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Age of intrusion and mineralization, Pasto Bueno, northern Peru

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CONTENTS

	Page
Introduction	1
Analyzed material and results	1
Discussion	5
References cited	5

ILLUSTRATIONS

Figure 1.	Metallogenic-location map, showing original andrecalculated ages for intrusive rocks	2
2.	Isochrons for mineralization at Pasto Bueno and for emplacement of the quartz monzonite stock	6

TABLES

Table 1.	Analytical data for sphene fission-track age determination	3
2.	Analytical data for K-Ar age determinations	4

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INTRODUCTION

Pasto Bueno, the only significant tungsten ore deposit in northern Peru, is located along the crest of the Andes approximately 3 kilometers north of the Cordillera Blanca batholith (fig. 1). Quartz veins containing tungsten and base-metal sulfides occur over several hundred meters on either side of the upper contact of the Consuzo quartz monzonite stock which was emplaced into a Jurassic-Cretaceous shale and quartzite sequence. The age of the quartz monzonite was originally reported as 9.5$\pm$2.8 m.y. (Landis and Rye, 1974). This age was determined from fission-tracks in sphene from unaltered intrusive rock (sample GR-6) and is here (table 1) recalculated to be 10.5$\pm$2.4 m.y. using updated calibration procedures. To confirm the age of the host quartz monzonite and to determine the age of ore deposition, one sample of magmatic biotite (GR-6, from sample for fission-track determination) and two samples of hydrothermal sericite (Auxilio and 7Man-408, from the Auxilio and Manuelita vein systems) were dated by the potassium-argon method (Dalrymple and Lanphere, 1969). Both argon and potassium analyses were determined by isotope dilution methods, and are reported in table 2.

This work was initiated by the first author in 1974, while a faculty member of the University of New Mexico. At that time the U.S. Geological Survey had an active research interest in the ore deposits of the Peruvian Andes.

ANALYZED MATERIAL AND RESULTS

The magmatic biotite K-Ar age for the Consuzo quartz monzonite is in good agreement at 10.2$\pm$0.17 m.y. with the sphene fission-track age of 10.5$\pm$2.4 m.y. from the same sample (GR-6). This sample is from the least-altered part of the stock and is weakly greisenized. It has quartz phenocrysts with prominent overgrowths, but has no pyrite or other sulfide minerals and no post-greisen hydrothermal alteration or weathering.

Hydrothermal vein sericite, which formed during ore deposition, was used to determine the age of the ore. The Auxilio vein is deep in the Consuzo quartz monzonite stock near the Loreto vein system, and the Manuelita vein (sample 7Man-408) is situated in Jurassic shale above the intrusive contact north of the Consuelo veins. Both veins locally contain massive pods of hydrothermal sericite admixed with minor fluorite and quartz. Field, petrographic, stable-isotope, and fluid-inclusion data indicate that the sericite is hypogene but formed near 200 °C after the main period of ore deposition, and has not later been subjected to higher temperatures or altered by later weathering or mineralizing events. No dikes or other intrusions younger than the stock are known from the surface or underground, both in the immediate area and in nearby deeply incised canyons.

The Auxilio and Manuelita sericites are dated at 8.9$\pm$0.12 and 7.8$\pm$0.10 m.y. (table 2) and, considering the analytical uncertainties, are significantly different from each other if conventional corrections for atmospheric argon are used. It is possible that the $^{40}Ar/^{36}Ar$ of argon dissolved in the hydrothermal fluid was greater than 296 (atmosphere) and that this argon was incorporated into some of the sericite during crystallization. If the data for the Auxilio and Manuelita sericites are plotted on a $^{40}Ar_{[total]}/^{36}Ar$ vs. $^{40}K/^{36}Ar$ diagram, an age of 6.9 m.y. is obtained, with an initial $^{40}Ar/^{36}Ar$ of 380 (fig. 2). This age is based on only two data points; more data would be needed to confirm this interpretation, but none of the sericite samples is large enough for the additional K-Ar work. Figure 2 also shows the 10.2 m.y. isochron for the magmatic biotite based on the standard atmospheric argon ratio.

The interpretation for the younger age requires a unique hydrothermal event some 3 m.y. later than the intrusion of the quartz monzonite, while the interpretation based on the older age requires ore deposition and alteration lasting a million years or so, but still beginning a million years later than the time of stock emplacement. Neither interpretation is at variance with other geochronologic studies which indicate igneous activity continued within the region during the period of ore deposition at Pasto Bueno. An unusually high $^{40}Ar/^{35}Ar$ of about 380 is quite plausible for the hydrothermal fluids. Strontium isotope studies of fluid-inclusion waters show some ore fluids at Pasto Bueno attained $^{87}Sr/^{86}Sr$ of 0.726, indicating fluid interaction with the Paleozoic-Precambrian basement rocks (Norman and Landis, 1981). Stable isotope studies (Landis and Rye, 1974) also support the presence of a deep circulating 'evolved' ore fluid component in the Pasto Bueno system.

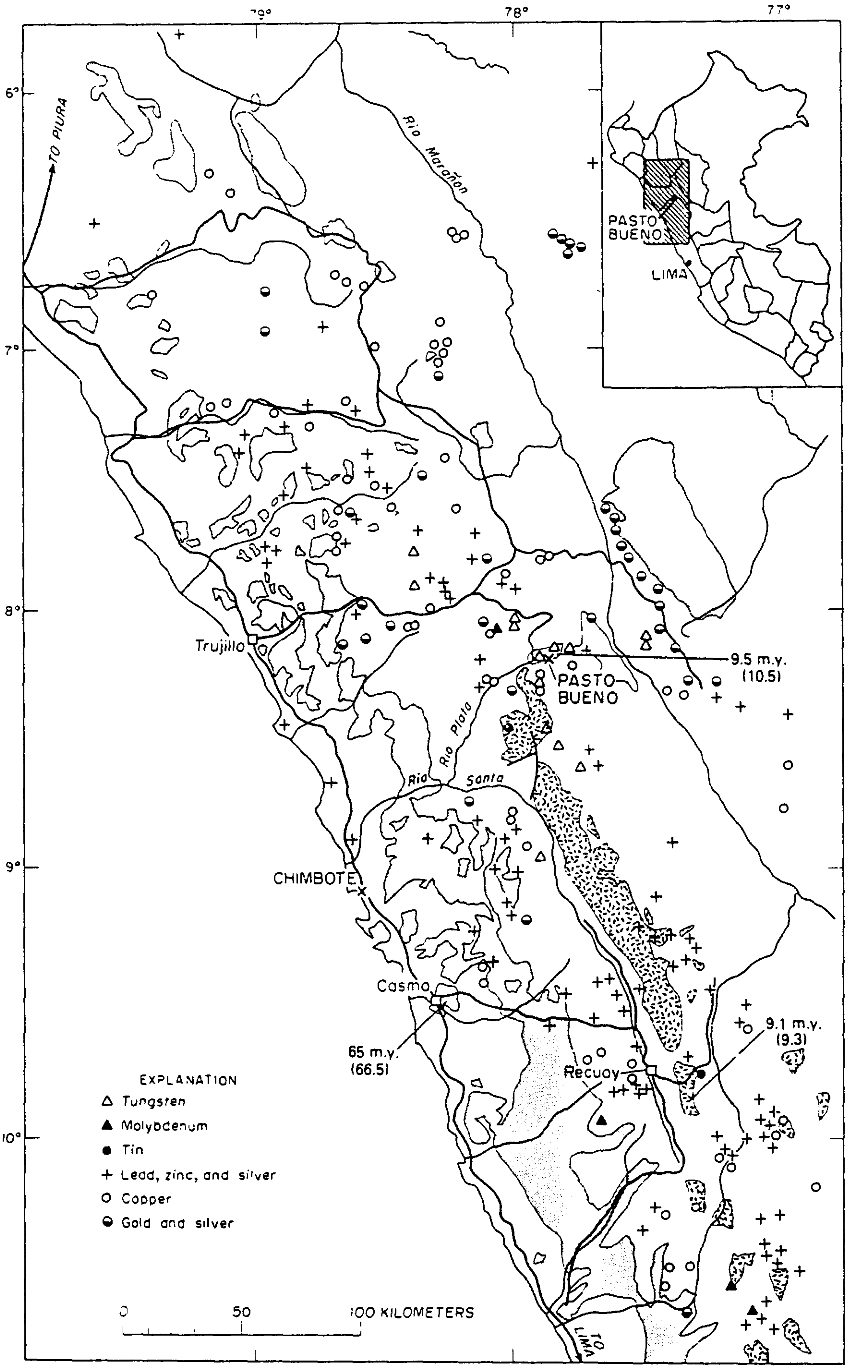

Figure 1. Metallogenic-location map, showing original and recalculated ages for intrusive rocks. The Cordillera Blanca batholith and associated stocks are stippled; the Late Cretaceous coastal batholith and plutonic bodies of uncertain age are shaded. A 65-m.y. (66.5) age for the Peruvian Coastal batholith and a 9.1-m.y. (9.3) age for the Cordillera Blanca pluton (near Casma and Recuay) are from Giletti and Day (1968). The Pasto Bueno Consuzo stock 9.5-m.y. (10.5) age is also indicated. Note the location of Pasto Bueno on the northern extension of the Cordillera Blanca, the regional trend of mineralization, and the extent of tungsten (Δ) mineralization NW and SE of Pasto Bueno. Numbers in parentheses are recalculated ages using new constants as listed in tables 1 and 2.

Table 1. Analytical data for sphene fission-track determinations

Sample No. -- mineral	Location displaced from 8°7.5' S 77°41.5' W (meters)		ρ_s t/cm^2	ρ_i t/cm^2	ϕ n/cm^2	T (m.y.)†	σ (m.y.)	Grains Counted
GR-6 Sphene	195 S	1,240 W	3.33×10^{5} (97)	1.45×10^{7} (361)	5.40×10^{15}	10.5	± 2.4	2

t = fission tracks; n = neutrons; ρ_s = spontaneous track density; ρ_i = induced track density; ϕ = neutrons/cm^2; T = calculated age in millions of years; σ = standard deviation of age calculation; λ_F = spontaneous decay constant = $7.03 \times 10^{-17} yr^{-1}$

( ) = Number of tracks counted.

† Age recalculated from Landis and Rye (1974) due to changes in fission-track calibration procedures.

Table 2. Analytical data for K-Ar age determinations

Sample	Location (Meters displaced from 8°7.5′ S., 77°41.5′ W.)		K (wt. %)	Radiogenic^{40}Ar (moles/gm).10^{-10}	Radiogenic^{40}Ar (percent)	Age[1] (m.y.)
GR-6 Biotite	515 S	2,960 W	7.77	1.37_4	33.9	10.2 (±0.17)
Auxilio Sericite	580 S	1,400 W	9.12	1.40_9	56.6	8.9 (±0.12)
7Man-408 Sericite	1,900 S	1,940 W	9.16	1.24_5	71.8	7.8 (±0.10)

[1] Uncertainty of one sigma

Decay Constants: ^{40}K: $\lambda_e = 0.581 \times 10^{-10} yr^{-1}$ $\lambda_\beta = 4.962 \times 10^{-10} yr^{-1}$

Abundance: $^{40}K = 1.167 \times 10^{-4}$ mole/mole K

DISCUSSION

Geological and geochemical data firmly establish that the Auxilio and Manuelita vein sericite formed from the same hydrothermal event that deposited the ore, but late in the paragenesis (Landis, 1972). This observation requires a unique interpretation for the K-Ar data which indicates a 6.9 m.y. hydrothermal event. Even with the uncertainties of a two-point isochron it is clear that the age of hydrothermal alteration and ore deposition is approximately 7 to 9 m.y. old. The K-Ar biotite age for the host quartz monzonite using atmospheric $^{40}Ar/^{36}Ar$ of 296 yields a 10.2 m.y. age which essentially is the same (10.5 m.y.) as that obtained by completely independent fission-track methods. The Pasto Bueno ore deposit must have formed 1 to 3 m.y. after the geologically 'apparent' host intrusion.

Although the exposed stock is only the passive host, structures developed during its emplacement controlled the location of later hydrothermal activity. Though it is not certain whether the greisen alteration is part of the late igneous activity or of the 3 m.y. later hydrothermal alteration, geologic and geochemical data (Landis, 1972) suggest that both the greisen and disseminated and vein copper-molybdenum ore in the stock are all part of the younger hydrothermal event. Pasto Bueno ore is associated with unexposed igneous rocks at depth, probably a younger phase of the Cordillera Blanca batholith, and not the quartz monzonite stock. This complements the conclusion drawn in other studies (Landis, 1972; Landis and Rye, 1974; Norman and others, 1976; Norman and Landis, 1981).

The 7 to 9 m.y. age for ore deposits is common for the Peruvian Andes. Cu-Pb-Zn-Ag deposits of central Peru appear to be less than 11 to 12 m.y. in age (Petersen, 1965; Eyzaguirre and others, 1975). The Yauricocha district deposits are approximately 7.3 m.y.[1] (Giletti and Day, 1968), Morococha is 7.4 m.y.[1] (Eyzaguirre and others, 1975) and Huachocolpa is bracketed by 8 to 4 m.y. pre-ore and post-ore igneous rocks (McKee and others, 1975). Unpublished K-Ar ages of 6 to 4 m.y. for intrusive phases of the Cordillera Blanca batholith (J.J. Wilson, personal commun., 1970) indicate that igneous activity continued well after the Pasto Bueno deposit was formed.

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[1]The age has been recalculated from that reported in the literature using the new K-Ar constants indicated in table 2.

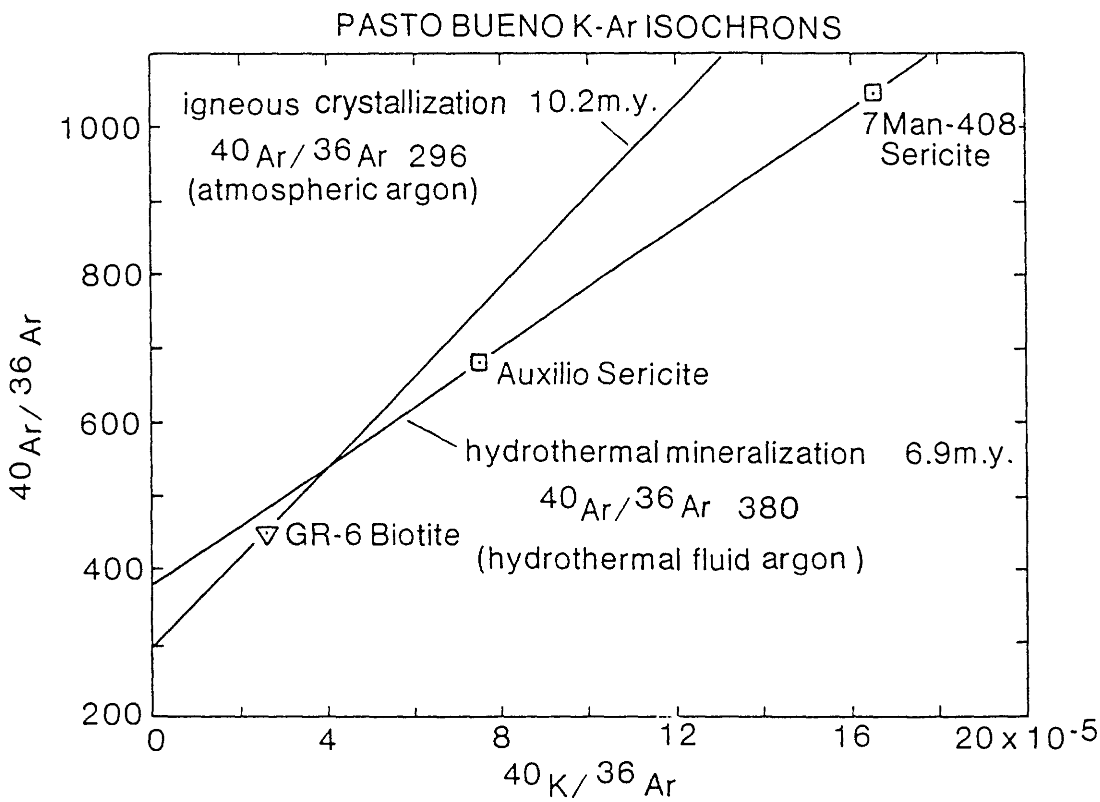

Figure 2. Isochrons for mineralization at Pasto Bueno and for emplacement of the quartz monzonite stock.