	0,8
U	0,8	0,9	0,4	0,6	1,6	0,8	1,3	0,5	0,7	1,0	0,6	0,8	1,2	1,7
Th	2,1	4,1	1,6	2,2	4,1	2,0	3,4	1,1	2,1	2,8	2,6	2,7	4,0	6,0
Hf	4,1	5,3	2,3	2,6	3,9	4,2	4,8	3,0	3,5	3,5	3,9	4,1	4,6	5,1
Ta	2,3	2,8	0,7	0,9	0,8	1,52	2,2	0,8	1,5	1,39	1,75	1,71	0,80	0,86
Sc	19,1	20,3	25,0	27,4	15,6	21,3	13,3	20,5	21,7	22,3	18,5	18,0	28,9	19,5
Cr	327	260	16	39	31	6	70	212	285	178	70	55	32	38
Ni	216	160	22	34	35	5	37	152	180	82	34	39	25	26
Co	51	51	40	41	26	36	28	48	50	39	33	35	31	27
FeO/MgO	1,32	1,30	2,31	2,03	2,25	2,38	2,08	1,46	1,31	1,70	2,26	2,30	2,35	2,01
La/Sm	3,9	4,5	2,6	3,2	3,8	3,6	4,5	2,6	3,3	3,4	3,9	3,8	3,5	4,0
Sm/Yb	4,2	4,6	2,0	2,3	2,8	2,1	2,9	2,8	3,2	2,9	2,9	2,9	2,1	2,6
La/Yb	16,6	20,6	5,1	7,3	10,7	7,6	12,9	7,1	10,5	9,9	11,3	11,1	7,3	10,2
Eu/Eu*	0,94	0,96	0,96	0,96	0,89	0,95	0,95	0,95	0,95	1,02	1,01	0,98	0,83	0,78
Ba/La	12,2	9,9	11,0	15,7	31,0	13,8	18,0	24,6	24,6	22,7	15,7	16,3	24,3	17,3
Ba/Ta	126	123	193	270	918	192	241	375	298	292	198	210	660	471
La/Ta	10,3	12,4	17,6	17,3	29,7	13,9	13,4	15,3	12,1	12,9	12,6	12,9	27,2	27,3
Th/La	0,09	0,12	0,14	0,14	0,17	0,09	0,12	0,10	0,12	0,16	0,12	0,12	0,18	0,25
Ta/Hf	0,55	0,53	0,29	0,34	0,210	0,36	0,45	0,25	0,42	0,40	0,44	0,41	0,18	0,17
Th/U	2,7	4,7	4,3	3,5	2,6	2,6	2,7	2,5	3,2	2,8	4,6	3,5	3,2	3,6
εNd		3,6	4,7	4,7	2,1		3,2	2,3		3,4	3,1	3,1	3,2	2,9
$^{143}Nd/^{144}Nd$		0,512821	0,512880	0,512881	0,512743		0,512801	0,512758		0,512813	0,512799	0,512799	0,512805	0,512789
$^{87}Sr/^{86}Sr$		0,703885	0,703284	0,703230	0,704148	0,70351	0,703716	0,703877		0,703902	0,703764	0,703734	0,703851	0,704031
$^{206}Pb/^{204}Pb$			18,525	18,509			18,373	18,364		18,453				18,538
$^{207}Pb/^{204}Pb$			15,580	15,561			15,567	15,582		15,588				15,599
$^{208}Pb/^{204}Pb$			38,313	38,178			38,197	38,295		38,325				38,441
Latitude	36°36.8’	37°15.76’	369959.52’	37°35.09’	37°06.’	37°41.8’	37°0.54’	*	37°19.45’	37°56'	37°49.5’	37°41.79’	37°10.77’	37°5.99’
Longitude	68°35.5’	69°39.13'	68°53.29'	69°28.57'	68°51.24’	69°34'	68°56.64'	68°56.3’	68°57.30’	69°06'	69°46’	68°27.82’	70°14.95’	70°8.83’
[1] age	23,76	23,4	19,1		4,85	[2] 4.5	2,07		1,3	1,78	1,55	1,39	1,44	~ 1 Ma
error	0,08	0,4	0,8		0,03	0,4	0,11		0,03	0,1	0,07	0,14	0,08	

[1] All but Parva Negra age are groundmass $^{40}Ar/^{39}Ar$ (gm) ages from Kay (2001). Details in papers in progress.

[2] K/Ar age from Ramos and Barbieri (1988).

*All ages from Mercer (1976).

Data are from Kay (2001), Kay et al. (2005a, b, c).

of striking isotopic and chemical parallels to oceanic intraplate magmas in the Hawaiian Islands (Kay *et al.* 1993b). As in Hawaii, the main plateau (shield) lavas can be modeled as the deepest and highest percentage melts of the most isotopically enriched mantle source (Fig. 3). These similarities are consistent with the Somuncura magmas having a link to a mantle thermal anomaly or “hotspot”-like mantle. Most trace element and isotopic differences between Somuncura and Hawaiian lavas can be related to interaction of the Somuncura magmas with an arc-like component inherited from lithospheric or upper asthenospheric mantle sources. Evidence for such an arc-like component is strongest in western plateau flows (Comallo region) which have transitional arc-like trace elements (La/Ta ratios = 20-25, Fig. 2) and enriched isotopic signatures (Fig. 3). Further east, a transition to higher $^{87}Sr/^{86}Sr$ ratios at a given ΣNd and higher Ba/La ratios in plateau compared to pre-plateau magmas (Figs. 2

Table 2: Major and Trace Element Chemistry of Patagonia Plateau Lavas - Chenqueniyeu-Somuncura Region

	Eocene	Eocene?	Late Oligocene To Early Miocene					Pliocene to Pleistocene	
			Somucura Magmatic Province						
	C° Cortado	El Cain	preplateau	plateau	plateau	postplateau			Chenqueniyeu
	IJ1	M7	CH1	RH3	RH2	M2A	TM1	SOM2	PAT3
SiO_2	48,77	49,07	48,73	49,19	50,93	48,27	52,90	50,30	46,59
TiO_2	2,04	2,61	2,30	1,85	1,79	3,01	2,70	1,91	1,90
Al_2O_3	16,22	17,89	16,18	15,97	15,94	17,30	15,17	15,21	15,61
FeO	10,59	10,48	10,32	12,03	11,25	11,26	9,91	10,20	10,40
MnO	0,20	0,16	0,17	0,12	0,12	0,22	0,11	0,11	0,11
MgO	7,38	4,82	8,08	6,75	7,04	4,62	5,10	8,14	10,64
CaO	8,50	6,99	8,47	8,69	8,03	8,69	7,34	8,25	9,24
Na_2O	3,86	4,37	3,27	3,80	3,63	3,99	4,01	3,68	3,38
K_2O	2,25	2,25	1,13	0,78	0,66	1,82	1,90	1,38	1,80
P_2O_5			0,67	0,35	0,32	0,72	0,59		0,45
Total	99,81	98,64	99,32	99,53	99,71	99,90	99,73	99,18	100,12
La	27,1	43,2	28,3	16,5	13,1	41,1	28,2	15,4	20,3
Ce	56,2	86,6	56,4	35,7	29,3	80,6	61,0	36,4	46,0
Nd	29,6	36,6	27,2	19,8	15,4	38,1	40,6	19,2	23,7
Sm	6,39	7,98	6,08	4,95	4,40	7,67	8,61	4,68	6,05
Eu	2,37	2,46	1,98	1,62	1,48	2,38	2,83	1,48	1,83
Tb	0,926	1,021	0,816	0,795	0,708	0,990	1,09	0,768	0,848
Yb	2,18	2,05	1,58	1,72	1,66	2,11	1,77	1,59	2,16
Lu	0,301	0,275	0,207	0,230	0,214	0,271	0,254	0,210	0,304
Sr	660	1011	681	549	457	958	745	544	833
Ba	755	836	472	272	196	944	818	287	423
Cs	0,2	0,4	0,3	0,1	0,1	0,4	0,2	0,5	2,1
U	0,7	1,4	0,8	0,3	0,3	1,1	0,5	0,6	1,2
Th	2,3	4,9	2,9	1,6	1,5	4,3	2,1	2,4	3,8
Hf	3,4	5,9	3,7	3,0	2,7	4,4	4,4	3,5	3,9
Ta	1,8	3,8	2,5	1,4	1,1	3,6	1,7	1,7	1,4
Sc	22,0	12,5	18,8	21,7	20,4	19,7	16,3	19,5	28,0
Cr	202	14	257	315	260	49	141	311	434
Ni	157	46	168	242	196	27	83	189	236
Co	42	36	45	60	51	38	38	42	53
FeO/MgO	1,43	2,17	1,28	1,78	1,60	2,44	1,94	1,25	0,98
La/Sm	4,2	5,4	4,7	3,3	3,0	5,4	3,3	3,3	3,3
Sm/Yb	2,9	3,9	3,8	2,9	2,7	3,6	4,9	2,9	2,8
La/Yb	12,4	21,1	17,9	9,6	7,9	19,5	15,9	9,7	9,4
Eu/Eu*	1,19	1,03	1,07	1,01	1,04	1,04	1,09	0,97	0,98
Ba/La	27,9	19,4	16,7	16,5	15,0	23,0	29,0	18,6	20,9
Ba/Ta	409	223	192	197	176	265	496	174	295
La/Ta	14,7	11,5	11,5	11,9	11,8	11,5	17,1	9,3	14,2
Th/La	0,09	0,11	0,10	0,10	0,11	0,10	0,07	0,15	0,19
Ta/Hf	0,54	0,64	0,66	0,46	0,41	0,81	0,37	0,48	0,37
Th/U	3,6	3,6	3,9	5,3	4,6	3,8	4,2	3,9	3,2
εNd	3,9	3,2	+1.5		-0,8	+2.8	-0,6		4,8
$^{143}Nd/^{144}Nd$	0,512838	0,512802	0,512712		0,512600	0,512732	0,512609		0,512884
$^{87}Sr/^{86}Sr$	0,703772	0,703938	0,704023		0,704689	0,704061	0,704525		0,703588
$^{206}Pb/^{204}Pb$	18,612		18,584		18,197	18,570	18,516		18,413
$^{207}Pb/^{204}Pb$	15,597		15,611		15,607	15,640	15,628		15,567
$^{208}Pb/^{204}Pb$	38,432		38,474		38,394	38,538	38,585		38,259
Latitude	41°28'	41°39'	42°38'	42°36'	42°36'	41°29'	42°28'	41°45'	41°29'
Longitude	69°25'	68°18'	68°10'	67°12'	67°12'	68°36'	67°00'	*	70°41'
Age			[1] 29.2	[1] 26.9		[1] 20.6	[1] 16.6		
Error			1,53	0,78		0,63	0,4		

[1] Ages are groundmass $^{40}Ar/^{39}Ar$ ages done at Lehigh University, USA.

* All ages from Mercer (1976).

Data are from Kay et al. (1993) and unpublished.

Table 3: Major and Trace Element Chemistry of Patagonia Plateau Lavas - Sarmiento Region

Estimated age	Eocene			Late Oligocene/Early Miocene					2.7 Ma?	Pleistocene
	[1]Formation El Canquel.						[1]Formation Sierra Quadrada			
	Cerro Mendive		dike				Meseta de Canquel		Las Pulgas	La Laurita
	[1]PC96	[1]LAC4	[1]PC4	SARM8	SARM7	SARM3a	[1]PC1B	[1]PC1C	SARM5	AG4
SiO_2		47,24	46,40	48,91	48,69	50,60	52,00	50,30	48,18	47,33
TiO_2		1,89	2,11	1,77	1,97	2,26	3,29	3,14	2,78	2,29
Al_2O_3		15,47	14,15	14,60	15,18	15,32	16,15	15,66	15,54	13,70
FeO	11,53	11,90	12,00	12,21	10,90	10,52	9,94	9,46	10,59	10,56
MnO		0,19	0,14	0,16	0,17	0,08	0,11	0,10	0,16	0,17
MgO		7,65	9,77	9,13	7,26	5,86	3,48	3,22	6,73	12,33
CaO		10,15	9,15	7,59	9,91	7,70	6,27	8,54	9,15	6,81
Na_2O	3,85	3,47	3,80	4,46	3,86	3,87	4,19	3,94	4,25	3,87
K_2O		0,94	1,17	0,64	1,43	1,79	3,51	3,94	2,23	2,00
P_2O_5				0,34	0,38	0,58	0,92	0,87	0,63	0,54
Total		98,90	98,69	99,81	99,75	98,58	99,86	99,17	100,24	99,60
La	27,7	25,6	46,8	15,9	21,5	29,3	53,5	50,6	45,8	61,9
Ce	55,0	53,8	88,7	32,6	42,0	54,9	102,9	97,4	88,4	121,5
Nd	24,6	25,6	40,0	17,1	22,6	31,7	54,6	50,9	45,2	53,5
Sm	5,65	5,61	7,45	4,58	5,32	7,19	10,12	9,58	8,71	10,24
Eu	1,73	1,72	2,18	1,46	1,64	2,19	2,95	2,79	2,49	2,81
Tb	0,78	0,85	0,97	0,74	0,75	0,95	1,127	1,06	1,00	1,15
Yb	1,77	2,03	1,79	1,64	1,49	1,69	1,67	1,21	1,44	1,57
Lu	0,211	0,27	0,221	0,208	0,191	0,199	0,188	0,138	0,171	0,176
Sr	562	534	764	427	642	663	889	904	870	
Ba	277	289	420	185	251	355	926	1030	426	600
Cs	1,0	0,38	2,4	0,4	0,2	0,3	1,4	0,7	0,5	1,0
U	0,8	0,96	1,6	0,6	0,7	1,1	1,1	1,2	1,3	2,2
Th	3,1	3,45	5,6	2,0	2,3	3,4	5,7	5,6	4,8	7,6
Hf	3,4	3,65	4,7	3,6	3,5	4,5	8,4	8,2	6,0	7,3
Ta	2,3	2,47	3,5	2,1	2,0	2,9	5,4	5,6	3,8	4,8
Sc	23,4	24,48	22,0	21,9	18,2	18,0	12,1	11,0	18,3	14,3
Cr	283	250,26	304	284	263	228	145	114	229	569
Ni	178	159,39	204	201	188	136	116	128	97	425
Co	55	52,99	56	58	50	42	31	39	41	53
FeO/MgO		1,56	1,23	1,34	1,50	1,80	2,86	2,94	1,57	0,86
La/Sm	4,9	4,6	6,3	3,5	4,0	4,1	5,3	5,3	5,3	6,0
Sm/Yb	3,2	2,8	4,2	2,8	3,6	4,3	6,1	7,9	6,1	6,5
La/Yb	15,7	12,6	26,1	9,7	14,4	17,3	32,0	41,8	31,9	39,4
Eu/Eu*	1,00	0,96	0,97	0,99	1,00	1,01	1,02	1,02	0,98	0,96
Ba/La	10,0	11,3	9,0	11,6	11,7	12,1	17,3	20,3	9,3	9,7
Ba/Ta	120	117	119	86	125	122	172	184	113	126
La/Ta	12,0	10,3	13,2	7,4	10,7	10,1	9,9	9,0	12,1	13,0
Th/La	0,11	0,13	0,12	0,13	0,11	0,12	0,11	0,11	0,10	0,12
Ta/Hf	0,67	0,68	0,75	0,60	0,58	0,65	0,65	0,68	0,63	0,65
Th/U	3,7	3,6	3,6	3,3	3,1	3,1	5,2	4,6	3,7	3,5
εNd	+5.8		4.9		3,7		-0,2	-0,8	-1,3	0,0
$^{143}Nd/^{144}Nd$	0,512937		0,512888		0,512826		0,512628	0,512595	0,512570	[2]0.51264
$^{87}Sr/^{86}Sr$	0,703233		0,703337		0,703949		0,705251	0,705222	0,704897	0,704908
$^{206}Pb/^{204}Pb$	19,208							18,243	18,322	18,078
$^{207}Pb/^{204}Pb$	15,615							15,628	15,588	15,736
$^{208}Pb/^{204}Pb$	38,909							38,402	38,436	38,938
Latitude	~44°5'	~44°5'	~44°5'	45°43'	45°46'	45°24'	~44°12'	~44°12'	45°26.5'	44°28.5'
Longitude	~68°14'	~68°14'	~68°8'	68°20.5'	68°39'	69°51'	~68°23'	~68°23'	69°36.5'	70°15'

[1] See map in Lema and Cortés (1987) for locations, Sarmiento 1:250,000 topographic map.

[2] Nd isotopes from Stern et al. (2000).

PC96	Cerro Mendive, north of El Sombrero, Chubut.
LAC4	Cerro Mendive, north of El Sombrero, Chubut.
PC4	Dike crossing route 25 west of El Sombrero and east of Sierra de la Guanaco.
SARM8	Southeast of Lago Colhué Huapí near oil well south of route 20, overlies Sarmiento tuffs.
SARM7	Roadcut on north side of Route 20 south of Lago Colhué Huapí, north of Puesto J. Coya.
SARM3a	Upper flow north route 20.
PC1B, PC1C	Massive flows in niddle part of Meseta de Canquel sequence near Estancia Riscoso. B is below C.
SARM5	North of route 20, ridge above abandoned Almacen de Las Pulgas, considered to be Pliocene
AG4	La Laurita locality south of Cerro de los Chenques, outcrip on route 20.

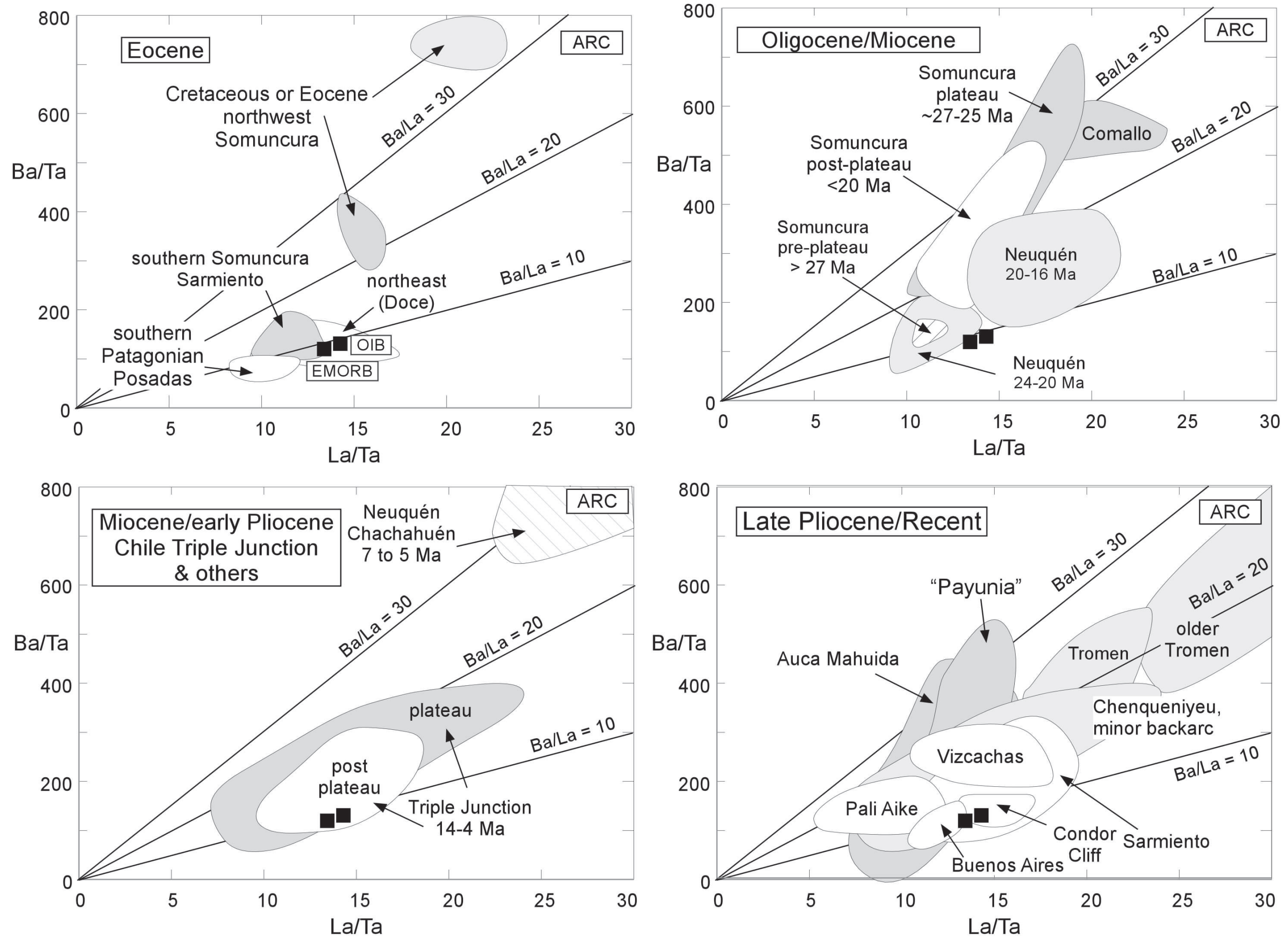

Figure 2: Plot of Ba/Ta versus La/Ta ratios for Eocene to Recent Patagonian plateau mafic and retroarc andesitic to andesitic centers. Data for plateau lavas include analyses from Hawkesworth *et al.* (1979), Stern et al. (1990), D'Orazio et al. (2001), Ramos and Kay (1990), Kay *et al.* (1993a, b), Gorring *et al*. (1997), Gorring (1997), Kay (2001), Gorring *et al*. (2003), Tables 1 to 4 and unpublished data. Values for typical OIB and EMORB lavas from are from Sun and McDonough (1989). Localities shown in Figure 1.

and 3) indicate the entry of this component into the mantle magma source during plateau formation (Kay *et al.* 1993b). High Ba/La ratios in the plateau flows are consistent with a subcrustal origin. The simplest explanation is that this high Ba/La component is derived from the disintegration of the subducted slab that gave rise to Paleocene arc lavas (Rapela *et al*. 1988) to the west.

A problem in explaining the Somuncura plateau magmas is the cause of such a "hotspot-like" mantle thermal anomaly. Oceanic plate and paleogeographic reconstructions show that this event was not contemporaneous with important arc volcanism or ridge collision to the west. The lack of any clear tectonic cause led Kay *et al*. (1993b) to suggest an association with a 'hot-spot'-like thermal instability generated by mantle disturbances related to major late Oligocene plate reorganization. Subsequently, de Ignacio *et al*. (2001) amplified this suggestion by arguing that the Somuncura magmas were generated by asthenospheric corner flow that lead to a transient thermal anomaly above the subducting plate at the time of plate reorganization. They suggested that the intake of hot asthenosphere was induced by slab rollback and was focused by assumed favorable concave-up geometry of the subducting plate.

Near the same time, Muñoz *et al*. (2000) argued that ~ 29 to 19 Ma lava flows to the west in Chile (38°S to 43°S) were related to extensional lithospheric thinning. This event was attributed to asthenospheric upwelling in a slab window that formed in response to changes in subduction zone geometry and that also produced the Somuncura magmas. Problems with this model include creating a slab window in the absence of ridge collision or other evidence for a gap in the subducting plate, lack of evidence for major extension in the Somuncura region, and the sheer volume of the Somuncura flows (Fig. 1).

More recently, Kay *et al*. (2004) have argued that the formation of the Somuncura plateau magmas may be related to a change in the rate of motion of the South American plate relative to the "hot-spot" mantle reference frame. In particular, Silver *et al.* (1998) argued that the Andean deformation cycle beginning at ~25 Ma was driven by an increase in the relative motion of South

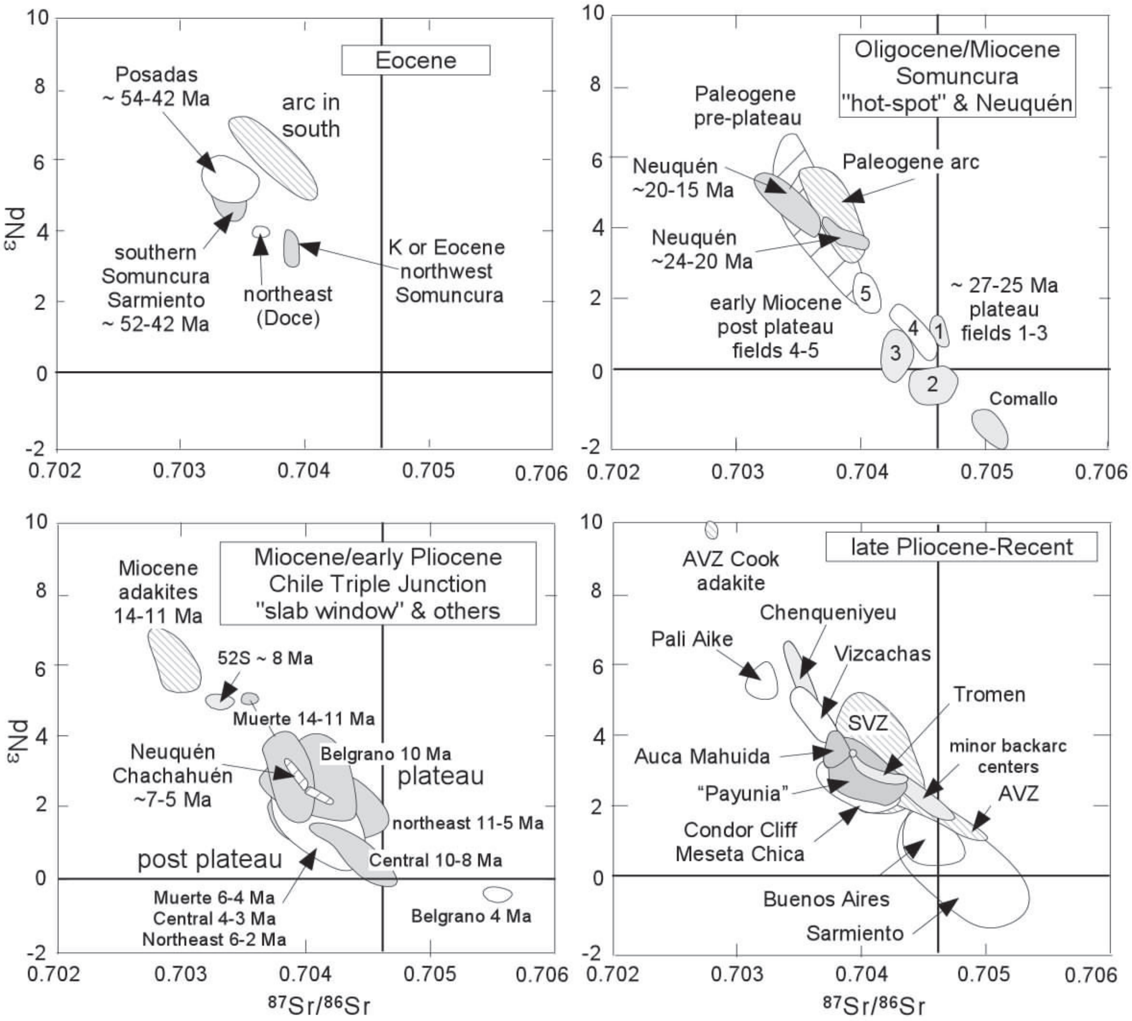

Figure 3: Plot of εNd versus $^{87}Sr/^{86}Sr$ for Patagonian plateau and arc flow. Data for plateau lavas are from the same sources as in Figure 2. Arc data include analyses from papers by Stern, Hickey Vargas, Hildreth, Lopez Escobar, Frey, Dungan, and other sources (see Gorring, 1997 and Kay (2001). Localities shown in Figure 1.

America with respect to Africa. O'Connor *et al.* (1999) have shown that the motion of Africa was faster relative to hotspots after 20 Ma than before 45 Ma. Unfortunately, there are still no reliable constraints on relative rates between 45 and 20 Ma, but it is significant that the eruption of the Somuncura province is contemporaneous with an upsurge of African plate hotspots between 30 and 19 Ma (e.g., O'Connor *et al.* 1999).

Early Miocene Plateau Sequences in Central and Northern Patagonia

The voluminous late Oligocene Somuncura plateau flows were followed by lower volume early Miocene mafic intraplate-like alkaline basaltic flows that erupted from a series of centers between ~45°S and 36°S. Such flows are largely absent south of 46°S. Prominent fields include those in the Huantraico and southern Payunia regions in the Neuquén Basin region (36°S to 38°S), in the Somuncura province, and in the Sarmiento region to the south (Fig. 1). Unlike the late Oligocene Somuncura flows, these flows erupted retroarc to a volcanic arc that was reinvigorated as the subducting oceanic plate convergence vectors changed from highly oblique to more normal. Flows with ages from 24 to 20 Ma in the Neuquén basin region and all of those to the south have intraplate trace element signatures with no arc-like high field strength depletions (La/Ta < 17 in Fig. 2). At the same time, their isotopic signatures reflect more depleted mantle sources (~24-20 Ma Neuquén, post plateau fields 4 and 5 in Fig. 3) than the late Oligocene Somuncura plateau flows. In detail, those in the Somuncura region are more isotopically enriched than those in the Neuquén Basin region (Fig. 3).

Another notable feature of the Neuquén Basin plateau flows is that those erupted after 20 Ma have Ba/La and La/Ta ratios transitional to those in arc rocks (Fig. 2) along with more depleted isotopic signatures than other early Miocene plateau flows (Fig. 3). The change near 20

Ma in the Neuquén Basin region could reflect an increase in the velocity of South America relative to the "hot-spot" mantle reference frame associated with a slight shallowing of the subducting Nazca slab that introduced subduction-derived components into a more depleted mantle wedge (Kay 2001; Kay et al. 2004). Many authors have discussed a change from a moderately extensional to a more contractional stress regime in this part of the southern Andes after 20 Ma (e.g., Jordan et al. 2001).

Late Miocene to Pliocene Plateau Sequences east of the Chile Triple Junction

The largest concentration of late Miocene to early Pliocene plateau flows in Patagonia occurs east of the Chile Triple junction between 47°S and 49°S in the Muerte/Belgrano/Central/northeast region (Fig. 1). This magmatism has been linked to opening of an asthenospheric «slab-window» in the subducting plate that formed in association with collision of the segment of the Chile rise that collided with the Chile trench at ~12 Ma by Ramos and Kay (1992) and Gorring et al. (1997). The presence of the ~ 12 Ma Cerro Pampa group slab-melt adakites with their distinctly MORB-like $^{87}Sr/^{86}Sr$ isotopic ratios (Fig. 3) in the retroarc from 47°S to 49°S is consistent with partial melting of the hot, young subducting Nazca slab at this time (Kay et al., 1993b; Ramos et al., this issue). Relatively higher Ba/La, La/Ta, $^{87}Sr/^{86}Sr$ (Figs. 2 and 3) and $^{206}Pb/^{204}Pb$ ratios in western plateau (Muerte and Belgrano) than in eastern plateau (Meseta Central) flows are consistent with a more depleted upper mantle, a younger crust and the greater influence of a subducted crustal component in the west (Gorring and Kay 2001). The more variable chemistry of the post-plateau flows correlates with lower melting percentages from more isotopically heterogeneous local magma sources.

The eruption of extensive plateau magmas east of the ridge segment that collided at ~12 Ma, but only minor volumes of plateau magmas south of 50°S (Fig. 1) east of where segments of the ridge collided before 12 Ma is best explained by incorporation of a mantle thermal anomaly in the «slab-window» to the north, but not to the south (Gorring et al. 1997). The more isotopically enriched intraplate–like chemistry of the plateau flows east of the ridge that collided at ~ 12 Ma supports such a scenario (Figs. 2 and 3). The significantly more depleted isotopic signatures of the flows from small ~8 Ma centers near ~52°S, east of Pali Aike (Figs. 1 and 3; D'Orazio et al. 2001) are consistent with a mantle source less affected by thermally perturbed "hot-spot" like asthenospheric mantle.

Persistently lower Ba/La ratios in southern Patagonia plateau flows compared to northern Patagonian flows (compare Triple Junction flows with Somuncura and Auca Mahuída/Payunia flows; Fig. 2) can be associated with less important and less persistent Tertiary frontal arc magmatic activity (Rapela et al. 1988; Ramos and Kay 1992; Ardolino et al. 1999) and subduction of hotter, younger less hydrated oceanic crust in the south (Fig. 1; Cande and Leslie 1986).

Pliocene to Recent Mafic Plateau Sequences north of 38°S

The most extensive eruptions of late Pliocene to Recent Patagonian plateau lavas occurred in southern Mendoza and northern Neuquén between 35°S and 38°S (Llancanelo, Payúnia and Auca Mahuída fields, Fig. 1; Bermudez et al. 1993; Munoz et al. 1989) where retroarc alkaline magmatism had been absent since the early Miocene. Like the extensive late Oligocene Somuncura and late Miocene/Pliocene Triple Junction magmas, these plateau magmas have an intraplate-like chemistry that shows little to no tendency for arc-like high-field strength element depletion (La/Ta < 16, Fig. 2; Table 4). Like the Somuncura plateau flows, they can have Ba/La ratios that reach over 30, (Fig. 2). Most can be modeled as melts of an enriched mantle source (Stern et al. 1989; Kay 2001) whose isotopic signature was generally similar to that of the Chile Triple Junction and Somuncura province plateau magmas. Reported ages are generally less than 3 Ma ($^{40}Ar/^{39}Ar$ in Table 1; Bermudez et al., 1993: Cobbold and Rossello 2003). Their eruption style and chemistry are compatible with a transpressional tectonic regime that initiated in the Pliocene as a more oblique convergence regime developed along the Andean margin. This stress change is well seen in the westward rotational displacement of the main activity of the Pliocene to Recent arc between 38°S and 40°S (Muñoz et al., 1989).

The best-analyzed of the Payunia region flows are those in the Auca Mahuída field (Fig. 1). the trace element chemistry of these flows (Table 1), which erupted from a series of nearly monogenetic cones, is distinct from that of the late Oligocene Somuncura plateau and the Mio-Pliocene Chile Triple junction flows in that an evolutionary pattern from voluminous plateau flows to low volume alkaline post-plateau sequences is not seen (Kay 2001). Instead, the chemistry of all of the Auca Mahuída magmas fits with derivation from a common mantle source (Fig. 3). A paucity of silicic melts and a general lack of crustal contamination reflect a refractory middle to lower crust that largely had lost any low temperature melting component during the Permo-Triassic crustal melting event that produced extensive rhyolite volcanism in the region.

The eruption of the extensive Pliocene to Recent Payunia flows between 35°S and 38°S can be linked to melting of hydrated mantle after a transient Miocene episode of shallow subduction (Kay 2001, 2002b). Some of the best evidence for a Miocene episode of shallow subduction in this region is the eruption of the largely andesitic to dacitic ~ 8 to 5 Ma Chachahuén volcanic complex (Fig. 1) with it's arc-like trace element signature (Fig. 2; Table 1), some 500 km east of the trench. This episode of shallowing of the subducting Nazca plate is considered to have initiated at the onset of contractional

Table 4: Major and Trace Element Chemistry of Plio-Pleistocene Plateau Lavas (Lago Viedma to Lago Argentino)

	Meseta Chica				Cerro del Fraile			Meseta Vizcachas			
	base	middle	middle	top	top	middle	base	Chile	Ea. Entrerriana		C° Fortaleza
SAMPLE	VL1B	VL1D	VL1F	VL1G	DL1	DL2	DL3	A49	MV1	MV2	CON3
SiO_2	51,22	49,36	49,01	48,82	53,03	54,43	51,52	52,73	51,36	51,81	51,63
TiO_2	1,73	1,71	1,98	2,05	1,68	1,92	2,58	1,42	1,67	1,83	2,51
Al_2O_3	16,96	15,21	15,20	15,14	15,10	14,45	15,02	15,58	15,99	17,04	14,60
FeO	10,00	11,02	10,38	10,40	10,32	10,17	11,60	10,46	10,27	9,55	10,27
MnO	0,13	0,15	0,16	0,16	0,12	0,13	0,18	0,16	0,06	0,15	0,16
MgO	5,62	8,10	9,21	9,31	7,04	5,83	5,99	7,23	6,80	4,73	7,30
CaO	7,79	7,68	8,53	8,56	8,76	7,70	8,45	8,9	8,32	8,68	8,86
Na_2O	3,33	3,53	3,30	3,42	3,14	3,55	3,54	3,11	3,49	3,90	3,21
K_2O	1,55	1,20	1,25	1,29	0,30	1,05	1,00	0,52	0,92	1,42	0,93
P_2O_5	0,33	0,44	0,47	0,51	0,20	0,28	0,54	0,14	0,33	0,47	0,33
Total	98,66	98,4	99,49	99,66	99,69	99,51	100,42	100,25	99,21	99,58	99,8
La	26,9	26,8	26,0	28,3	9,2	17,1	22,5	9,3	18,2	30,8	19,8
Ce	56,7	53,4	54,9	58,6	21,1	35,7	49,7	21,7	40,2	63,9	42,9
Nd	27,2	27,1	26,6	29,7	13,8	20,1	29,9	10,6	17,2	30,7	24,5
Sm	5,57	5,56	5,68	6,19	3,85	5,30	7,18	3,38	4,60	6,43	5,94
Eu	1,69	1,64	1,72	1,83	1,34	1,60	2,35	1,20	1,49	1,82	1,91
Tb	0,795	0,821	0,803	0,844	0,710	0,866	1,040	0,697	0,702	0,859	0,915
Yb	2,03	1,92	1,87	1,85	1,68	1,96	2,12	1,70	1,80	2,21	1,77
Lu	0,273	0,247	0,261	0,260	0,216	0,247	0,263	0,235	0,229	0,310	0,225
Sr	533	559	591	629	288	260	441	336	484	588	465
Ba	271	301	283	305	100	169	273	99	262	366	231
Cs	0,13	0,29	0,74	0,64	0,99	0,54	0,38	0,36	0,23	0,54	0,64
U	0,99	1,01	0,99	1,07	0,36	0,87	0,65	0,34	0,77	1,58	0,75
Th	3,97	3,74	3,53	3,69	1,46	3,45	2,54	1,34	2,63	4,99	2,63
Hf	4,8	4,4	4,2	4,5	2,7	4,2	4,7	2,4	3,3	4,7	4,3
Sc	21,9	20,7	23,8	24,6	21,2	18,8	20,8	21,8	21,6	22,5	21,2
Ta	1,6	1,8	1,8	1,9	0,6	1,2	1,5	0,6	1,1	1,8	1,4
Cr	168	225	353	328	279	203	182	232	256	58	241
Ni	57	190	201	188	177	126	104	157	116	27	127
Co	38	52	51	50	47	40	45	48	50	34	45
FeO/MgO	1,78	1,36	1,13	1,12	1,47	1,74	1,94	1,45	1,51	2,02	1,41
La/Sm	4,8	4,8	4,6	4,6	2,4	3,2	3,1	2,8	4,0	4,8	3,3
Sm/Yb	2,7	2,9	3,0	3,3	2,3	2,7	3,4	2,0	2,6	2,9	3,4
La/Yb	13,3	14,0	13,9	15,3	5,5	8,7	10,6	5,5	10,1	13,9	11,2
Eu/Eu*	0,98	0,94	0,97	0,97	1,03	0,93	1,05	1,01	1,02	0,93	1,01
Ba/La	10,1	11,2	10,9	10,8	10,8	9,9	12,1	10,6	14,4	11,9	11,6
Ba/Ta	168	171	162	158	164	139	179	162	233	204	170
La/Ta	16,7	15,2	14,9	14,7	15,2	14,0	14,8	15,3	16,2	17,2	14,6
Th/La	0,15	0,14	0,14	0,13	0,16	0,20	0,11	0,14	0,14	0,16	0,13
Ta/Hf	0,33	0,40	0,41	0,43	0,22	0,29	0,33	0,25	0,34	0,38	0,31
Th/U	4,01	3,69	3,57	3,46	4,03	3,98	3,90	3,97	3,40	3,16	3,50
εNd			+1.9		+5.9				+3.9		+3.2
$^{143}Nd/^{144}Nd$			0,512739		0,512941				0,512842		0,512804
$^{87}Sr/^{86}Sr$			0,704129		0,703268				0,703757		0,703866
$^{206}Pb/^{204}Pb$			18,695		18,993				18,767		18,856
$^{207}Pb/^{204}Pb$			15,634		15,638				15,623		15,656
$^{208}Pb/^{204}Pb$			38,731		38,883				38,691		38,887
Lat	~49°32'S	~49°32'S	~49°32'S	~49°32'S	~50°32'S	~50°30'S	~50°30'S		~50°32'S	~50°32'S	50°14.1'
Long	~72°20'W	~72°20'W	~72°20'W	~72°20'W	~72°38'W	~72°38'W	~72°38'W		~71°45'W	~71°45'W	70°53.5'
Age (Ma)	~ 3.5	~ 3.5	~ 3.5	~ 3.5	~1.7±0.5		~ 3.2±1	All ages from Mercer (1976).			

VL1B to VL16 - Meseta Chica north of Lago Viedma, northeast of Estancia Primavera.

DL1, DL2, DL3: Top, middle and base of plateau basalt section at Cerro del Fraile south of Estancia Chorrillo Malo.

A49. Meseta Vizcachas in Chile, Estancia Las Cumbres.

MV1, MV2 - flows from the west side of Meseta Vizcachas, southeast of Calafate, just north of Estancia Entrerriana.

CON3 - Cerro Forteleza south side of Rio Santa Cruz.

deformation in the early Miocene and to have peaked coincident with widespread deformation across the retroarc at the time of the eruption of the Chachahuén Complex (Kay 2001, 2002b). Subsequent steepening of the subducting plate in late Pliocene to Pleistocene times fits with preferential melting of hydrated mantle exposed to a thickening asthenospheric wedge. Closer to the arc, late Pliocene to Holocene lavas in and west and north of the Tromen volcanic massif show progressively less influence of slab-related fluid and arc-like components in their geochemical signatures through time (Fig. 2; Saal et al. 1993; Kay 2001). The geochemical signatures in the Holocene flows are consistent with a decrease in a subducted component as the amount of extension increased to the west.

Late Pliocene to Recent Plateau Sequences south of 38°S

South of 38°S, smaller volume Pliocene to Recent mafic flows are scattered throughout the retroarc (Fig. 1). These flows generally represent small percentage mantle melts from regionally heterogeneous sources (Figs. 2 and 3; new analyses in Tables 2 to 4; Stern et al. 1989; Gorring et al. 2003). Stern et al. (1989) divided them into «transitional» (e.g., Chenqueniyeu and other light gray fields in Figs. 2 and 3) and «cratonic» (e.g., Pali Aike, Meseta Chica, Condor Cliff, Buenos Aires, Sarmiento) groups with "cratonic" centers occurring east of the Cenozoic orogenic front. Transitional centers were distinguished by their more arc-like trace element and isotopic signatures (Stern et al. 1989; López-Escobar et al. 1995). Many of the transitional centers seem to be localized by transpressional stresses exemplified by the Liquiñe-Ofqui fault system (see López-Escobar et al. 1995). Elsewhere, flows in the Meseta del Lago Buenos Aires region (Fig. 1) just east of the Chile Triple Junction have been related to a slab-window that opened in association with collision of the segment of the Chile ridge that collided with the Chile trench at ~ 6 Ma (Ramos and Kay 1992; Gorring et al. 2003). Further south, D'Orazio et al. (2001) and Haller et al. (2002) have related small volume flows south of 50°S to older 'slab-windows' associated with pre-12 Ma collisions of the Chile segments.

Overall, the "cratonic" centers show a regional south to north trend from high to low ΣNd values and ^{206}Pb/^{204}Pb ratios along with low to high ^{87}Sr/^{86}Sr ratios (see Fig. 3; Tables 2 to 4; Kay and Gorring, 1999). Their isotopic variations can be modeled by mixing plume-type mantle components (high-MU and MORB with EMI, EMII, and BSE - bulk silicate earth) as discussed by Stern et al. (1989). In a simple way, end-member "cratonic" types can be defined by the Pali Aike and Sarmiento centers (Kay and Gorring 1999; Figs. 2 and 3). The Pali Aike type and Vizcachas region flows have chemical affinities like xenoliths from Pali Aike (see Stern et al., 1989) and the Meseta Central (Gorring and Kay, 2000). The subdued arc-like affinities in the older Meseta Vizcachas flows (Stern et al. 1989; Haller et al. 2001, Fig. 2) could reflect addition of arc components related to the subduction of the Antarctic plate. The Pali Aike type looks to be associated with a mantle source like that which give rise to the Eocene Posadas flows. In contrast, the Sarmiento type along with the Meseta del Lago Buenos Aires region flows have isotopic affinities with the voluminous late Oligocene Somuncura and Mio/Pliocene Triple Junction region plateau lavas. Flows in this group are best related to mantle sources affected by the Somuncura and Triple Junction «thermal» events and related to asthenospheric "slab-window" sources.

Conclusions: Tectonic triggers on a regionally hot mantle

To a first order the spatial and temporal distribution of episodes of Patagonian plateau magmatism can be rationalized in terms of the regional tectonic evolution of southern South America in the following ways:

1) The melting events that produced the voluminous Eocene Basalto Posadas and the late Miocene to Pliocene flows east of the Chile Triple Junction as well as other smaller Miocene to Pleistocene lavas in southern Patagonia can be associated with Eocene and Miocene-Recent collisions of the Farallón-Aluk and the Nazca-Antarctic ridges with the Chile trench. Few of these lavas have any chemical affinity with arc magmas consistent with subduction of young hot oceanic crust and a paucity of Tertiary arc magmatism to the west. The volumes of the largest flows suggest that mantle conditions, like those expected with "wet-spot" mantle and "hot-spot" like asthenospheric conditions were present when these magmas erupted through the slab-windows.

2) The melting event that produced the voluminous Pliocene to Pleistocene Payunia province and related magmas to the north can be associated with the steepening of a formally shallow subduction zone. This melting would occur as steepening lead to an influx of asthenospheric mantle causing melting of a mantle wet-spot. A changing slab dip can explain the presence of arc-like volcanic centers (e.g., Chachahuén) far east of the trench and chemical features of the Payunia lavas. A remaining problem is that the shear volume of the magmas suggests an additional factor arising from local mantle conditions.

3) A tectonic reason for the melting event that produced the voluminous Oligocene/early Miocene Somuncura plateau and post-plateau flows is the most difficult. The best explanation remains a thermal anomaly associated with mantle instabilities related to either a time of major changes in plate convergence vectors or very slow relative motion of South America with respect to the underlying hotspot reference frame.

Arc-like Ba/La ratios in the lavas across the region and La/Ta ratios > 20 in the western flows fit with the introduction of arc components into the mantle source as a result of interaction between hot mantle and an old Paleogene slab.

4) Smaller volume plateau flows fit with eruption in association with localized extension along transpressional fault systems.

Overall, the absolute heat source required to produce extensive amounts of Tertiary to Recent Patagonian plateau magmas in the absence of significant extension remains a problem. One explanation is that the Patagonian mantle has been on the verge of melting since the Mesozoic breakup of Gondwana and the tectonic perturbations discussed above have served as provocations to melt an already hot mantle. The intraplate-like chemistry of the most voluminous Patagonian plateau flows is consistent with an asthenospheric plume-like mantle source beneath the Patagonian lithosphere.

Acknowledgements

The authors thank Miguel Haller for the invitation to contribute a paper to this special issue. Numerous geologists have aided in the field work, collection of samples, and the discussion of the ideas on which this paper is based. Among these individuals are Alberto Ardolino, Mario Franchi, Jose Cortés, Marcelo Marques, Carlos Rapela, Mario Mazzoni, Daniel Ragona, Tomas Zapata, Daniel Rubiolo, Maria Fernandez, Robert Kay, and Matthew Burns. Ar/Ar ages were determined in the laboratories of Peter Zeitler (Lehigh University) and Peter Copeland (University of Houston).

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Recibido: 4 de mayo, 2004
Aceptado: 10 de octubre, 2004