

page 40

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

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(Received for publication September 1987)

**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 peraluminous 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  $24.80 \pm 0.14$  nl/g (1 $\sigma$ ).

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

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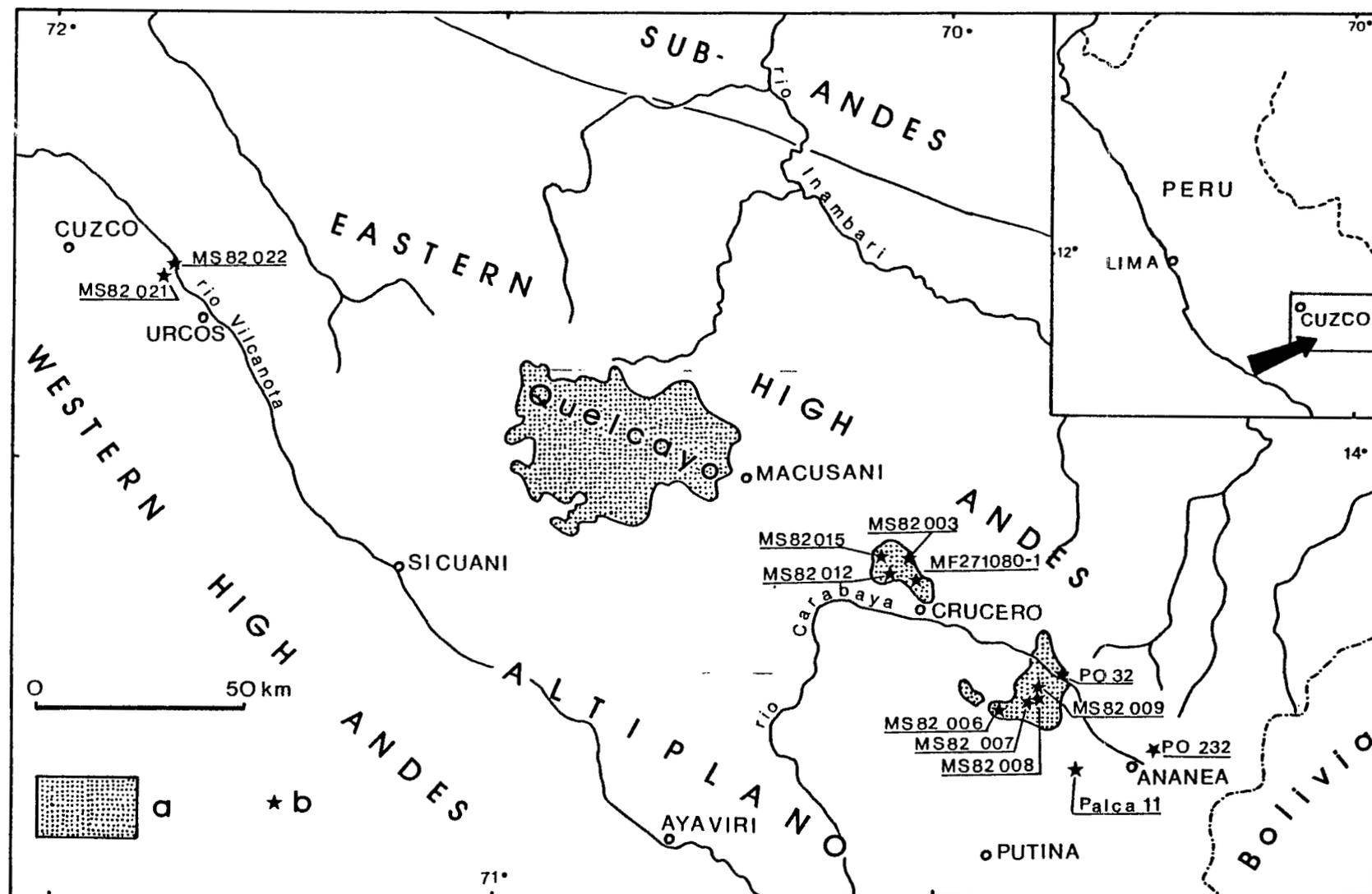


Fig. 1. Cenozoic and Pleistocene magmatism in the eastern High Andes of Peru: a) main volcanic outliers, b) position and numeration of the study samples.

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  $18.8 \pm 1.5$  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 MS82008 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<sub>2</sub>O 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 Pucacorco, 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 Pucacorco 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 <sub>2</sub> O (%)	$\frac{^{40}\text{Ar}_{\text{rad}}}{^{40}\text{Ar}_{\text{tot}}}$ (%)	<sup>40</sup> Ar <sub>rad</sub> (nl/g)	Age (Ma ± 1σ)	
<b>Crucero Region</b>							
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.)
<b>Cusco Region</b>							
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 (Lavenue *et al.*, 1984; Lavenue *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  $^{40}\text{Ar}$  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 already reported by Clark *et al.* (1983).

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.

*Acknowledgements*—Fieldwork was carried out in 1980 and 1982 under a cooperative scientific agreement between INGENMET (Peru) and ORSTOM (France). We are indebted to ORSTOM Lima and ATP Geodynamique II (INAG, Paris) for field assistance and support. ORSTOM (Paris) and the Institut Dolomieu, UA 69 (CNRS) Grenoble supported radiochronologic dating.

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