Thermal evolution of the Miers Bluff Formation from apatite fission track (Livingston Island, Antarctic Peninsula region)

Evolución térmica de la Formación Miers Bluff a partir de trazas de fisión en apatitos (Isla Livingston, Península Antártica)

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ABSTRACT

El análisis de las trazas de fisión en apatitos procedentes de los metasedimentos de bajo grado metamórfico de la Formación Miers Bluff (Península Hurd, Isla Livingston, Islas Shetland del Sur) muestra que el enfriamiento posterior al pico metamórfico comenzó hace unos 28 Ma. Este momento coincide con el fin de la actividad magmatica en este arco volcánico. Probablemente, el metamorfismo puede estar relacionado con la actividad magmática de este arco volcánico (140-30 Ma). La modelización de las trazas de fisión sugieren que la exhumación de la Península Hurd comenzó hace 13 Ma. La actividad volcánica reciente de la cuenca de Bransfield no está recogida en las huellas de fisión de los apatitos de la formación Miers Bluff.

RESUMEN

El análisis de las trazas de fisión en apatitos procedentes de los metasedimentos de bajo grado metamórfico de la Formación Miers Bluff (Península Hurd, Isla Livingston, Islas Shetland del Sur) muestra que el enfriamiento posterior al pico metamórfico comenzó hace unos 28 Ma. Este momento coincide con el fin de la actividad magmatica en este arco volcánico. Probablemente, el metamorfismo puede estar relacionado con la actividad magmática de este arco volcánico (140-30 Ma). La modelización de las trazas de fisión sugieren que la exhumación de la Península Hurd comenzó hace 13 Ma. La actividad volcánica reciente de la cuenca de Bransfield no está recogida en las huellas de fisión de los apatitos de la formación Miers Bluff.

Key Words: *apatite fission track, thermal history, Miers Bluff Formation, Antarctic Peninsula region.*

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Introduction

The Miers Bluff Formation which crops out only on Hurd Peninsula, Livingston Island, is considered as a correlative of the Trinity Peninsula Group, exposed on the Northern end of the Antarctic Peninsula, and the Greywacke-Shale Formation, exposed on the South Orkney Islands. Despite some uncertainty, in general, a Triassic to Permian age for these rocks is admitted. The low grade metasedimentary rocks of the *Miers Bluff Formation* are a part of the basement of the Antarctic Peninsula magmatic arc and therefore they recorded the Mesozoic and Cenozoic episodes of deformation, magmatic intrusions and metamorphism.

The aim of this paper is to investigate the cooling history (below 120ºC) of these basement rocks by means of the study of their apatite fission track record. Because these rocks are affected by advanced diagenesis or in some cases by low grade metamorphism (anchizone – epizone, e.g. Arche *et al.*, 1992a; Kelm and Hervé, 1994; Willan *et al.*, 1994; Tokarski *et al.*, 1997) they reached the apatite effective track retention temperature (~100°C). Therefore it is expected that fission track analysis would allow us to date the end of this thermal process and to precise the *Miers Bluff Formation* cooling path down to present time.

Geological setting

The South Shetland archipelago belongs to a magmatic arc related with the subduction processes that took place beneath this margin during the Mesozoic and Cenozoic. The subduction allows the convergence between the Phoenix and the Antarctic plates. The convergence seems to have finished 4 Ma ago and has been suggested that the opening of the Bransfield Basin, a back arc basin located between the South Shetland Archipelago and the Antarctic Peninsula, began in this period. Then, the islands are mainly composed of calc-alkaline volcanic and plutonic rocks of Cretaceous to Tertiary age (140 to 40 Ma, Willan and Kelley, 1999). However, these rocks intruded over an older basement of low grade metamorphic rocks. One of the basement rocks best sections is located on Hurd Peninsula, Livingston Island, where crops out the Miers Bluff Formation.

The Miers Bluff Formation consists of feldspathic greywackes, shales, arkosic arenites, siltstones and minor conglomerates (e.g. Smellie *et al.*, 1984; Arche *et al.*, 1992a, 1992b; Pallàs *et al.*, 1992; Tokarski *et al.*, 1997). Their thickness is >1600 m and it has a turbiditic character, being the source area a continental magmatic arc margin (Smellie, 1991; Arche *et al.*, 1992b, Marfil *et al.*, 1994). The Miers Bluff Formation age is not well

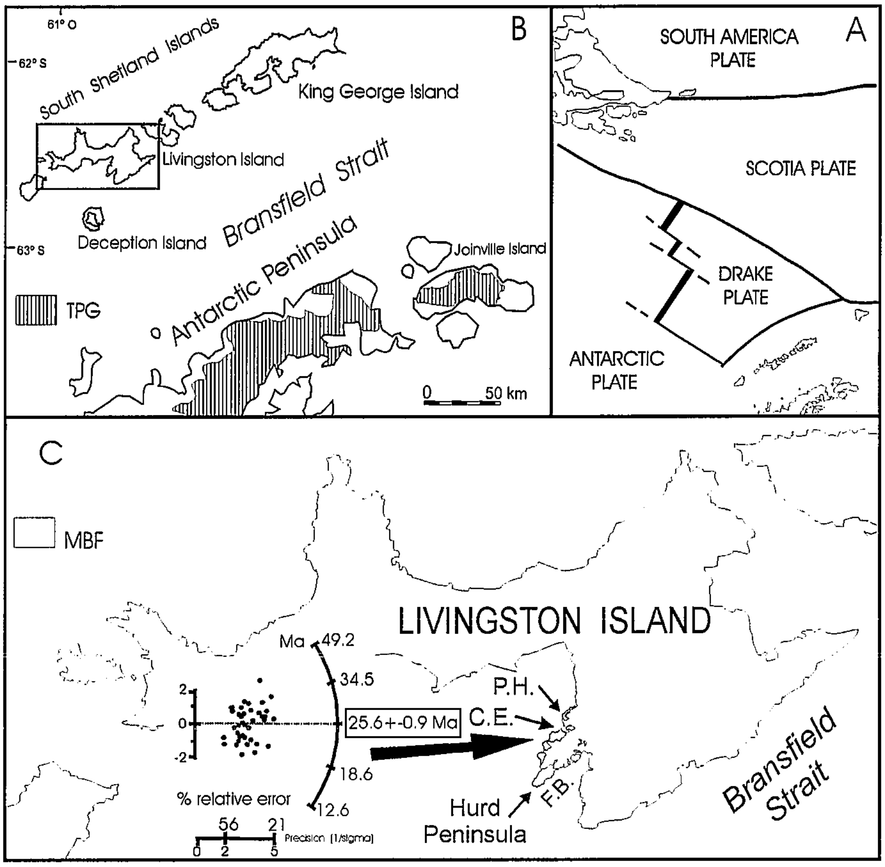

Fig. 1.- Location maps of the Northern Antarctic Peninsula region showing the geological setting. (A) Regional and tectonic setting. (B) Trinity Peninsula Group (TPG) outcrops. (C) Miers Bluff Formation (MBF) outcrops. The central FT age of the studied sample is shown. P.H.: Punta Hespérides. C.E.: Caleta Española. F.B.: False Bay.

Fig. 1.- Mapa con la localización de la región norte de la Península Antártica. (A) Características tectónicas. (B) Afloramientos del Grupo Península Trinidad (TPG). (C) Afloramientos de la Formación Miers Bluff (MBF). Se indica la edad central de las huellas de fisión estudiadas en este trabajo. P.H.: Punta Hespérides. C.E.: Caleta Española. F.B.: Bahía Falsa.

known. A Permo-Triassic age has tentatively be assigned to this formation by correlation with similar sequences (Trinity Peninsula Group) dated from the stratigraphic age of fossil plant remains and radiometrically. The U-Pb age of detrital euhedral zircons (*ca.* 320 Ma) from Miers Bluff Formation and Trinity Peninsula Group rocks is believed to represent the age of crystallization of the source granitoids (Loske *et al.*, 1988; Hervé *et al.*, 1991). A recalculated value for a six points Rb-Sr whole rock isochron on shales gives 205±19 Ma (Thomson, 1992). The Miers Bluff Formation beds on Hurd Peninsula are folded and in many cases overturned.

Post-depositional changes in Miers Bluff Formation rocks have been studied mainly trough the illite crystallinity (Kübler index); Arche *et al.* (1992a) studied 6 samples from the Caleta Española area (see Fig. 1) and Tokarski *et al.* (1997) analysed 22 samples from several places of the entire Hurd Peninsula. Taking into account these works and those of Smellie (1991), Kelm and Hervé (1994) and Willan *et al.* (1994), a few samples indicates epizone or anchizone, and many of them indicates advanced diagenesis. Tokarski *et al.* (1997) did not found relationship between stratigraphical position of the samples and illite crystallinity and concluded that, probably, "diagenesis" postdated folding. Therefore these rocks reached the apatite annealing temperature (> 100°C) and the apatite fission tracks record is expected to be related to post-depositional thermal evolution.

The Miers Bluff Formation is intruded by several small stocks of granitic

Sample	N	ρ_s 10^5 t/cm^2 (N_f)	ρ_i 10^5 t/cm^2 (N_i)	ζ	ρ_m 10^5 t/cm^2 (N_m)	Dispersion $P(\chi^2)$ %	S.E. %	Age TF Ma ± 1σ	L μm ± 1σ (N_L)
HA-2425	40	1.89 ± 0.07 (639)	4.63 ± 0.12 (1566)	333	3.767± 0.038 (9964)	31	11	25.6 ± 0.9	14.27 ± 1.30 (109)

Table I.- Fission tracks analytical data. N: number of grains dated. ρs: fossil track density. Nf: number of fossil tracks counted. ρi: induced track density. Ni: number of induced tracks. ρm: standard track density. Nm: standard number of track. P(χ2): Chi square probability of Galbraith (1981). S.E.: standard error of the central age. L: mean value and standard deviation of the confined track length distribution. NL: number track length. TF: fission tracks.

Tabla I.- Datos analíticos de las huellas de fisión. N: numero de granos datado. ρs: densidad de trazas fósiles. Nf: número de trazas fósiles medidas. ρi: densidad de trazas inducidas. Ni: número de trazas inducidas medidas. ρm: densidad estándar de trazas. Nm: numero estándar de trazas. P(χ2): probabilidad Chi cuadrado de Galbraith (1981). S.E.: error estándar de la edad central. L: valor medio y desviación estándar de la distribución de trazas confinadas. NL: número de longitudes de trazas medidas. TF: trazas de fisión.

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rocks (e.g. in Punta Hespérides and near False Bay coast). The K-Ar whole rock age of the Punta Hespérides intrusion gives a late Cretaceous age (73±3 Ma, Kamenov, 1997). The Miers Bluff Formation is also cross-cut by numerous basic dykes and small sills, many of them with K-Ar ages ranging between 30 and 60 Ma (Willan and Kelley, 1999). These rocks are part of the magmatic arc generated by subduction processes that took place beneath this margin during the Mesozoic and Cenozoic (see Smellie *et al.*, 1984).

Sampling and fission track dating

The studied material are medium to fine detritical Miers Bluff Formation rocks. The samples have been collected from several points around the Caleta Española area (Fig. 1). Apatite were obtained by conventional separation methods including crushing and heavy liquids/magnetic separation steps. Observations under a stereomicroscope showed apatite grains have lost their prismatic habit, indicating transport, consistent with the sedimentary origin of the Miers Bluff Formation. These detrital apatites are characterized by large size variations and a low transparency. They are supposed to come from the same source granitoids as the bulk of the Miers Bluff Formation sedimentary material. Taking into account the previously discussed geochronological data, the apatites age of crystallisation would be close to 320 Ma.

The apatite grains were prepared for fission track dating by the external detector method using the usual procedures of the Grenoble laboratory (Calmus *et al.*, 1999, Bigot-Cormier *et al.*, 2000). Only one grain mount was prepared for irradiation in the Orphée nuclear reactor of the Centre d'Etudes Nucléaires of Saclay (France). The results are presented in Table I. Both dispersion parameters: x^2 test of Galbraith (1981) and standard error of the apatites central age (Table I) show that there exists only one age population among the apatite grains dated. The ages obtained by the two observers are concordant and the resulting weighed value for this sample is 25.6±0.9 Ma. The mean fossil track length of 14.3±1.3 mm suggests a fast cooling (see below).

During a cooling process, fission tracks start to be recorded in apatites at 110±10°C, according to their chemical (chloro to fluorapatite) composition. However, fission tracks are about totally recorded only below *ca.* 60°C. Between 60 and 110°C, in the so-called partial annealing zone (PAZ), their etchable track length is progressively alterated, from about 15 mm to zero. The distribution of the fossil tracks total etchable lengths in apatites, *via* the measurements of confined tracks, is a good qualitative index of the cooling path of a sample through the PAZ. However, taking into account one model of thermal track annealing, it is possible to reconstitute, from its apatite track data (age and confined track lengths distribution), the cooling history of one rock since its last cooling below about 110°C. We used here the Monte-Trax optimisation model (Laslett Durando) of Gallagher *et al.* (1993). It suggests a two-stages cooling history, first from 28±2 to 23±4 Ma (~115-50°C) followed by a slight reheating (*ca.* 66°C) until 13±2 Ma and second from this time to present (Fig. 2).

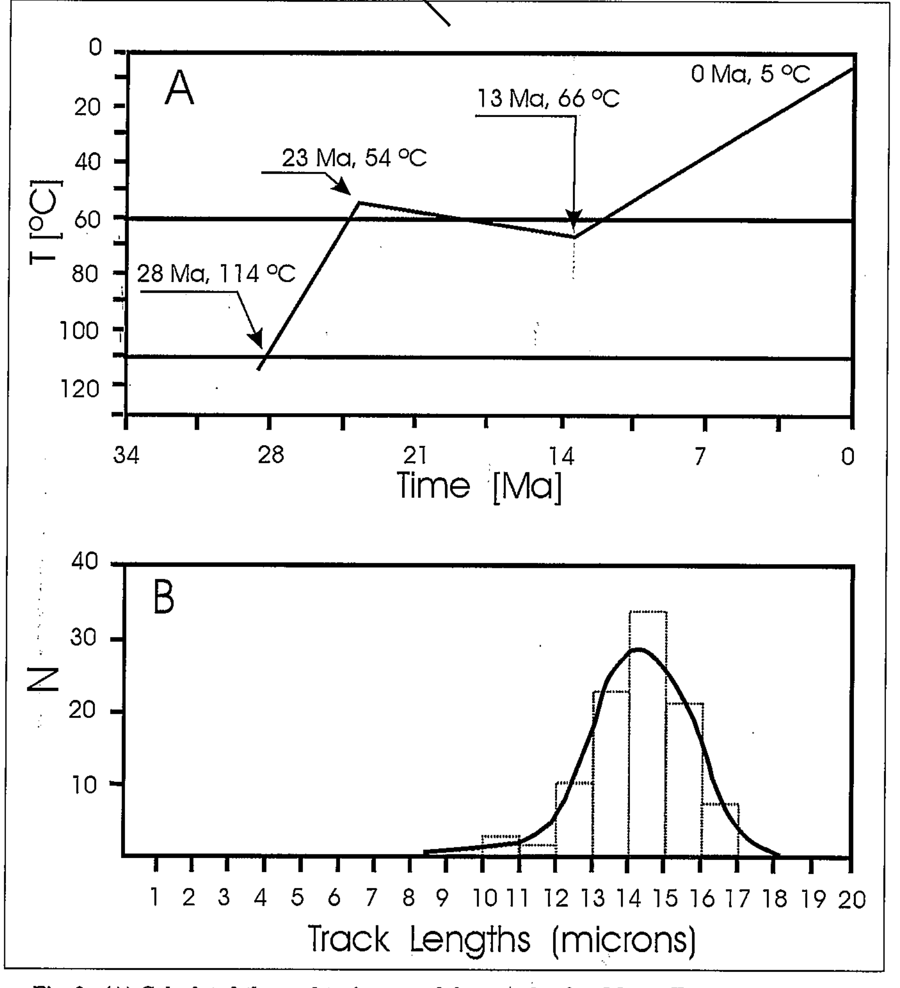

Fig. 2.- (A) Calculated thermal trajectory of the sample after Monte-Trax modelling. (B) Histogram of the modelled track length. Observed age = 25.9 Ma; predicted age = 26.06 Ma; oldest predicted track = 28 Ma; observed mean track length = 14.270µ; predicted mean track length = 14.214µ; observed track length standard deviation = 1.3; predicted track length standard deviation = 1.501.

Fig. 2.- (A) Trayectoria térmica calculada mediante el modelo Monte-Trax. (B) Histograma de las longitudes de huellas modelizadas. Edad observada = 25,6 Ma; edad pronosticada = 26,06 Ma; traza más antigua pronosticada = 28 Ma; longitud media de las trazas observadas = 14,270µ; longitud media de las trazas pronosticada = 14,214µ; desviación estándar de la longitud media de las trazas observadas = 1,3; desviación estándar de la longitud media de las trazas pronosticadas = 1,501.

Discussion and Conclusions

As the crystallization age of the Miers Bluff detrital apatites was close to 320 Ma, but their fission track age is 25.6±0.9, a thermal event posterior to crystallisation is necessary to account for the observed track annealing. From previous studies (see above) the Miers Bluff Formation reached an advanced diagenesis stage, some anchimetamorphism and sporadically epimetamorphism, and therefore was heated to >100°C, enough to totally anneal previously recorded tracks. Thus the beginning of track registration in our sample, *ca.* 28 Ma, represents a lower limit to the age of this metamorphism. On the other hand, the beginning of track recording in the apatites of the Miers Bluff Formation probably represents the end of metamorphism. This age is concordant with the end of magmatic intrusion period in the South Shetland magmatic arc (140-30 Ma, see compilation of Willan and Kelley, 1999). Therefore we suggest that the thermal anomaly associated with the magmatic intrusions produced the low-level metamorphism of the Miers Bluff sediments.

The fission track data discussed in this work also show that the recent exhumation of Hurd Peninsula and probably of the whole Livingston Island began around 13 Ma ago. Finally, no Quaternary thermal event appears in the fission track modelised cooling history of the Miers Bluff Formation, which suggests that if a thermal anomaly is associated to the <1 Ma volcanic activity, related in this region with the volcanic activity in the Bransfield back-arc basin, it is not recorded in the Miers Bluff Formation apatites.

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