CENTRAL ANDEAN MANTLE-DERIVED BASALTS AND NEOGENE MANTLE ENRICHMENT BENEATH THE PUNA PLATEAU

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INTRODUCTION

A barrier to understanding Andean magmatic source regions and processes in the Puna-Altiplano plateau has been a lack of chemical constraints from primitive and near-primitive mantle-derived magma. The observation is that Miocene and younger magmas erupted through the thickened crust of the plateau show enriched isotopic and trace element signatures. These chemical signatures have been variably ascribed to old enriched mantle, subducted sediment, subducted tectonically eroded forearc crust, in situ crustal contamination, or some combination of these processes (see review by Kay and Abbruzzi 1996). The purpose here is to address the nature and evolution of the mantle source region by examining the chemistry of primitive Plio-Pleistocene and Oligocene mafic magmas from the southern Central Volcanic Zone (CVZ). The data indicate that the Puna mantle has been enriched through the subduction process since the Late Oligocene. The existence of primitive Plio-Pleistocene mafic magmas in the region of highest average elevation in the Central Andes also raises questions as to how dense magmas rise through thickened crust.

TECTONIC SETTING OF THE MAFIC MAGMAS

The lavas considered here outcrop in the reion of the southernmost CVZ near 27° S (Fig. 1). The Oligocene lavas occur in the forearc of the modern CVZ in the Segerstrom belt (26° 52', 68° 49'). They sit backarc to the main andesitic-dacitic Oligocene volcanic arc (see Kay et al. 1994) and are among the early lavas erupted in the modern Andean magmatic cycle. These lavas constitute one of the scattered occurrences of Oligocene backarc mafic lavas that extend from at least 30° S to 22° S latitude. Two samples yield whole rock K/Ar ages of 24.0±0.9 and 24.3±0.9 Ma. The Plio-Pleistocene magmas erupted some 50 km to the east in the modern CVZ volcanic arc from mafic cinder cones on the flanks of the Incahuasi (top at 6610 m) and San Francisco volcanic centers near 26.9° S, 68.25° W latitude. Their young morphology and their superposition over dacitic lavas on San Francisco dated at 1.2±0.7 Ma limit their age to < 2 Ma. The cinder cones are at a minimum elevation of 5000 m.

These Pleistocene lavas as well as other young Puna basaltic and basaltic andesite lavas have erupted from cinder cones and fissure flows associated with normal/strike slip fault zones. The fault zones separate major crustal blocks and are major zones of crustal weakness. The San Francisco and Incahuasi region flows are some of the mafic flows near the northeast-trending fault zone which includes the Escarpe Robertson fracture of Gonzalez-Ferran et al. (1985) and extends northward towards the elongate, fault-controlled Salar de Antofalla. The most mafic Puna flows are Late Miocene to Pleistocene in age and overlap the most recent period of motion on these

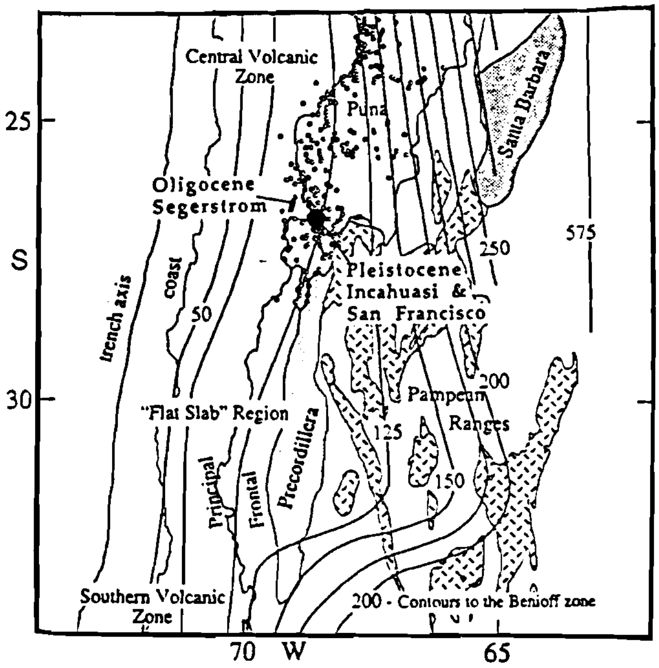

Figure 1. Map of central Andes showing mafic lava sample sites relative to modern tectonic framework. Circles are representative Neogene volcanic centers. Modern active Central Volcanic Zone terminates at Ojos de Salado volcano on southern edge of dot marking location of Incahausi and San Francisco volcanoes.

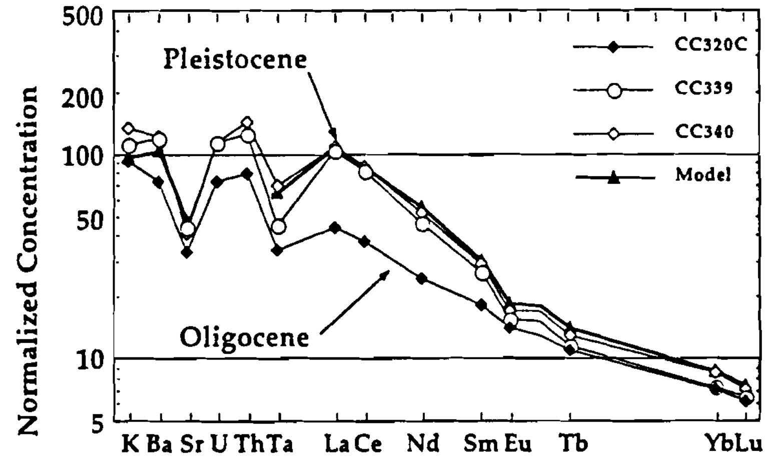

Figure 2 - Extended trace element patterns normalized to MORB for volatile elements and chondrites. Factors (ppm): K (116), Ba (3.77), Sr (14), U (0.015), Th (0.05), Ta (0.02), La (0.378), Ce (0.976), Nd (0.716), Sm (0.23), Eu (0.0866), Tb (0.589), Yb (0.249) and Lu (0.0387). Data in Table 1.

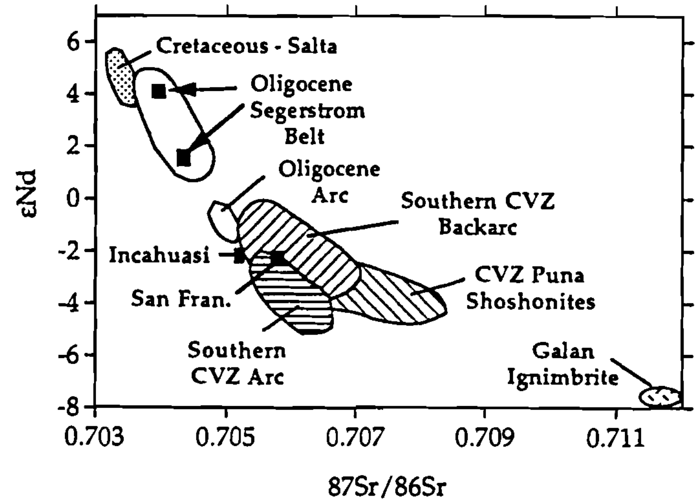

Figure 3 - Plot of ϵNd versus $^{87}Sr/^{86}Sr$ for Oligocene Segerstrom and Pleistocene Incahuasi and San Francisco lavas relative to Cretaceous alkaline, Oligocene arc, southern CVZ mafic (<60% SiO_2) and Puna shoshonitic lavas, and Cerro Galan ignmibrite to east. Note Incahuasi and San Francisco data overlap southern CVZ mafic lavas. Data from Kay et al. (1994), Kay and Abbruzzi (1996), Francis et al. (1989) and references therein.

faults. Kay et al. (1994) have proposed that this fault motion is genetically linked with catatrophic loss ("delamination") of continental Puna lithosphere since the Late Miocene.

CHEMISTRY OF THE MAFIC LAVAS: EVIDENCE FOR NEOGENE MANTLE ENRICHMENT AND MIXING WITH PONDED SILICIC MAGMA IN THE THICKENED CRUST

The primitive nature of the Oligocene and Pleistocene lavas whose analyses are shown in Table 1 is indicated by their low FeO/MgO ratios, their high MgO (>9%), Cr (500 to 690 ppm) and Ni (155-200 ppm) concentrations, and their phenocryst populations. In detail, the most mafic Oligocene basalt (CC320c - 49% SiO_2) has a higher FeO/MgO ratio (1.0 versus 0.8) and less primitive phenocrysts (olivine - Fo82; clinopyroxene - En46Fs9Wo45; plagioclase - AN72) than the Pleistocene lavas (CC339 and CC340). The Pleistocene lavas are characterized by about 53% SiO_2, primitive FeO/MgO ratios (0.77-0.82), primitive phenocrysts (olivine: FO88-89; clinopyroxene: En48Fs8Wo44 - CC339 only) that are in equilibrium with a magma of the whole rock composition, and a lack of plagioclase phenocrysts.

Table 1 - COMPOSITIONS OF NEAR PRIMITIVE PUNA MAGMAS

	Oligocene	Pleistocene			
	Segerstrom	Incahuasi	San Fran.	Model*	L. Verde
SAMPLE	CC320C	CC339	CC340	Magma	LV364
SiO_2	49.18	53.55	53.08	48.49	74.00
TiO_2	1.24	0.90	1.19	1.39	0.30
Al_2O_3	15.32	14.80	14.81	15.12	13.39
FeO	9.64	7.22	7.40	8.72	1.28
MnO	0.14	0.13	0.15	0.17	0.06
MgO	9.09	9.36	8.99	10.88	0.36
CaO	10.18	8.33	8.36	9.91	1.29
Na_2O	2.73	2.97	3.14	2.96	3.97
K_2O	1.29	1.57	1.86	1.36	4.16
P_2O_5	0.31	0.28	0.31	0.35	0.15
Volatiles	0.43				0.45
Total	99.55	99.11	99.29	99.35	99.41
La	16.9	39.1	40.9	41.4	38.4
Ce	36.5	79.9	83.7	85.0	77.6
Nd	17.8	33.3	37.0	39.7	24.9
Sm	4.22	6.07	6.77	7.11	5.2
Eu	1.23	1.37	1.49	1.65	0.75
Tb	0.654	0.681	0.770	0.839	0.456
Yb	1.78	1.81	2.13	2.20	1.82
Lu	0.243	0.254	0.279	0.291	0.228
Sr	471	618	579	675	141
Ba	276	450	460	396	750
Cs	0.57	0.93	0.92		9.8
U	1.1	1.7	1.7		10.4
Th	4.0	6.2	7.2		29.7
Hf	3.0	4.0	4.1	4.1	4.4
Ta	0.69	0.90	1.4	1.3	2.1
Sc	31.7	23.4	23.6	28.0	3.0
Cr	689	602	507	618	<1
Ni	155	197	188	229	<1
Co	46	37	37	45	1
FeO/MgO	1.06	0.77	0.82	0.80	3.55
Ba/La	16.4	11.5	11.2	9.6	19.5
La/Sm	4.0	6.4	6.0	5.8	7.4
La/Yb	9.5	21.6	19.2	18.8	21.1
Eu/Eu*	0.92	0.79	0.76	0.83	0.55
La/Ta	24	43	29	32	18
Th/U	4.0	3.6	4.2		2.9
$^{143}Nd/^{144}Nd$	0.512857	0.512538	0.512525	0.512544	0.512389
ϵNd	+4.3	-2.0	-2.2	-1.8	-4.9
$^{87}Sr/^{86}Sr$	0.703978	0.705230	0.705797	0.705782	0.706500@
$^{206}Pb/^{204}Pb$		18.979	18.890		18.90
$^{207}Pb/^{204}Pb$		15.618	15.631		15.67
$^{208}Pb/^{204}Pb$		38.976	39.008		39.04

*Model - composition calculated by subtracting 18% of Laguna Verde Ignminbite LV364 from San Francisco lava CC340.

@Isotopic composition approximated from other ignimbrites in region. Referenced to ϵNd.

Comparison of the Oligocene and Pleistocene magmas suggests that the Pleistocene magmas are from a more enriched mantle source then the Oligocene magmas. Evidence comes from higher $^{87}Sr/^{86}Sr$ and lower $^{143}Nd/^{144}Nd$ ratios (Fig. 3) and higher normalized light REE and Ba levels (Fig. 2) at roughly the same heavy REE level. As discussed below, this "enriched" component is difficult to explain solely by crustal contamination in the thickened Puna crust. The data support an enriched mantle source as predicted by modeling of less primitive CVZ back-arc lavas by Francis et al. (1989), Mantovani and Hawksworth (1990), and Kay et al. (1994).

That is not to say that no crustal contaminants enter the Pleistocene magmas as they ascend. In fact, their relatively high SiO_2 contents (53%), their negative Eu anomalies despite a lack of plagioclase phenocrysts and high Sr contents (>600 ppm), and their sparse feldspar and quartz xenocrysts are best explained by a crustal contaminant (see also Kay et al. 1994). Addition of ≈ 18% of a silicic crustal melt like the nearby Pliocene Laguna Verde ignimbrite (74-77% SiO_2; Table 1 and Fig. 2), seems a likely process. Removing such a component from the Pleistocene lavas results in a primitive magma (Table 1) that differs primarily in having lower SiO_2 (48.5%), K_2O (1.36%), U, and Th, and higher MgO (10.9%) and CaO (9.9%) concentrations. Importantly, the "enriched" source signals of the Pleistocene lavas - high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ ratios and REE pattern (Figs. 2 and 3) - are little modified by such a process. The model is not perfect as too much U and Th is removed and a negative Eu anomaly remains. The model is somewhat improved by a silicic component with a larger Eu anomaly and lower U and Th contents. However, the lower Sr and REE contents of such a contaminant would have even less effect on the "enriched" signal of the mantle-derived magma.

The best explanation is that the Pleistocene magmas are primitive mantle-derived magmas that mixed on ascent with pockets of silicic melts ponded at levels in the crust where both feldspar and quartz were crystallizing. The presence of only sparse olivine phenocrysts and the near primitive character of the San Francisco lava shows that only a small amount of fractionation occurred and that ascent was rapid. This is more consistent with contamination being primarily through mixing with ponded silicic magmas rather through fractionation-assimilation (AFC) processes. Even extreme AFC models like that of Aitcheson and Forrest (1994) have problems producing these magmas if the Laguna Verde ignimbrite is representative of the contaminant. The conclusion of an enriched mantle beneath the southern Puna in the Pleistocene seems inescapable.

The Late Oligocene Segerstrom basalts put a timescale on this mantle enrichment as they are derived from a less enriched mantle. Other support for at least post middle Cretaceous enrichment comes from the depleted isotopic signatures (modern day ratios - $^{87}Sr/^{86}Sr \approx 0.7033$; ϵ Nd ≈ +5) in ≈ 85 Ma lavas from the Salta region east of the Puna (Kay et al. 1994). The mechanism of mantle enrichment must thus be linked to the Neogene subduction process.

REFERENCES

Aitcheson, S.J., and Forrest, A.H., 1994. Quantification of crustal contamination in open magmatic systems. Jour. Petrology, 35, 461-488.

Gonzalez-Ferran, O., Baker, P.E., and Rex, D. C. 1985, Tectonic-volcanic discontinuity at latitude 27° South, Andean Range, associated with Nazca plate subduction. Tectonophysics 112: 423-441.

Francis, P.W., Sparks, R.S.J., Hawkesworth, C.J., Thorpe, R.S., Pyle, D.M., Tait, S.R., Mantovani, M.S., and McDermott, F., 1989, Petrology and geochemistry of volcanic rocks of the Cerro Galan caldera, northwest Argentina. Geol. Mag. 126: 515-147.

Kay, S.M. and Abbruzzi, J.A., 1996, Magmatic evidence for Neogene lithospheric evolution of the central Andean "flat-slab" between 30° and 32° S, Tectonophysics: in press.

Kay, S. Mahlburg, Coira, B., and Viramonte, J., 1994, Young mafic back-arc volcanic rocks as guides to lithospheric delamination beneath the Argentine Puna Plateau, Central Andes. J. Geophys. Res. 99: 24323-24339.

Kay, S.M., Mpodozis, C., Tittler, A., and Cornejo, P., 1994, Tertiary magmatic evolution of the Maricunga mineral belt in Chile, International Geology Review 36: 1079-1112.

Mantovani, M.S. and Hawkesworth, C., 1990, An inversion approach to assimilation and fractional crystallization processes in the Central Andes. Contrib. Mineral. Petrol. 105: 289-302.

APPENDIX - ANALYTICAL METHODS

Major elements by electron microprobe at Cornell Univ. (CC339, CC340) and by atomic absorption and wet methods at Chilean survey (CC320c; LV364). Trace elements by Instrumental Neutron Activation Analyses (INAA) and isotopic ratios on VG Sector mass spectrometer at Cornell University. Sr normalized to $^{86}Sr/^{88}Sr = 0.1194$. Standard values: $^{87}Sr/^{86}Sr$ on NBS987 = 0.710265 (±.000036) and $^{143}Nd/^{144}Nd$ on La Jolla + 0.511847(±0.000036). ϵ Nd based on La Jolla at -15.15. Within-run 2σ errors = ± 0.000005 to 0.000007. Pb ratios corrected for mass fractionation using $^{206}Pb/^{204}Pb = 16.937$, $^{207}Pb/^{204}Pb = 15.493$, and $^{208}Pb/^{204}Pb = 36.705$ for NBS SRM981.

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