SERVICIO NACIONAL
DE GEOLOGIA
Y MINERIA·CHILE

CONGRESO GEOLOGICO CHILENO 1·9·9·1

RESUMENES EXPANDIDOS
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EVALUATION OF MAGMA SOURCES FOR CENTRAL ANDEAN VOLCANICS

J.P. Davidson*, S.L. Silva**, A. Escobar°, T. Feeley* y W. Bohrson*

Volcanic rocks from the currently active arc of the central Andes (central volcanic zone or CVZ) are enriched in incompatible trace elements and are significantly different from typical intraoceanic basalts in terms of Sr and Nd isotope composition. These characteristics could result from:

1. Derivation from a source in the ancient subcontinental mantle lithosphere, which has been enriched in Rb relative to Sr and in LREE and other incompatible elements for a significant period of time[1].
2. Source contamination - that is the incorporation of continental crust carried down into the subduction zone as sediment on the subducted slab, or as tectonically eroded crustal fragments[2], or
3. Large-scale crustal contamination of mantle-wedge derived magmas as they pass through the central Andean crust[3, 4].

How 'Primitive' are Andean Basalts?

An argument commonly levied against large-scale contamination (a crustal contribution of >10% by mass) is that even the 'basalts' -the most mafic rocks erupted- show these characteristics. The implication is that significant contamination of a basaltic liquid would produce a more differentiated product (an andesite or dacite).

It is seldom appreciated that there is a considerable range in differentiation among rocks described as basalts, from mafic compositions that may have been in equilibrium with the mantle (16% MgO, 47% SiO_2) to those which are slightly less silica rich than basaltic andesites (5-6% MgO, 52% SiO_2). This range is arguably as large as the entire range in differentiation among 'evolved' rocks, from basalts to dacites (Fig. 1).

Even the most primitive CVZ magmas are only marginally basaltic and are highly differentiated relative to liquids that might be in equilibrium with mantle composition (Fig. 1). In order to derive parental CVZ magmas from a mafic arc basalt significant fractionation of mafic basalt is required (more than 20% olivine for instance). Alternatively, significant quantities of crust can be added to modify the composition. More than 50% of 'bulk continental crust' can early be added to a mafic basalt without reducing MgO and Ni concentrations

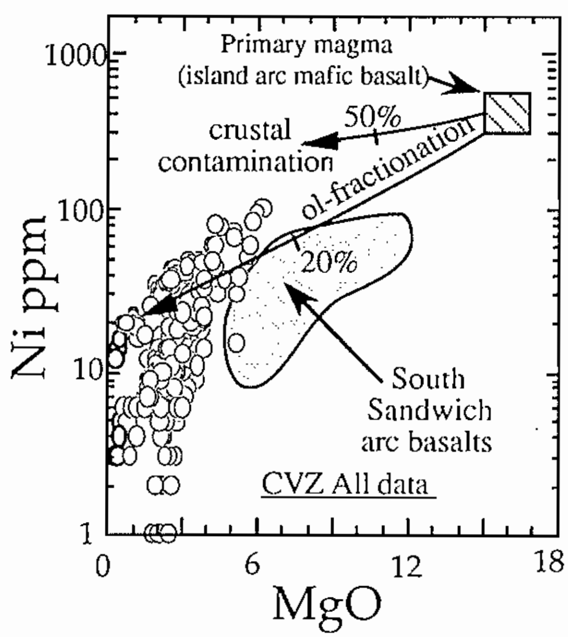

FIG. 1. Ni and MgO concentrations in CVZ lavas; Field of South Sandwich island arc data is shown for comparison. Note in general that contamination/mixing results in higher Ni for a given MgO content than simple fractional crystallization, ad that central Andean data show this characteristic.

* Department of Earth and Space Sciences, UCLA, Los Angeles, California 90024, U.S.A.
** Department of Geology, Indiana State University, Terre Haute, Indiana 47809, U.S.A.
° Servicio Geológico de Bolivia, Calle Frederico Zuazo 1673, Casilla 2729, La Paz, Bolivia.

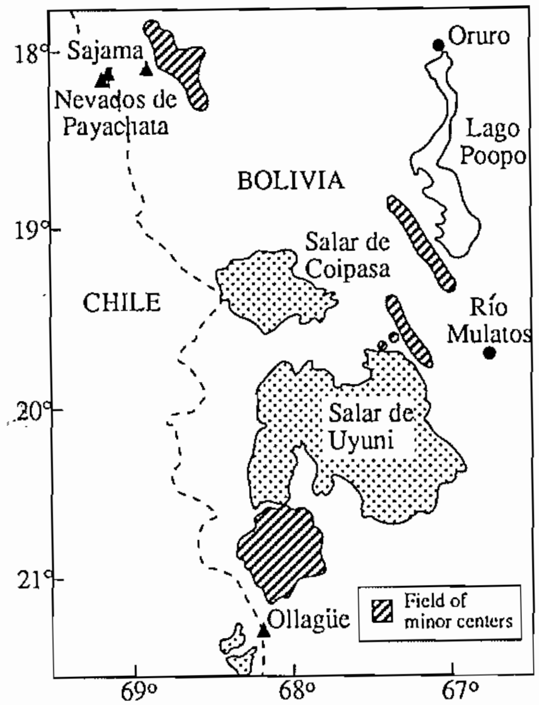

FIG. 2. Location of fields of minor (largly mafic) volcanic centers.

below those found in CVZ basalts and basaltic andesites (Fig. 1).

When we consider the most mafic compositions erupted in the CVZ, it is not possible to unequivocally determine whether they have differentiated through closed system processes from a primary magma derived from an 'enriched' mantle source (either in the lithosphere or asthenosphere grossly contaminated by a subducted crustal component), or represent basalts similar to those at island arcs which have been modified by open system differentiation during ascent. One constraint does seem pertinent in this regard though; oxygen isotopic compositions of CVZ lavas are almost exclusively non-mantle like (>+6%), requiring at least some crustal contribution.

The rocks which we collect at volcanic edifices are invariably rich in plagioclase and amphibole phenocrysts, reflecting fairly shallow level differentiation probably in sub volcanic magma chambers. Any chemical trends generated by the earlier stages of differentiation have therefore been overprinted.

The Importance of Minor Mafic Centers

We propose that one possible way to evaluate the nature of this early stage of differentiation is by examining minor mafic centers which occurr largely to the east of the main arc in Bolivia. The large stratovolcanoes of the arc front are supplied from shallow magma chambers, the locations of which are confined to a narrow zone which is a function of the subduction zone geometry. In contrast, the distribution of the minor centers appears to be controlled by structural lineaments within the crust. Magmas may therefore be tapped from depth in the lower crust or mantle and *not* subjected to further differentiation in shallow magma chambers. Thus we may 'see through' the second stage processing that typifies the arc stratovolcanoes.

Field Relations and Petrography

Three main fields of minor centers have been sampled (Fig. 2). The area immediately to the west of Sajama volcano comprises largely olivine-bearing basaltic andesites (described as mugearites by Salinas *et al.* [3]), These occur as restricted plateau-like flows issuing from small cones which have been subdued by erosion. The centers define a broad north-west/southeast orientation. To the north east and east of Ollagüe volcano are a number of small volume centers with no systematic distribution. Many of these actually comprise rather differentiated highly porphyritic dacite flow complexes, although some sparse mafic centers occur, such as at Chiguana and Cerro Luntapa. Lake terraces on the sides of most centers indicate that they are older than the last high stand of Salar de Uyuni at 20,000 years[4].

The third field of minor centers occurs well within the altiplano, to the west of Lago Poopo. Here, the centers are predominantly basaltic, olivine phyric (~FO_{85}) and define two very regular northwest-south east lineaments. Again, common lake terraces on lava flows indicate that the centers are no younger than 20.000 years. A secondary south-west/north-east lineament is apparently defined by two phreatomagmatic maars: Laguna Nekhe Kkota and Jayu Kkota.The intersection of this lineament with the westernmost of the north-west/south-east trends is marked by a small alkali basalt center; Chiar Kollu. Coincidentally this is the only minor center sample which has been thoroughly analyzed to date, and is characterized by ^{87}Sr-^{86}Sr of 0.7041, and strong LREE enrichment[5].

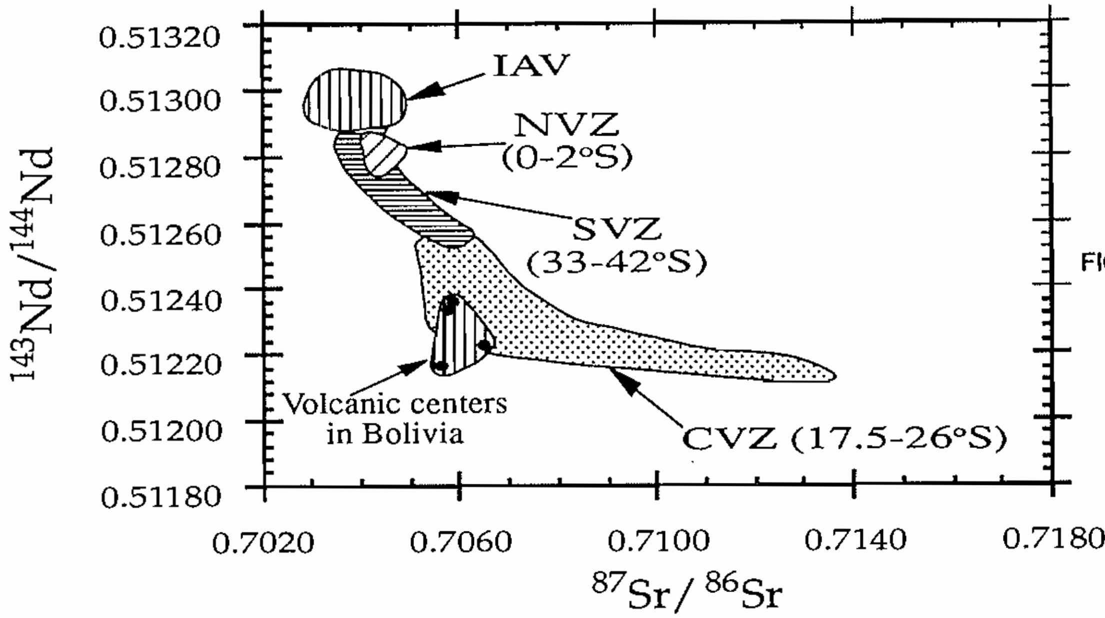

FIG. 3. Preliminary isotope data for minor mafic volcanic centers in, Bolivia, compared with island arc isotopic data (IAV), and data from the Andean arc (NVZ, CVZ, SVZ: Northern, Central and Southern volcanic zones, respectively.

Petrographically, none of the other centers which we have sampled resemble the lavas of Chiar Kkollu. Preliminary isotopic data indicate that even though the centers are considerably more mafic than typical compositions erupted along the arc front, they have similar $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ -perhaps displaced to slightly lower $^{143}Nd/^{144}Nd$ (Fig. 3). This could be taken to indicate that the mantle source is indeed isotopically enriched, except that petrographic evidence for considerable crustal contamination is present in the Bolivian centers. Xenocryst and xenolithic material is ubiquitous in varying degrees. Quartz xenocrysts are most common, and generally occurs as large rounded inclusions with a reaction rim of clinopyroxene, and occasionally glass. Xenocryst content may be up to 2% in some samples. Given the restitic character of the quartz, and assuming derivation from a felsic basement, this may represent up to 30% crustal contamination by mass. Clearly the Sr and Nd budget of the volcanic rocks may have been severely modified by digestion of the crust. In one case, small (>2 mm) porous crustal inclusions were separated from the host material and analyzed for Nd isotope ratios. The $^{143}Nd/^{144}Nd$ ratio was indistinguishable between lava and xenolith, suggesting that isotopic equilibration, at least on a small scale, has occurred. A detailed geochemical evaluation of the sample suite, including microsurgical analysis of the crustal inclusions is planned.

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