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New Cenozoic K-Ar ages on volcanic rocks from the eastern High Andes, southern Peru

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Abstract—New K-Ar ages of Cenozoic volcanic rocks from the southeastern Peruvian Andes, where geochronologic data are still scarce, are presented in this paper. North of Lake Titicaca, the new data provide evidence of various late Oligocene to Pliocene volcanic pulses. In the Crucero intramontane basin (14°20'S, 70°W), basaltic andesites, dacites, rhyolites, and ash-flow tuffs interbedded in fluvial and lacustrine sediments yield ages ranging from 25 to 22 Ma, characterizing a late Oligocene to early Miocene volcanic pulse. In the same area, widespread acidic ash-flow tuffs and rhyolites, with ages ranging between 17 and 12 Ma, demonstrate that volcanism was also active during mid- to late Miocene times. Finally, the younger ages show that volcanism was still active during the mid-Pliocene and Pleistocene in the southeastern Peruvian Andes.

Resumen—Se presentan nuevas edades radiocronológicas K-Ar de rocas volcánicas cenozoicas de los Andes Surorientales del Perú de donde se conocen todavía pocos datos geocronológicos. Al norte del Lago Titicaca, estas nuevas dataciones demuestran la existencia de varios pulsos de actividad volcánica entre el Oligoceno superior y el Pleistoceno. En la cuenca intramontañosa de Crucero (14°20'S, 70°W), andesitas basálticas, dacitas, riolitas e ignimbritas intercaladas en sedimentos aluviales y lacustres, han dado edades con rango de 25 hasta 22 Ma, lo que evidencia una fase de intenso volcanismo durante el Oligoceno tardío al Mioceno temprano. En la misma zona, grandes mesetas de ignimbritas y riolitas, con edades comprendidas entre 17 y 12 Ma, atestiguan de una fuerte actividad volcánica durante el Mioceno medio a tardío. Por fin, edades recientes comprueban una actividad volcánica significativa en los Andes Surorientales del Perú durante el Plioceno y el Pleistoceno.

INTRODUCTION

ANDEAN magmatism in the Eastern Cordillera of the Central Andes is volumetrically minor compared to that in the Western Cordillera and it has received little attention in the past. Recently, however, metallogenic, petrographic, and geochemical investigations have provided new information on this very unusual magmatism. Thus, a crustal origin has been proposed for the Oligo-Miocene peralumilous plutonism from northern Bolivia and southeastern Peru (Clark *et al.*, 1983; Kontak *et al.*, 1984) and for the late Miocene and Pliocene ignimbritic volcanism of southeastern Peru (Herrera *et al.*, 1984; Kontak and Pichavant, 1984; Noble *et al.*, 1984).

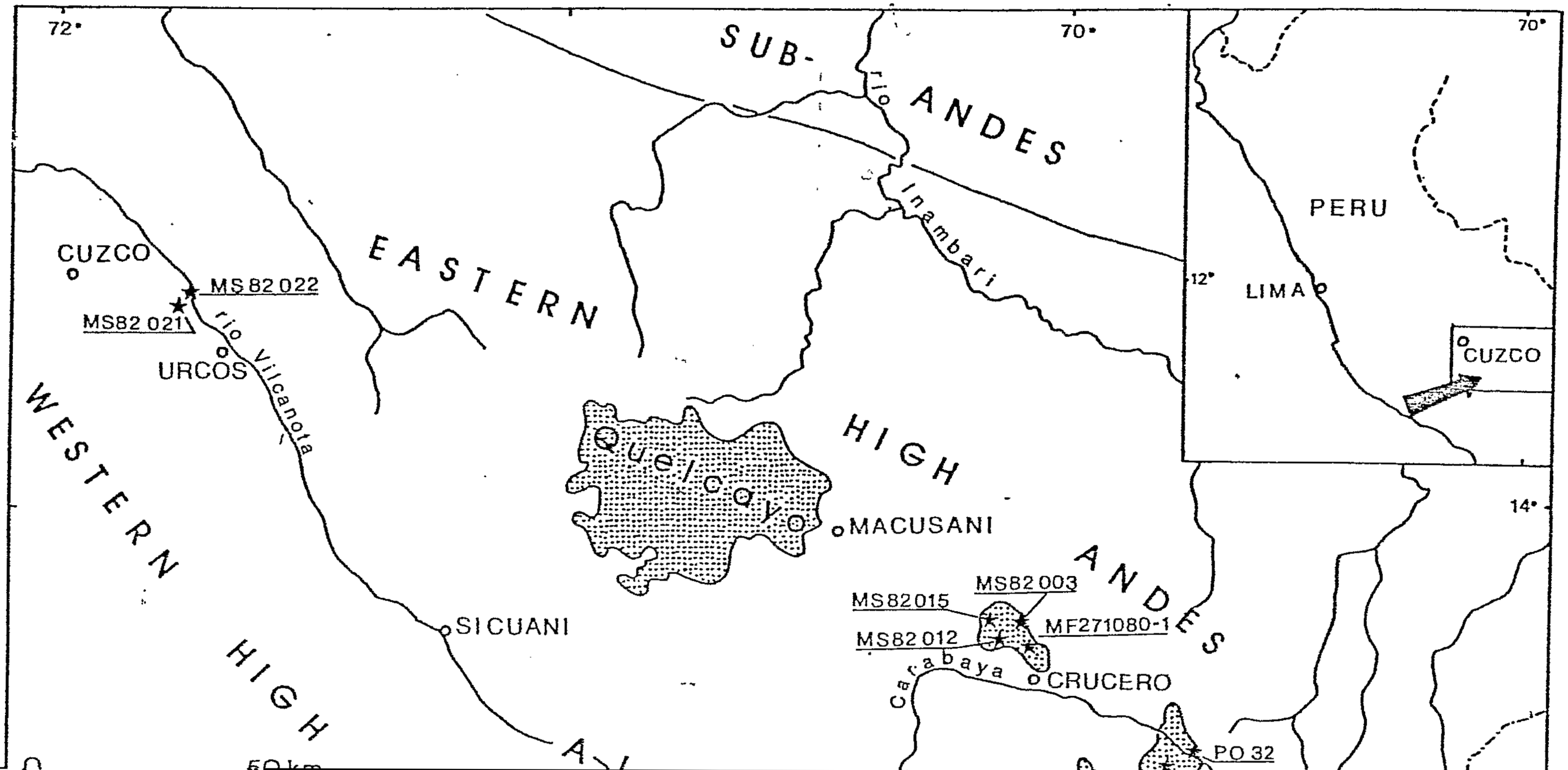
The genesis of these crustal derived magmas is of fundamental interest. Nevertheless, the relationship of their genesis with the Pacific subducting plate (the trench axis of which is approximately 500 km from the Eastern Cordillera at present) and/or with other tectonic processes remains uncertain. This magmatism is also of great economic interest because of its enriched lithophile elements (Noble *et al.*, 1984), some of which — such as tin, tungsten, and zinc — have mining potential (Clark *et al.*, 1984).

In this context, new K-Ar radiochronological data from Tertiary and Pleistocene volcanics of the southeastern Peruvian Andes are presented (Fig. 1), from which area only limited data were previously available. This study dated primarily volcanic rocks of acidic composition; however, some basalts of latest Oligocene to earliest Miocene age provide the first indication of a mantle-derived magmatism contemporaneous with crustal-derived magmatism.

METHODS

The new radiochronologic data are presented in Table 1. Procedures used for sample preparation, potassium determinations, argon extraction-purification, and mass isotopic analyses were slightly modified from those of Bonhomme *et al.* (1975). Isotopic and decay constants used were compiled by Steiger and Jager (1977). Error was calculated according to the method of Mahood and Drake (1982). Argon calibration used the G1-0 standard sample (Odin, 1982), with a value of 24.80±0.14 nl/g (1σ).

Some of the studied samples showed very low radiogenic argon content with respect to total argon


72°
70°
SUB-ANDES
rio Inambari
EASTERN HIGH ANDES
WESTERN HIGH
CUZCO
MS 82 022
MS82 021
URCOS
rio Vilcanota
Quelccaya
MACUSANI
SICUANI
MS82 003
MS82 015
MF271080-1
MS82 012
Carabaya
CRUCERO
PO 32
PERU
LIMA
CUZCO
12°
14°
50 km

[redacted]

concentration. The effect of this on the reliability of the dating is discussed below.

RESULTS AND GEOLOGIC RELATIONSHIPS

The Crucero-Ananea Region (North of Lake Titicaca)

Volcanic rocks from the Cayconi Formation. The Cayconi Formation, type section near Crucero (Laubacher *et al.*, in press), consists of alluvial reddish sandstones and conglomerates, and palustrine light colored shales and sandstones. These sediments are interbedded with volcanic rocks of basaltic and basalt andesitic, dacitic, rhyodacitic, and rhyolitic composition. The Cayconi Formation unconformably overlies a basement composed of Paleozoic, Permo-Triassic, and Cretaceous rocks that have been deformed at least three times: *i)* during the Paleozoic, *ii)* during the Permian and *iii)* during the Eocene (Laubacher, 1978; Laubacher *et al.*, in press). The age of the last phase is not well defined, but it is probably late Eocene (Noble *et al.*, 1974). The K-Ar ages obtained here on eight rock samples definitively places this volcanism at the Oligocene/Miocene boundary (Odin, 1982) — *i.e.*, between 25 and 22 Ma.

Sample MS82008 must be discussed in more detail. The K-Ar isotopic age of this sample is 18.8 ±1.5 Ma, which is some 6 Ma younger than samples MS82007 and MS82009, which were collected a short distance from MS82008 and apparently in the same volcanic sequence. The radiogenic argon content of MS28008 is not significantly lower than that of the two other samples; therefore, this young age cannot be attributed to analytical error. In contrast, a strong alteration of the rock is observed in thin section and is confirmed by a H_2O content of 10% (Laubacher *et al.*, in press). This alteration may be caused by hydrothermal transformation, indicated by the intense seritization of the feldspars. As the analysis was performed on the whole rock, it may be that the datum 18.8 Ma has no geologic meaning and is an intermediate value between the age of cooling (25 to 22 Ma) and the time of alteration (younger than 18 Ma). Examples of similar behavior for neighboring regions are reported by Soler and Bonhomme (1988).

Palca XI sample. The Palca XI sample was collected from a small rhyolitic stock (~1 hectare of extension) near Cerro Pucaorco, approximately 2 km to the north of the Palca XI mine (Fig. 1). Four kilometers to the south of the mine, another rhyolitic stock — similar in composition but larger (Injoque *et al.*, 1983) — forms the Cerro Choquene. This stock intrudes Cretaceous sandstones, shales, and conglomerates of probable mid-Tertiary age that correlate with the Cayconi Formation. A middle to late Tertiary age was therefore suggested for these stocks (Laubacher, 1978). The mined vein, mineralized with W-Zn-Ag-Sn-Cu, is emplaced in a large NNW-SSE zone located between these two stocks. Unpublished reports suggest a genetic relationship between the mineralization and the rhyolitic stocks. The Palca XI rhyolite sample of the Cerro Pucaorco has been dated at roughly 12.5 Ma, confirming previous field observations, but it is somewhat older than the 8.3 Ma age reported by Clark *et al.*, (1984) for mineralization of the Palca XI mine itself. Both are approximately coeval with late Miocene ignimbrites of Ma-

Table 1. Location, petrographic, and K-Ar isotopic data for the samples studied.

Samples and Location		Petrographic Definition	Fraction Analyzed	K_2O (%)	$\frac{^{40}Ar_{rad}}{^{40}Ar_{tot}}$ (%)	$^{40}Ar_{rad}$ (nl/g)	Age (Ma ± 1σ)
Crucero Region							
MS82003	14°15'S, 70°04'W	rhyodacitic tuff	FK	11.49	98.1	8.77	23.5 ± 0.3
MS82006	14°34'S, 69°50'W	rhyolitic tuff	V	4.47	61.1	3.32	22.9 ± 0.6
			B	8.88	82.4	6.75	23.5 ± 0.4
MS82007	14°33'S, 69°47'W	andesite	R	2.56	54.2	2.058	24.8 ± 0.7
MS82008	14°32'S, 69°46'W	andesite	R	2.07	48.3	1.263	18.8 ± 1.5
MS82009	14°32'S, 69°46'W	andesite	R	1.97	39.1	1.574	24.6 ± 1.3
MS82012	14°15'S, 70°07'W	rhyolite	FK	10.90	96.8	7.84	22.2 ± 0.2
MS82015	14°13'S, 70°08'W	rhyolite	FK	10.19	97.2	7.41	22.4 ± 0.3
MF271801	14°17'S, 70°03'W	andesite	R-I	1.32	20.9	1.016	23.7 ± 1.8
			R-II	1.32	24.5	0.954	22.3 ± 0.7
Palaca II	14°42'S, 69°41'W	rhyolite	FK	7.57	81.5	3.10	12.7 ± 0.6
			B	8.80	78.5	3.44	12.1 ± 0.3
PO232	14°40'S, 69°29'W	acidic tuff	V	6.19	27.6	0.76	3.79 (n.d.)
Cusco Region							
MS82021	13°37'S, 71°42'W	latite	R	3.77	8.99	0.850	7.2 ± 0.5
MS82022	13°35'S, 71°43'W	latite	R	3.89	18.18	0.074	0.59 ± 0.25

Analytical procedure and constants from Lavenu *et al.* (in press). R, whole rock; V, glass; B, biotite; KF, K-feldspar.

cusani, for which Noble *et al.* (1984) reported an age of 9.4 Ma. A mid-Miocene age of ~16 Ma (Laubacher *et al.*, in press) was obtained from an ignimbritic ash-flow sample collected approximately 20 km north of the Palca XI mine. This mid- to late Miocene magmatism is coeval with many other magmatic and mineralized occurrences (see references in Soler and Bonhomme, 1988), with ages ranging between 14 Ma and 7 Ma.

Tuff PO232. Sample PO232 was collected from the Cerro Viscachani 3 km to the northeast of Ananea (Fig. 1). It is partially a reworked tuff, interbedded in the palustrine part of the Arco-Aja Formation defined approximately 20 km north of Ananea near the hamlet of Ancocala. Field observations have suggested a Pliocene to early Pleistocene age for the Arco-Aja Formation (Fornari *et al.*, 1982) and the 3.79 Ma age of the interbedded tuff dates the lacustrine formation as Pliocene. The Arco-Aja Formation, therefore, may be considered as a time equivalent of the La Paz Formation (Lavenu *et al.*, 1984; Lavenu *et al.*, in press; Laubacher *et al.*, 1984).

The Cuzco Region

Latite MS82021. Sample MS82021 was collected on the southern edge of the Rumicola volcano, which marks the eastern termination of the Cuzco Valley approximately 20 km to the southeast of Cuzco (Fig. 1). Field observations suggest a Quaternary age for this volcanism; thus, the 7.2 Ma isotopic determination (see Table 1) might not be valid. This whole-rock sample contains only about 9% radiogenic argon, which result was obtained in replicate analyses. In these conditions, an excess of ^{40}Ar may be suspected. Similar excesses of radiogenic argon in biotites from tuffs of the Pliocene La Paz Formation have already been measured. This interpretation may be valid for sample MS82021, which is also rich in biotite.

Latite MS82022. Sample MS82022 came from the Huambutillo volcano located at the confluence of the Vilcanota River and the stream in the Cuzco Valley, which volcanic center is regarded as more or less contemporaneous with the Rumicola. Thus, the 0.59 Ma age (see Table 1), even if reported with a large uncertainty, seems to be more satisfactory — the percent radiogenic argon content here being high enough to be regarded as correctly supporting the age.

CONCLUSIONS

This study has led to the following conclusions:

1) A basic to acidic volcanism of latest Oligocene to earliest Miocene age is dated in the Crucero Basin. It is contemporaneous with peraluminous plutonism al-

2) The Pliocene age of the Arco-Aja Formation is demonstrated by the 3.79 Ma date of an interbedded tuff. Therefore, the Arco-Aja and La Paz Formations (Ballivian *et al.*, 1978) — both of Pliocene age — can be correlated. The tuff of the Arco-Aja Formation is approximately coeval with the Chijini Toba dated at 3.27 Ma (Clapperton, 1979) and with the youngest Macusani ignimbritic ash flow dated at 4.2 Ma (Barnes *et al.*, 1970). These data confirm that, during Pliocene times, volcanism was very active on the southwestern edge of the Eastern Cordillera of southern Peru and northern Bolivia.

3) The Pleistocene age of the volcanites of the Cuzco area is partly confirmed.

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REFERENCES

Ballivian, O., Bles, J. L., and Servant, M. 1978. Le Plio-Quaternaire de la région de La Paz (Andes orientales, Bolivie). *Cahiers de l'ORSTOM, Série Géologique* 10 (1), 101-113.

Barnes, V. E., Edwards, G., McLaughlin, W. A., Fridmann, L., and Joensuu, O. 1970. Macusanite occurrence, age and composition, Macusani Peru. *Bulletin of the Geological Society of America* 81, 1539-1546.

Bonhomme, M. G., Thuizat, R., Pinault, Y., Clauer, N., Wendling, A., and Winckler, R. 1975. *Méthode de Datation Potassium-Argon: Appareillage et Technique.* Institut Géologique, Université de Louis Pasteur, Strasbourg, Notes Techniques 3, 53 p.

Bonhomme, M. G., Audebaud, E., and Vivier, G. 1985. K-Ar ages of Hercynian and Neogene rocks along an east-west profile in southern Peru. *Communicaciones (Santiago)* 35, 27-30.

Clapperton, A. H., Palma, V. V., Archibald, D. A., Farrar, E., Arenas, M. J. F., and Robertson, R. C. R. 1983. Occurrence and age of tin mineralization in the Cordillera Oriental, southern Peru. *Economic Geology* 78, 514-520.

Clark, A. H., Kontak, D. J., and Farrar, E. 1984. A comparative study of the metallogenic and geochronological relationship in the northern part of the Central Andean tin belt, SE Peru and NW Bolivia. *Proceedings, VI IAGOD Symposium, Stuttgart*, 269-279.

Fornari, M., Herail, G., and Laubacher, G. 1982. El oro en la Cordillera Suroriental del Perú: El placer fluvioglacial de San Antonio de Poto (Dpto. de Puno) y sus relaciones con la mineralización primaria de la Rinconada. Actas, V *Congreso Latinoamericano de Geología, Buenos Aires* 4, 369-386.

Herrera, J. V., Pichavant, M., and Esteyries, C. 1984. Le volcanisme ignimbritique peralumineux Plio-Quaternaire de la region de Macusani, Pérou. *Comptes Rendus de l'Académie des Sciences, Paris, Série II* 298, 77-82.

Injoque, J., Miranda, C., Carlier, G., Sologuren, W., and Tijero, L. 1983. Evidencia de basamento pre-cambriano en la región de Inchupalla, Puno. *Boletin de Sociedad Geológica del Perú* 70, 25-28.

Kontak, D. J., and Pichavant, M. 1984. Petrology of the peraluminous volcanics from Macusani, SE P[illegible]

Kontak, D. J., Clark, A. H., and Farrar, E. 1984. The magmatic evolution of the Cordillera Oriental, southeastern Peru. In: *Andean Magmatism: Chemical and Isotopic Constraints* (Edited by Harmon, R. S., and Barreiro, B. A.), pp. 203-219. Shiva, London.

Laubacher, G. 1978. *Géologie de la Cordillère Orientale et de l'Altiplano au Nord et au Nord-Ouest du Lac Titicaca (Pérou).* Travaux et Documents de l'ORSTOM 95, 217 pp.

Laubacher, G., Bonhomme, M., Fornari, M., Herail, G., and Vivier, G. 1984. Le bassin d'Ananea-Ancocala, temoin de l'evolution Plio-Quaternaire des Andes sud-orientales du Perou. *Réunion Annuelle Sciences de la Terre, Bordeaux* 336.

Laubacher, G., Sébrier, M., Fornari, M., and Carlier, G., 1988. Oligocene and Miocene continental sedimentation, tectonics, and S-type magmatism in the southeastern Andes of Peru. *Journal of South American Earth Sciences*, in press.

Lavenu, A., Bonhomme, M. G., Vatin-Perignon, N., and De Pachtere, P. 1988. Neogen magmatism in the Bolivian Andes (between 16° and 18°S), Part 1: Numerical stratigraphy (K/Ar) and tectonics. *Journal of South American Earth Sciences*, in press.

Lavenu, A., Fornari, and M., Sébrier, M. 1984. Existence de nouveaux épisodes Quaternaires dans l'Albaroa péruvo-bolivien. *Cahiers de l'ORSTOM, Série Géologique* 14 (1), 103-114.

Mahood, G. A., and Drake, R. E. 1982. K-Ar dating of young rocks: A case study of the Sierra La Primavera, Jalisco, Mexico. *Bulletin of the Geological Society of America* 93, 1232-1241.

Noble, D. C., McKee, E. H., Farrar, and E., Petersen, U. 1974. Episodic Cenozoic volcanism and tectonism in the Andes of Peru. *Earth and Planetary Science Letters* 21, 213-220.

Noble, D. C., Vogel, T. A., Peterson, P. S., Landis, G. P., Grant, N. K., Jerek, P. A., and McKee, E. H. 1984. Rare-element enriched S-type ash-flow tuffs containing phenocrysts of muscovite, andalousite and sillimanite, southeastern Peru. *Geology* 12, 35-39.

Odin, G. S., 1982. *Numerical Dating in Stratigraphy.* J. Wiley and Sons, Chichester, 1040 p.

Soler, P., and Bonhomme, M. G. 1988. New K-Ar age determination of intrusive rocks from the Cordillera Oriental and the Altiplano of central Peru: Identification of magmatic pulses and episodes of mineralization. *Journal of South American Earth Sciences* 1 (2), 169-177.

Steiger, R. H. and Jager, E. 1977. Subcommission on Geochronology: Convention on the use of decay constant in geo- and cosmochronology. *Earth and Planetary Science Letters* 36, 359-362.