

Regional patterns in arc magma composition in the Andean Central Volcanic Zone (13°S-28°S)

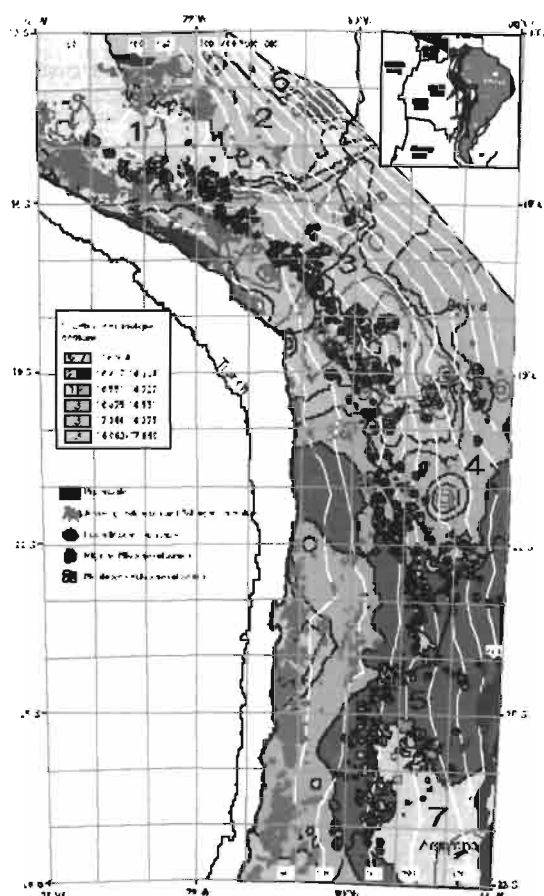
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INTRODUCTION

Cenozoic volcanism in the CVZ formed on continental crust that changed thickness from less than 40 to > 70 km. Enhanced uplift between c. 30 and 15 Ma is documented by large clastic sediments wedges and ignimbrites at the Western Andean Escarpment (Wörner et al., 2000a). We evaluated >1100 rock samples for major and trace elements as well as a large subset for isotopes over 1600 km along the CVZ (Fig. 1), which we combine with selected published data.

These samples fall into different geological and geochemical groups defined by Pb-Sr-Nd isotopic ratios, radiometric age (prior-during-after crustal thickening ~150 - 0 Ma), and incompatible elements (e.g. Sr/Y, Sm/Yb, Zr/Nb ratios) on a CVZ-wide scale. Pb-Sr-Nd isotopes are independent of SiO₂; they are dominated by Proterozoic and Paleozoic crustal assimilation and, especially Pb-isotopes delineate distinct basement domains. Miocene rocks (24 – 15 Ma) have lower incompatible trace element concentrations, Mio-Pliocene rocks (15 – 3 Ma) are slightly enriched in incompatible elements, and most of the Plio-Pleistocene-Holocene lavas (< 3 Ma) are variably enriched in incompatible elements. The incompatible trace element variations between Miocene and Mio-Pliocene-Pleistocene-Holocene lavas are caused by garnet in the residue of assimilation with Proterozoic crustal and/or during high-P fractional crystallization (Kay et al., 1999).



CENOZOIC VOLCANISM

Rocks between 24-15 Ma (Miocene) are syn-uplift volcanics and are calc-alkaline andesites, dacites, and rhyolites. They comprise stratovolcanoes and large volume ignimbrites that have been erupted from caldera complexes. Lavas from 15 to 3 Ma (Mio-Pliocene) are represented mostly by stratovolcanoes, dome-clusters and only minor and more local ignimbrites. Pliocene-Pleistocene and Holocene volcanoes (≤ 3 Ma) form the present volcanic chain of stratovolcanoes. Back-arc Neogene volcanic activity behind the main magmatic arc is limited to large faults, where rhyolitic ignimbrites to basaltic andesite flows have been erupted.

Fig. 1: Map showing the distribution of Neogene volcanoes and main Paleozoic and Mesozoic intrusion outcrops in their domain. Isotopic-map based on 834 ²⁰⁶Pb/²⁰⁴Pb ratios. White lines are the contours of the Wadati-Benioff zone with depth in kilometers.

GEOCHEMISTRY

Along CVZ the Pb-Sr-Nd isotopes are independent of SiO₂. Pb isotopic ratios are divided into three groups: a low ²⁰⁶Pb/²⁰⁴Pb = 17.5 to 18.5, middle ²⁰⁶Pb/²⁰⁴Pb = 18.5 to 18.7 and high ²⁰⁶Pb/²⁰⁴Pb = 18.7 to 18.9. These Pb ratios reflect the composition of the underlying basements and delineate different domains because Pb-isotopes are dominated by crustal contributions. These are called from N to S domains 1-2-6-3-4-5-7 in this work (Fig. 1 and 2).

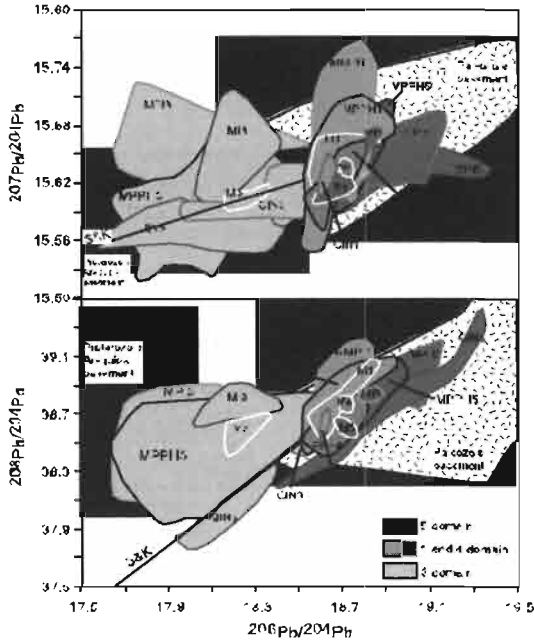


Fig. 2: ²⁰⁷Pb/²⁰⁴Pb, ²⁰⁸Pb/²⁰⁴Pb vs. ²⁰⁶Pb/²⁰⁴Pb isotope diagrams showing clearly the different Pb-isotopes groups based in Pb isotope ratios of Proterozoic rocks (2-1 Ga), Paleozoic rocks (510–260 Ma), JIN=Jurassic intrusions (190-130 Ma), CIN=Cretaceous intrusions (90-60 Ma), M= Miocene lavas (25-15 Ma), MPPH=Mio-Pliocene-Pleistocene-Holocene volcanoes (15-0 Ma), and MPI= Mio-Pliocene ignimbrites (< 15 Ma), MI= Miocene ignimbrites (15-29 Ma). These samples independent of age at any given zone show that Pb-isotope derived from the type of basements and delineate distinct groups y/or domains (e.g. domain 3 derived from Proterozoic basements and domains 1-4-5 derived from Paleozoic basements). The ignimbrites are slightly in ²⁰⁸Pb/²⁰⁴Pb and ²⁰⁷Pb/²⁰⁴Pb ratios for a given ²⁰⁶Pb/²⁰⁴Pb than those of lavas and intrusion. S&K=average crustal growth curve of Stacey and Kramers (1975).

Incompatible trace element patterns for Neogene volcanics are typical of continental-margin arc magmas. Mesozoic to Middle Miocene igneous rocks are lower in incompatible elements (e.g. Sr/Y, Sm/Yb ratios), Mio-Pliocene (~15-3 Ma) lavas show slightly higher ratios while Pliocene and recent (<~ 3 Ma) are variably enriched in incompatible elements and heavy rare earth elements HREE. To the south in domains 4 and 5 (latitude: 22°S-28°S) volcanics tend to have lower Sr/Y, Sm/Yb ratios while between 15°S and 20°S in (domains 3-1) they tend to have higher ratios (Fig. 3 and 4b).

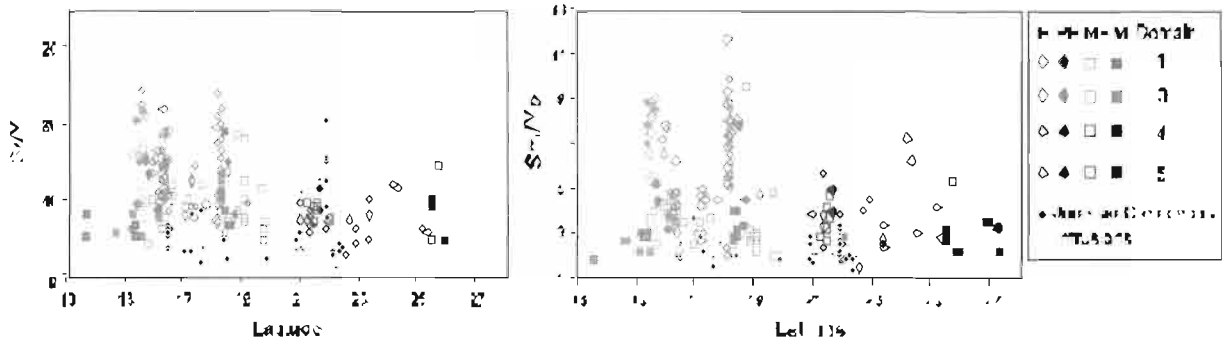


Fig. 3: Diagrams Sr/Y and Sm/Yb for igneous rocks (SiO₂ < 59%) along the CVZ show that in a given domain (e.g. 1-3-4-5), Miocene lavas and older rocks tend to be lower in Sr/Y – Sm/Yb and Pliocene-Pleistocene-Holocene lavas south of 22°S from the 4-5 domains tend to have lower Sr/Y and Sm/Yb base-line values while the lavas from 1-3 domains have higher Sr/Y and Sm/Yb values. H=Holocene (0-0.8 Ma), PP=Plio-Pleistocene (0.8-3 Ma), MP=Mio-Pliocene (3-15 Ma), M=Miocene lavas (15-25 Ma).

The plot of Sr (ppm) versus Sr-isotopes shows two trends (Fig. 4a): A high-Sr trend (>800 ppm) at intermediate $^{87}\text{Sr}/^{86}\text{Sr}$ (0.7055 to 0.7070) in Mio-Pliocene and Recent andesite-dacites from domains 3-1 and the second trend to higher $^{87}\text{Sr}/^{86}\text{Sr}$ (>0.7070) but lower Sr (> 300 ppm) in Neogene ignimbrites of domains 1-3-5 (Fig. 4a). According to where assimilation and differentiation occurred in the crust, Sr behaves either compatibly where plagioclase is stable (low pressure, second trend) or incompatibly where plagioclase is unstable at higher pressures (Davidson et al., 1990) where garnet is stable (50 to 70 km, first trend). Other incompatible elements (e.g. Zr/Nb vs. Sm/Yb= measure of garnet in residue) show that most Mio-Pliocene and Recent lavas from domains 3-1 have higher Sm/Yb indicating assimilation with a stronger role for garnet (Fig. 4b).

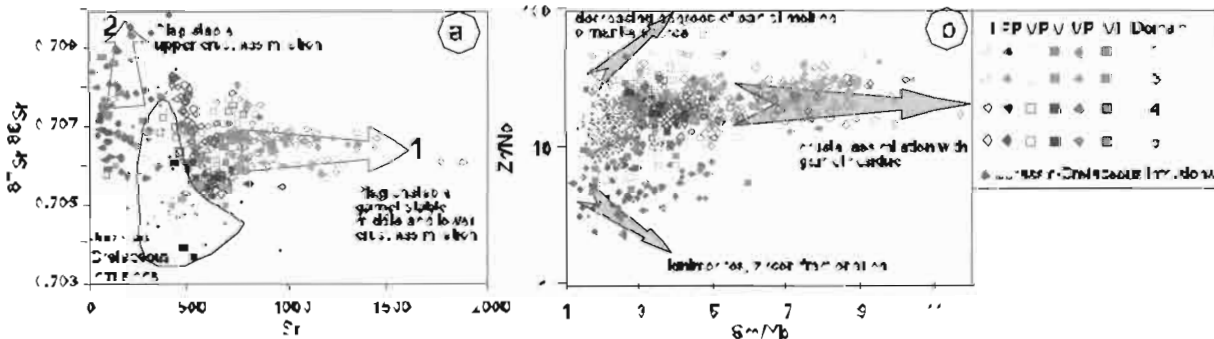


Fig. 4: a) $^{87}\text{Sr}/^{86}\text{Sr}$ versus Sr relations for Neogene volcanoes from domains 1-3-4-5 compared with Jurassic-Cretaceous rocks, the Mio-Pliocene to recent lavas from domains 3-1 given to where plagioclase is unstable but garnet stable and the Miocene to recent ignimbrites tend to plagioclase is stable. b) The diagram between Zr/Nb vs. Sm/Yb, show also that the Mio-Pliocene to recent lavas from domains 3-1 tend to be where garnet is in the residue. MPI= Mio-Pliocene ignimbrites (< 15 Ma), MI= Miocene ignimbrites (15-29 Ma).

There is a general pattern of decreasing ϵNd and increasing $^{87}\text{Sr}/^{86}\text{Sr}$ for each domain along the CVZ rocks (Fig. 5). Nd-Sr isotope variations reflect the process of crustal contamination: the smallest crustal contamination is observed for Cretaceous intrusions ($\leq 10\%$); in domains 1-4-5 Miocene andesites have $\leq 30\%$ and the maximum crustal contamination have the Mio-Pliocene to Recent andesites and dacites 40 %, in domain 3 Miocene have 20% and the Mio-Pliocene to Recent andesites-dacites have 30% (Fig. 5). Higher $^{87}\text{Sr}/^{86}\text{Sr}$ in ignimbrites from domains 1-5-3 indicate that they have an additional crustal component added by contamination of low Sr magmas (Fig. 4a) late in the differentiation process (Fig. 5).

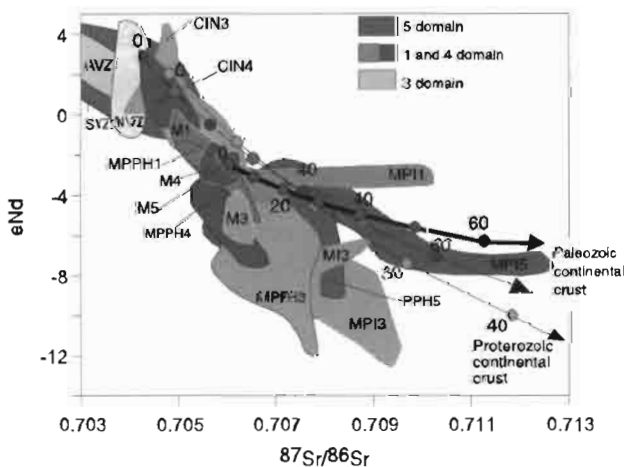


Fig. 5: Plot of ϵNd vs. $^{87}\text{Sr}/^{86}\text{Sr}$ for CVZ, show a determine domain with different trends, but in general from low to high $^{87}\text{Sr}/^{86}\text{Sr}$ and high to low ϵNd . Curves show results of simple mixing model between the different rocks in each domain (e.g. for domain 3 between Cretaceous granite (67 Ma) and Proterozoic gneiss (2 Ga), domains 1-4 between Cretaceous basalt (105 Ma) and Paleozoic gneiss (460 Ma), domain 5 between Miocene andesite (19.6 Ma) and Paleozoic orthogneiss (460 Ma). Circles mark percentages of crustal contamination of specific domain. NVZ=north volcanic zone (Bourdon et al., 2002), SVZ=south volcanic zone (Kay et al., 2005) and AVZ=austral volcanic zone (Stem and Killian 1996)

CRUSTAL COMPOSITION VERSUS CRUSTAL THICKNESS AND BASEMENT AGE

Higher Sr/Y and Sm/Yb between Miocene and Pleistocene-Holocene volcanic rocks in domains 1-3 is mostly controlled by low Y and Yb in the younger rocks (< 6 Ma) caused by garnet in the residue of mafic lower crustal assimilation (e.g. granulites and amphibolites) and/or during high-P fractional crystallization after crustal thickening. Any involvement of slab melts to explain the "adakitic" signature is excluded. To the South in domains 4-5 Sr/Y and Sm/Yb are lower although crustal thickness is similar to domains 1-3. This difference may reflect the effect of more silicic crustal composition to the south and/or shallower crustal assimilation in thick crust. High Sr/Y and Sm/Yb ratios in a particular rock can thus not be simply taken as a proxy for thick crust as crustal compositions and depth of assimilation also must play a role.

Nd-Sr-Pb isotopes and incompatible elements of rocks older than Miocene show limited evidence of crustal interaction not involving garnet, in accordance with a thin crust at these times.

The crustal contamination in Mio-Pliocene to Recent lavas (~11-0 Ma) increases to 20% after crustal thickening.

Regional differences exist in other trace element ratios as well. This supports the notion that the crust not only controls the isotopes composition of magmas but also their trace element patterns through variable mineralogies in a crustal residue during assimilation. Significant isotopic and trace element differences are also observed for rocks of the same age but at slightly different locations. Thus, caution needs to be applied when plotting any geochemical data vs. age for rocks from a wide regional distribution as local basement compositional control maybe more important than age in controlling their geochemical composition.

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