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CHEMICAL SIGNATURES FROM MAGMAS AT THE SOUTHERN TERMINATION OF THE CENTRAL ANDEAN VOLCANIC ZONE: THE INCAPILLO/BONETE AND SURROUNDING REGIONS

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INTRODUCTION

The Incapillo Caldera in La Rioja province, Argentina near 27.8°S latitude (Fig. 1) is at the southern end of the Pleistocene to Recent Central Andean Volcanic Zone and marks the end of active volcanism at this latitude. The termination of volcanism in both space and time in this region is best related to the loss of critical mass of the asthenospheric wedge above the shallowing subducting Nazca plate. Here, we present a preview of new data on the chemistry and ages of Late Miocene to Pleistocene volcanic units in the Incapillo/Bonete region and compare them with contemporaneous volcanic units to the north and west. The very steep REE patterns and extreme high field element depletion in many of these units are among the most extreme in Phanerozoic units on Earth approaching those in Archean TTG suites (1). These ratios reflect extreme conditions in the continental lithosphere as the arc magmatic front migrated and volcanism ceased above the shallowing slab.

NEOGENE VOLCANIC UNITS IN THE INCAPILLO/JOTABECHE TRANSECT

The Incapillo-Bonete region is located east of the Oligocene to Miocene Maricunga Belt in Chile where arc volcanism ended at ~ 5 to 6 Ma with the eruption of the Jotabeche caldera rhyodacites and the small andesitic flows of the Pircas Negras unit (2,3). Contemporaneously, andesitic/dacitic volcanism (59-65 % SiO_2) began in the Incapillo/Bonete region as indicated by K/Ar ages that range from 6.5 to 3.5 Ma at the Nevado Pissis volcanic complex (15 ages), of 5.2±.6, 5.0±1.6, 4.2±.3 and 3.5±.1 Ma in the Bonete Chico region, of 5.6±1, 4.7±.5, 4.2±.4, and 3.6±.5 Ma in Sierra de Veladero, and of 4.7±0.5 Ma below the southern Incapillo units (Fig. 1). Pircas Negras type flows (57-63% SiO_2) erupted between the Incapillo region and the Maricunga Belt yield ages of 4.7±0.5, 3.2±0.3, and 1.9±0.2 Ma. Volcanism across the region ended with the emplacement of the silicic andesitic to rhyolitic domes and ignimbritic units (63-70% SiO_2) of the Incapillo caldera that have yielded ages of 2.9±.4, 1.9±.7, 1.6±.5, and 1.1±.4 Ma.

CHEMICAL SIGNATURES ASSOCIATED WITH TERMATION OF VOLCANISM

The Incapillo/Bonete region volcanic rocks have chemical signatures similar to those of Late Miocene Maricunga Belt lavas to the west and Late Miocene/ Pliocene units west of the modern CVZ to the north (Fig. 1). Distinctive characteristics include steep REE patterns as indicated by high La/Yb ratios and marked arc-like high field strength element depletion as indicated by high La/Ta ratios (Fig. 2). The steep REE patterns are due to both light REE enrichment and heavy REE depletion. These characteristics contrast with the lower La/Yb and La/Ta ratios of the Oligocene to Early Miocene units throughout the region and of the post-3 Ma magmas in the southern CVZ.

Chemical signatures of the Incapillo region and other volcanic rocks east of the Maricunga Belt can be correlated with the location, age and amount of volcanic activity at the arc front. In general, backarc Oligocene to Middle Miocene lavas are concentrated just east of the Maricunga arc and are characterized by low La/Yb and La/Ta ratios ('Normal' in figure 2). The picture changes at ~ 6 Ma as volcanism terminates in the Maricunga arc with the eruption of the Jotabeche and Pircas Negras units (2, 3) and spreads eastward across the backarc (Fig. 1). Most of the Late Miocene Maricunga arc units along with post-7 Ma Incapillo/Bonete region volcanic units are characterized by high La/Yb ratios that reach extreme values (> 60, Fig. 2) compared to other Andean volcanic rocks (<35). These volcanic rocks also have high La/Ta ratios with the highest values occurring in andesitic lavas. The highest La/Yb ratios are in 7 to 5 Ma Pircas Negras

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andesitic and Jotabeche rhyodacitic units in the Maricunga arc and in Valle Ancho and Incapillo/Bonete region lavas with ages near 5 Ma. As in the Maricunga belt, volcanism at the Incapillo center terminated with eruption of dacitic/rhyolitic magmas with high La/Yb and moderate La/Ta ratios (Fig. 2).

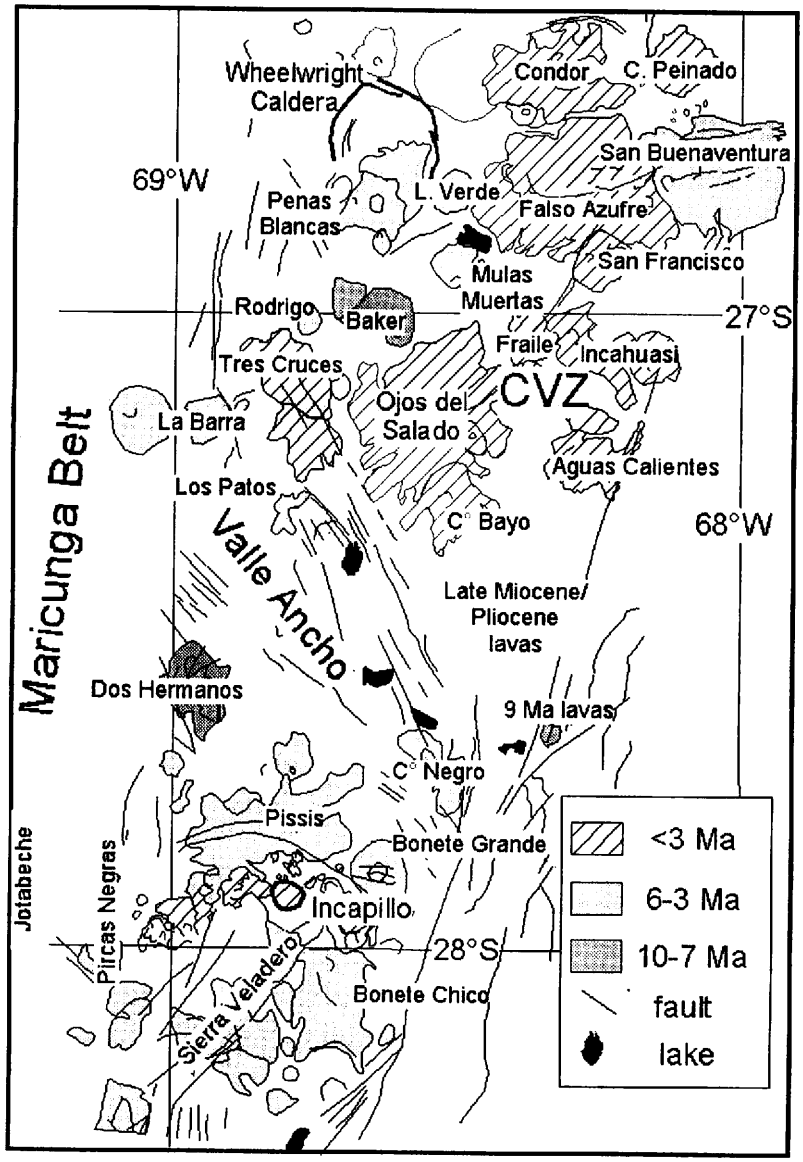

Fig. 1. Simplified map showing principal volcanic centers and faults in the southernmost CVZ (Central Volcanic Zone), Valle Ancho and Incapillo regions. Map is based on TM satellite imagery, unpublished mapping, and Mpodozis *et al.* (4, 5). Active CVZ extends from the Ojos del Salado complex north through the Cerro Peinado center. Maricunga volcanic belt is off the map to the west. Jotabeche center is west of Incapillo caldera (dark ring). Arc volcanism ended at 7-5 Ma in the Maricunga belt. From ~7-4 Ma volcanism was active across the region. Pleistocene activity south of the Ojos Salado center terminated at the Incapillo ignimbrite and dome complex at ~1 Ma.

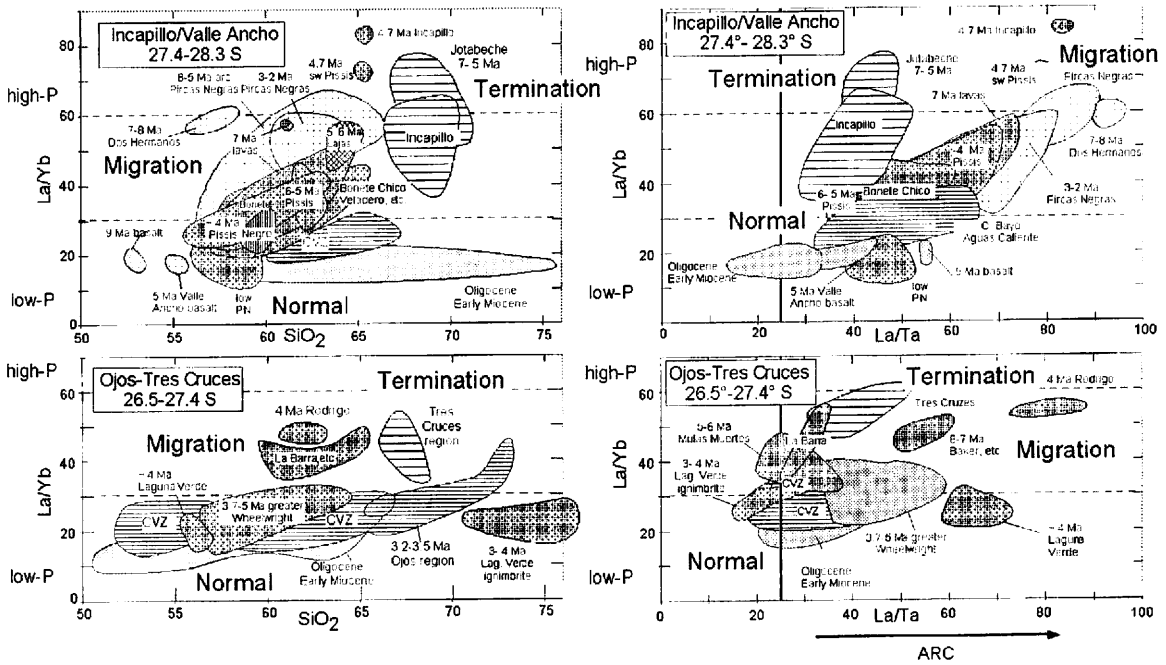

Fig. 2. Plots of La/Yb ratios *versus* SiO_2 and La/Ta ratio for over 260 Tertiary to Recent arc and backarc volcanic samples from the southern CVZ, Maricunga arc, Valle Ancho, and Incapillo/Bonete regions shown in figure 1. Oligocene to Early Miocene (light gray) and <3 Ma CVZ (horizontal stripes) units in the 'Normal' stage erupted in the Maricunga backarc and after arc migration in the CVZ. Units in the 'Migration' stage (plaid and dotted) erupted from ~7 to 4 Ma as the arc front migrated from the Maricunga belt to the Bonete region and the CVZ. Units labeled 'Termination' erupted in the final stages of the Maricunga arc, the Bonete region, and in the Tres Cruces region in the CVZ forearc. Note that the very high La/Yb and La/Ta ratios are particularly common in the Incapillo/Valle Ancho transect but also occur as the arc migrates in the Tres Cruces center of the Ojos-Tres Cruces region. The plot of La/Yb ratios *versus* SiO_2 content shows that a wide range of La/Yb ratios occur at the same SiO_2 content and that the most extreme values are concentrated in the andesitic to rhyodacitic units Data are from Mpodozis *et al.* (4), Kay *et al.* (2, 6), and our unpublished files. Analytical methods are discussed in Kay *et al.* (6).

A similar pattern of high La/Yb and La/Ta ratios occurs in volcanic units erupted in the Tres Cruces region between the Maricunga Belt and the modern CVZ to the north (Fig. 1). As shown in figure 2, andesitic/dacitic lavas from the 4.9 Ma La Barra and 4.4 Ma Rodrigo centers are chemically similar to Late Miocene Maricunga arc, Pircas Negras and Bonete/Incapillo region lavas. In contrast, dacitic units with ages < 3 Ma from the Tres Cruces region are chemically like Pleistocene Incapillo units. As in the Maricunga arc and the Bonete/Incapillo region, these volcanic rocks are the last to erupt in the region. The Late Miocene magmas erupted during the time of eastward arc migrations whereas the Tres Cruces center magmas represent the last gasp of magmatism in the forearc as the frontal arc was stabilized in the modern CVZ to the east. In contrast to the Tres Cruces region volcanic rocks, Pleistocene to Recent lavas in the CVZ have lower La/Yb and La/Ta ratios that are similar to those of most central Andean lavas.

DISCUSSION AND CONCLUSIONS

The distinctive pattern of La/Yb and La/Ta ratios of lavas that erupted as volcanism ceased in the Maricunga arc, Incapillo/Bonete arc, and Tres Cruces forearc regions reflect processes in the continental lithosphere and mantle wedge above a shallowing slab (see Fig. 3). In each region, the last stages of volcanism above the shallowing slab are characterized by the eruption of oxidized, mantle melts that are increasingly dominated by partial melts of garnet-bearing crust.

High La/Yb ratios are best attributed to residual garnet associated with melting of garnet lherzolite in the cooling mantle wedge above the dehydrating, shallowing slab, and to melting of garnet granulitic to eclogitic facies crustal rocks (6). Incorporation of heavy REE in residual garnet in a crustal residue is required to explain the very high La/Yb ratios in dacitic/rhyolitic magmas. This residue can be associated with partial melting of: 1) thickened in situ garnet-bearing lower crust; and 2) pieces of crust removed by subduction erosion from the continental margin (7) and the base of the forearc and arc crust, carried down the subducting slab, and incorporated in the zone of melt generation. Removal of the forearc continental

lithosphere is consistent with accommodation of the continental lithosphere above the shallowing slab (see Fig. 3). Incorporation of a component from the base of the arc and forearc crust is supported by the absence of extremely steep REE patterns in southern CVZ lavas that also erupted through thick in situ crust.

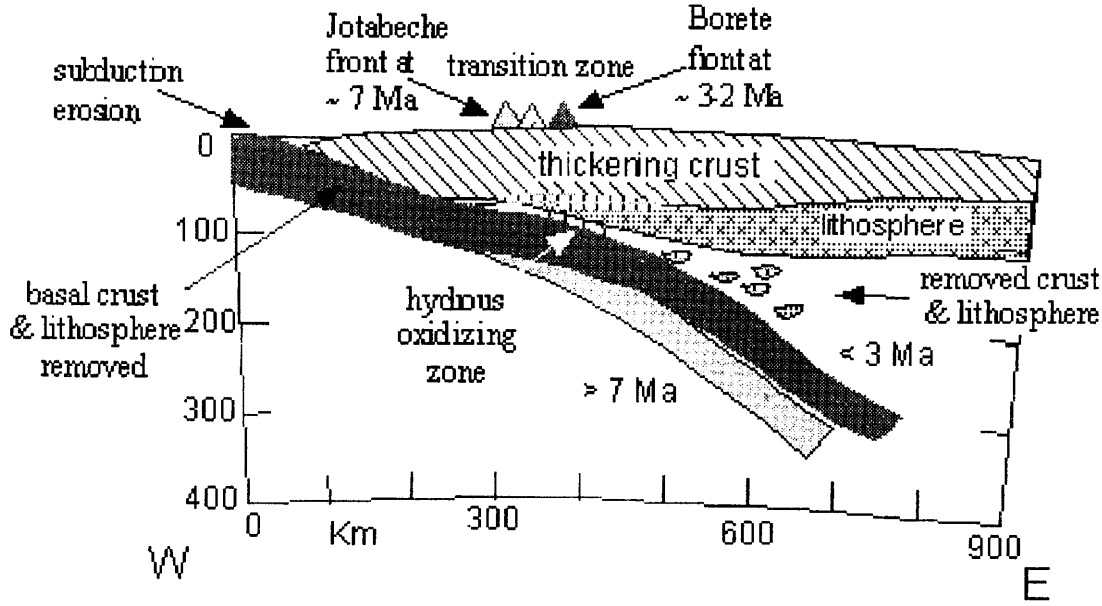

Fig. 3. Lithospheric cross section near 26° to 27°S latitude showing geometry of subducting slab at ~ 7 and 3 Ma. Processes affecting lithosphere and magma source region evolution as the arc front migrates eastward are indicated.

Large degrees of high field strength element depletion in lavas reflected in high La/Ta ratios are consistent with progressively more oxidizing and hydrous conditions in the narrowing mantle wedge above the shallowing slab as the arc front migrates and magmatism dies. An important role for a mantle component in producing these high La/Ta ratios is dictated by mafic andesitic lavas with > 200 ppm Cr, La/Yb ratios up to 25, and La/Ta ratios up to 55. A consequence of oxidizing, hydrous conditions is stability of Ta-bearing oxide phases like rutile in the slab environment (8) as slab shallows beneath the dying arc.

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