ISOTOPIC AND GEOCHEMICAL EVOLUTION OF THE CENOZOIC BASALTS FROM RIO NEGRO, PATAGONIA, ARGENTINA.

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Summary

The geochemical systematics of Patagonian volcanic rocks of the Rio Negro Province, Argentina, indicate different mantle source characteristics that have been derived from two-or more- mantle sources:

The oldest rocks, (basaltic andesites) so far detected only in the west have the lowest concentrations of incompatible elements (LREE 30xchondritic) and the highest radiogenic isotopic ratios ($^{87}Sr/^{86}Sr$ up to 0.70502; $^{143}Nd/^{144}Nd$ down to 0.51254, repectively). The low incompatible element contents indicate high degrees of partial melting. Their negative Nb- and Ta-anomalies, normalized to primitive mantle and enrichment in Sr, Ba and K, indicate crustal contamination and/or mixing with lithospheric subducted slab.

The geochemistry of the younger rocks (mainly trachybasalts, basalts and tephrites/basanites) show ocean island basalt (OIB) affinity. Only in the west are some of these lavas slightly depleted in HFSE (with negative Nb-anomalies). The younger lavas show characteristics that can be summarized as follows: **a**. variable concentrations of incompatible elements suggesting different degrees of partial melting of mantle source-rocks. **b**. very similar patterns of incompatible elements are present in samples from the far west (close to the Andes) and from the easternmost outcrops (some 300 Km east of the Andes), indicating a similar petrogenesis not related to subduction processes. **c**. in the east of the area lavas with highly enriched LREE (up to 400x chondritic) occur that can not be explained by a single-stage low degree of partial melting in the source. Compositions of these lavas, normalized to primitive mantle, show distinct negative K-anomalies which might be represent K-depleted magma source(s).

Introduction

Cenozoic volcanic rocks of Argentina east of the Andes have been studied by several authors. While our investigations took place in northern Patagonia, most of these studies concerne the volcanic rocks of southern Patagonia (Baker et al., 1981, Skewes et al., 1979, Ramos et. al., 1992, Kay et al., 1993, Stern et al., 1996, Gorring et al., 1997). Skewes and Stern (1979) concluded that the origin of the alkali basalts near 33°S, (the southernmost part of Patagonian) could be attributed to the mechanical and/or thermal perturbation of the subcontinental mantle due to eastward subduction of Pacific oceanic lithosphere and not to continental rifting or hot-spot traces. However, they came to the conclusion that the Pali-Aike alkali basalts that carry garnet-bearing ultramafic inclusions do not contain components derived from the subducted oceanic lithosphere and have major element geochemistry similar to that of basaltic intraplate oceanic island alkali basalts.

A model proposing that Patagonian magmatism was induced via an eastwards migrating 'slab-window' was advanced by Ramos et al. (1992) and Gorring et al. (1997) on the basis of studies of Cande et al. (1986, 1992) and Baker et al. (1981). Large volumes of OIB-like lavas dating from 12-7 Ma, occurring between 46°S and 49°S were regarded as having been caused by upwelling of sub-slab asthenosphere through a huge gap ('window') in the subducted plate(s) in the area of the Chile Triple Junction (Fig 1). Stern et al. (1990) used high-precision analyses of trace-elements and isotopes in a study of Pliocene and Quaternary alkali basalts from Patagonia. They concluded that lavas in the east are characterized by a geochemistry typical of ocean island basalts, whereas lavas in the west have been influenced from the subducted plate. Unfortunately the number of their analyzed samples (24) was very small in relation to the very large area (34.5°S-54°S) they investigated.

We have attempted to deduce the nature of the sub-continental mantle and the possible influence of a subducting slab through the geochemistry of Cenozoic alkali-basalts and tholeiitic basaltic andesites NW of the Meseta de Somuncura. For that purpose a W-E-profile along the 41°S latitude was systematically sampled This 300 km profile extends from Comallo to Quepuniyeu (Fig.1)

Geological setting

The 'basement' of Comarca Nordpatagonica (Stipanicic and Methol, 1980, Labudia and Bjerg, 1994) is of pre-Tertiary age. Three main faults follow E-W, NE-SW and NW-SE trends and they are responsible for the block faulting in that area.

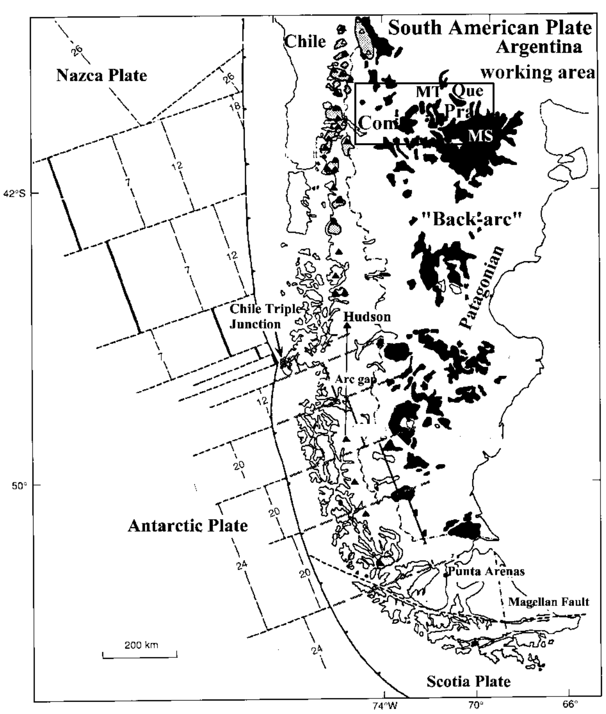

Fig. 1 Cenozoic basaltic magmatic provinces (black) of Patagonian and sampling area of this study. Sampling locations: MS: Meseta de Somuncura, Que: Quepuniyeu, Pra: Praguaniyeu, MT: Meseta del Toro, Com: Comallo. Map from Ramos and Kay (1992).

The majority of the Pliocene and Pleistocene alkali-basalt outcrops follow these main fault lineations. The basalts overlie or intrude Maastrichtian-Danian sediments whose regional distribution shows that in the northern-central part of Patagonia they were deposited in depressions surrounding fault delimited blocks which had been previousuly subjected to a long period of erosion (Labudia et al. 1994).

Bulk-rock chemistry

The oldest samples, which outcrop in a restricted area in the west (Comallo) are basaltic andesites (Table 1), according to the alkali/silica classification sheme of Le Bas (1986). Most of the other samples plot in the tephrite/basanite/trachybasalt fields, with the remainder plotting in the basalt, basaltic trachyandesite and phono-tephrite fields. According to their normalized incompatible elements patterns it is possible to distinguish four main lava groups (Fig. 2).

The basaltic andesites (Com group) are characterized by low concentrations of incompatible trace elements and lacking of upper mantle xenoliths. The primitive-mantle normalized incompatible element abundances show remarkably flat patterns and pronounced negative Nb- and Ta- anomalies. Their LREE-contents are about 10x the PM and the La/Yb-ratios range from 2.94 to 5.14. The lavas also show high LILE/HFSE ratios (e.g. Ba/La ratios between 32.5-57.7).

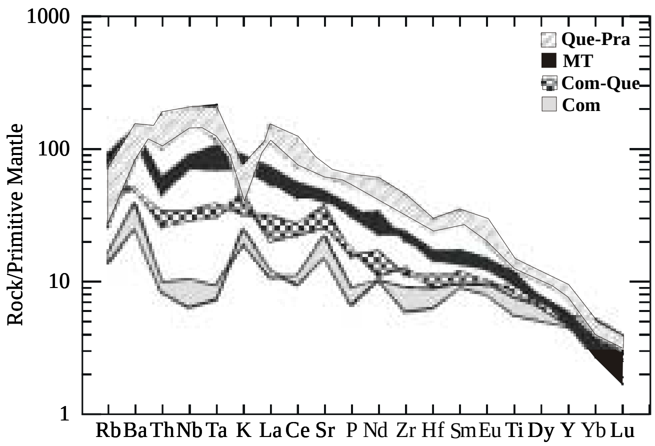

Fig 2.Primitive-mantle (Sun and McDonough 1989) normalized incompatible elements patterns showing four lava-groups.

Lavas from the eastern part of the area (Que-Pra group) have low K/Nb values ranging from 70-200 and show (Fig. 2) the highest incompatible element contents of all the samples (Table 1). They also have steep REE paterns (La/Yb=48). Another group of lavas from the east (Que) show patterns of incompatible element abundances that are strikingly similar to those of xenolith bearing lavas from the westernmost part (Comallo). These samples lack of the very common distinct negative K anomaly (Fig.3) in the east and have K/Nb ratios ranging from 205 to 280. The primitive mantle-normalized incompatible element abundances display patterns (Com-Que, Fig.2) that plot between the most depleted group Com and the most enriched group Que-Pra.

Lavas from the central part (MT = Meseta del Toro) show no distinct K-depletion (K/Nb=225-375). They have significantly lower Th contents relative to other incompatible elements when normalized to the primitive mantle (Fig. 2). Furthermore, it is evident that the MT lavas have, with exception of Rb and Ba, significantly lower incompatible element abundances than the Que-Pra group lavas.

Isotopic data

In the $^{143}Nd/^{144}Nd$ vs, $^{87}Sr/^{86}Sr$-diagram (Fig. 3) all samples plot into the OIB-field. The basaltic andesites (Com group) have isotopic signatures that are distinctly different from those of all other analyzed lavas. Their Sr-isotopes are the most radiogenic, with $^{87}Sr/^{86}Sr$ ranging from 0.7047 to 0.7050 and their $^{143}Nd/^{144}Nd$ values vary from 0.512544 to 0.512684. Not only different characterized mantle sources of the basaltic andesites and alkali basalts can be detected. Also the alkali basalts can be divided isotopically into at least two groups. The first group comprises some of the samples from east (Que-Pra group: upper part of the alkali basalts field in Fig. 3). Their $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ values vary from 0.70345 to 0.70379 and 0.52180 to 0.52186 respectively. They represent the less radiogenic in Sr and the most radiogenic in Nd lavas from all investigated samples. The other group comprises mainly MT and Com-Que samples (in Fig. 3 the lower part of the alkali basalts field), but also some of the Que-Pra lavas plot into the same area.The isotopic composition of this group shows relatively wide range in $^{87}Sr/^{86}Sr$ (0.70388 to 0.70441) and $^{143}Nd/^{144}Nd$ (0.512724 to 0.512820). Hawkesworth et al. (1979) and Gorring et al. (1997) reported isotope compositions from the southern Patagonian basalts (Fig 3) which are similar to our data.

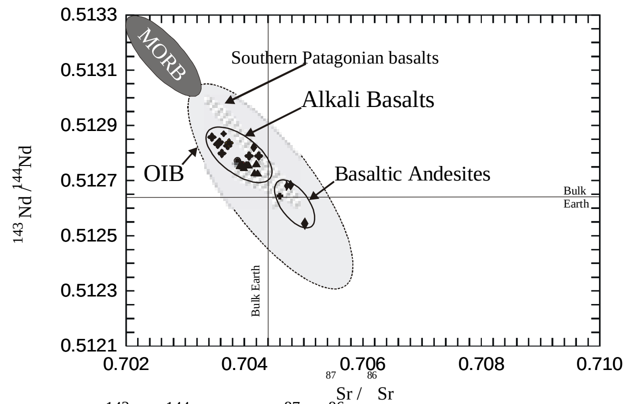

Fig. 3. $^{143}Nd/^{144}Nd$ vs. $^{87}Sr/^{86}Sr$-isotopes of representative samples from Rio Negro Province, Patagonia. Southern Patagonian basaltlts from Hawkesworth et al., (1979) and Gorring et al. (1997).

Disussion

The Com group has low concentrations of incompatible elements and pronounced Nb- and Ta-anomalies, relative HFSE depletion (Fig. 2) suggeststing that the magmas either experienced crustal contamination or were modified by melts and/or fluids, derived from the downwards moving of the Nacza plate slab. The lack of mantle xenoliths suggests magma generation at too shallow level in the mantle and, more important, low ascent rates. The Que-Pra group lavas have the highest contents of incompatible elements and high La/Yb ratios (La/Yb=48). Preliminary calculations show that these extremely LREE enriched lavas could not have been directly derived from asthenospheric mantle or plume by partial melting, as they require unrealistic low degree of partial melting.

However a two stage melting process or premelting metasomatic enrichment could explain the very high LREE abundunces. Applying the Köhler and Brey (1990) barometer, and the Brey and Köhler (1990) thermometer, for the enclosed spinel-lherzolite xenoliths, the estimated equilibrium P-T conditions are 28 kbars and 1050°C, suggesting that the depth for magma generation may have been as greater as 100 km.

The post-basaltic andesite lavas from the west (Com = Comallo), as mentioned above, are very similar to the lavas from the easternmost area (Fig. 4, Com-Que group). Stern et al. (1990) argue that the westernmost lavas are strongly modified by the subducted slab of oceanic lithosphere. Furthermore they conclude that the degree of partial melting beneath Patagonia decreases from west to east. However negative Nb- and Ta- anomalies that are diagnostic for involvement of arc magma components are absent or insignificant in our samles. In Fig. 4 the negative correlation between Ce/Y and Zr/Nb ratios suggests that lavas with the highest Ce/Y and the lowest Zr/Nb have experienced the smallest degree of partial melting. From this plot it is also evident that there is no systematic correlation between the degree of partial melting and sample locality; e.g lavas from east plot together with lavas from west. All lavas, with exception of the

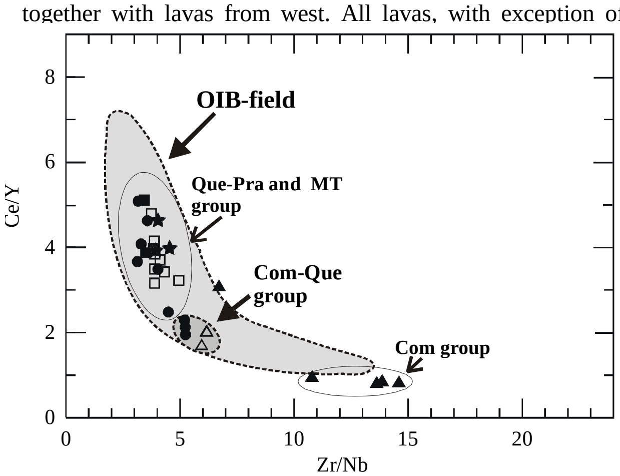

Fig. 4. The cenozoic volcanic rocks from Rio Negro Province Patagonia, plot in the OIB-field (Fitton et al., 1988).

Com group plot within the OIB-field (Fitton et al. 1988) emphasizing their derivation from the asthenosphere. Data from the Com-group (basaltic andesites) plot outside of the OIB-field (filled triangles). They have low Ce/Y and high Zr/Nb ratios suggesting low degree of LREE enrichment and high Nb depletion and are consistent with flat patterns of incompatible elements and pronounced Nb- and Ta anomalies shown in Fig 4.

Gorring et al. (1997) and Ramos and Kay (1992) presented a genetic model for the southern Patagonian basalts. In this model, the eruption of the Miocene basaltic lavas occurred over ‘slab-windows’ as they pass further under the backarc areas. Trace elements and isotopic characteristics are similar to those of typical OIB lavas. In the west lavas were mixed with minor amounts of the subducted slab. Melting processes took place in the garnet peridotite field and according to their calculations the degree of partial melting decreases from west to east. Since our data for the northern Patagonia are similar to those of the south we compare the relationships and give a contrasting model.

Overall trace elements and isotopic characteristics show strong OIB affinity. In the west the xenolith-free lavas (Com group, Fig. 2) show flat patterns of incompatible elements, pronounced negative Nb- and Ta- anomalies and the most radiogenic Sr-isotopes. However, samples from Meseta de Somuncura (Fig. 1) have similar patterns of incompatible elements without negative Nb- and Ta- anomalies (Kay et al. 1993). It is evident that these older lavas in the west are akin to the Meseta de Somuncura volcanism but they have been modified by either components from the subducted slab or by crustal contamination. All other lava-groups (Com-Que, MT and Que-Pra) do not show any evidence for addition of subducted slab components or modification after contamination with crustal material. Their patterns (Fig. 4) display variable degrees of partial melting, broadly consistent with the observations made by Gorring et al. (1977) and Ramos and Kay (1992). However, their conclusion that a trend of decreasing degree of melting occurs from west to east is not valid for the investigated area, because, as can be seen in Fig 2, the group Com-Que comprises lavas from the westernmost and from the easternmost regions. Gorring et al. (1997) and Ramos and Kay suggest that lavas derived after melting of garnet lherzolite in the asthenosphere. Our results confirm this conclusion. Quantitative estimations show that the Com-Que group has been derived after 5-6% partial melting of a garnet lherzolite source with modal composition 60% olivine, 20% orthopyroxene, 11% clinopyroxene and 9% garnet. For the MT group we calculated 0.4-1% partial melting of the same garnet lherzolite source. As mentioned above the Que-Pra group differs from the other two groups in that they have pronounced negative K-anomalies and the highest contents of incompatible elements suggesting different magma source(s) from those of Com-Que and MT lavas. Quantitative estimations indicate two stage melting process and/or premelting metasomatic enrichment at depths of at least 80 km.

According to the slab window model basaltic lavas are produced by asthenospheric mantle upwelling these windows that opened between the subducted Nazca and Antarctic plates due to Miocene-Pliocene ridge collisions (Gorring et al., 1997). Furthermore they suggest that such slab-windows are temporally and spatially associated with adakitic magmas derived from melting of the young subducting oceanic slab (Kay et al. 1993). Though chemical and isotopic characteristics from southern and northern Patagonia are similar the tectonic settings are different. In northern Patagonia there are no evidences for slab-windows and/or associated adacitic magmas. Therefore, volcanism in this region cannot be correlated with slab-windows. On the other hand if a mantle plume, seated in large depth, below the Patagonian lithosphere, reacts with H_2O-CO_2 rich fluids could initiate the low melting degrees observed in the investigated region.

Conclusions

The basaltic lavas in northern Patagonia have chemical and isotopic signatures with remarkable strong OIB affinity. The Com lava-group in the west displays negative Nb and Ta anomalies that can be attributed to mixing with subducted slab material or to crustal contamination. All other lava-groups do not show any interaction with the subducted lithospheric slab. Lavas derived from the asthenosphere after 5-6% melting of a garnet-lherzolite were found in far west and in far east outcrops as well showing that no trend of decreasing degree of melting from west to east exists as suggested by Gorring et al., (1997) and Ramos and Kay (1992) even if the trace-element richest lavas are from the east (Fig. 2). The mantle source for the northern patagonian volcanism seems to be rather correlated with mantle plume than with slab-windows that might be responsible for the southern patagonian lavas.

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Table 1 Representative analyses of northern Patagonian Lavas

	Que-Pra		MT	Com-Que		Com
Sample	Que35	Pra2	Alv11	Com4	Que49	Com34
SiO_2	41.31	39.54	46.85	47.61	45.04	53.92
TiO_2	2.75	3.25	2.49	2.06	2.26	1.63
Al_2O_3	12.42	9.65	15.47	15.49	16.87	15.78
$Fe_2O_3^T$	12.87	14.39	12.16	12.04	12.97	10.61
MnO	0.21	0.22	0.17	0.16	0.18	0.15
MgO	9.55	13.63	6.90	8.21	7.13	6.43
CaO	12.34	11.29	8.37	8.96	10.67	8.57
Na_2O	4.20	4.29	4.10	3.77	3.34	3.44
K_2O	1.98	1.20	1.92	1.47	0.69	0.72
P_2O_5	1.17	1.40	1.00	0.40	0.36	0.18
Total	98.81	98.87	99.45	100.17	99.52	101.44
Nb,ppm	123	148	88	24.9	27.8	7.1
Ta	5.051	8.844	6.09	1.326	1.766	0.476
Zr	385.7	509.2	329.4	148.1	144.7	98.4
Y	37.3	42.8	28.4	24.4	24.9	25.4
Sr	1502	1503	1101	550	1014	459.4
Rb	32.8	17.1	97.7	30.9	18.4	11.2
V	222.6	169.8	178	189.9	297.3	191.6
Ba	1058	588	1102	355	450	231
La	80.2	105.99	68.568	14.175	26.583	8.21
Ga	21.3	22.6	19.7	19.7	18.9	18.2
Zn	114.1	130.1	100.5	90.1	78.6	87
Cu	70.3	47.2	42.7	55.5	58.7	38.8
Ni	143	376.3	104.5	122.2	44.7	111.1
Co	41.62	55.34	41.69	40.48	46.20	36.26
Cr	343.3	466.7	148.9	211.5	44.7	242.8
Sc	18.5	16.83	16.08	22.9	28.29	21.41
La	80.2	105.99	68.57	14.17	26.58	8.21
Ce	136.6	218.69	135.99	40.854	56.977	21.223
Nd	63.08	82.809	58.999	15.46	30.602	13.378
Sm	12.78	15.798	9.382	4.416	6.298	4.361
Eu	3.397	4.938	2.979	1.635	1.999	1.555
Tb	1.178	1.772	1.229	0.896	0.989	0.926
Yb	2.255	2.561	1.982	1.855	1.855	1.896
Lu	0.248	0.278	0.226	0.186	0.279	0.194
Th	9.446	16.131	8.96	2.965	2.381	1.256
Hf	7.532	9.323	7.096	2.868	3.356	1.888
$^{87}Sr/^{86}Sr$	.70358	.70396	.70497	.70439	.70424	.70478
$^{143}Nd/^{144}Nd$	.51284	.51276	.51275	.51274	.51279	.51268

Que: Quepuniyeu, Pra: Praguaniyeu, MT: Meseta del Toro, Com: Comallo.

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