550.93 : 552.3+.4

K–Ar Ages of Altered Rocks from the Michiquillay Mine, Peru

Ken SHIBATA* and Kinsuke UCHIDA**

1. Introduction

Michiquillay is a major undeveloped porphyry copper deposit which is located in the Peruvian Cordillera just east of the Continental Divide (Fig. 1). The deposit is situated in the middle of the sedimentary terrain that extends from the Ecuadorian border down to the S13° parallel (BELLIDO and DE MONTREUIL, 1969). Recently detailed study on mineralization of this district has been made by one of the authors (UCHIDA, 1975, 1976a, 1976b). In an attempt to reveal the time of mineralization, we have carried out K–Ar age determinations on granodiorite porphyry in the Michiquillay district. This paper reports and briefly discusses the results of age determinations. We are indebted to Mr. S. Uchiumi for technical assistance.

2. Geological setting

In the Michiquillay district, Lower (?) Cretaceous quartzite and shale, and Middle Cretaceous limestone widely occur, repeating gentle foldings which have WNW–ESE axes. The Michiquillay stock of Tertiary age intruded these Cretaceous strata (HOLLISTER, 1974). The stock is described as granodiorite porphyry in this paper from both the petrographic and chemical aspects (UCHIDA, 1975, 1976a), though it has been described as quartz monzonite porphyry in the previous

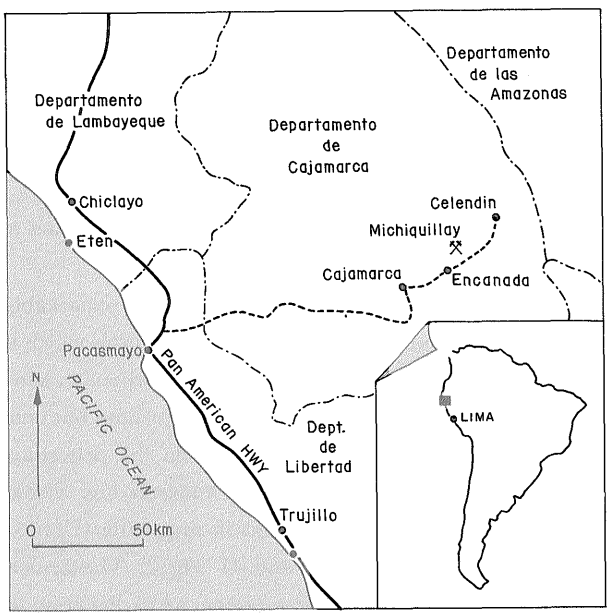

Fig. 1 Location map of the Michiquillay deposit.

* Geochemistry and Technical Service Department
** Exploration and Mining Engineering Department, Sumitomo Metal Mining Co., Ltd.

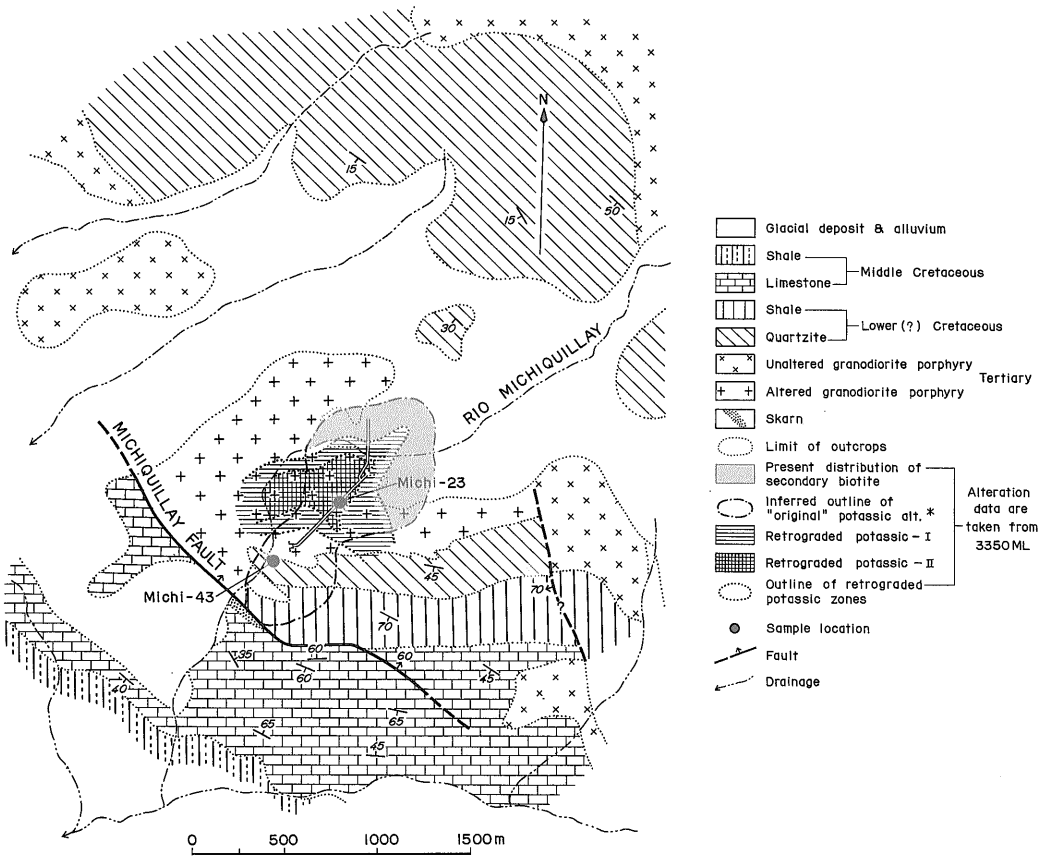

Fig. 2 Geological map of the Michiquillay deposit and its adjacent area. Surface geology is modified after ASARCO (unpub. 1969).
* The outline of the ore grade mineralization approximately coincides with that of "original" potassic alteration on the same level.

references. Mineralization occurs at about the center of the stock, showing a NE–SW elongation (Fig. 2).

Granodiorite porphyry in and adjacent to the ore body is remarkably suffered from both hydrothermal and supergene alteration. Hypogene alteration minerals which have been recognized so far are biotite, sericite, epidote, chlorite, quartz, k-feldspar, carbonate, kaolinite and andalusite. Neither anhydrite nor gypsum has been observed as yet. A conspicuous but unique alteration zoning can be observed. Five zones are clearly discernible based on the petrographic observation, the structural and textural relationship of the constituent minerals and veinlet systems, chemical properties (UCHIDA, 1975, 1976a), and minor elements in magnetite (UCHIDA, 1976b). These are potassic, phyllic, propylitic, retrograded potassic-I, and -II (Fig. 2). The former three are considered to have been concentrically zoned originally and to represent an earlier episode. On the other hand, the latter two are considered to have been formed through the superimposition of a later stage alteration on the earlier alteration products. The alteration zones formed through this episode are inferred to have been from center outward, (1) quartz-sericite-andalusite, (2) quartz-kaolinite-

(chlorite), and (3) quartz-kaolinite-carbonate-(chlorite). By the superimposition of this alteration, the pre-formed potassic zone is suffered from the retrogressive alteration to form the retrograded potassic zones. The retrograded potassic-I stands for the zone that is moderately affected and it approximately corresponds to the above (2) with some relict minerals of the potassic assemblage. The retrograded potassic-II represents the strongly affected zone and it probably corresponds to the above (1). In this zone, most of the alteration minerals of the earlier stage have been completely obliterated and the original texture is hardly observed (UCHIDA, 1975, 1976a).

Major hypogene ore minerals are pyrite, chalcopyrite, magnetite, hematite and molybdenite. Besides these, following accessory minerals have been recognized so far; cubanite, pyrrhotite, valleriite, enargite, tetrahedrite(?), sphalerite and galena. These hypogene ore minerals are considered to have been formed both temporally and spatially related with the alteration zoning to form the mineralization zones. Through the earlier stage mineralization, which is considered contemporaneous with the earlier stage alteration, an outward zoning "magnetite-chalcopyrite-molybdenite-(pyrite)"was formed coaxally and coextensively with the alteration zoning"potassic-phyllic-propylitic" (UCHIDA, 1975, 1976a). This is quite similar to the model proposed by LOWELL and GUILBERT (1970). During the later stage mineralization, which is considered contemporaneous with the later stage alteration, another mineralization zoning "molybdenite · sphalerite · galena-pyrite-gold-tetrahedrite ·enargite" appears to have been formed from the center outward (UCHIDA, 1975, 1976a). Thus the presently observed mineral zoning symmetry that apparently shows a complex pattern can be accounted for by the superimposition of the two episodes of hydrothermal activity.

3. Analyzed samples and analytical methods

K–Ar age determinations were carried out on two samples from the Michiquillay deposit in order to reveal the time difference between the two episodes of hydrothermal activity. The localities of the samples are shown in Fig. 2. Sample Michi-43 is a secondary biotite separated from an altered granodiorite porphyry from the potassic alteration zone of the earlier episode, whereas Michi-23 is a whole-rock sample of altered granodiorite porphyry taken from the retrograded potassic-II zone that is considered to represent the central part of the later episode. The details of the rock samples are given in the following.

Michi-43 (DDH core)

Locality: About 26.2 m from the collar of DDH I-21-B, Michiquillay mine, Encañada, Cajamarca, Peru (7°03′S, 78°20′W)

Rock: Altered granodiorite porphyry, consisting mainly of secondary biotite, chlorite, sericite, quartz, plagioclase (relict), secondary K-feldspar, associated with small amounts of pyrite, chalcopyrite, magnetite (hematite), leucoxene, sphene.

Michi-23 (Chip sample)

Locality: About 420 m from the portal of the 3500 m level adit, Michiquillay mine, Encañada, Cajamarca, Peru (7°03′S, 78°20′W)

Rock: Altered granodiorite porphyry, consisting mainly of quartz and sericite, associated with

small amounts of andalusite, pyrite, chalcopyrite.

Argon extraction and purification were made in a pyrex high vacuum system. Samples were fused in a molybdenum crucible at about 1300°C for 30 minutes, and argon was purified with hot titanium sponge. Isotopic ratios of argon were measured on a Reynolds type mass spectrometer. Potassium was determined by atomic absorption analysis. Constants used for age calculation are: $\lambda_\beta = 4.72 \times 10^{-10}$/y, $\lambda_e = 0.584 \times 10^{-10}$/y, $^{40}K/K = 0.0119$ atom %.

4. Results and discussion

The results of K–Ar age determinations are given in Table 1. A secondary biotite separated from the potassic zone, where the effect of the superimposition of the retrograded potassic alteration was considered to be minimal, gives an age of 28.2±4.9 m.y. The age may indicate the time of the potassic alteration. A whole-rock sample of altered granodiorite porphyry taken from the probable center of the retrograded potassic alteration, where the effect of the second stage alteration has been maximal, gives an age of 18.7±1.4 m.y. This rock consists mainly of quartz and sericite, and almost all of potassium in the rock is contained in sericite. Therefore the obtained age may represent the time of sericite formation and accordingly the time of the retrograded potassic alteration.

LAUGHLIN *et al.* (1968) reported two K–Ar dates from the Michiquillay district. A K–Ar age of 46.4 m.y. was obtained for hornblende from a small hornblende granodiorite stock occurring about three miles northeast of the Michiquillay ore body. An age of 20.6 m.y. was obtained for biotite from a sulfide-bearing rock exposed in an explanatory adit. This sample must have been taken from the potassic alteration zone and must certainly be a secondary biotite according to their description. LAUGHLIN *et al.* (1968) consider that the hornblende age is anormalously old owing to the incorporation of excess ^{40}Ar, and that the intrusion of granodiorite could be as late as 20 m.y. as indicated by the mineralization age. However, the possibility of excess ^{40}Ar incorporation in hornblende in shallow-emplaced rocks such as granodiorite porphyry from the Michiquillay district, seems to be very little. Moreover potassium content of the analyzed hornblende is not very low (0.7% K). Accordingly, it is more probable that the hornblende age represents the time of intrusion for granodiorite porphyry, although the possibility of excess ^{40}Ar cannot completely be ruled out.

The difference in the age of biotite from the potassic alteration zone; 20.6 and 28.2 m.y., may be interpreted as either (1) the biotite dated by LAUGHLIN *et al.* may have been thermally affected to give an apparently younger age, as the effect of later stage alteration is more or less observed throughout the tunnel where Laughlin *et al.* sampled, or (2) the potassic alteration occurred in two stages.

Using all the available age data, the history of the igneous and hydrothermal activities in the Michiquillay district is summarized as follows,

Table 1 K–Ar ages of altered rocks from the Michiquillay mine, Peru.

Sample No.	Mineral	K_2O (%)	^{40}Ar rad (10^{-6} ccSTP/g)	Atmospheric ^{40}Ar(%)	Age (m.y.)
Michi–43	biotite	7.69	7.21	88.1	28.2±4.9
Michi–23	whole rock	3.86	2.40	73.4	18.7±1.4

Unaltered porphyry	hornblende	~46.4 m.y.
Potassic alteration	biotite	28.2 (to 20.6) m.y.
Retrograded potassic alteration	sericite	18.7 m.y.

Although there still remains some doubt as to the varidity of these age data,as LAUGHLIN *et al.* (1968) pointed out, the above history well accords with geological and chemical observations.

References

BELLIDO, E. and DE MONTREUIL, L. (1969) Aspectos generales de la metalogenia del Peru. *Geologia Economica*, No. 1, Servicio de Geologia y Mineria del Peru.

HOLLISTER, V. F. (1974) The Michiquillay porphyry copper deposit. *Mineralium Deposita*, vol. 9, p. 261–269.

LAUGHLIN, A. W., DAMON, P. E. and WATSON, B. N. (1968) Potassium-argon dates from Toquepala and Michiquillay, Peru. *Econ. Geol.*, vol. 63, p. 166–168.

LOWELL, J. D. and GUILBERT, J. M. (1970) Lateral and vertical alteration mineralization zoning in porphyry ore deposits. *Econ. Geol.*, vol. 65, p. 373–408.

UCHIDA, K. (1975) *The effect of a later stage mineralization on the alteration-mineralization zoning in a porphyry copper deposit.* Unpublished D. Sc. Thesis, Fac. Sci. Hiroshima Univ.

——— (1976a) ———————(resume). *Mem. Fac. Sci. Hiroshima Univ.* (in preparation).

——— (1976b) Minor elements in magnetite from unaltered and altered rocks at the Michiquillay porphyry copper deposit. *Mining Geol.* (Tokyo) (in preparation).

ペルー Michiquillay 鉱山産変質岩の K-Ar 年代

柴田 賢・内田 欽介

要 旨

ペルーのポーフィリー・カッパー鉱床 Michiquillay 鉱山の変質した花崗閃緑斑岩から分離した黒雲母の K-Ar 年代は，28.2 ± 4.9 m.y. であり，これは potassic alteration の時期を示すものと考えられる．一方，セリサイト石英岩の全岩年代は 18.7±1.4 m.y. で，この年代は後期の変質作用の時期を示すものであろう．

（受付：1976年6月7日；受理：1976年6月17日）