BIOTITES $^{40}AR/^{39}AR$ AND ZIRCON FISSION TRACK DATING IN THE ZALDÍVAR PORPHYRY COPPER, NORTHERN CHILE

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INTRODUCTION

The dating of mineral having isotopic systems with different closure temperature provides an excellent opportunity to study the cooling history of ore deposits that are genetically related to intense hydrothermal activity such as the porphyry copper deposits (PCDs), regarding the selection of appropriated minerals whose isotopic system have not been modified by alteration or thermal events.

The Zaldívar deposit is located 175 km SE of the city of Antofagasta, in the western margin of the Atacama plateau of Northern Chile. The main pit, at the intersection of a NW and a NE trending fault system, is mainly dug in the Llamo porphyry (Fig. 1), a subvolcanic, NNE elongated granodioritic to rhyolitic intrusion emplaced within the Late Eocene-Early Oligocene West Fissure Structural Belt, which includes several of the world's largest PCDs. The Llamo porphyry is responsible for the primary mineralization event, its intrudes the Zaldívar porphyry, a sub-volcanic rhyolite of 290 ± 4 Ma age, as well as the fine-grained to porphyritic andesites from the Augusta Victoria Formation (between 66.6 ± 2.2 and 41.2 ± 2.2 Ma) (Fig. 1).

A previous geochronology study by Richards et al., 1999, in one sample collected at the Llamo porphyry reported a crystallization age (U/Pb in zircon) of 38.7±1.3 Ma and a weighted mean $^{40}Ar/^{39}Ar$ plateau of 37.40 +/- 0.18 Ma. Although this result is in agreement with data from other PCDs in the neighboring area (Escodida and Chimborazo), it can only be considered preliminary, as the exact location of the sample within the deposit is unknown. The present research is a more focused study aiming to further constrain the thermal history of the Zaldívar deposit during the period that follows the hydrothermal magma-related mineralizing event.

METHODS AND ANALYTICAL RESULTS

The sample preparation and all experimental and analytical work were carried out in the Department of Isotopic Geology at the Vrije Universiteit Amsterdam.

The ceasing time of the main magma-related hydrothermal system would be defined by applying the $^{39}Ar/^{40}Ar$ isotope dating method (closure temperature of about 350°C) (Harrison et al, 1985), on relatively unaltered igneous biotites phenocrysts from the Llamo porphyry. Complementarily, the application of zircon fission-track (ZFT) dating method may shed light on the time of cooling of the whole thermal event as fission tracks produced in zircons are only retained at temperature below ca. 250°C (Tagami et al., 1996); this temperature is lower than those usually defined for hydrothermal events in porphyry copper systems (mostly above 300°C),

$^{40}Ar/^{39}Ar$ systematics in biotites where carried out by the laser step heating technique in an argon laser probe. Incremental-heating experiments yield ages that vary from 37.68 ± 0.4 (sample S-05, Fig. 1) to 35.55 ± 0.7 Ma (sample S-03, Fig. 1). No major compositional or textural difference can be found between the older and younger biotites, except for biotites from sample S-03. These biotites show physical, optical and compositionally properties markedly different from those found in all other studied samples, and they are most likely of hydrothermal origin. Despite the different origin of biotites, the yielded age is undistinguishable between the igneous and hydrothermal biotites; therefore not separation will be made on further interpretations.

To minimize the effect of outliers and to identify modes in the data that will lead to a better age determination, the ages were analyzed on a cumulative probability plot (Fig. 2). The plot for all the measured samples indicates that the most probable date for this set of samples is 36.5 Ma, similar to the weighted mean age of all samples 36.57 ± 02.

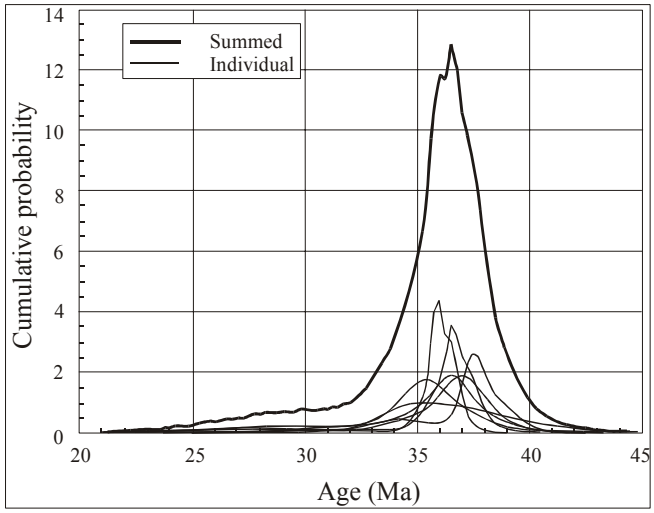

Figure. 2. Cumulative probability plot of step-heating $^{39}Ar/^{40}Ar$ ages in biotites from the Llamo porphyry. The enveloping curve is generated by summing the probability curves for each individual sample.

Because hydrothermal alteration events may disturb to varying degrees the $^{40}Ar/^{39}Ar$ systematics and in consequence affect the final outcome of the ages, it is necessary to evaluate this potential perturbing effect in the lights of the hydrothermal alteration observed in the analyzed samples. All studied samples are within the potassic alteration zone, which is stable between 350° to 700° C (Titley, 1982), and are not affected by lower temperature hydrothermal alteration such as phyllic or propylitic. The potassic alteration is overprinted by the supergene alteration that characterized by the kaolinitization of biotites and feldspars.

Because the closure temperature for the $^{40}Ar/^{39}Ar$ system in biotite is below the lower temperature range defined for potassic alteration, and the supergene kaolinite is not stable at temperatures higher that 300°C (Hemley et al., 1971, *in* Moore and Nash, 1974). The system $^{40}Ar/^{39}Ar$ should not be thermally disturb by the hydrothermal alteration, and the only perturbation that may be expected would be chemical and will be related to the supergene alteration.

All studied samples yield comparable ZFT ages of about 29 Ma, independently of the provenance of the sample or the host rock of the zircon grains (Andesites, Llamo porphyry or Zaldívar porphyry) (Fig. 1). In fact, sample S-03 taken east of the Portezuelo fault, the major structure in the site, and sample S-11 taken west of this fault, show comparable ZFT ages, although they yield contrasting $^{39}Ar/^{40}Ar$ ages (Fig 1). The weighted mean age of all ZFT ages is 29.08 ± 1.2 Ma.

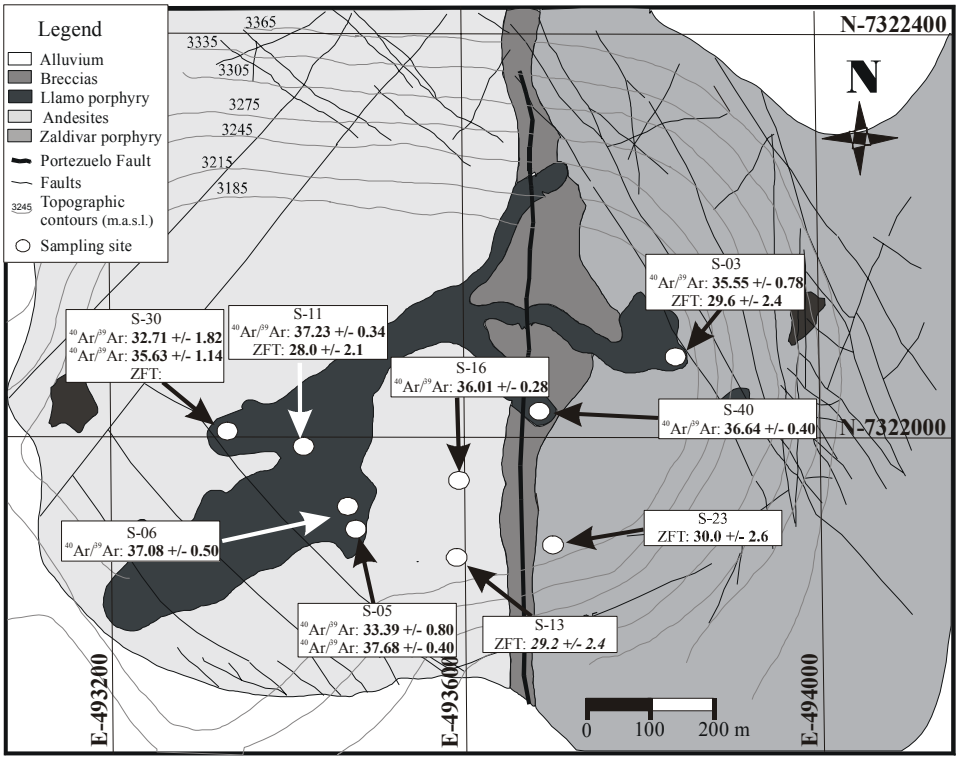

Figure 1. Geochronology data from $^{40}Ar/^{39}Ar$ in biotites and zircon fission track (ZFT).

DISCUSSION AND CONCLUSIONS

The weighted mean age for the $^{40}Ar/^{39}Ar$ ages in biotites from Llamo porphyry yield 36.57 ± 0.2 Ma and is in satisfactory agreement with, but more comprehensive than, the 37.4 ± 1.8 Ma also measured in igneous biotites reported by Richards et al., 1999. Because the closure temperature for the $^{40}Ar/^{39}Ar$ system in biotites is about 345°C, the biotite $^{40}Ar/^{39}Ar$ age will constrain the time at which the samples were cooled below this temperature, furthermore the homogeneous plateau ages imply that reheating has never occurred. As the closure temperature for the $^{40}Ar/^{39}Ar$ system in biotite is closely similar to the lower temperature defined in the magma-related hydrothermal fluids (~350°C) (Campos et al., 2001), the yielded $^{40}Ar/^{39}Ar$ ages will represent the ceasing of the main mineralizing hydrothermal system.

The crystallization age for the Llamo porphyry defined by U/Pb in zircon is 38.7 ± 1.3 Ma (Richards et al., 1999), in combination with $^{40}Ar/^{39}Ar$ ages (ca. 36.5 Ma) and fluid inclusions microthermometry data (Campos et al., 2002), defines a time span between the crystallization of the intrusives and the ceasing of the main mineralization-alteration event at the Zaldívar deposit of about 2 Ma, in agreement with the intrusive-mineralization-alteration timing defined for other PCDs of northern Chile (e.g. Reynolds, 1997; Clark et al., 1998).

In the Escondida mine (5 km south of Zaldívar), a PCD that is coeval with Zaldívar deposit (Richards et al., 1999), the magmatic activity continues long after the main mineralization event and is represented by a suite of dacitic dikes that yield ages as young as 31 Ma (K-Ar whole-rock) (Alpers and Brimhall, 1988). This value is comparable with the ZFT age defined in the Zaldívar mine (29, 1 ± 1.2 Ma). Although no direct evidences of post mineralization magmatic activity similar to the one observed in the Escondida area has been found in the Zaldívar deposit, the ZFT age most probably is dating the end of the magmatic activity in the Zaldívar-Escondida area, specifically signaling the time when the whole site cooled through the temperature of ca. 250°C.

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