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17. At a future eclipse it would be useful to station several people, with no more instructions than those given in Halley's pre-eclipse notice, at close intervals across the northern limit, to determine the distance over which ambiguous reports like Shelton's would be made.
18. Since Halley's objective—to accurately determine the edges of totality—depended critically on Shelton's location during the eclipse, we accept his statement that Shelton was *at* Darrington to be informed and precise, and not to mean, for example, *in the vicinity of* Darrington. Because of the very small size of the town, this pinpoints Shelton's location well within 200 m.
19. We thank T. C. Van Flandern for providing the lunar ephemeris for 1715; R. Linkletter, P. Asmus, F. J. Howell, and K. Strait for helping with the organization of the 1979 IOTA eclipse project; and all observers who reported observations from near the edges of the 1976 and 1979 eclipse paths.

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Origin of Lead in Andean Calc-Alkaline Lavas, Southern Peru

Abstract. *Lead isotope data from Quaternary andesitic lavas of the Arequipa and Barroso groups of southern Peru and from regional Precambrian granulitic gneisses reveal a lead component in the lavas from the gneisses. The lava leads can be accounted for by two-component mixtures of lead from mantle and lower crustal sources, although the mixing process need not have occurred in the lower crust.*

The origin of andesitic lavas is a problem of fundamental importance in earth science because various models of the earth's continental crust (*1*) lead to bulk chemical compositions that approximate that of andesite. Thus the problem is probably closely related to the origin of the continents. The widespread occurrence of andesitic rocks in belts along continental margins (for example, in the Andes and Cascade Mountains) is in accord with this concept.

Although numerous theories for andesite petrogenesis can be found in the literature, the theories are now based on some form of plate tectonic mechanisms in which partial melting occurs at depth as one plate is subducted beneath a second one. Both plates may be of oceanic affinity (for example, Mariana arc), or one may be of continental affinity (for example, the Andes). The main questions are the nature of the source material and the extent of possible contamination as the lavas rise to the surface.

In principle, isotope tracer studies with Sr, Pb, and Nd, which are produced by the decay of Rb, U and Th, and Sm, respectively, may provide answers or place limitations on possible answers to these questions. Some of the more definitive studies have been done in oceanic settings where the possible complications introduced by rocks of the thick continental crust are removed. In the Mariana (*2*, *3*) and Tonga-Kermadec (*4*) island arcs, isotope tracer studies have shown that andesitic lavas are generated by partial melting of mantle or mantle-derived materials. One cannot, however, generalize the Tonga-Mariana studies to all oceanic rocks because there is strong evidence for subduction of sediments in the Banda arc (*5*) and possibly in other localities such as parts of the Aleutian arc (*6*).

Less definitive information is available for andesitic lavas from continental margins, although several investigations indicate that it may be possible to sort out the complexities of the interaction of continental and oceanic lithospheric slabs in those environments. The most detailed data are available for the Andes Mountains, the topic of these discussions. One of the first and most comprehensive geochemical studies of Andean volcanic rocks was initiated by James *et al.* (*7*), who studied two groups of andesitic rocks in the vicinity of Arequipa, Peru: the Arequipa and Barroso volcanics, of Quaternary age. On the basis of data for trace elements and Sr isotope relationships, James *et al.* (*7*) concluded that the late Cenozoic andesitic-dacitic lavas of southern Peru are derived from partial melting in the continental lithosphere that underlies the crust. This model was favored even though the high ^{87}Sr/^{86}Sr ratios (0.706 to 0.708) in the lavas are typical of continental crust (as opposed to mantlerocks where the range is generally 0.7025 to 0.7045) because in a Rb/Sr isochron diagram the Arequipa and Barroso volcanic data defined "pseudo-isochrons" corresponding to apparent ages of 400 × 10^6 years. These regularities were considered unlikely to result from contamination of mantle-derived lavas with various crustal materials. Instead, disequilibrium partial melting in mantlerocks was favored (*8*). Later investigations that added O isotopic data (*5*) showed that the Arequipa and Barroso volcanics require at least a small crustal component to account for their ^{18}O/^{16}O ratios. This component was attributed to subducted graywacke sediments, which

Table 1. Isotopic composition and concentration data for Andean igneous rocks; ppm, parts per million.

Sample No.	^{206}Pb/ ^{204}Pb	^{207}Pb/ ^{204}Pb	^{208}Pb/ ^{204}Pb	Pb (ppm)	U (ppm)	Th (ppm)	Th/U (by weight)
			Arequipa volcanics				
PE 24	17.794	15.623	38.784	12.47	0.87	5.27	6.06
PE 26	18.019	15.626	38.737	12.20			
PE 47	17.845	15.612	38.724	11.35			
PE 49	17.844	15.610	38.643	16.40	0.77	5.07	6.58
PE 82	17.984	15.592	38.603	13.38	0.66	3.16	4.79
PE 83	17.948	15.603	38.657	16.17			
			Barroso volcanics				
PE 129	18.277	15.597	38.527	22.11	3.77	12.84	3.41
PE 130	18.291	15.589	38.471	10.66			
PE 131	18.246	15.584	38.467	15.67	3.84	12.79	3.33
PE 144	18.157	15.581	38.540	15.90	2.86	11.30	3.95
PE 145	18.166	15.588	38.708	16.46	1.63	8.81	5.41
			Charcani gneiss				
PE 37	16.940	15.552	38.950	10.70	0.213	23.23	109.1
PE 111	17.029	15.587	38.973	26.15	0.346	18.50	53.5
BAR 37	16.997	15.561	38.951	7.53	0.281	3.60	12.8
BAR 39	17.046	15.540	39.392	10.32	1.483	20.69	13.9
BAR 40	16.950	15.552	39.333	18.28			
BAR 43	17.088	15.548	39.610	6.35	0.834	15.0	18.0
BAR 44	16.792	15.556	37.987	17.97	0.164	8.4	51.0
BAR 45	16.847	15.544	38.592	10.67	0.254		
BAR 46	16.929	15.586	38.689				
			Mollendo granulites				
PE 18	16.110	15.463	40.455	12.26	0.164	5.62	34.3
PE 19	16.008	15.435	40.196	11.31	0.132	17.42	132.0
BAR 64	16.091	15.477	41.015	5.75	0.212		
BAR 68	16.496	15.531	38.789	16.20	0.281	1.49	5.3

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could account for the O data without significantly affecting the $^{87}Sr/^{86}Sr$ ratios, which were still attributed mainly to derivation from the lithosphere (*5*). Other investigators, however, believe that the high $^{87}Sr/^{86}Sr$ ratios in andesitic lavas of southern Peru and northern Chile result from contamination of mantle-derived melts with Sr from crustal sources (*8*–*10*).

The $^{143}Nd/^{144}Nd$ ratios from two lavas of El Misti Volcano, a member of the Arequipa volcanics, are too low to be accounted for by mantle sources or sediments or volcanic rocks of subducted oceanic crust (*3*). A Nd component from the continental crust seems required.

Here we address the contamination problem through Pb isotope relationships. The U, Th, and Pb data for the lavas and some of the regional Precambrian crustal rocks are given in Table 1. All volcanic rocks are from the Arequipa and Barroso suites of James *et al.* and have the same sample numbers (*7*). The Precambrian gneisses are partly from the collection of James *et al.* (PE) and partly from samples collected for this study (BAR). Ages of 2000 × 10^6 years have been reported for the gneisses at Mollendo (*11*), along the Pacific Coast, 80 km southeast of Arequipa. The gneisses at Arequipa may be in part coeval, but James (*12*) has measured an age of 1000 × 10^6 years on one zircon sample from Charcani gneiss. No specific age information is available for any of the gneisses in Table 1.

The Pb isotope data, plotted in isotope correlation diagrams in Fig. 1, show that Pb in the volcanic lavas cannot be generated simply by partial melting of volcanic rocks of the subducted oceanic slab (ORL), by subducted pelagic sediments (S), or by mixtures of the two. We believe that production of the lavas is initiated in the mantle, and that the lavas therefore contain a Pb component that originated in the mantle. This seems required because calc-alkaline andesitic rocks occur in oceanic settings where crustal materials have not participated in producing the Pb of the lavas (*2*–*4*). In the present case, the Pb in the mantle component might be given by the ores and rocks from the Disputada mine area in central Chile, east of Santiago (*D* in Fig. 1), where the $^{87}Sr/^{86}Sr$ ratios in the rocks are uniformly 0.704 (*13*), the value generally observed in oceanic settings. We will therefore assume that the Disputada Pb ratios adequately represent the mantle component.

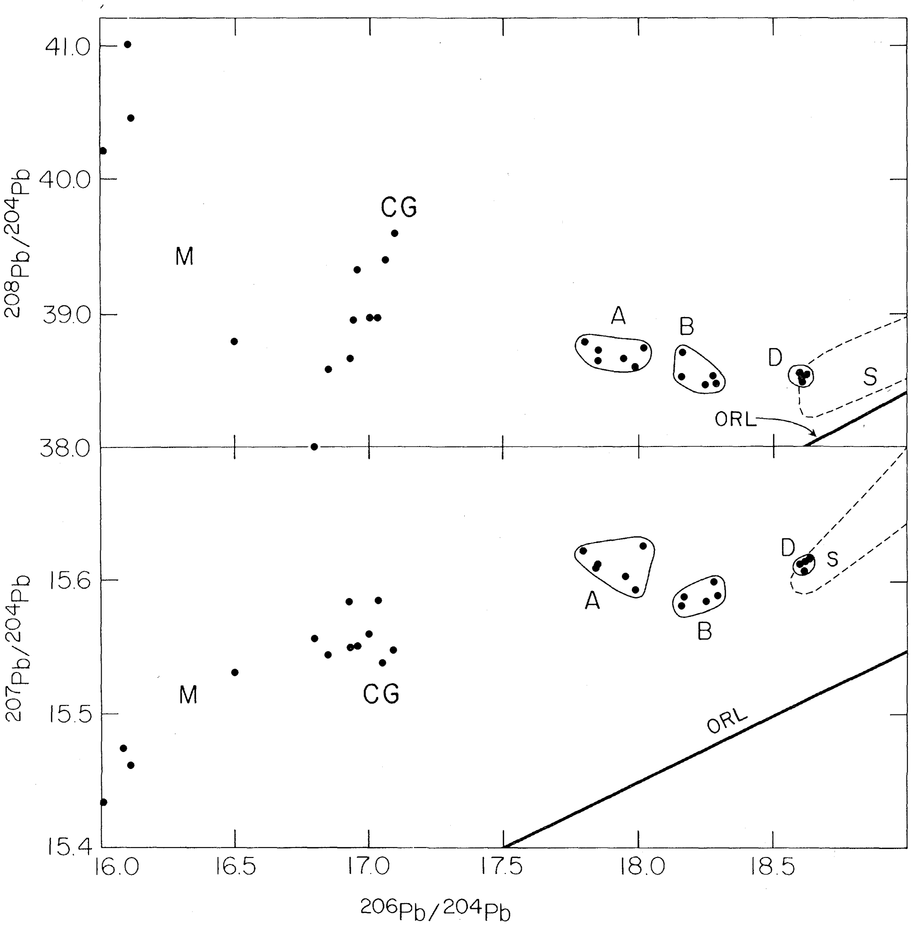

Fig. 1. Lead isotope correlation diagram. Abbreviations: *A*, Arequipa volcanics; *B*, Barroso volcanics; *M*, granulites at Mollendo; *CG*, Charcani gneiss at Arequipa; *D*, Disputada mine district, central Chile (*16*); *ORL*, regression line for oceanic volcanic rocks; and *S*, pelagic sediments from the Pacific Ocean.

Figure 1 shows that the Pb isotope ratios for the gneisses of the basement complex at Mollendo and Arequipa approximately define isotope correlation trends that include the young volcanic Pb, and that pass through the fields of the Disputada Pb. The gneisses could therefore be the source of the crustal Pb component. There are two ways of obtaining the low $^{206}Pb/^{204}Pb$ ratios of the lavas: selective contamination from potassium feldspars of upper crustal rocks of the Precambrian basement complex or from lower crustal granulitic rocks. Potassium feldspars have high Pb contents and essentially no U or Th, causing $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios to be "frozen in" at the time of crystallization. In this case the $^{208}Pb/^{204}Pb$ ratio as well as the $^{206}Pb/^{204}Pb$ ratio should be lower than the comparable ratio in the Disputada Pb, the index of mantle Pb, which is contrary to observation. Granulites require high-pressure conditions of metamorphism and are generally considered to form in the lower crust. Direct measurements (*14*) as well as Pb isotope ratios in Precambrian granulites (*15*) show that U is excluded more strongly than Pb from such rocks, but that Th does not tend to be depleted with respect to Pb. These observations are in accord with the isotopic data from the lavas. Tilton inferred a granulite contamination mechanism in a report based solely on isotope data from the lavas (*16*). The high $^{87}Sr/^{86}Sr$ ratios can also be accounted for by either of the models cited above, since the gneisses in Table 1 have high $^{87}Sr/^{86}Sr$ values (*7*), although the 400 × 10^6 year "pseudo-isochron" is not explained in any obvious way.

The U and Th concentration data in Table 1 provide further support for the granulite contamination model. Whereas Th/U ratios in igneous rocks are generally between 3.5 and 3.8, the distinctly higher ratios in the granulite at Mollendo and the Charcani gneiss at Arequipa (Table 1) are mirrored in the Arequipa and Barroso volcanics. The Th/U data also suggest that the Arequipa volcanics contain a larger granulite component than the Barroso volcanics, in agreement with the Pb and Sr isotope data.

Since in southern Peru the crust is nearly twice as thick as in most continental areas (*17*), the question arises of how much crustal thickness influences the geochemical data. Several investigators have noted that many Sr isotope data for

Quaternary Andean lavas are compatible with an increase in crustal Sr with increasing crustal thickness (8, 9). Andean Pb data are much less extensive, and adequate comparisons between the two decay systems are thus not possible. In principle, data for lavas from southern Peru of varying ages might resolve the problem. The Arequipa and Barroso lavas have been extruded recently when the crust had attained its present thickness of 60 to 70 km in the Arequipa district (17). On the other hand, for calc-alkaline lavas of the Toquepala Group, near the Toquepala mine, 300 km southeast of Arequipa, James reports a Rb-Sr age of 70×10^6 years and an initial ^{87}Sr/^{86}Sr ratio of 0.7042 (18). This ratio is much lower than those for the Arequipa and Barroso lavas and is in general agreement with ratios for similar lavas from oceanic settings. Since thickening of the Andean crust has probably occurred during the Cenozoic era (17), the crust should have been much thinner, perhaps of normal thickness at the time the Toquepala lavas were extruded. Two Pb isotope analyses from the Toquepala ore (19) show a general similarity to the Disputada mine Pb rather than the Arequipa and Barroso volcanic Pb. The mineralization at the mine has not been dated directly, but porphyry intrusives associated with the ore have yielded K-Ar ages of 57×10^6 years (20). These data suggest that crustal thickness has exerted a strong control on the isotopic ratios; however, broader sampling is needed to ascertain whether the lack of an imprint of granulite or other crustal rocks is due to a local peculiarity of the Toquepala data rather than to crustal thickness.

The petrogenetic arguments presented here are derived mainly from Pb isotopic data and in a narrow sense apply solely to that element. In fact, if one uses the concentration data in Table 1 and reasonable values of mantle-derived magmas to calculate lava compositions on the basis of simple bulk assimilation, it is difficult to account for the major element chemistry of the rocks. James (21) has reviewed this problem in detail for major and trace element data of the Barroso and Arequipa lavas. We believe that the granulite component in the lavas reflects selective contamination with Pb, Sr, and probably other trace elements as well. Carter *et al.* (22) reached a similar conclusion from Sr and Nd isotopic studies on Tertiary volcanics from northwestern Scotland and the basement rocks of the associated Precambrian continental crust.

Although our data give clear indication of the presence of a granulitic Pb component in the young lavas, the observations do not in themselves indicate the environment in which the mixing occurred. In view of the gross tectonic dissection of the Andes in the study area, the mixing could have happened at higher levels in the crust than are required to produce granulite. The Pb must, however, have been derived from rocks that were once in the lower crust.

GEORGE R. TILTON
Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D.C. 20015, and Department of Geological Sciences, University of California, Santa Barbara 93106

BARBARA A. BARREIRO
Department of Geological Sciences, University of California, Santa Barbara

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Evidence for Homologous Actions of Pro-Opiocortin Products

Abstract. *α-Melanocyte-stimulating hormone (α-MSH), a modified fragment of adrenocorticotropic hormone, derives from the same biosynthetic route as β-endorphin and is stored by the same arcuate neurons. Microinjection of α-melanocyte-stimulating hormone and several related peptides into the periaqueductal gray matter significantly reduced responsiveness to pain and had a behavioral profile similar to that produced by β-endorphin.*

Some neurons contain at least two putative neurotransmitters or neuromodulators. In particular, neurons arising from the hypothalamic arcuate nucleus contain substances with α-melanocyte-stimulating hormone (α-MSH) and β-endorphin immunoreactivities. Whereas β-endorphin is a known opioid with well-characterized receptors and numerous potent behavioral effects (1), α-MSH [*N*-acetyl-ACTH(1-13)-amide], which contains the behaviorally active sequence ACTH(4-10) (2), is less well characterized as a peptide with a unique central nervous system function.

The arcuate β-endorphin-containing neurons appear to synthesize active peptides from a common precursor, pro-opiocortin. This glycoprotein, characterized primarily in the pituitary by Mains *et al.* (3) and Roberts and Herbert (4), contains the full structure of β-lipotropin (β-LPH), β-endorphin, and ACTH(1-39), as well as a 16,000-dalton peptide of unknown function. The structure of pro-opiocortin in bovine pituitary has been obtained by complementary DNA (cDNA) sequencing (5). Within the brain, immunohistochemical studies with light microscopy (6) and electron microscopy (7) have demonstrated that all of the components of pro-opiocortin are found within the same neuron. The final products in the brain show a preponderance of β-endorphin over its precursor, β-LPH, and of α-MSH over its precursor, ACTH (8). Furthermore, the immunohistochemical and biochemical studies show that these peptides are packaged in a fashion consistent with their ability to be released (6, 7, 9). Studies in human subjects have demonstrated

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