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Late Quaternary monogenetic volcanoes along Río Salado, Southwest Mendoza Province, Argentina

Volcanes monogénicos del Cuaternario Tardío a lo largo del Río Salado, sudoeste de la provincia de Mendoza, Argentina

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ABSTRACT

On the eastern flank of the Andes, to the north of Río Salado in southwest Mendoza Province (35°07'S-35°10'S), there are 4 monogenetic cones with blocky lava flows. A western group of small volcanoes, Hoyada, Lagunita and Loma Negra, with a total volume of ~0.2 km^3, are composed of amphibole-bearing basaltic andesite, and the eastern, more voluminous Hoyo Colorado volcano, with 0.44 km^3 is composed of olivine (+ oxidised amphibole) basaltic andesite. Although data indicate they were emitted through successive, strombolian eruptions, they are overall coeval and the youngest Late Pleistocene volcanoes located in an "extra-Andean" setting, ~70 km east of the main volcanic front. The magmas of the western group of monogenetic cones show petrographic and geochemical characteristics that support processes of crustal interaction during ascent. In contrast, the magmas of the Hoyo Colorado volcano had a more direct ascent. Structural characteristics of the basement rocks to the volcanoes and the current seismotectonic activity of the Andes at this latitude indicate that the monogenetic cones of Río Salado were emplaced in a dominantly compressive tectonic regime.

Key words: Monogenetic volcanoes. Blocky lava. Basaltic andesite. Late Quaternary. Southern Andes. Mendoza Province.

RESUMEN

Al norte del Río Salado, en la parte suroccidental de la Provincia de Mendoza, existen 4 volcanes monogenéticos de lava de bloques. Se trata de un grupo occidental de tres pequeños volcanes, Hoyada, Lagunita y Loma Negra, que totalizan ~0,2 km^3, de composición andesítico-basáltica de anfíbol y otro volcán más voluminoso, Hoyo Colorado con 0,44 km^3, ubicado 8 km al este, de composición andesítico-basáltica de olivino y anfíboles totalmente oxidados. Aunque existen evidencias que indican erupciones estrombolianas sucesivas, no simultáneas, se considera que fueron emitidas en forma coetánea y corresponden a las manifestaciones efusivas más recientes, de edad pleistocena tardía-holocena, localizadas en un ámbito extra-andino, a ~70 km al este del frente volcánico principal. Las lavas del grupo occidental de volcanes monogenéticos muestran evidencias petrográficas y geoquímicas que indicarían un ascenso con desarrollo de procesos de interacción cortical. Los magmas del volcán Hoyo Colorado habrían tenido un ascenso más directo. Las características estructurales de las rocas del basamento de estos conos y las evidencias del tipo de actividad sismotectónica en el segmento andino donde se ubican, indican que los volcanes monogenéticos del Río Salado habrían sido emplazados a través de una corteza caracterizada por un régimen tectónico de carácter dominantemente compresivo.

Palabras claves: Volcanes monogenéticos. Lava bloques. Andesita-basáltica. Cuaternario tardío. Andes del Sur. Provincia de Mendoza.

INTRODUCTION

The volcanic front along the southern Andes is a chain of edifices that mostly developed between the highest mountain peaks located on the Andean watershed divide, generally above 3,000 m a.s.l. However, from 34°S and southward, a group of scattered lower-altitude (<2,300 m a.s.l.) monogenetic and composite volcanoes are distributed on the eastern flank of the Andes (e.g. Dessanti, 1951; Araña et al., 1984), as well as on the well-preserved eastern piedmont. Due to their lower altitude and distance from the glacial sources, these "extra-Andean" volcanoes were not affected by glacial action, as were the frontal volcanoes, so their ages remain difficult to determine.

Between 34°S and 36°S, the Andean orogen varies in width from 120 to nearly 160 km, from the Central Depression in Chile to the Llancanelo Depression in Argentina. The axis of the volcanic front parallels margins of the orogen at a distance that also varies, but normally is closer to the western margin of the Cordillera de los Andes (Fig. 1). Thus, the western flank of the Andes is steeper and more eroded than the wider eastern flank, which has been characterised by a semi-arid landscape, with low erosion rates, probably since the Neogene.

In the Río Diamante area, on the eastern piedmont of the Andes, at least 16 extra Andean volcanoes, including one stratocone, El Diamante volcano, with a hight of ~870 m above its base and other smaller cones and explosion craters, are conspicuous on satellite images. Farther south, to the west of El Sosneado, another extra Andean group is also noteworthy. Some of the youngest volcanoes of this group are studied herein, including the cluster of Hoyada, Lagunita and Loma Negra volcanoes (35°7.5' to 35°9'S-69°53'W) and the Hoyo Colorado volcano (35°10'S-69°47.5'W), which are located immediately north of the Río Salado (Fig. 1). These emission centres belong to the Transitional Southern Volcanic Zone (TSVZ, after Tormey et al., 1991), an intermediate Andean geochemical segment characterised by complex interaction processes including crustal contamination, polybaric differentiation and an open-system thermodynamic evolution (Davidson et al., 1998).

The main purpose of this study is to characterise physically and chemically the monogenetic volcanic centres located to the north of Río Salado, in the southwest part of Mendoza Province, Argentina. It is aimed to compare them with nearby frontal volcanoes such as Planchón (Tormey et al., 1989; 1995, and Naranjo et al., 1999), and other eastern Andean volcanoes. Their relative ages are also estimated.

GEOLOGICAL FRAMEWORK

The basement of the studied volcanoes comprises Jurassic and Lower Cretaceous marine and continental sedimentary rocks, folded along a nearly north-south axis (e.g. Caminos et al., 1993). Tertiary volcanic rocks, also folded, uncomformably overlie the Mesozoic formations. Erosion and redeposition generated debris flows to the east, which comprise the piedmont to the uplifted Andean terrain. Two north-south steeply dipping faults are also noticeable at the western and eastern margins of the area that comprises an anticline core (Fig. 2).

THE VOLCANOES ALONG RÍO SALADO

The studied volcanoes comprise a group of three centres on the west and another volcano to the east (Fig. 2). All of them were built up on the eastern slope of pre-existing hills, facing to the SE, so that their lavas were directed south-eastward causing all cones to be open in that direction. The volcanic facies, including the small quantity of pyroclastic deposits associated with the vents indicate a low explosive, strombolian-type, eruptive style for all these monogenetic volcanoes.

The western group of three small volcanoes is aligned in a NNW direction over a distance of 3.5 km. Individual

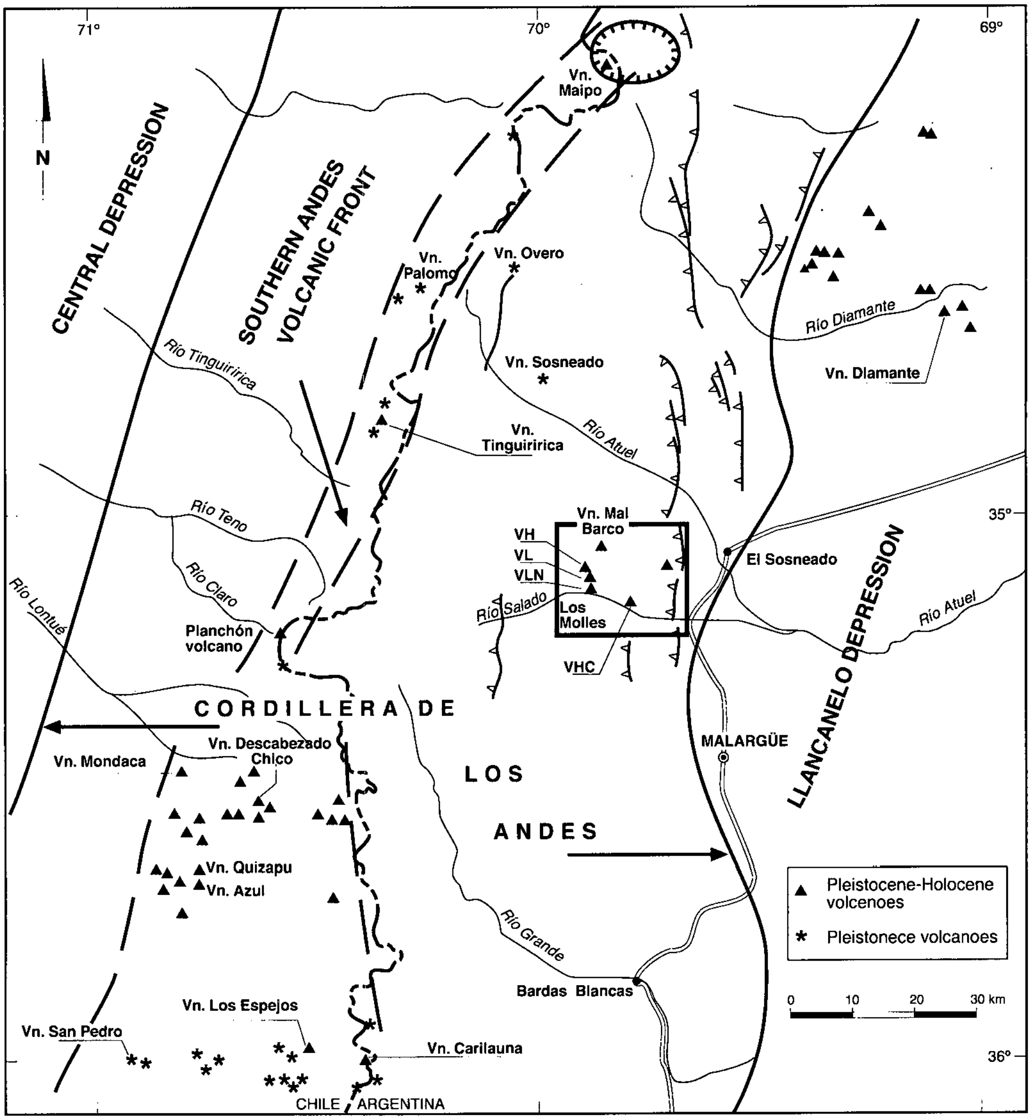

Figure 1. Location of studied monogenetic cones on the eastern flank of the Andes, eastward of the main volcanic front. VH: Hoyada volcano; VL: Lagunita volcano; VLN: Loma Negra volcano; VHC: Hoyo Negro volcano.

emission centres are, from north to south: Volcán Hoyada (VH), Volcán Lagunita (VL) and Volcán Loma Negra (VLN). Eight kilometres to the east of this group is the Hoyo Colorado volcano (VHC). Another two volcanoes, the Mal Barco and Mesillas, are located between the western group and VHC, but these show conspicuous degradation, indicating greater ages (Fig. 2).

Volcán Hoyada

The Hoyada volcano is a simple flat shaped crater surrounded by a veneer of tephra-fall deposit. The crater is 450 m across, open to the SSE, and the source of blocky basaltic-andesite lava, which flowed to the east (Fig. 3). The lava is 2.5 km long by ~0.4 km wide, with a total volume of ~0.03 km^3. The morphology of the lava consists of a 100 m wide central channel bounded by three elevated lateral banks or levées, which reveal a decrease of flow depth and flow width with time during the eruption. A similar decrease in flow depth and width has been interpreted as a consequence of the decline in flow rate during a certain period of the Lonquimay lava eruption in 1988-90 (Naranjo et al., 1992). At 1.5 km, the Hoyada lava diverted into two lobes, which subsequently drained the central chan-

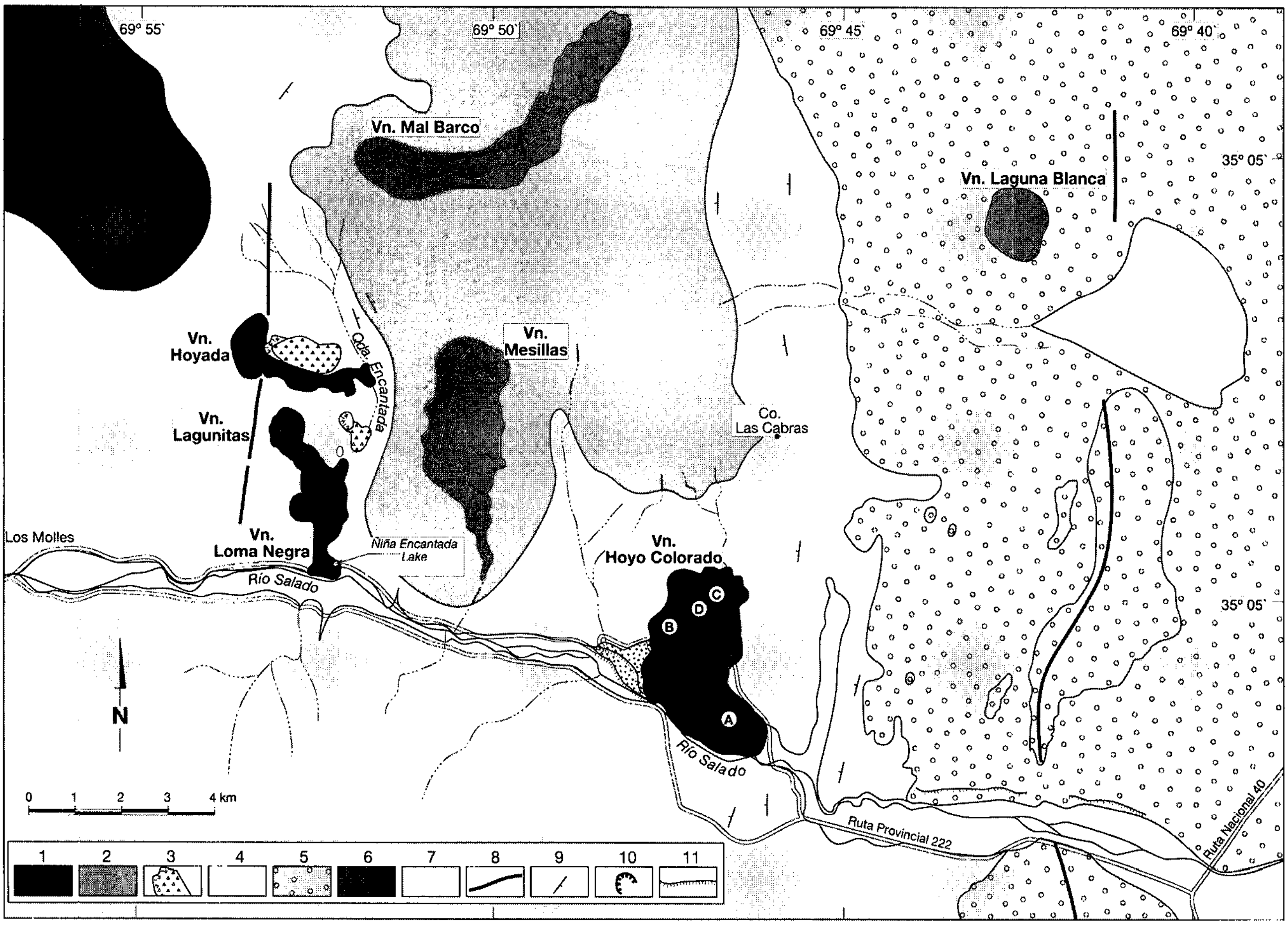

Figure 2. Geological sketch map of the area around the Río Salado monogenetic cones (modified after Caminos et al., 1993). (1) Studied young volcanoes; (2) Older volcanoes; (3) Local landslides; (4) Quaternary alluvial deposits; (5) Trans-Andean piedmont deposits, mainly debris flows (Tertiary?); (6) Tertiary volcanics; (7) Jurassic-Cretaceous marine and continental sedimentary rocks; (8) Faults; (9) Strike and dip of beds; (10) Crater; (11) Terrace scarp.

nel. The crater as well as the northern side of the lava flow, was affected by a landslide of the western slope of Quebrada Encantada (Fig. 2).

Volcán Lagunitas

The Lagunitas volcano is a small conical-shaped volcano, with a 0.8 km basal diameter, 150 m height and 350 m crater diameter, also open to the south (Fig.3). The inner wall cliff shows that it is formed by an alternation of lavas and pyroclastic deposits. A blocky lava flowed to the SE reaching 2.2 km long and 0.5 to 1 km wide. The total volume for the cone and lava flow is estimated as ~0.1 km^3. A conspicuous lava channel developed up to 1 km from the source. The channel is bounded by three lava levées. The outermost prominent levées are of the "initial levées" type, after the classification presented on Etna (Sparks et al., 1976). They are composed of alternating massive lava with rough, partly broken, upper and lower surfaces. They were formed as the lava first passed over the terrain when the lava had its maximum depth in proximal areas and the flow rate was the highest. When the front of the flow began to move over steeper ground, the flow may have accelerated and caused a decrease in the channel depth, forming the initial levées.

Upon reaching Quebrada La Encantada, the Lagunitas lava was finally bounded by the Loma Negra cone and lava to the south, and the eastern slope of the gully to the east. Subsequently, that SE stagnanted first lobe forced diversion of lava into a new northern lobe, bounded by the gully slopes. This dammed an ephemeral stre-

Figure 3. Aerial photograph showing from top (north) to bottom (south): Hoyada, Lagunita and Loma Negra monogenetic volcanoes, to the north of Río Salado.

am causing a small lake form, and triggering a small landslide on the western slope of the gully (fig. 3).

Volcán Loma Negra

The Loma Negra volcano is a ~190 m high cone, with a basal diameter of 0.6 km and a 60° sector crater 300 m diameter open to the SE. Its blocky lava is 1.7 km long with variable width (0.3-0.7 km) and, together with the cone, reaches a total volume of ~0.076 km^3. Arched ridges of 100-200 m wavelength develop from the open crater (Fig.3). The lava front widens to 0.7 km at the Río Salado valley, where it is ~50 m thick. A phreatic explosion occurred on the east margin of the lava flow forming a crater, currently occupied by the small (~60 m diameter) Niña Encantada lake. Both, the Loma Negra cone and lava bounded the Lagunitas lava; consequently the Loma Negra eruption is older. Remnants of a 1-2 m thick tephra-fall deposit, including scoriaceous lapilli and bombs (<50 cm), occur 1.5 km to the south of this cone.

Volcán Hoyo Colorado

The Hoyo Colorado volcano comprises a horseshoe-shaped, 400 m diameter, lava crater, open to the SE. An initial blocky lava flow poured out and descended to the 1.5 km wide Río Salado valley (Fig.4). The lava flow

Figure 4. Aerial photograph showing Hoyo Colorado monogenetic volcano and lava-lobes.

blocked the valley along a 3.1 km segment of the river. The initial lava pulse (A in Fig. 2) is 55 m thick, with an area of 5.1 km^2 and an estimated volume of ~0.28 km^3. An overflow of 3.14 km^2 also occurred, which consists of three wide (<1 km) lobes. These correspond to successive pulses. One lobe (B in Fig. 2) was diverted laterally to the south and a second lobe flowed to the east (C in Fig. 2), the central and final lobe was bounded and canalised to the SE (D in Fig. 2). All show arc ridges on the surface, which consist of almost concentric ovals from 1 to 5.5 km in the long diameter (Fig. 3). The overflow volume was estimated as ~0.16 km^3; thus, the total volume of the Hoyo Colorado volcano reaches 0.44 km^3, which is more than twice the total volume of the western group of cones.

PETROGRAPHY AND GEOCHEMISTRY

Both the western group (Hoyada, Lagunitas and Loma Negra) and Hoyo Colorado are monogenetic cones which exhibit a similar fresh, noneroded aspect, probably all being approximately coeval. Although they are only 8 km apart, and with similar eruptive styles, they show noticeable petrographic differences between them. The western group comprises basaltic andesite lavas and pyroclasts, with oxide-rimmed hornblende, and scarce interstitial plagioclase and olivine in the matrix. Scoriaceous bombs of this western group are yellow and amphibole crystal-rich. These contrast with the Hoyo Colorado basaltic andesite lavas which are olivine-rich phases including scarce oxidised amphibole, with plagioclase microlites in the matrix.

Araña et al. (1984) observed that within the 34°-37°S segment, alkaline magmas on the eastern flank of the Andes occasionally presented amphibole phenocrysts, but that within the Quaternary, calcalkaline magmas were more predominant.

Major element analyses of selected samples from the studied cones indicate compositions in the calcalkaline field (Fig. 5), within the same differentiation trend as the Planchón volcano (Naranjo et al., 1999), which is located in the volcanic front at a similar latitude (Fig. 1). They do not show any systematic K_2O enrichment east of the front, although K_2O enrichment occurs and reaches a maximum in the extra-Andean basalts of the Argentine Patagonia (e.g. Gorring et al., 1997; Muñoz and Stern, 1988).

Incompatible trace and rare earth element patterns show steep slopes and are similar in all studied specimens from the Río Salado cones (Fig. 6). On the other hand, the rare earth element contents are located between the basalts of the volcanic front (Planchón volcano) and those exhibited by Pleistocene alkaline basalts from the Patagonian plateau (e.g. Gorring et al., 1997). This transitional signature is particularly noticeable in the light rare earth elements, where the studied basaltic andesites are enriched with respect to the basalts of the volcanic front (Fig. 6).

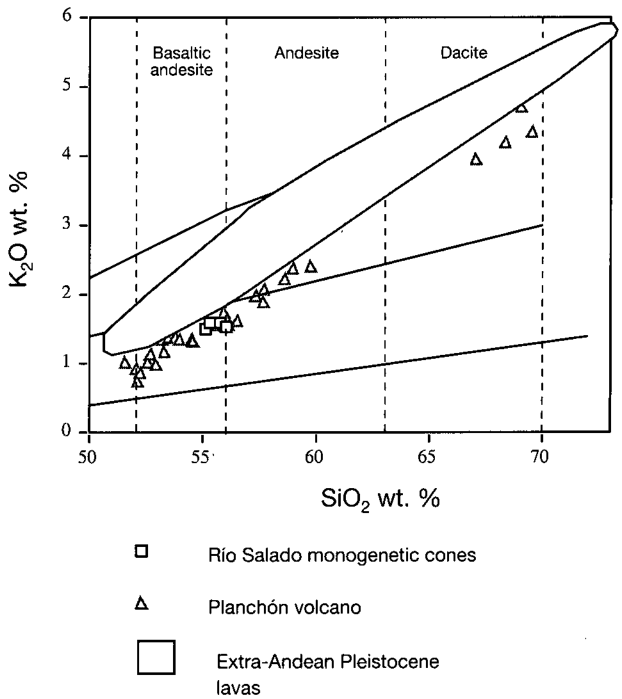

Figure 5. K_2O vs SiO_2 diagram for Río Salado monogenetic cone samples. Planchón volcano lavas and "extra-andean" Pleistocene lavas are also ploted for comparison. Major element analyses were obtained at Sernageomin Laboratory.

DISCUSSION

The light rare earth element enrichment shown by the studied volcanoes, located ~70 km east of the Andean volcanic front, is probably caused by an eastward diminishing degree of partial melting within the asthenosphere. The data support the hypothesis of a single asthenospheric origin for the magmas of the Río Salado monogenetic cones, although through petrogenetic processes probably became altered by crustal residence episodes.

Another general characteristic of the lavas from the Río Salado area is that their mineralogical paragenesis show an impoverishment in plagioclase phenocrysts, while at least the western group of monogenetic cones show a predominance of hornblende phenocrysts. This is an important difference from the typical lavas from the volcanic front south of 34°S, where plagioclase is always present as a phenocryst phase. The abundance of amphibole and scarcity of plagioclase may indicate differentiation at moderate to high confining pressure and elevated water contents. However, it presents a paradox to have hydrous magmas for the western monogenetic cones but notably less hydrous for the Hoyo Colorado volcano, only 8 km apart.

The geochemical diversity within the Transitional Southern Volcanic Zone between 34°S and 37.5°S (Tormey et al., 1991) may represent a zone of mixing, assimilation, storage and homogenisation at subcrustal levels (Hildreth and Moorbath, 1988). It is also assumed here that in addition to the favourable conditions for fluid circulation within the asthenospheric wedge, there must exist direct pathways for ascending magmas from the melting zones to avoid attainment of a crustal signature. While western cones show amphibole as a phenocryst phase with disequilibrium textures indicating a polybaric evolution, the less hydrous magmas from Hoyo Colorado volcano may represent more direct ascending conditions and so a more real reflection of the magma source, only slightly altered by crystal fractionation of olivine (Fig. 7).

It is important to consider the structural emplacement characteristics as an effect on the mechanical conditions of the lithosphere for the magma evolution. The monogenetic eruptive style of the studied volcanoes supports

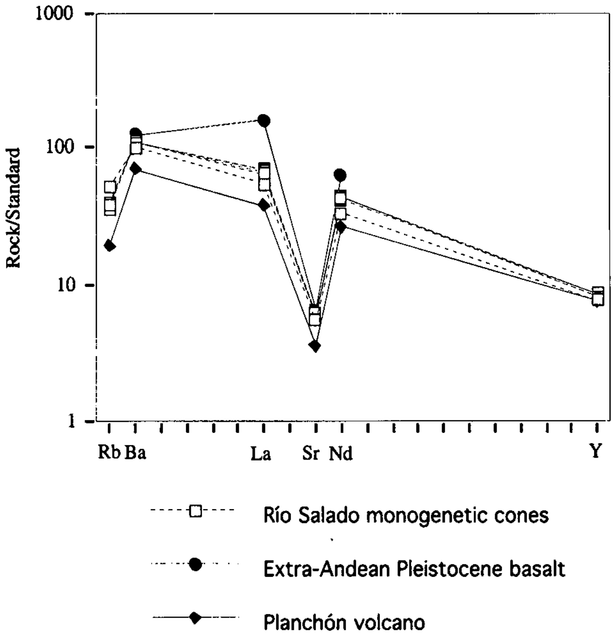

Figure 6. Trace elements diagram for Río Salado volcano samples, compared with a Planchón volcano basalt and an " extra-andean" Pleistocene basalt. Normalization values are: Rb=1; Ba=3.77; Nb=2.5; La=0.33=; Sr=136; Nd=0.63 ; Y=2.2.

the presence of structures as rapid-ascent pathways, although a more complex evolution may also be required for the petrogenesis of the magmas. It is also noteworthy that all these cones were emplaced along a fold- and thrust-belt (e.g. Dessanti, 1951; Caminos et al., 1993). The belt shows a number of narrow north-south striking east-vergent thrusts where Jurassic and Cretaceous successions are exposed (Koslowski et al., 1993). On the other hand, normal displacements on NW-striking faults have been described along the San Rafael block (Cisneros and Bastías, 1993), but these are located in a separate domain 100 km northeast of the studied cones.

Some kilometres northwest of the Río Salado area, on the Chilean side of the Andes, crustal seismic data from a temporarily installed network indicate NW-SE and NE-SW strike-slip focal solutions for a number of earthquakes (Alvarado et al., 1997). It is here suggested that these represent shallow conjugate faults, compatible with an east-west compressional stress regime. A similar model has been proposed by other authors based on selected intracrustal earthquakes (Acevedo, 1985). It is controversial as to how magma-ascent pathways may exist within a compressional crust. Some authors have restricted the occurrence of volcanism to non-compressional periods (Araña et al., 1984). Alternatively, pathways may be created in the direction of the maximum horizontal stress (Nakamura, 1977), which are difficult to generate within the thick fold- and thrust-belt.

Likewise, the fold- and thrust-tectonics suggests the minimum regional stress is vertical, but such mechanical conditions make the rapid ascent of magmas difficult, favouring instead the storage of magmas within the crust. To some extent, this is compatible with the geochemical signal shown by the analysed samples. Thus, two main factors would control the magma ascent; enough magmatic pressure to overcome the lithostatic pressure and the presence of crustal discontinuities that allow magma transit to the surface.

CONCLUSIONS

From 34°S and southward, several groups of scattered, mostly monogenetic and composite volcanoes are found at a distance of ~70 km or more to the east of the active Andean volcanic front. Although geochronologic data are lacking, they probably vary from Late Pleistocene to Holocene, based on their deeply degraded to very fresh volcanic structures, respectively. These volcanoes were emplaced on the eastern flank of the Andes, such as the studied examples, as well as on the well-preserved eastern Andean piedmont. The studied examples are the youngest volcanoes and comprise small monogenetic cones and blocky basaltic andesite lava flows. On the east, the Hoyo Colorado volcano is more voluminous (0.44 km^3) than the western group of three small volcanoes, the Hoyada, Lagunita and Loma Negra monogenetic cones (total ~0.2 km^3), located 8 km to the west.

Despite their physical and age similarities, and short distance separating them, the eastern and western cones exhibit petrographic variations that suggest different crustal ascent mechanisms for their magmas. The magmas of the eastern Hoyo Colorado cone have undergone a more direct ascent than those of the western group have, which may have developed crustal interaction processes. Such variations are also evident when compared with the stratovolcanoes of the Andean front at similar latitudes, such as the Planchón volcano and other TSVZ volcanoes, and with the alkali basalts of the extra-Andean Patagonia.

Structural characteristics of the basement rocks and the current seismotectonic activity at these latitudes may indicate that the monogenetic cones of Río Salado

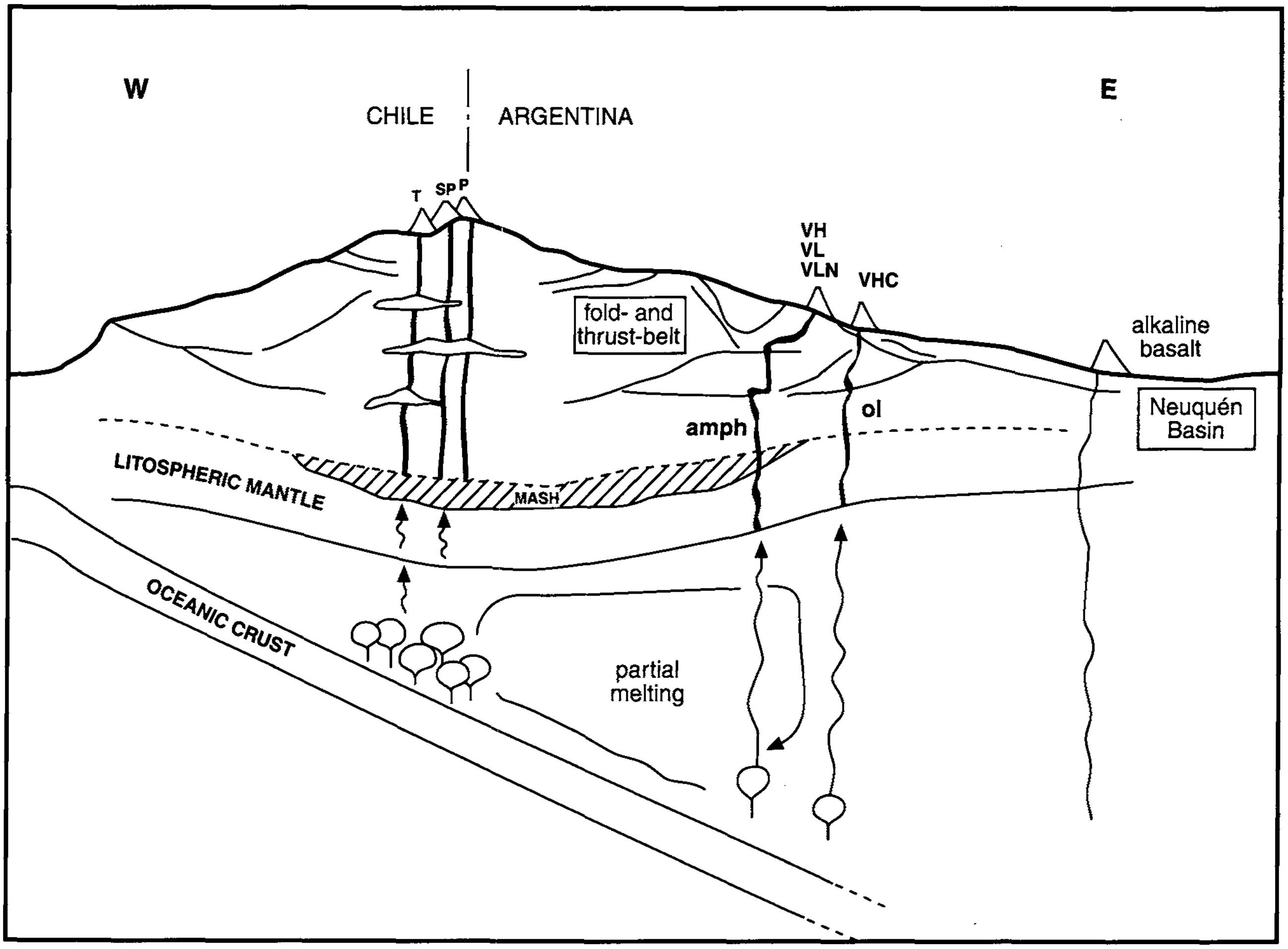

Figure 7. Sketch of volcanotectonic environment for TSVZ. T: Tatara volcano; SP: San Pedro volcano; P: Planchón volcano; VH: Hoyada volcano; VL: Lagunita volcano; VLN: Loma Negra volcano; VHC: Hoyo Negro volcano.

were emplaced in a dominantly compressive tectonic regime.

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