Comunicaciones, N° 35 (1985): 101 - 104
Departamento de Geología – Universidad de Chile - Santiago

RELACIONES ENTRE ISOTOPOS DE OXIGENO EN ROCAS VOLCANICAS DE LOS ANDES Y DE PATAGONIA

OXYGEN ISOTOPE RELATIONSHIPS IN VOLCANIC ROCKS FROM THE ANDES AND PATAGONIA

RUSSELL S. HARMON
Department of Geological Sciences Southern Methodist University, Dallas, Texas 75275, USA.

JOCHEN HOEFS
Geochemisches Institut, der Universitat Gottingen, D-3400 Gottingen, F.R G.

DAVID F. STRONG
Department of Earth Sciences Memorial University of Newfoundland, St. John's, A1B-3X5 Newfoundland, Canada.

The mantle and the different crustal reservoirs which may be important in the petrogenesis of volcanic arc 'andesites' and intraplate 'basalts' can be reasonably well discriminated on the basis of their O-isotope composition because source-liquid fractionations are small at magmatic temperatures and because low-temperature crustal processes such as hydrothermal alteration, weathering, and sedimentation tend to produce large and distinctive isotope fractionations. A primary feature of the upper continental crust is that it is more enriched in ^{18}O than the mantle or mafic lower crust. Rocks which have been through a cycle of surface residence typically tend to be particulary ^{18}O-rich. Closed-system crystal fractionation of a magma can produce only small ^{18}O enrichments in a suite of cogenetic volcanic rocks. Thus, it is to be expected that magma derived from the mantle with have lower $^{18}O/^{16}O$ ratios than magmas generated within either the lower or upper continental crust. However, the recycling of ^{18}O-rich hydrothermally altered oceanic crust and sediments into the mantle via subduction processes could, in theory, produce small but significant ^{18}O enrichments in the upper mantle.

We have determined $^{18}O/^{16}O$ ratios (as $\delta^{18}O$ values relative to the SMOW standard) for 110 Late Cenozoic calc-alkaline volcanic rocks from the Andean Cordillera of Ecuador, Bolivia, Argentina, and Chile between the equator and 46°S, and for 45 Late Cretaceous-recent tholeiitic and alkalic basalts from the Patagonia Region of Argentina between 45-47°S. These data have been combined with 107 O-isotope analyses from the literature (Magaritz et al., 1978; James, 1982; Longstaffe et al., 1983; Stern et al., 1984 a,b) for Late Cenozoic Andean calc-alkaline volcanic rocks between 2°N and 55°S to yield a data base sufficiently large to examine regional O-isotope relationships and thus define the role of continental crust in the origin of Andean and Patagonian lavas.

The overall range in $^{18}O/^{16}O$ ratios for the 217 Andean samples is +5.2 to +14.0 °/oo and for the Patagonian samples is +5.1 to +8.2°/oo. It is significant that the ~9°/oo range in $^{18}O/^{16}O$ ratios observed along the strike of the Andean Cordillera is very much larger than observed in any other individual calc-alkaline orogenic province, whereas the ~3°/oo range in $^{18}O/^{16}O$ ratios observed for Patagonia is similar in magnitude to that for other continental intraplate basalt provinces. The lowest $\delta^{18}O$ values observed in both tectonic settings are equivalent to those for mid-ocean ridge basalts (Muechlenbachs and Clayton, 1972; Pineau et al., 1976) and ocean island basalts (Garlick, 1966; Taylor, 1968; Kyser et al., 1982), whereas the highest values are comparable to those characteristic of upper crustal partial melts (Taylor and Turi, 1976).

Of the Andean samples, some 95% are within the more restricted $\delta^{18}O$ range of +5.5 to +9.5°/oo, with the range of $^{18}O/^{16}O$ ratios for each of the three main Andean volcanic provinces being significantly smaller than that for the Andean Cordillera as a whole: Northern Volcanic Zone (NVZ: 5°N–2°S) = +6.5 to +7.8°/oo, Central Volcanic Zone (CVZ: 16–28°S), = +6.9 to +14.0°/oo, and Southern Volcanic Zone (SVZ: 33–55°S) = 5.1 to 11.1°/oo. In the NVZ, where the continental crust is Cretaceous and younger in age and of normal thickness (c. 40 km) and the seismic zone deep (c. 140 km), the lavas are basalts (<55% SiO_2) and andesites (55-63% SiO_2). In this region $\delta^{18}O$ variations are independent of chemical and radiogenic isotope composition. By contrast, in the CVZ, where the Precambrian-Paleozoic continental crust is up to twice the normal thickness (c. 50-70 km) and the seismic zone deep (c. 140 km), the volcanics tend to be more evolved andesites, dacites (63-68% SiO_2), and rhyolites (>68% SiO_2) although basalts are present in the region. Here there is a general tendency for $\delta^{18}O$ values and radiogenic isotope ratios to be compositionally dependent. In general, the more silicic rocks in a CVZ volcanic center tend to be the more ^{18}O rich, such as at Cerro Galan in Argentina where $\delta^{18}O$ values systematically increase from +8.2 to +8.5°/oo for basalts, to +8.4 to +9.6°/oo for andesites, and finally to +8.6 to +14.0°/oo for dacites. However, some volcanoes exhibit the reverse compositional dependence of O-isotope ratios. For example, at the Sierra de Lipez center in Bolivia the progression of $\delta^{18}O$ values is +9.5°/oo for an andesite, +8.9°/oo for four dacites, and +8.0°/oo for a rhyolite. In both cases, O-isotope ratios are well-correlated with radiogenic isotope ratios, the more ^{18}O-rich samples having the higher Sr– and Pb-isotope ratios. By-in-large, the Arequipa and Barroso volcanics in south Peru at 16-18°S, which were erupted through the old Precambian basement of the South American craton, have lower and less variable $\delta^{18}O$ values (+6.9 to +7.9°/oo, $\bar{x}$ = +7.2°/oo) than the CVZ volcanic centers to the south in north Chile, southwest Bolivia, and northwest Argentina (+7.3 to +14.0°/oo, $\bar{x}$ = +8.6°/oo) which are built upon a younger accretionary crust. O-isotope relationships are quite complex in the SVZ, where a youthful, Mesozoic-Cenozoic crust of slightly thin to normal thickness (c. 30-40 km) overlies a relatively shallow (c. 90 km) seismic zone. In the central province from 37-42°S, where the continental crust is thinest, $^{18}O/^{16}O$ ratios are very low (+5.2 to +7.4°/oo), both $\delta^{18}O$ values and radiogenic isotope ratios are independent of chemical composition. For example, at Villaricca basalts, andesites, and rhyolites all have $\delta^{18}O$ values between +5.8 to +6.3°/oo. The restricted range of O-isotope variations in this segment of the SVZ is only slightly larger than that observed by Stern and Ito (1983) and Woodhead et al. (1985) for the Marianas (+5.1 to +6.9°/oo), an oceanic island arc where continental crust is absent. Basalts in this region have an average $\delta^{18}O$ value of +5.9°/oo, which is indistinguishable from the +5.8 ± 0.5°/oo value characteristic of mid-ocean ridge basalts. In both the northern (33-37°S) and southern (42-46°S) segments of the SVZ, where the continental crust is thicker, $^{18}O/^{16}O$ ratios become higher and begin to exhibit a compositional dependence. The range of $\delta^{18}O$ value in both regions is some 0.5°/oo higher than for the central segment (northern SVZ = 6.7°/oo, central SVZ = 6.3°/oo, southern SVZ = 6.8°/oo). In the austral segment of the SVZ from 49-55°S there is a strong latitudinal dependence of $^{18}O/^{16}O$ ratios. Here $\delta^{18}O$ values average +7.6°/oo at the Nunatak and Aguilera volcanic centers in the vicinity of 50-52°S and progressively decrease south toward the plate margin with the Mt. Burney volcano at ~53°S having an average $\delta^{18}O$ value of +6.7°/oo and the Cook Island center at 55°S having an average $\delta^{18}O$ value of +5.6°/oo (Stern et al., 1984a).

The Patagonian plateau basalts encompass a wide range of compositions from Late Cretaceous tholeiites, through Miocene alkali basalts, to Late Cenozoic potassic leucite basanites. The ranges in $\delta^{18}O$ values for the Patagonian lavas, in general stratigraphic order, are: tholeiitic basalts = +5.6 to 8.1°/oo ($\bar{x}$ = +6.9°/oo), alkali basalts = +5.1 to +7.9°/oo (x = +6.5°/oo), and basanites = +5.7 to +8.0°/oo ($\bar{x}$ = +6.5°/oo). Two alkali basalts from El Pedrero volcano have $\delta^{18}O$ values of +5.3°/oo and +5.7°/oo. Across the region as a whole, $^{18}O/^{16}O$ ratios are independent of chemical and radiogenic isotope composition, but exhibit an age dependence, the younger lavas tending to be less ^{18}O rich.

This study demonstrates that crustal materials have been involved in 'andesite' magmagenesis to different extents along the Andean Cordillera. In the central segment of the SVZ, calc-alkaline basaltic magmas were likely derived from the asthenospheric mantle with little or no contribution from recycled sediments. These magmas rose largely unmodified through the thin continental crust of the region, where differentiation occurred by low pressure crystal fractionation without concomitant assimilation of upper crust. In the NVZ and northern and southern segments of the SVZ the continental crust played a more important role in magmagenesis. The ^{18}O enrichments observed in the more silicic rocks of these regions are attributed to minor or moderate amounts of crustal assimilation which occurred during differentiation by a combined crystal fractionation-assimilation process. The significant ^{18}O enrichments observed in CVZ volcanics of all compositions requires a large crustal component in these lavas. Parental magmas in the CVZ may have been generated in the same mantle source region as those in the SVZ and NVZ, but substantially modified chemically and isotopically both during transit through the exceptionally thick lower continental crust of the central Andes and by subsequent low-pressure crystal fractionation-assimilation in the upper crust. The Patagonian O-isotope data are best explained by a model in which in the various basalts are produced by different degrees of partial melting of a mantle source region that was heterogeneous with respect to its O-isotope composition.

REFERENCES

Garlick, G.D., 1966. Oxygen isotope fractionation in igneous rocks. Earth Planet. Sci. Lett., 1, p. 361-368.

James, D.E., 1982. A combined O, Sr, Nd, and Pb isotopic and trace element study of crustal contamination in central Andean Lavas I. Local geochemical variations. Earth Planet. Sci. Lett. 57, p. 47-62.

Kyser, T.K., O'Neil, J.R., and Carmichael, I.S.E., 1982. Genetic relations among basic lavas and ultramafic nodules: Evidence from oxygen isotope compositions. Contrib. Mineral. & Petrol., 81, p. 88-102.

Longstaffe, F.J.; Clark, A.H.; McNutt, R.H., and Zentilli, M., 1983. Oxygen isotope compositions of Central Andean plutonic and volcanic rocks, latitudes 26°-29°South. Earth Planet. Sci. Lett., 64, p. 9-18.

Magaritz, M.; Whitford, D.J., and James D.E., 1978.Oxygen isotopes and the origin of high Sr^{87}/Sr^{86} andesites. Earth Planet. Sci. Lett., 40, p. 220-230.

Muehlenbachs, K. and Clayton, R.N., 1972. Oxygen isotope studies of fresh and weathered submarine basalts. Can. Jl. Earth Sci. 9, p. 172-184.

Pineau, F.; Javoy, M.; Hawkins, J.W. and Craig, H., 1976. Oxygen isotope in marginal basin and ocean ridge basalts. Earth Planet. Sci. Lett. 28, p. 299-307.

Stern, C.R.; Futa, K., and Muehlenbachs, K., 1984a. Isotope and trace elements date for orogenic andesites from the Austral Andes. In Andean Magmatism: Chemical and Isotopic Contstraints (R.S. Harmon and B.A. Barreiro, eds.), Shiva Pub. Ltd. p. 31-46.

Stern, C.R.; Futa, K.; Muehlenbachs, K.; Dobbs, F.M.; Muñoz, J.; Godoy, E., and Charrier, R., 1984b. Sr, Nd, Pb and O isotope composition of Late Cenozoic volcanics compositions of Late Cenozoic Volcanic, northern most SV2 (33-34°S). In Andean Magmatism: Chemical and Isotopic Contstraints (R.S. Harmon and B.A. Barreiro, eds.), Shiva Pub. Ltd. p. 96-105.

Stern, C. and Ito, E., 1983. Trace elements and Isotopic contstraints on the source of magmas in the active volcano and Mariana Island Arcs, Western Pacific. Jl. Vol. Geotherm. Res., 18, p. 461-482.

Taylor, H.P., 1968. The Oxygen isotope geochemistry of igneous rocks. Contrib. Mineral. Petrol., 19, p. 1-71.

Woodhead, J.; Harmon, R.S., and Frazer, D., 1985. Nature, in press.