ISOTOPIC CONSTRAINTS ON MIOCENE TO RECENT EVOLUTION OF THE CENTRAL ANDEAN LITHOSPHERE OVER THE "FLAT-SLAB"

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RESUMEN: Relaciones isotópicas de Pb, Sr y Nd de rocas volcánicas pertenecientes al "flat-slab" son utilizadas como indicadores de cambios litosfericos debido a la horizontalización de la Placa de Nazca. Las relaciones isotópicas reflejan entre otras cosas un engrosamiento cortical de la Cordillera Principal, un basamento no radiogenico de ≈ 1100 Ma en la Precordillera, y la posibilidad de un componente litospherico basal que debe haberse desplazado hacia el este durante la horizontalización en rocas volcánicas de las Sierras Pampeanas.

KEY WORDS: Shallow subduction, arc volcanism, isotope, Miocene to Recent, lithosphere, crust

INTRODUCTION

Pb, Sr and Nd isotopic ratios of Late Oligocene to Pliocene volcanic rocks in the Central Andean "flat-slab" region (28° S to 33° S; Fig. 1) can be used as tracers for crustal and mantle processes occurring above a shallowing subduction zone. These tracers are most powerful when combined with geophysical and geologic data that constrain lithospheric geometries. The purpose here is to integrate Pb, Nd and Sr isotopic constraints (Figs. 2 and 3) on "flat-slab" magma sources into a refined lithospheric model (Fig. 4) for the late Miocene to Recent evolution of the "flat-slab".

LITHOSPHERIC CONSTRAINTS FROM GEOPHYSICAL AND GEOLOGIC DATA

Constraints on the modern lithospheric geometry of the "flat-slab" come from seismic studies (e.g., Smalley and Isacks 1990) that define the shape of the seismic zone and put limits on lithospheric and asthenospheric thicknesses (see Fig. 4). Reconstructions of past lithospheric geometries are based on modern day analogues in the Southern Volcanic Zone (SVZ; Fig. 1) chosen by matching the geologic setting and chemistry of "flat-slab" magmatic rocks with those in the SVZ. Using this method, Kay et al. (1991) concluded that early Miocene "flat-slab" volcanism occurred over a steeply dipping slab like that south of 35° S, that mid Miocene volcanism occurred over a shallower slab like that near 33° S, and that late Miocene volcanism occurred over a shallower slab than exists in the SVZ. These comparisons imply an increase in Main Cordillera crustal thickness from ≈ 40 to 45 km at ≈ 20 Ma to near the poorly constrained modern value of ≈ 65 km at 6 Ma.

Temporal constraints on thickening come from field and seismic data that suggest that 170 to 190 km of early Miocene to Recent crustal (and lithospheric) shortening has occurred in three north-south trending belts (Allmendinger et al. 1990). From west to east, these belts are the Main Cordillera, the Precordillera fold and thrust belt, and the block faulted ranges of the Sierras Pampeanas (Fig. 1). Approximately 100 km of the surface shortening occurred in the Precordillera above a decollement that is now at ≈ 15 km. Another 50 to 60 km took place in the Main Cordillera, and the rest (20 to 30 km) in the Sierras Pampeanas. A combination of radiometric, stratigraphic and paleomagnetic data shows that shortening began at ≈ 20 Ma in the Precordillera, primarily occurred

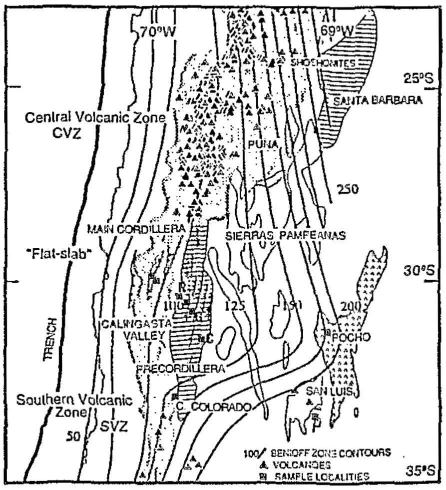

FIGURE 1 - Map of central Andes showing important geologic provinces in the "flat-slab" and adjacent Central and Southern Volcanic Zones. Base map and contours to seismic zone after Isacks (1988).

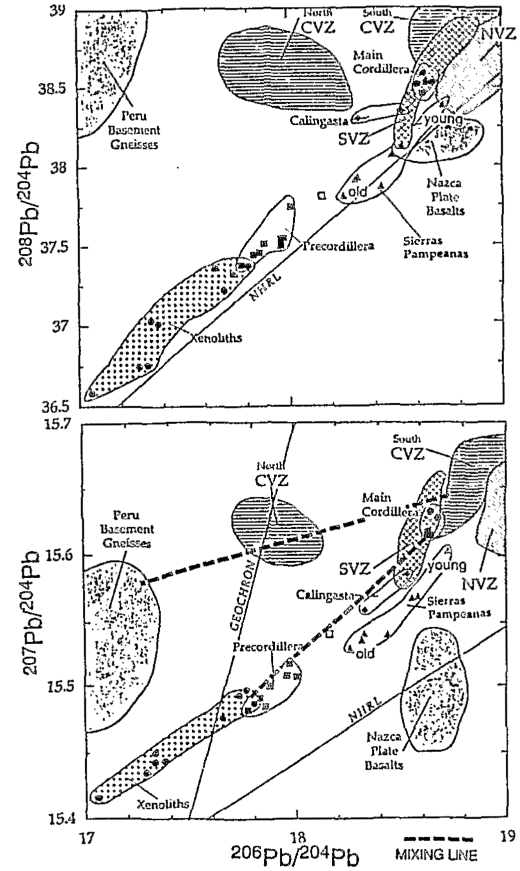

FIGURE 2 - Plots of central Andean Pb isotopic data. Fields for Peruvian, CVZ, CVZ, SVZ and Nazca plate rocks are from Davidson et al. (1988). Points are our unpublished data. NHRL is Northern Hemisphere Reference Line. CVZ mixing model is from Barreiro (1984).

in the early Miocene in the Main Cordillera, and was principally post-late Miocene in age in the Sierras Pampeanas (Allmendinger et al. 1990; Jordon et al. 1993). A temporal correlation between Main Cordilleran and Precordilleran crustal shortening and Main Cordilleran crustal thickening is consistent with crustal thickening primarily resulting from crustal shortening.

CONSTRAINTS ON "FLAT-SLAB" MAGMA SOURCES FROM ISOTOPIC DATA

Main Cordillera - Sr and Nd isotopic ratios in Main Cordilleran arc rocks (basaltic andesite to rhyolite in the early Miocene, hornblende andesite to dacite in the mid Miocene, dacitic ignimbrites in the late Miocene) fall in three age-dependent groups (Fig. 3). All of these samples have lower ϵ Nd and higher Sr ratios than early Miocene back-arc tholeiitic basalt to the east showing that they have an excess radiogenic crustal component that cannot be attributed to an ancient enriched mantle component. A trend of increasing Sr ratios and decreasing ϵ Nd with decreasing age among the arc groups shows that greater amounts of this crustal component were added through time. Given other evidence for a simultaneous increase in crustal thickness, larger amounts of radiogenic crustal contaminant can be explained by augmented interaction of mantle magmas with crust as ascent paths became longer and more difficult.

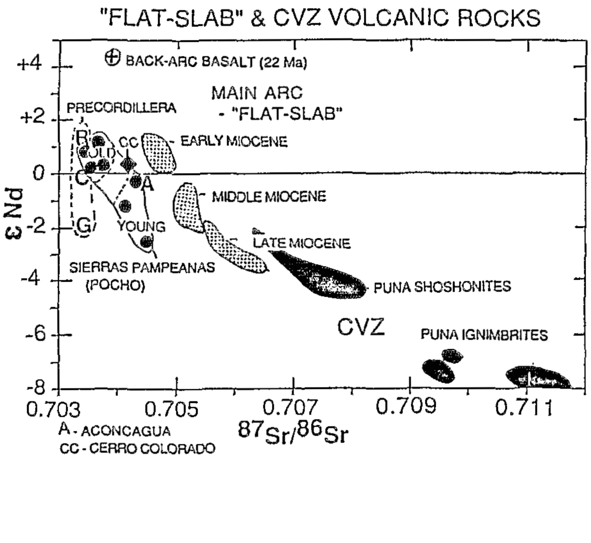

FIGURE 3 - Plot of Nd and Sr isotopic data for "flat-slab" and CVZ volcanic rocks. Main Cordillera data are from Kay et al. (1991). Points are our unpublished data. CVZ data is from the literature and our unpublished data.

An additional contribution to these magmas from a subducted sediment component is suggested by Pb isotopic data. Unlike Nd and Sr isotopic data, Pb isotopic data for Main Cordilleran magmatic rocks fall in a restricted field (Fig. 2). This field, like those of young Andean SVZ and southern CVZ arc rocks (Fig. 2), is within the typical range for arc rocks world-wide. This Pb signature is commonly attributed to the mixing of subducted upper crustal sediments with melts of the mantle wedge above the subducting slab. In the "flat-slab", this interpretation requires a subducted sediment component in the backarc as both backarc and arc rocks have similar Pb signatures. An alternative is that both subducted sediments and in-situ crustal contamination play a role. Either way, Main Cordillera sources have a distinctive Pb signature that is important in interpreting isotopic signatures of Mio-Pliocene Precordillera and Sierra Pampeanas volcanic rocks.

Precordillera - Pb, Sr, and Nd isotopic ratios of mid to late Miocene silicic andesitic and dacitic Calingasta Valley and Precordilleran rocks are unlike those of Main Cordillera rocks (Figs. 2 and 3). In fact, the Pb and Sr ratios in these rocks are the lowest yet reported in Miocene to Recent central and southern Andean rocks. The least radiogenic ratios are from a ≈ 7 Ma sample from the Cerro Blanco-Ullun center in the eastern Precordillera (C in Fig. 1). The overlap of these ratios with those of xenoliths from the unexposed Precambrian basement (discordant zircon fractions from a silicic xenolith give U/Pb age of 1188±123 Ma) shows that these nonradiogenic ratios reflect the basement. Thus, the trend of Precordilleran Pb isotopic ratios in Figure 2 can be explained by mixing basement with an orogenic arc component, just as northern SVZ Pb ratios were explained by mixing Peruvian basement with an orogenic arc component (Barreiro 1984; Fig. 2). In detail, eruption age and location are important in interpreting sources of Precordilleran Miocene magmas as more radiogenic samples are either older or farther west than less radiogenic ones. Calingasta Valley rocks (e.g., C. Colorado) whose isotopic compositions are the most radiogenic are the oldest and closest to the Main Cordillera.

Sierras Pampeanas - Sr, Nd, and Pb isotopic ratios of Mio-Pliocene Pampean volcanic rocks (Pocho and San Luis; Fig. 1) are intermediate between those of Precordillera and Main Cordillera rocks (Fig. 2 and 3). As in Precordilleran lavas, relatively low Pb and Sr isotopic ratios are best interpreted as reflecting continental basement. Relatively more radiogenic Pb and Sr ratios in Pampean than in Precordilleran lavas have three potential explanations: 1). eastern Pampean Precambrian basement is different, 2). Paleozoic magmatism has added an enriched component to the Pampean basement, and 3). Pampean lavas contain a more enriched sub-crustal component.

Further constraints on Pocho isotopic signatures come from the fact that basaltic andesitic to dacitic magmas erupted at ≈ 4 to 5 Ma are more like Main Cordillera rocks, whereas those erupted at ≈ 6 to 7 Ma are more like the Precordillera group. Two factors could be important: 1). crustal thickening leading to increasing amounts of a within-crust radiogenic component (like the Main Cordillera), and 2). increasing amounts of an enriched subcrustal component. An argument against crustal thickening being the only factor is that crustal shortening is minimal in the Sierras Pampeanas. An argument for a subcrustal component consisting of subducted sediment and continental lithosphere removed from the base of the Main Cordillera comes from combining, isotopic, structural and geophysical constraints.

A REFINED MODEL: MIOCENE TO RECENT MAGMATIC SOURCES AND THE LITHOSPHERIC EVOLUTION OF THE "FLAT-SLAB"

Steep Subduction : ≈ 25 to 20 Ma - The early Miocene geometry of the "flat-slab" was grossly like that of the steep subduction zone near 35° S in the modern SVZ. Main Cordilleran arc magmas formed in the usual way - release of fluids from the slab caused melting in the overlying asthenospheric wedge. These melts then passed into the continental lithosphere where they incorporated crustal and mantle material and fractionated at relatively low pressures before erupting. Minor amounts of back-arc olivine tholeiite erupted along a probable active fault zone. Structural and magmatic activity was virtually absent east of the Main Cordillera.

Initial Shallowing : ≈ 20 to 11 Ma - Shallowing of the subduction zone was underway by ≈ 18 to 20 Ma. Geological evidence for this shallowing comes from early Miocene high angle reverse faulting in the Main Cordillera, the early to mid Miocene broadening of the volcanic arc into the Precordillera, and the early Miocene initiation of thrusting and basin formation in the Precordillera. As a result, Main Cordilleran arc magmas began fractionating at greater depths and assimilating more crust as crustal thickness increased in response to crustal shortening. Upper crustal material was transported to deep levels in the Main Cordillera as Precordilleran crust was wedged into the Main Cordillera (Fig. 4). Magmas erupted in the east were more contaminated by Precordilleran-type basement. During this time, lithospheric geometry changed from like that in the SVZ today at ≈ 35° S to like that at 33° S. As a result the space for asthenospheric and lithospheric mantle above the slab decreased ≈ 30% out to 600 km east of the trench (≈ 20% to 800 km).

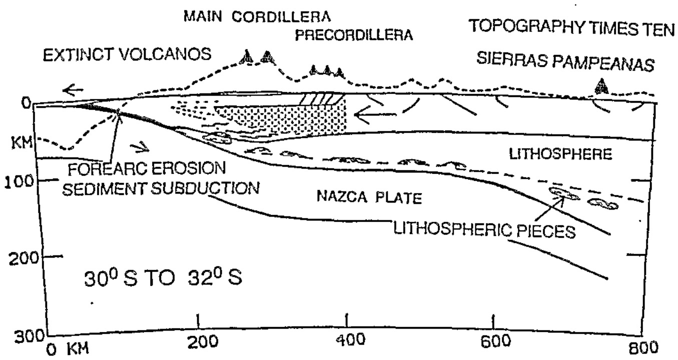

FIGURE 4 - Modern "flat-slab" lithospheric cross-section. Shape of subducting plate, lithospheric thickness, and topography from Smalley and Isacks (1990) and Isacks (1988). Volcano in Sierras Pampeanas represents Pocho volcanic field. Patterned wedge is crust from below decollement in Precordillera that is pushed into Main Cordillera (see Allmendinger et al. 1990).

Main shallowing phase ≈ 10 to 6 Ma - Important changes in "flat-slab" geology occurred between 10 and 5 Ma. Magmatic events included termination of Main Cordilleran andesitic volcanism at ≈ 10 Ma, broadening of the arc across the Precordillera into the Sierras Pampeanas at ≈ 7 Ma, the end of all volcanism in the Main Cordilleran and Precordillera between 7 to 6 Ma, and final Pampean volcanism at Pocho at ≈ 5 Ma. Structural events included important basin formation, thrusting in the Precordillera and uplift of the Sierras Pampeanas.

The dramatic eastward expansion of both magmatic and deformational fronts is taken to signal an important change in slab dip. Given the modern geometry of the seismic zone, the space for asthenospheric and lithospheric mantle above the subduction zone decreased ≈ 60% to a distance of 600 Km east of the trench (≈ 45% to 800 km) after the early Miocene. More than 30% of the continental mantle lithosphere within 600 km of the trench must have been displaced. This calculation is a minimum as it does not allow for lithospheric cooling as the subduction zone shallowed or for lithospheric thickening to accommodate 170 km of crustal shortening in < 600 km. A consequence implied by the section of Smalley and Isacks (1990) is that only crustal lithosphere is now present beneath the Main Cordillera. The proposition here is that continental lithosphere has been removed in pieces that have been carried into the asthenosphere by the mantle flow system circulating above the wedge. Indirect evidence for these lithospheric pieces potentially comes from the geochemistry of the Pocho volcanic rocks in the Sierras Pampeanas.

A consistent interpretation for the crustal component in the Pocho volcanic rocks is that it was, in part, derived from asthenosphere mantle melts that interacted with lithospheric pieces removed from beneath the Main Cordillera (Fig. 4). A temporal increase in this component in Pocho magmas is consistent with continued subduction. A rapid change in subduction zone geometry at ≈ 7 Ma would allow little time for such a component to be incorporated in ≈ 7 Ma Precordillera magmas which have a strong isotopic signature from the local basement.

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