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Thermochronologic constraints on the tectonic evolution of the western Antarctic Peninsula in late Mesozoic and Cenozoic times

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Abstract West of the Antarctic Peninsula, oceanic lithosphere of the Phoenix plate has been subducted below the Antarctic plate. Subduction has ceased successively from south to north over the last 65 Myr. An influence of this evolution on the segmentation of the crust in the Antarctic plate is disputed. Opposing scenarios consider effects of ridge crest – trench interactions with the subduction zone or differences in slip along a basal detachment in the overriding plate. Fission track (FT) analyses on apatites and zircons may detect thermochronologic patterns to test these hypotheses. While existing data concentrate on accretionary processes in Palmer Land, new data extend information to the northern part of the Antarctic Peninsula. Zircons from different geological units over wide areas of the Antarctic Peninsula yield fission track ages between 90 and 80 Ma, indicating a uniform regional cooling episode. Apatite FT ages obtained so far show considerable regional variability.

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Introduction and geologic setting

The area considered in this study includes the western part of the Antarctic Peninsula and the adjacent islands. In Mesozoic and Cenozoic times, it has been affected by tectonic processes related to the subduction of the Phoenix plate (oceanic lithosphere from the southeastern Pacific Ocean) below the Antarctic and South American plates. Models for the tectonic evolution of the studied area generally consider diachronous crustal growth by accretion and magmatism in the overriding plate, which was almost continuous from the early Mesozoic Gondwanide to the late Mesozoic and Cenozoic Andean activities (e.g., Storey & Garrett, 1985; Vaughan & Storey, 2000), forming a coherent structural domain. The outcropping basement in northern Graham Land is formed by a turbidite complex of Late Carboniferous to ?Jurassic age, the Trinity Peninsula Group (TPG; e.g., Smellie, 1991; Hervé at al., 2006), representing a former active continental margin in the Antarctic plate. This basement is accessible in large areas of the Antarctic Peninsula, but only in isolated places on the South Shetland Islands. In contrast, in southern Graham Land and Palmer Land the basement consists mostly of Triassic intrusive rocks and gneisses with Paleozoic protoliths (Millar et al., 2002). The TPG has been intruded or covered, respectively, by Triassic to Cenozoic intrusive and volcanic rocks along the western coast of the Antarctic Peninsula Volcanic Group (APVG; e.g., Pankhurst, 1983). These rocks represent a polyphase magmatic arc, since the Mid-Cretaceous related to the subduction of the Phoenix plate below the Antarctic plate. A Mesozoic fore-arc basin and an accretionary prism are preserved on Alexander Island in the south (Storey et al., 1996). The metamorphic complex associated with the southeastward subduction of the Phoenix plate is only accessible on Smith Island and in the Elephant Island Group in the north. Subduction ceased successively from south to north in Cenozoic times. The lithosphere of the upper plate was segmented in a strike slip or extensional regime, represented by the actively spreading Bransfield back-arc basin. The oceanic crust west of the Antarctic Peninsula is divided by NNW trending fracture zones. Some of these display a striking coincidence with the boundaries of island groups in the upper plate. Two hypotheses are being disputed concerning the reason for these similarities. The first proposes ridge crest – trench interaction in the downgoing plate (e.g., Barker, 1982; Larter & Barker, 1991; Johnson & Swain, 1995), occurring at specific times for the different blocks between the fracture zones. The second hypothesis proposes changing slip along a basal detachment in the overriding plate in Tertiary times, leading to a collapse of the accretionary prism and the formation of new structural highs (Jabaloy et al., 2003*)*.

Thermochronologic constraints

A synoptic overview of existing and recently obtained FT data is displayed in Figure 1. Details for the data presented in this paper for the first time are given in Table 1.

Zircon FT information on the crystalline basement of the Antarctic Peninsula is based on Faúndez et al. (2003). Age data for this unit are obtained directly only at a latitude corresponding to the northern part of Alexander Island.

There, a Triassic orthogneiss (Millar et al., 2002),

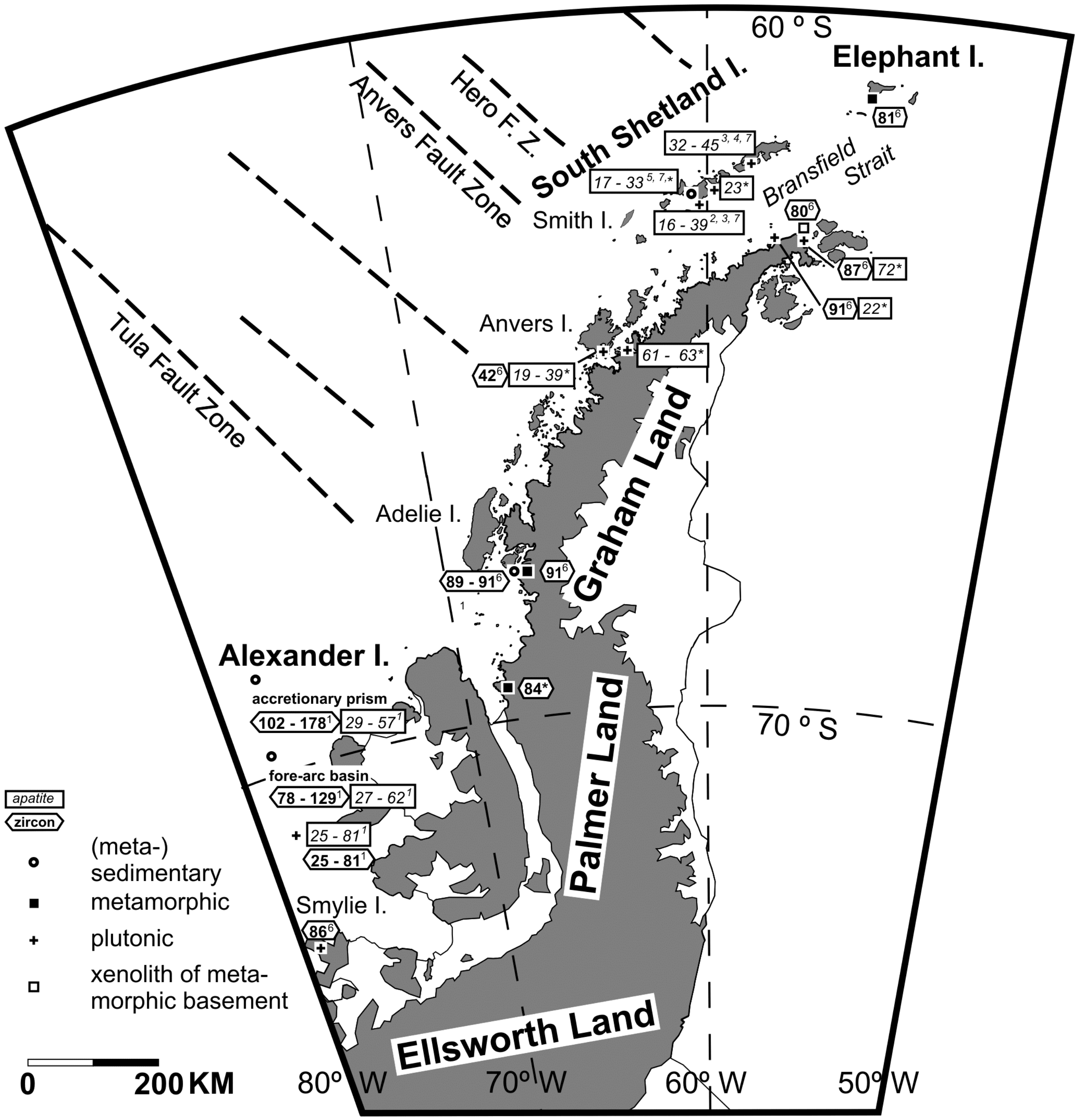

Figure 1. Overview of fission track data from the Antarctic Peninsula region: [1]Storey et al. (1996), [2]Sell et al. (2000), [3]Gonzalez-Casado et al. (2001), [4]Thomson et al. (2001), [5]Sell et al. (2001), [6]Faundez et al. (2003), [7]Sell et al. (2004), *this paper

formerly assumed to be of Paleozoic origin (Harrison & Loske, 1988), yielded a zircon FT age of 84±4 Ma. Further to the north, FT age data for the crystalline basement can only be obtained from granitic clasts in TPG type conglomerates. At a latitude corresponding to the southern coast of Adelie Island, the zircon FT ages are around 90 Ma. FT ages of xenoliths in an APVG-type Cretaceous granitic intrusion near the northern tip of the Antarctic Peninsula scatter around 85 Ma for zircons and 72 Ma for apatites (Table 1). No data are available for the quartzitic units of the metasedimentary basement, which is exposed over large areas of the Antarctic Peninsula. Similar metasediments in the southern part of the South Shetland Island yielded apatite FT ages between 33 and 17 Ma (Table 1).

Table 1. Analytical details of new apatite FT data from the Antarctic Peninsula

Sample Number	Locality	No. of crystals counted	Spontaneous ρ_s	Spontaneous (N_s)	Induced ρ_i	Induced (N_i)	$P\chi^2$ (%)	(ρ_s / ρ_i)	Dosimeter ρ_d	Dosimeter (N_d)	Central age (Ma) ± 1σ	Age dispersion (%)
82R	Cape Legoupil	19	0.355	(197)	4.132	(2,294)	>99	0.0859	1.570	(10,841)	21.8 ± 1.7	<0.1
990110004	Doumer Island	2	0.133	(14)	1.763	(185)	95	0.0757	1.580	(10,912)	19.4 ± 5.4	<0.1
BR 786 (*)	Port Neko	22	0.317	(181)	0.989	(571)	5	0.3205	1.161	(3,243)	62.8 ± 6.8	29.6
ESP 19	Cape Dubouzet	20	0.480	(584)	1.722	(2,097)	46	0.2785	1.601	(11,054)	72.1 ± 4.1	7.7
GER 11	Paradise Bay	6	0.589	(83)	2.463	(347)	97	0.2392	1.591	(10,983)	61.4 ± 7.6	<0.1
VF 11	Port Lockroy	20	0.484	(405)	3.317	(2,776)	33	0.1459	1.642	(11,338)	38.8 ± 2.4	8.4
VF 14	Hurd Peninsula	10	0.914	(212)	7.866	(1,825)	92	0.1162	1.632	(11,267)	30.7 ± 2.3	<0.1
VF 15	Hurd Peninsula	19	0.867	(444)	6.966	(3,569)	100	0.1244	1.622	(11,196)	32.7 ± 1.8	<0.1
SHE	Halfmoon Island	6	0.192	(55)	2.155	(616)	52	0.0893	1.611	(11,125)	23.3 ± 3.3	0.6

(1) Track densities (ρ) are in 10^6 tracks / cm^2; numbers of tracks counted (N) shown in brackets.
(2) All analyses by external detector method using 0.5 for the 4π/2π geometry correction factor.
(3) Ages calculated as central ages according to Galbraith and Laslett (1993) using dosimeter glass CN-5 with ζ-CN-5 = 325±7 for VF and z-CN-5 = 338±4 for AC (*);
all ζs based on repeated measurements on Durango, Fish Canyon, and Mt. Dromedary standards.
(4) $P\chi^2$ is the probability of obtaining χ^2 value for ν degrees of freedom where ν = no. of crystals - 1.

Plutonic rocks from the Antarctic Peninsula and adjacent islands, representing a magmatic arc, have been intensively dated by K-Ar, U-Pb, and Rb-Sr analyses. Compilations of intrusive ages e.g. by Thomson & Pankhurst (1983), Birkenmajer et al. (1986), and Leat et al. (1995) indicate episodes of magmatism in different regions at specific times, but without an obvious regional trend. Apparently, the magmatic activity was particularly intense around 110, 90, and 50 Ma. A continuous northeastward migration was deduced by Pankhurst & Smellie (1983) for volcanic and plutonic centres in the South Shetland Islands. Some of the intrusions, especially in the central part of the Peninsula, are overprinted by metamorphism and transformed into gneisses. These rocks cannot readily be distinguished from the crystalline basement. Zircon FT ages similar to 90 Ma, corresponding to cooling below about 280°C, have been obtained from samples covering the whole length of the Antarctic Peninsula down to Smiley Island (Faundez et al., 2003). Markedly younger ages around 42 and 29 Ma represent Cenozoic intrusions. Apatite FT ages from plutonic rocks, indicating the time of cooling below 100°C, display three groups. They are around 65±7 Ma on the west and north coast of the Antarctic Peninsula, 39±2 Ma near the southern part of Anvers Island, and around 20 Ma in all parts of the study area (Table 1). Some scatter is observed in the South Shetland Islands, where apatite FT ages are between 18 Ma in the southwestern and 45 to 32 Ma in the northeastern part, i.e. in some places very close to the magmatic event (Thomson et al., 2001; Sell et al., 2004). Cooling rates of these rocks seem to have accelerated since the early Oligocene (Gonzalez-Casado et al., 2001).

Metasedimentary rocks of a Mesozoic fore-arc basin yielded zircon FT ages between 129 and 78 Ma, while ages from a Mesozoic accretionary prism range from 178 to 102 Ma, always significantly younger than the ages of the host rocks, according to observations by Storey et al. (1996) on Alexander Island. Apatite ages for both groups are between 62 and 27 Ma. Cooling started around 100 Ma. This is consistent with apatite ages from plutonic and dyke rocks ranging from 81 to 25 Ma; generally close to the emplacement ages determined by other methods. An episode of accelerated cooling is indicated for the time between 40 and 35 Ma, coeval with the ridge – trench collision off-shore Alexander Island. Metasedimentary rocks from Livingston Island (South Shetland Islands) yielded ages between 33 and 17 Ma (see also Sell et al., 2001, 2004) in an area where subduction is still active.

Metamorphic schists from Elephant Island yielded a zircon FT age of 81±14 Ma (Faundez et al., 2003).

Interpretation

The most striking aspect of the recently gained thermochronological data set is the clustering of the zircon FT ages between 90±5 and 80±13 Ma (see Figure 2) over wide areas of the entire Antarctic Peninsula, despite the fact that the samples represent different geological units. These comprise (?)late Paleozoic to Cenozoic (meta-)sedimentary TPG-type rocks (including clasts of basement not exposed at present), metamorphic schists (partly high-pressure metamorphic; some of them corresponding to the basement in the south central part of the Antarctic Peninsula), APVG-type intrusive rocks of Cretaceous age, in one place bearing xenoliths of a metamorphic basement, and hosting dykes of hitherto unknown age. The data indicate a uniform episode of regional denudation and post-metamorphic cooling from temperatures in excess of 250-300°C in the Late Cretaceous, which is - on a regional scale - concomittant with the Palmer Land event on the Antarctic Peninsula (Vaughan et al., 2002) and the accretion of the Scotia Metamorphic Complex (Feraud et al., 2000). On a larger

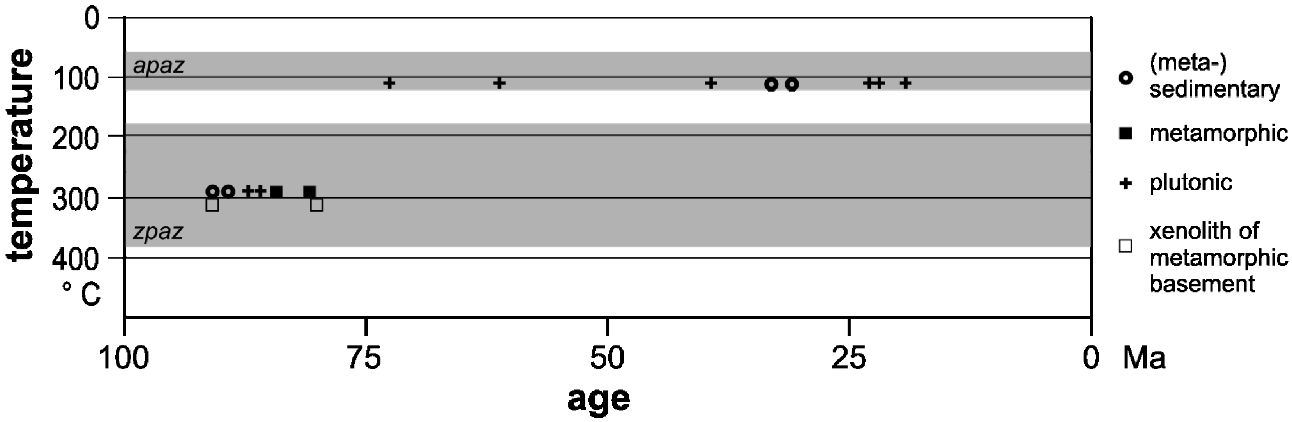

Figure 2. Age vs. temperature diagram for recently gained FT ages from Graham Land and northern Palmer Land (zircon data: Faundez et al., 2003; apatite data: this paper)**.**

scale, it is consistent with a period of deformation affecting the whole eastern Pacific domain (Vaughan & Livermore, 2005). The observations preclude any significant later thermal overprint, as should be expected in the case of subduction of ridge segments beneath the Antarctic Peninsula. Younger zircon FT ages of about 42±2 and 29±1 Ma represent Cenozoic intrusions, and possibly reveal a south to north trend towards younger ages.

The small number of apatite FT ages obtained so far does not show any evidence for an age gradient from south to north. Also, there is no obvious correlation between ages and fault blocks associated with the fracture zones in the oceanic crust of the downgoing plate. The new data from the Anvers Island group fit into one of the episodes of (accelerated) cooling described earlier for Alexander Island in the south (Storey at al., 1996) and Livingstone Island in the north (Sell et al., 2001), which are around 40-35 Ma and 28 Ma, respectively. The first episode may be correlated with a major change in the plate motions in the Pacific realm around 43 Ma, including significant effects along the plate margins (Lithgow-Bertelloni & Richards, 1998), e.g. changes between orthogonal and oblique subduction. A correlation to off-shore ridge – trench collision is possible in the case of Alexander Island. If the same process, albeit in a specific fault block, should be responsible for the cooling in the north, the ages should be much younger there. A correlation with the end of volcanic activity in the respective segment of the arc seems more probable in this area. Differences in slip along a basal detachment in the upper plate should form new structural highs, not only in the shelf area, as described by Jabaloy et al. (2003), but also in more internal parts of the mountain belt. Such highs may be characterized by specific uplift and cooling histories. The evident correlation of a cooling stage around 40 Ma, observed from Alexander Island over Anvers Island to the South Shetland Islands, and the uniform apatite FT ages around 65 Ma in the north-western part of the Antarctic Peninsula, do not support an interpretation with a significant structural along strike segmentation of the mountain belt. As an alternative, strike-slip tectonics, like in the southern Andes, appear to be supported by structural field observations in at least some parts of the Antarctic Peninsula and the adjacent islands. At present, the still insufficient spatial sample coverage does not yet allow further interpretation and modeling.

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