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Age constraints on host rocks of Los Uvares gold deposit: Magmatic pulses in southernmost Baja California, Mexico

A. Carrillo-Chávez[1], H. Huyck[2], M. Zentilli[3] and A. Griest[3]
[1] *UNICIT, Campus UNAM, Juriquilla, Querétaro, México.*
[2] *Lakewood, Colorado, USA.*
[3] *Dept. of Geology, Dalhousie University, Halifax, Canada.*

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RESUMEN

El yacimiento epitermal de oro diseminado de Los Uvares, localizado en la parte central del bloque Cabo San Lucas (CSLB) en la parte sur de la península de Baja California, ocurre en una tonalita cataclástica intrusionada por alaskita y diques parcialmente fracturados de diorita. Las edades isotópicas de potasio-argón (K-Ar) en hornblendas separadas de rocas intrusivas relativamente no alteradas en Los Uvares son: 137 ± 6 Ma (tonalita) y 128 ± 5 Ma (diorita). Las edades K-Ar son internamente consistentes con las edades relativas de la diorita y la tonalita derivadas de las relaciones de campo e indican un evento magmático Cretácico. Estas edades son más antiguas que las determinadas previamente para rocas similares del CSLB (rango: 109-42 Ma). Existen varias posibles explicaciones para la diferencia de edades; sin embargo, es muy probable que el yacimiento de Los Uvares ocurra en un complejo intrusivo que representa una fase más antigua (no reportada previamente) del pulso magmático Cretácico-Terciario del CSLB. Las edades de trazas de fisión en apatitas de los diques de diorita varían de 80 a 100 Ma. Estas edades sugieren que la actividad hidrotermal en Los Uvares culminó hace ~ 80 Ma, para posteriormente continuar con las etapas de enfriamiento/erosión.

PALABRAS CLAVE: Bloque Cabo San Lucas, edades de trazas de fisión, edades K-Ar, México.

ABSTRACT

Los Uvares disseminated gold epithermal deposit, in the central part of the Cabo San Lucas Block (CSLB) near the tip of Baja California peninsula, occurs in a cataclastically deformed tonalite intruded by alaskite and mildly faulted diorite dikes. Potassium-argon (K-Ar) isotopic ages on hornblende separates from relatively unaltered intrusive rocks at Los Uvares are: 137 ± 6 Ma (tonalite) and 128 ± 5 Ma (diorite). The K-Ar ages are internally consistent with the relative ages of diorite and tonalite from field relationships, suggesting a Cretaceous magmatic event. These ages are older than previous ages found for similar plutonic rocks in the CSLB (ranges of 109-42 Ma). It seems likely that the Los Uvares deposit occurs in an intrusive complex that represents an older phase (not previously reported) of the Cretaceous-Tertiary magmatic pulse in the CSLB. Fission-track ages on apatites in the diorite dikes range from 80 to 100 Ma. Fission-track data suggest that hydrothermal activity at Los Uvares ended by ~80 Ma, and that cooling/erosion followed.

KEY WORDS: Cabo San Lucas block, fission-track ages, K-Ar ages, Mexico.

INTRODUCTION

The Cabo San Lucas Block (CSLB) in southernmost Baja California peninsula is dominated by Cretaceous rocks of monzogranitic-tonalitic composition (Frizell *et al.*, 1984). These plutonic rocks intrude Paleozoic (?) metasedimentary rocks and are partially covered by middle Tertiary volcanic rocks and upper Tertiary sedimentary sequences. The tectonics of the CSLB is dominated by north-northwest trending normal faults, with minor east-west trending normal and strike-slip faulting. The most conspicuous structural feature is the La Paz fault, a north-trending mylonitized zone exhibiting both normal and strike-slip movement. La Paz fault is considered the western limit of the CSLB (Aranda-Gómez and Pérez-Venzor, 1989.)

The CSLB has been a target for gold and silver exploration since the late 1700's. More than 3000 kg of Au, 600 tons of Ag and 2500 tons of Pb have been recovered mainly from epithermal veins within plutonic and metamorphic rocks, and from disseminated gold deposits in cataclastically deformed igneous rocks (Escandón, 1983; Carrillo, 1990; Carrillo and Huyck, 1997). Currently some exploration projects are trying to resume gold production in the CSLB area.

The ore deposits within the CSLB can be classified into three main groups: (a) vein-related epithermal systems, (b) fault-related disseminated gold deposits, and (c) disseminated gold in metamorphic rocks. There are several descriptive works on rocks and ore deposits of the CSLB. However, isotopic geochronologic data and age constraints on intrusion and mineralization events are relatively scarce (Gastil *et al.*, 1976; Frizzel *et al.*, 1984; Murillo-Muñeton, 1991; Carrillo, 1991). The purpose of this paper is to summarize the geologic characteristics of the Los Uvares disseminated gold deposit and to place the deposit into the magmatic context of the CSLB using K-Ar and fission-track dating. The data presented in this paper may help to continue solving the problem of the reconstruction and tectonic evolution of the Baja California peninsula (Urrutia-Fucugauchi, 1995).

GEOLOGY OF LOS UVARES DEPOSIT

Los Uvares gold deposit occurs in cataclastically deformed tonalite and alaskite, and in younger mildly-faulted diorite dikes (Romero, 1988; Carrillo, 1990). It occurs in a fault zone, which is approximately 1.5 km long and 12-25 m wide, dipping 50º - 65º northeast. The country rock is dominantly a hornblende-tremolite tonalite. Deformation of the tonalite is relatively minor away from the mineralized shear zone (<20% cataclasis), but it increases towards the ore zone (20-100% cataclasis). Alaskite is a minor constituent (<3% volumetrically) of the host rocks; it forms dikes that cut the tonalite, which are in turn cut by a diorite. Petrographically, it was found that cataclastic deformation of alaskite dikes ranges locally up to 30%. Diorite dikes cut the other intrusive rocks, contain less gold than the rest the host rocks, and exhibit <5% cataclastic deformation.

Los Uvares host rocks have been affected by several events, which have been summarized by Carrillo (1990) and Carrillo and Huyck (1997). Gold is temporally associated with sericite-quartz-pyrite±chlorite±chalcopyrite alteration in brecciated tonalite and fractured diorite. The highest gold grades occur within the cataclastically deformed tonalite.

Previously proposed genetic models for Los Uvares deposit are: (a) porphyry gold, and (b) tonalite dike-fault (Escandón, 1983; Romero, 1986). The petrographic evidence suggests that the Los Uvares is a fault-related disseminated gold deposit. A comparison between Los Uvares and other gold deposits suggests that Los Uvares is similar to epithermal gold deposits (Carrillo, 1990; Carrillo and Huyck, 1990; 1997).

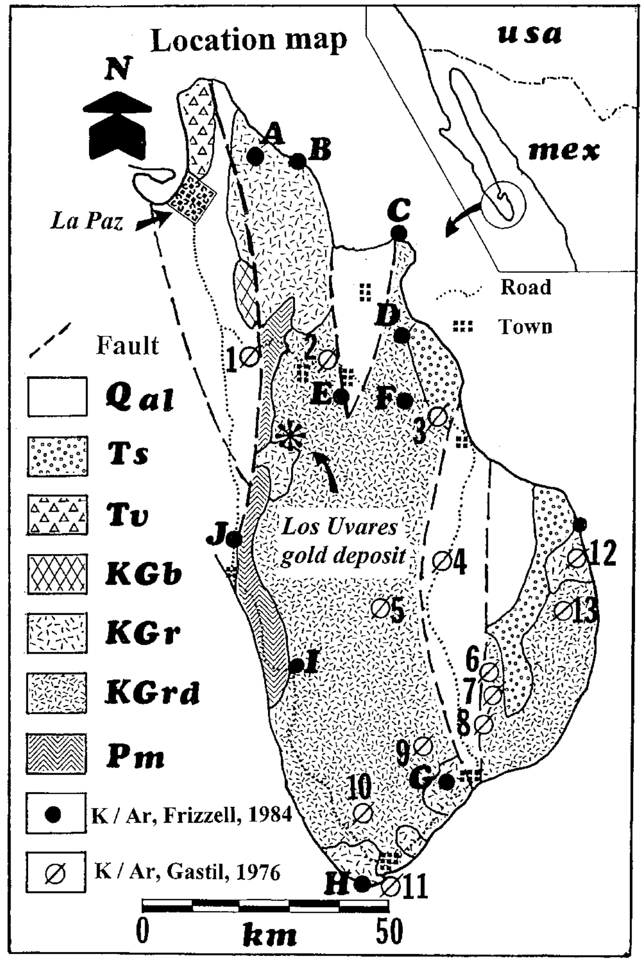

Fig. 1. Geologic map of the Cabo San Lucas Block (**CSLB**) and location of Los Uvares gold deposit. **Qal** = Quaternary deposits; **Tv** = Tertiary volcanic rocks; **Ts** = Tertiary sedimentary rocks; **KGb** = Cretaceous gabbroic rocks; **KGr** = Cretaceous granitic rocks; **KGrd** = Cretaceous granodioritic rocks; **Pm** = Paleozoic-Jurassic (?) metamorphic rocks; ∅ = **Samples 1-13** from Gastil et al., 1976; ● = **Samples A-J** from Frizzell *et al.*, 1984. (Note: samples of Murillo-Muñeton, 1991 not shown).

AGE DETERMINATIONS OF CSLB AND LOS UVARES

Potassium-Argon

Potassium-argon dates for a variety of crystalline rocks, reported in earlier studies, are shown in Table 1. Sample locations are shown in Figure 1 (Frizzel *et al*., 1984; Gastil *et al*., 1976; Murillo-Muñetón, 1991. Murillo-Muñeton's locations are not given and the corresponding samples on Table 1 are not plotted on Figure 1). No further details on methodology, sampling and laboratory methods are known for these previous works. From the available data, the ages of the intrusive rocks in the CSLB are of particular interest. Gastil and others (1976) reported ages ranging from 109 to 64 Ma. Note that it is not clear which decay constants were used by them, as the constants were changed at approximately that time (Steiger and Jager, 1977). Using the "Old Age" to "New Western" conversion would shift the age range to 116 - 61 Ma. More recently, Frizzell and others (1984) and Murillo-Muñetón (1991) have reported K-Ar igneous rock ages in the 109-68 Ma and 100 - 70 Ma ranges, respectively. The dominant age range for intrusive rocks, based upon these three studies, is a Cretaceous-Tertiary episode in the range 109 - 64 Ma.

In contrast, from this study we obtained at Los Uvares K-Ar dates of hornblende separates from relatively unaltered intrusive rocks in the range of 137 ± 6 Ma (tonalite) and 128± 5 Ma (diorite). These ages are generally older than previous age determinations for similar plutonic rocks in the CSLB. Older ages have been recognized in plutonic rocks of the northern portion of the Baja California peninsula (Urrutia-

Table 1

Isotopic ages for different rocks of the Cabo San Lucas Block. See location in Figure 1. **Samples 1-13** from Gastil *et al.*, 1976; **samples A-K** from Frizzell *et al.*, 1984; **samples a-h** from Murillo-Muñetón, 1991. (*Data from Frizzell *et al.*, 1984, do not show the errors; **Sample K is from the south west coast of Cerralvo Island, about 15 km northeast of sample C: #Data from Murillo-Muñeton, 1991, are from an abstract and no locations are given)

SAMPLE	ROCK DATED	MINERAL DATED	AGE (Ma)
1	Granodiorite	**not available**	85.5± 1.7
2	Tonalite	**not available**	108.6 ± 2.6
3	Tonalie	**not available**	79.8± 1.5
4	Tonalite	**not available**	72.8± 1.6
5	Dacite Porphyry	**not available**	64.5± 2.0
6	Diorite	**not available**	73.0± 2.0
7	Diorite	**not available**	69.5± 2.0
8	Diorite	**not available**	74.1± 1.5
9	Granite	**not available**	75.7± 1.5
10	Ademelite	**not available**	72.4± 2.9
11	Tonalite	**not available**	68.8± 0.9
12	Tonalite	**not available**	84.6± 3.8
13	Tonalite	**not available**	81.6± 2.0
A*	Granite	**Biotite**	93 ± ?
B*	Granodiorite	**Biotite/Hornblende**	87 ± ?
C*	Tonalite	**Hornblende**	99 ± ?
D*	Tonalite	**Biotite/Hornblende**	90 ± ?
E*	Tonalite	**Biotite**	109 ± ?
F*	Granodiorite	**Biotite**	73 ± ?
G*	Granite	**Biotite**	77 ± ?
H*	Granite	**Biotite**	68 ± ?
I*	Granodiorite	**Biotite**	84 ± ?
J*	Tonalite	**Biotite**	95 ± ?
K**	Granite	**Biotite**	82 ± ?
a#	Muscovite Schist	**Muscovite/Biotite**	87 ± 4
b#	Amphibolite Schist	**Hornblende**	116 ± 6
c#	Augen Gneis	**Biotite**	50 ± 4
d#	Biot.-Musc. Granite	**Muscovite**	100 ± 5
e#	Biotite Granite	**Biotite**	91 ± 5
f#	Biotite Granodiorite	**Biotite**	76 ± 4
g#	Hornblende Diorite	**Hornblende**	78 ± 4
h#	Biotite Granite	**Biotite**	70 ± 3

Fucugauchi, 1986). In general, it is believed that the northern sector of the peninsula (Peninsular Range Batholith) is older than the southern sector (CSLB) (Gastil *et al.*, 1975; Krummenacher *et al.*, 1975; Urrutia-Fucugauchi, 1986; Ortega-Rivera *et al.*, 1997).

Possible alternative explanations for older ages at the CSLB are: (1) systematic errors, (2) sampling bias, with magmatic sections misrepresented, (3) multiple intrusive events - reheating - resetting of isotopic system, (4) transgressive regional cooling of batholiths associated with geothermal gradient motion independent of erosional level changes due to progressive uplift and erosion, and (5) selective erosion or lack of outcrops in part of the record (Urrutia-Fucugauchi and Morton-Bermea, 1997). However, the older ages of the CSLB could well represent an older terrain not previously dated. Urrutia-Fucugauchi (1986) presents radiometric data on igneous rocks from the extensive magmatic province of north-western Mexico. His results show that magmatic activity changed systematically with time from about 140 Ma to present. Figure 2 shows a histogram of CSLB isotopic ages used in Figure 1 and Table 1, and a comparison with the regional radiometric pattern for northwestern Mexico (Urrutia-Fucugauchi, 1986).

Fission-track dates from Los Uvares

The “blocking temperatures” for hornblende and apatite are different (~500ºC for hornblende and ~200ºC for apatite), and it is not possible to obtain the same ages for these two minerals using K-Ar for hornblende and fission track for apatites (Hawkesworth and Vab Calstern, 1992). Fission track dates on apatites in diorite dikes and tonalite were used to confirm the K-Ar ages measured and to determine the best model for age of mineralization relative to diorite intrusion (Figure 3). Model ages of diorite samples (Table 2) range from 80 to 100 Ma. However, adjacent tonalite samples yield bimodal track length histograms, suggesting that these rocks were not heated above track-annealing temperatures (<120°C) during a late Cretaceous thermal event, possibly related to mineralization.

Representative results of tonalite samples are shown in modeling the distribution of confined track lengths for sample UV26-40 (Figure 3). The track length distributions are calculated using the Laslett and others (1987) annealing model in the following way; the sample is given broad thermal history boundary constraints (inferred from the known geology), and the model then calculates the accumulated track length population through a series of time steps to the present. After each time step, track-length population is calculated. The model determines the goodness-of-fit to the measured distribution using Kolmogorov-Smirnov statistics. The program repeats this process iteratively and selects the 250 best solutions. Each time a solution is obtained it is either rejected or accepted, and the worst previously accepted solution is rejected. After more than ten thousand iterations, this procedure results in a group of 250 solutions that fit the observed data at the 95% confidence level.

Figure 3 (A, B, C) shows histograms of the distribution of possible closure ages (the time of initial cooling below 120°C) for the 250 best solutions and the computed time-temperature paths of these models. In model 2, the sample cooled from 150 - 100 Ma, was heated from 100-90 Ma and cooled again to a present-day temperature of 20º-25°C. In model 3, the sample cooled from 150-90 Ma was heated from 90 - 80 Ma and cooled to a present-day temperature of 20 - 25°C. The upper and lower lines show the range of possible time-temperature paths that provide acceptable solutions for each model. If the thermal event is older (model 2),

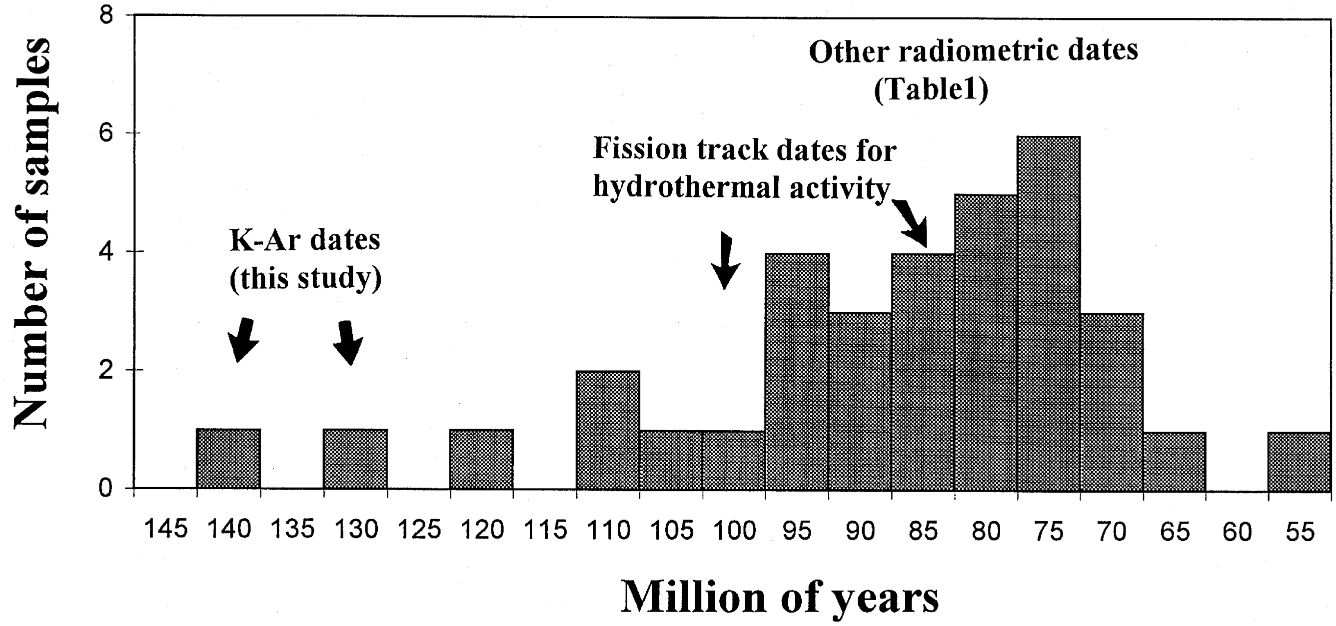

Fig. 2. Histogram of Cabo San Lucas Block isotopic ages used in Figure 1 and Table 1, and comparison with the K-Ar dates from this study. Peak and ending of hydrothermal activity at Los Uvares (100-80 Ma) is shown.

Table 2

Brief description of the samples from Los Uvares gold deposit for fission-track analysis and pooled ages. See Figure 3 for model ages.

SAMPLE Nº	DESCRIPTION	POOLED AGE
UV / 32-78	Diorite dike 50 m below ore zone. Unimodal track length distribution, somewat skewed; mean track length 13.533 microns. 237 lengths measured.	80 ± 6
UV / 27-93	Diorite dike 16 m above ore zone.	93 ± 10
UV / 26-40.20	Tonalite 20 m above ore zone. Bimodal track lengths. Mean track length 13.074 microns. 237 track lengths measured. Rock cooled below 100°C, then was reheated to less than 100°C, then cooled relatively slowly.	See Figure 3 for age models.
UV / 27-56.10	Tonalite 55 m above ore zone. Bimodal track length distribution. Mean track length 13.213 microns. 214 track lengths measured. Reheating episode similar to sample UV/26-40.20 occurred in this sample.	80 ± 6

the maximum temperature is constrained within the range of 105 - 110°C. If the thermal event is more recent (model 3) the maximum temperature must have been less than 95°C, and the maximum temperature must have been about 95 - 105°C. The closure age of the system is tightly constrained to the range 96 - 100 Ma. In both models, the calculated

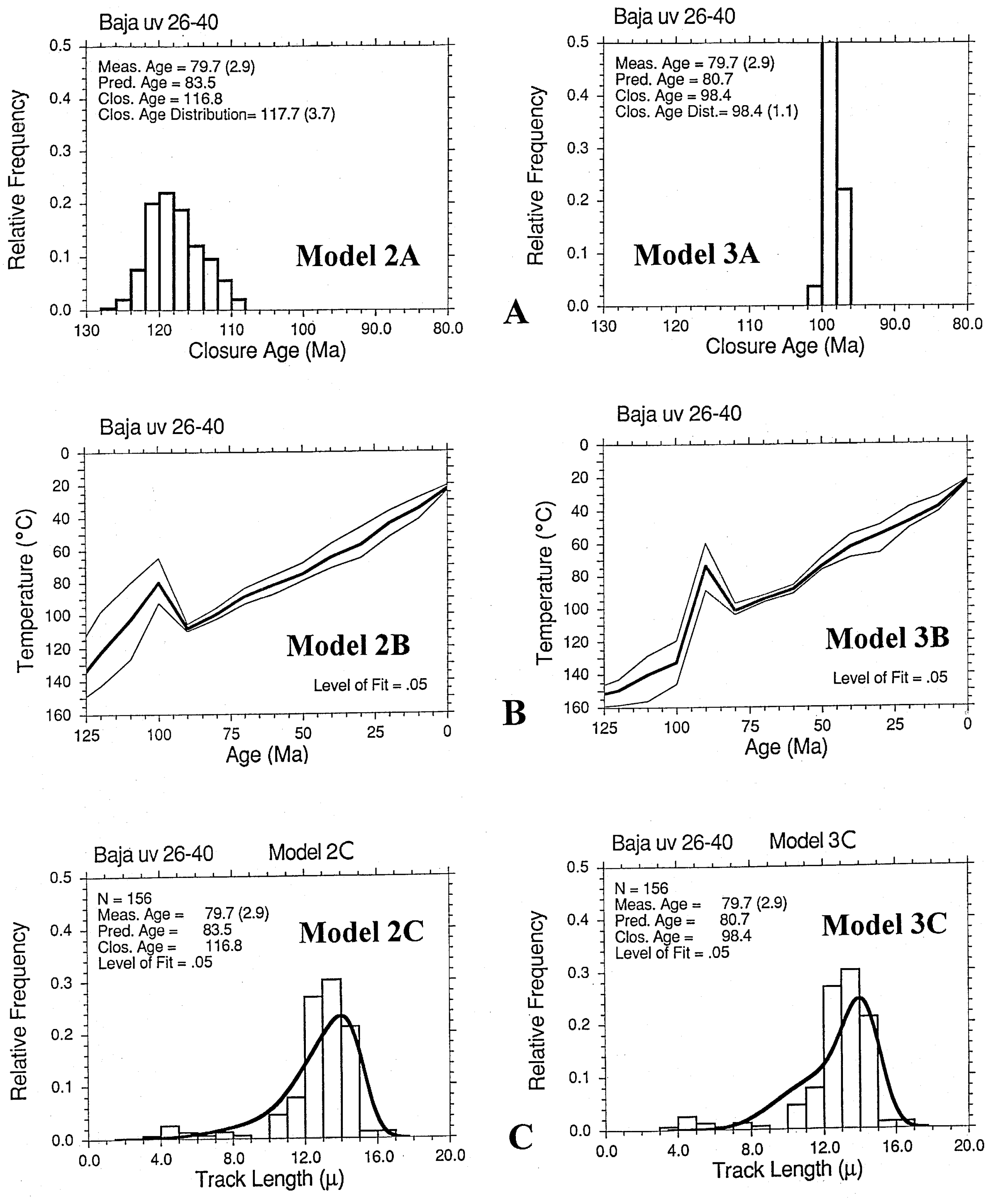

Fig. 3. Models 2 and 3 for **closure age (A)**, **age (B)** and **fission track lengths (C)** for tonalite sample UV / 26-40.20. See Table 2 for sample description.

distribution of "short tracks" (less than 9 microns) is shown as a "tail" on the main peak. Due to the difficulties inherent in modeling and measuring accurate distributions of confined "short" track (less than 9 microns long), we are unable to choose between the two model time-temperature paths. Additionally, the fission-track dates for the diorite samples do not distinguish between the two models shown. In time, ^{40}Ar-^{39}Ar analysis of sericite may help to better constrain the thermal history of the Los Uvares gold deposit.

CONCLUSIONS

Although the difference between K-Ar and fission track dates of hornblende and apatite from Los Uvares host rocks is due to the different blocking temperature for both minerals, we consider the following scenario of intrusion and reheating of host rocks to be very likely.

1. The isotopic ages of the igneous host rocks of the Los Uvares gold deposit are generally older than previously reported isotopic ages. It is likely that the igneous rocks at Los Uvares deposit represent an older phase of a Cretaceous-Tertiary magmatic pulse in the Cabo San Lucas Block, which was intruded at 137 - 128 Ma.

2. Faulting and cataclasis occurred prior to emplacement of each successive intrusion resulting in decreasing cataclastic grade from the oldest (tonalite) to the youngest (diorite).

3. The igneous complex cooled gradually, passing through the closure temperature for apatites (120°C) around 100-90 Ma.

4. The igneous complex was hydrothermally reheated between 100 and 80 Ma, causing partial resetting of apatites in undeformed (i.e. relatively impervious) tonalite, by raising the country rock temperature to 95º-110°C and completely resetting the apatites in the diorite. This episode could be related to two other intrusions at depth and to sericite-quartz-pyrite-gold hydrothermal alteration.

5. The hydrothermal activity ended by 80 Ma. Cooling and erosion followed.

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A. Carrillo-Chávez[1], H. Huyck[2], M. Zentilli[3] and A. Griest[3]
[1] *UNICIT-Instituto de Geología, UNAM, Campus Juriquilla, A. P. 15, Juriquilla, Querétaro 76230 México. E-mail: jaimeale@servidor.unam.mx*
[2] *P.O. Box 28161-16, Lakewood, CO 80228, USA.*
[3] *Dept. of Geology, Dalhousie Univ., Halifax, Nova Scotia B3H 3J5, Canada.*