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Fission track thermo-chronological study of the Barnard Point pluton (Livingston Island, Western Antarctica)

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ABSTRACT

The apatites of four tonalite samples, taken between near sea level and an altitude of 390 m, of the Barnard Point pluton (Livingston Island, South Shetland Islands) have been dated by fission track. The four central ages are concordant at 18.7±1.2 (mean and standard error) Ma. Confined track distribution and optimisation of the data indicate that track recording started about 40-35 Ma ago. The cooling of the massif below 120° C seems to have increased from the lower Oligocene (approx. 30 Ma.), contemporaneously with an extensional tectonic episode and a subsequent denudation process. The recent (< 1 Ma) Bransfield rift volcanic activity is not recorded in the Barnard Point pluton apatites.

Palabras clave: Antarctica, Apatite fission track, Barnard Point pluton, South Shetland Islands, Thermo-chronological history.

Estudio termo-cronológico por trazas de fisión del plutón de Punta Barnard (Isla Livingston, Antártida Occidental)

RESUMEN

Se han datado mediante trazas de fisión cuatro muestras de tonalitas del plutón de Punta Barnard (Isla Livingston, Islas Shetland del Sur), recogidas entre cerca del nivel del mar y 390 m de altitud. Las cuatro edades coinciden en 18,7±1,2 Ma (media y desviación standard). Las distribuciones de trazas confinadas y la optimización de los datos indican que el registro de trazas comenzó alrededor de los 40-35 Ma. El enfriamiento del macizo por debajo de 120° C parece haberse acelerado desde el Oligoceno inferior (aprox. 30 Ma), contemporáneamente con un episodio tectónico extensional y un subsiguiente proceso de denudación. La actividad volcánica reciente (< 1 Ma) asociada con el proceso de rifting en el Estrecho de Bransfield no ha quedado registrada en los apatitos del plutón de Barnard Point.

Key words: Antártida, Historia termocronológica, Islas Shetland del Sur, Plutón de Punta Barnard, Trazas de fisión en apatitos.

INTRODUCTION AND GEOLOGICAL SETTING

The South Shetland archipelago is an island arc located approximately 100 km NW of the Antarctic Peninsula between longitudes 63ºW - 54ºW and latitudes 61ºS - 63ºS, which extends NE-SW more than 500 km from Smith Island to Clarence Island. To the north-west of the archipelago, toward the Drake Passage, a wide continental platform gives way to the 4000 m deep South Shetlands Trench. To the SE lies the Bransfield Basin, a narrow submarine basin up to 2000 m in depth. SE from Bransfield Strait is the Antarctic Peninsula.

Livingston Island and the entire central part of the South Shetland archipelago belong to a magmatic arc related with the subduction processes that took place beneath this margin during the Mesozoic and Cenozoic (Fig. 1). For a detailed revision of the geological evolution see, for example, Ashcroft, 1972; Barker, 1982; Dalziel, 1984). Then, the islands are mainly composed of calc-alkaline volcanic and plutonic rocks of Cretaceous to Tertiary age (130 to 20 Ma, Willan and Kelley 1999). However, these rocks intruded over an older basement of sedimentary and low grade metamorphic rocks. On the southern part of Livingston Island (Fig. 2), around False Bay (Hurd Peninsula and Barnard Point), crops out one of the best sections of the Antarctic Peninsula basement, that here is composed by:

a) metasediments of the Miers Bluff Formation with more than 1600 m of feldspathic greywackes, shales, arkosic arenites, siltstones and minor conglomerates, folded and in many cases overturned (e.g. Smellie *et al.*, 1984; Arche *et al.*, 1992a, 1992b; Tokarski *et al.*, 1997). A Permo-Triassic age has tentatively been assigned to this formation by correlation with similar sequences of the Trinity Peninsula Group.

b) granite intrusions represented by small stocks and plutons (e.g. Barnard Point). These rocks are part of the magmatic arc generated by subduction processes that took place beneath this margin during the Mesozoic and Cenozoic (Andean plutons, Willan and Kelley, 1999).

c) several large dyke swarms, which intruded all

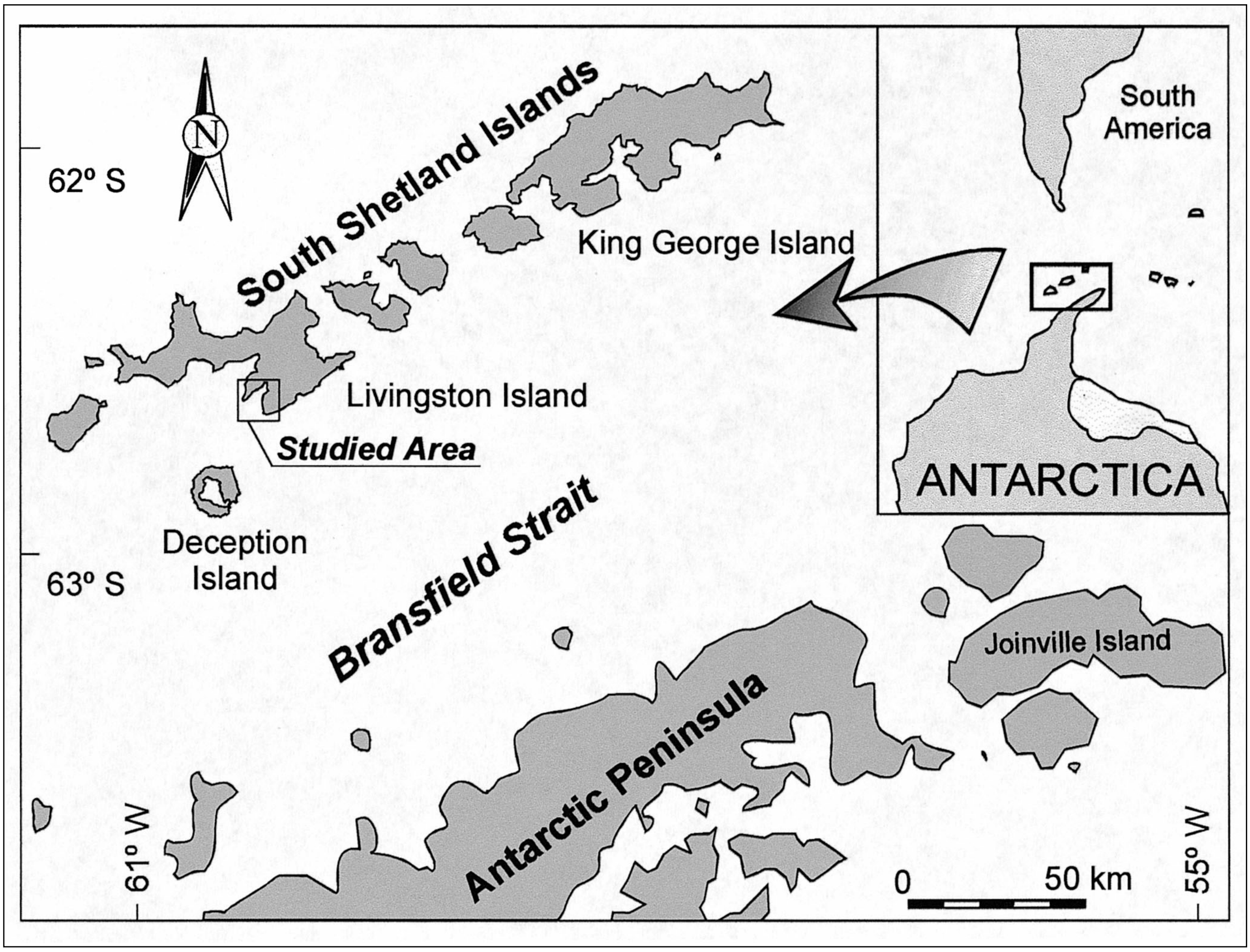

Fig. 1. Location of the South Shetland Islands, Livingston Island and the studied area.

Fig. 1. Situación de las Islas Shetland del Sur, la Isla Livingston y la zona estudiada.

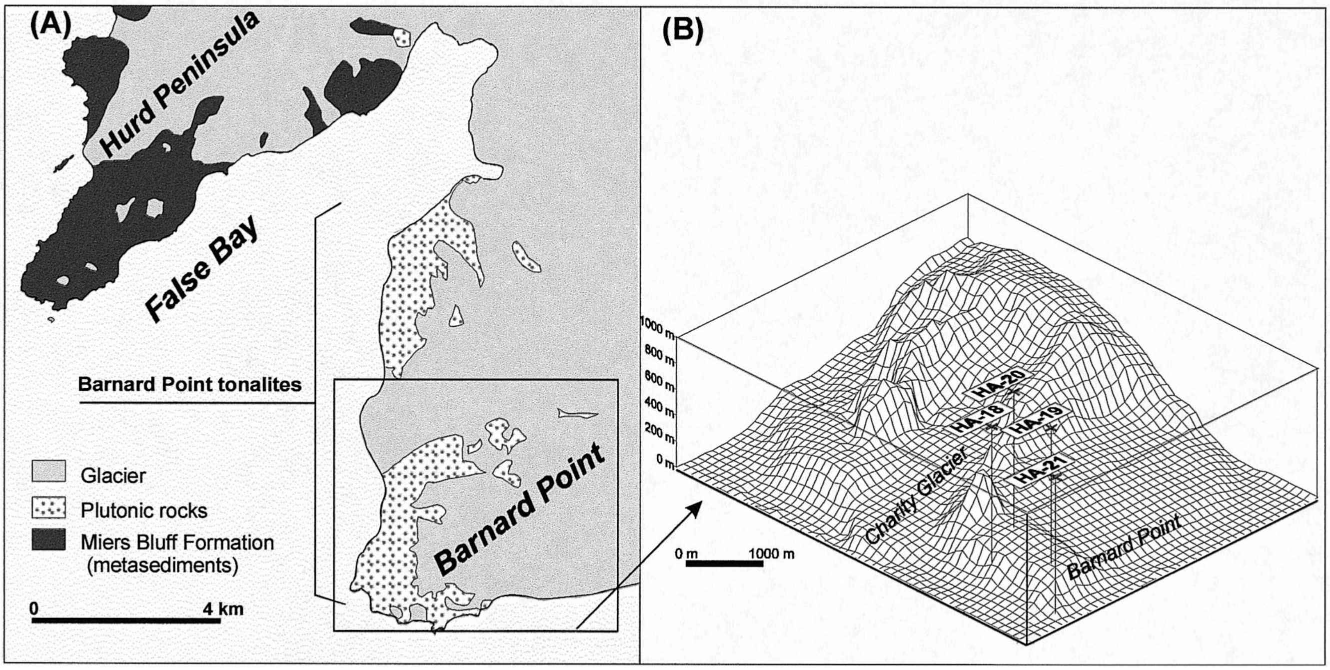

Fig. 2. Geological sketch map of Barnard Point and part of Hurd Peninsula (A), and 3D topographic model of Barnard Point area showing the location of the sampling points (B). See more comments in the text.

Fig. 2. Esquema geológico de la Punta Barnard y de una parte de la Península Hurd (A), y modelo topográfico en 3D de la zona de la Punta Barnard mostrando la situación de los puntos de muestreo (B). Ver más comentarios en el texto.

the previously described lithologies. Two different sets can be separated, the first is composed of hydrothermal veins and lodes of a probable Jurassic-Cretaceous age and the second, probably more recent, is constituted by basic dykes.

Finally, in the Bransfield Basin domain are located several Quaternary subaerial volcanic edifices, e.g., Deception, Bridgeman and Penguin islands, and the geophysical data show also several submarine volcanic edifices, some of them probably active (e.g. Gràcia *et al.,* 1996). These volcanic processes are related with the rifting and back-arc formation in the Bransfield Strait region.

Previous tectonic studies (e.g. Willan, 1994; Santanach *et al.*, 1996; González-Casado *et al.*, 1999, 2000) have established that in the Bransfield Basin domain the present stress tensor is extensional, with a NW-SE extension direction related with the Bransfield Strait rifting. And there is also agreement that prior to this extensional episode, two fracturing events with strike-slip stress tensors occurred.

This work is a part of the first Apatite Fission Track (AFT) study carried out in the South Shetland Islands region. Preliminary AFT studies have been done by our group also on samples of the Miers Bluff Formation, Hurd Peninsula, Livingston Island and on samples from granitic intrusions from King George Island (Sell *et al.*, 2000, 2001).

SAMPLING, FISSION TRACK DATING AND AFT MODELISATION

Because of the extensive ice cover in the region, rock-outcrops are small and discontinuous (Fig. 2-A), which together with the existence of important mechanical weathering rates made difficult the sampling in the field. The Barnard Point pluton has been sampled in 4 points (see Fig. 2-B) located at heights ranging from 5 to 390 m a.s.l.

Apatites were obtained by conventional separation methods including crushing and heavy liquids/magnetic separation steps. 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). The irradiation of mounted grains was made in the Orphée nuclear reactor of the Centre d'Etudes Nucleaires of Soclay, France. The results are presented in Table 1. The four central ages are concordant at 18.7 ± 1.2 (mean and standard error) Ma.

An optimisation of the fission track data (central age and confined track length distribution, Fig. 3) by the Monte Tax algorithm of Gallagher (1995), using the Lasletter *et al.* (1987) track stability for Durango apatite, shows that track registration started approx. 40-35 Ma ago and that cooling of the Barnard Point pluton accelerated from the lower Oligocene (approx. 30 Ma).

Figure 3 shows the modelisation for sample HA-20, being the results: observed age: 22.3 Ma, pre-

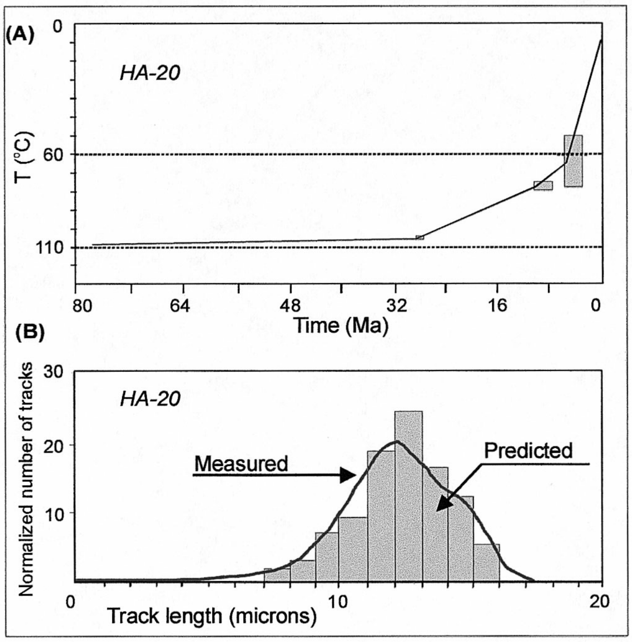

Fig. 3. Fission track length modelisation (T/t paths) for sample HA-20. (A) Calculated thermal trajectory of the sample after Monte-Trax modelling. (B) Histogram of the modelled track length.

Fig. 3. Modelización de longitudes de trazas de fisión (recorridos T/t) para la muestra HA-20. (A) Trayectoria térmica calculada mediante el modelo Monte Trax. (B) Histograma de las longitudes de huellas modelizadas.

Sample	**N**	ρ_f **10⁵ t/cm²** (N_f)	ρ_i **10⁵ t/cm²** (N_i)	**Dispersion P(χ^2)** %	**S.E.** %	ρ_m **10⁵ t/cm²** (N_m)	**FT-Age Ma ± 1σ**	**L μm ± 1σ** (N_l)
HA-18	49	6.82 (283)	2.18 (904)	>99	<1	3.767 (9964)	19.6±1.1	
HA-19	42	6.89 (245)	2.55 (908)	>99	<1	3,767 (9964)	16.9±1.0	11.99±2.11 (113)
HA-20	36	1.14 (347)	3.15 (960)	>99	<1	3,767 (9964)	22.6±1.2	12.21±1.77 (151)
HA-21	45	7.82 (298)	3.03 (1155)	95	<1	3,767 (9964)	16.2±1.0	

Table 1. Fission tracks analytical data; N, number of grains dated; ρf, fossil track density; Nf, number of fossil tracks counted; ρi, induced track density; Ni, number of induced tracks; P(χ^2), Chi square probability of Galbraith (1981); S.E., standard error of the central age; ρm, standard track density; Nm, standard number of tracks; L, mean value and standard deviation of the confined track length distribution; N_l, number of measured track length; FT, fission tracks.

Tabla 1. Datos analíticos de las trazas de fisión; N, número de granos datados; ρf, densidad de trazas fósiles; Nf, número de trazas fósiles medidas; ρ_i, densidad de trazas inducidas; Ni, número de trazas inducidas; P(χ^2), probabilidad Chi cuadrado de Galbrait (1981); S.E., error estándar de la edad central; ρm, densidad estándar de trazas; Nm, número estándar de trazas; L, valor medio y desviación estándar de la distribución de trazas;. N_l, número de longitudes de trazas medidas; FT, trazas de fisión.

dicted age: 22.4 Ma, observed mean length: 12.2 µm, predicted mean length: 12.1 µm and oldest track: 40-35 Ma.

DISCUSSION AND CONCLUSIONS

The apatite fission tracks from Barnard Point tonalite pluton registered an important cooling event around 40-35 Ma ago. In the Antarctic Peninsula region, during this period, took place a continental fragmentation episode (e.g. Ashcroft, 1972; Barker, 1982; Dalziel, 1984; Smellie *et al.*, 1984).

The Barnard Point tonalite pluton presents Rb-Sr and K-Ar (whole rock and mineral) ages in the 46-40 Ma range. Its cooling below 400° C is estimated to have occurred 40.9 ± 2.7 Ma (Willan and Kelley, 1999), a figure that is consistent with the cooling event registered by the apatite fission tracks.

Apatite fission tracks optimisations, temperature-time paths, registered around 30-20 Ma an acceleration of the cooling that is contemporaneous with an extensional tectonic episode and with the intrusion of magmatic rocks (dykes and sills). This cooling event must also be related with a denudation process connected with the extension.

The <1 Ma Bransfield rift volcanic activity (e.g. Smellie *et al.*, 1984; Willan and Kelley, 1999) is not recorded in the Barnard Point pluton apatites, which suggests that sampling points were located during that period in a high structural position.

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