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First Cenozoic glaciers in West Antarctica

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Abstract: One of the most significant global climatic events in the Cenozoic was the transition from greenhouse to icehouse conditions in Antarctica. Tectonic evolution of the region and gradual cooling at the end of Eocene led to the first appearance of ice sheets at the Eocene/Oligocene boundary (ca. 34 Ma). Here we report geological record of mountain glaciers that preceded major ice sheet formation in Antarctica. A terrestrial, valley-type tillite up to 65 metres thick was revealed between two basaltic lava sequences in the Eocene–Oligocene Point Thomas Formation at Hervé Cove – Breccia Crag in Admiralty Bay, King George Island, South Shetland Islands. K-Ar dating of the lavas suggests the age of the glaciation at 45–41 Ma (Middle Eocene). It is the oldest Cenozoic record of alpine glaciers in West Antarctica, providing insight into the onset of glaciation of the Antarctic Peninsula and South Shetland Islands.

Key words: Antarctica, King George Island, Eocene, mountain glaciers.

Introduction

The Antarctic Cenozoic contains an important record of deterioration of global climate. The break-up of Gondwanaland, the opening of the Tasman and Drake Passages, and the progressive isolation of Antarctica by the Antarctic Circumpolar Current led to the transition from a warm, ice-free climate in early

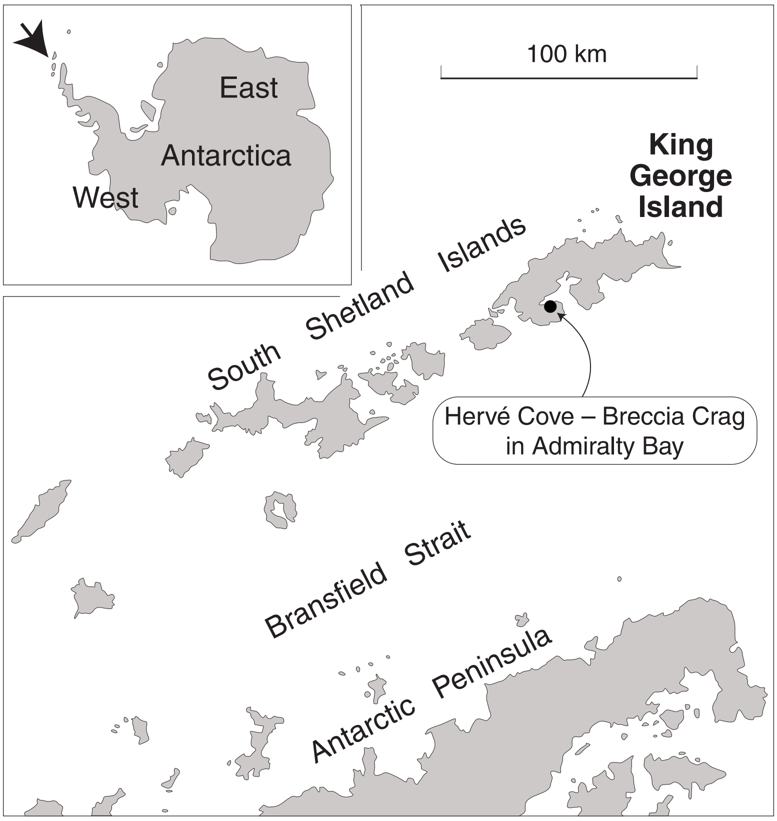

Fig. 1. Location of Hervé Cove and Breccia Crag in Admiralty Bay on King George Island, South Shetland Islands, West Antarctica.

Eocene to a colder climate and glacial conditions at the end of Eocene and younger epochs. The first evidence of major climate change with cooling through the late Paleogene is reported from the latest Eocene or Eocene/Oligocene boundary (ca. 34 Ma). Sedimentological (Ehrmann and Mackensen 1992; Coxall *et al.* 2005), floral (Birkenmajer and Zastawniak 1989; Francis 1999, 2000), faunal (Feldmann and Woodburne 1988; Aronson and Blake 2001; Dzik and Gaździcki 2001; Reguero *et al.* 2002; Myrcha *et al.* 2002; Kriwet and Gaździcki 2003; Gaździcki 2004), and oxygen isotopic (Mackensen and Ehrmann 1992; Kennett and Warnke 1993; Gaździcki *et al.* 1992; Salamy and Zachos 1999; Dutton *et al*. 2002; Ivany *et al.* 2004) data indicate cooling, terrestrial and marine ice sheet growth, and initiation of Cenozoic glaciation at that time interval both in East and West Antarctica (Barron *et al.* 1991; Barrett 1996, 2001; Abreu and Anderson 1998; Thomson 2004). While glacial history of Antarctica has been mostly revealed from deep sea drillings (Zachos *et al.* 2001), West Antarctica shows also a fairly well-preserved glacial record exposed on South Shetland Islands and the Antarctic Peninsula (Birkenmajer 1991; Dingle and Lavalle 1998; Dingle *et* *al.* 1998). The Cenozoic strata on King George Island display a sequence of alternating glacial and interglacial events, with at least two regional ice sheet expansions during the Oligocene Polonez Glaciation (32–26 Ma) and the Miocene Melville Glaciation (23–20 Ma) (Birkenmajer 2001; Troedson and Smellie 2002; Troedson and Riding 2002).

It is unclear when the first significant ice accumulations began to develop since the postulated Eocene Kraków Glaciation (Birkenmajer *et al*. 1986) was disproved using strontium isotope stratigraphy (Dingle and Lavalle 1998; Troedson and Smellie 2002). In this paper we present new evidence of alpine glaciers that preceded major ice sheet formation in West Antarctica, providing insight into the onset of Cenozoic glacial history of the region.

Geological setting

The Eocene–Oligocene Point Thomas Formation on King George Island shows a sequence of subaerial basalt to andesitic basalt, a part of the Cenozoic

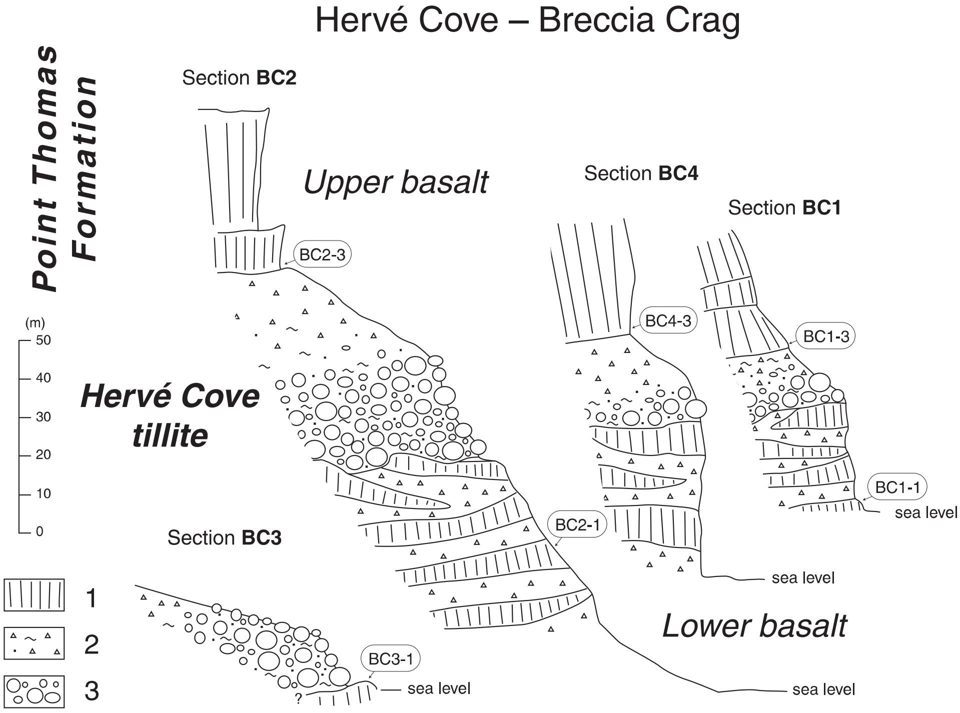

Fig. 2. Sections of the Hervé Cove tillite in volcanic sequence of the Point Thomas Formation showing detailed location of samples analyzed for the K-Ar dating. For location of the sections see Fig. 3. 1 – basalt to andesitic basalt; 2 – volcanic tuffs and breccia; 3 – diamictite.

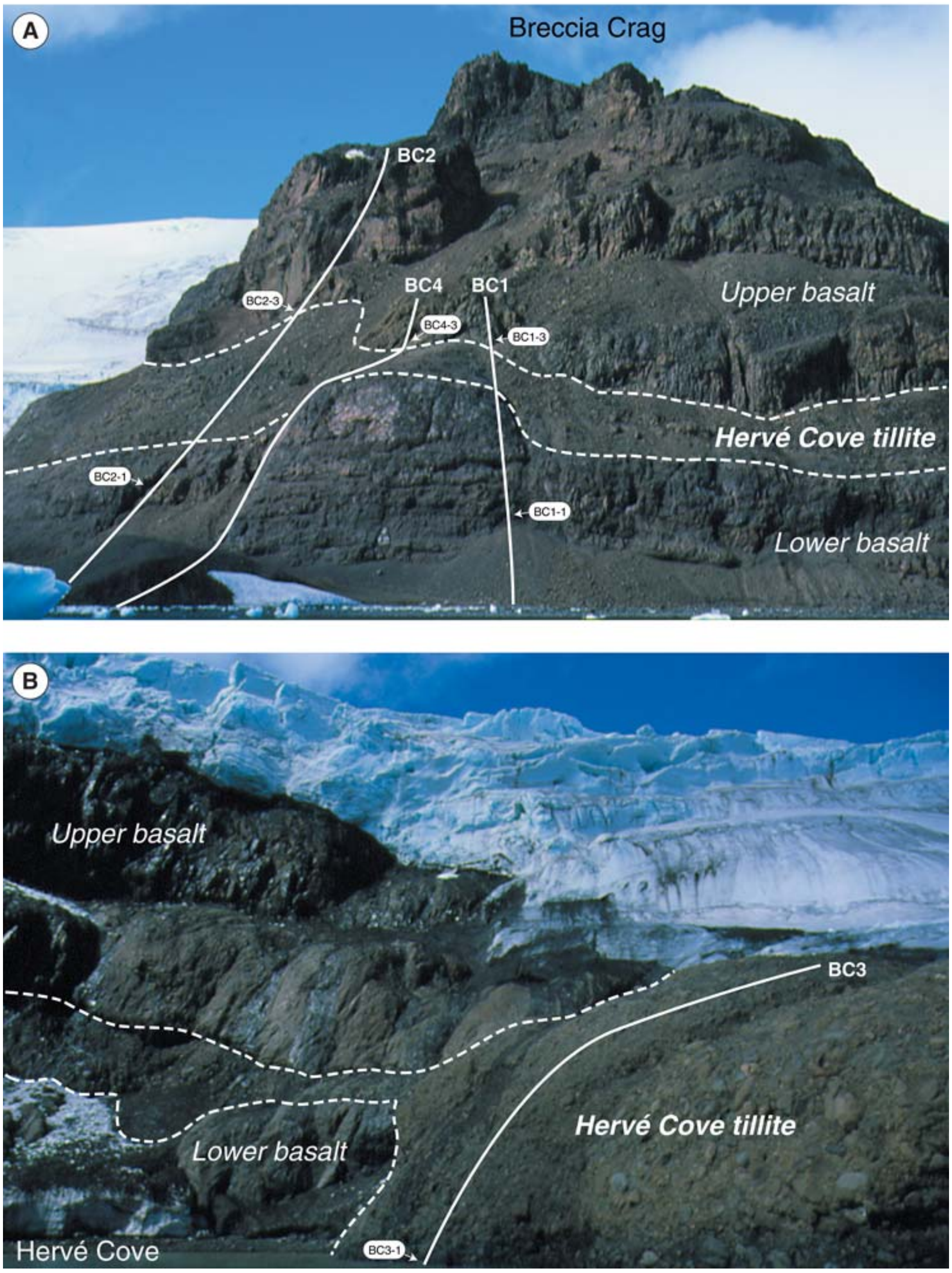

Fig. 3. Outcrops of Hervé Cove tillite at Breccia Crag (**A**) and Hervé Cove (**B**), Ezcurra Inlet, Admiralty Bay, King George Island seen from the north. BC1 to BC4 are sections illustrated in Fig. 2. BC1-1, BC1-3, BC2-1, BC2-3, BC3-1, and BC4-3 are samples analyzed for the K-Ar dating.

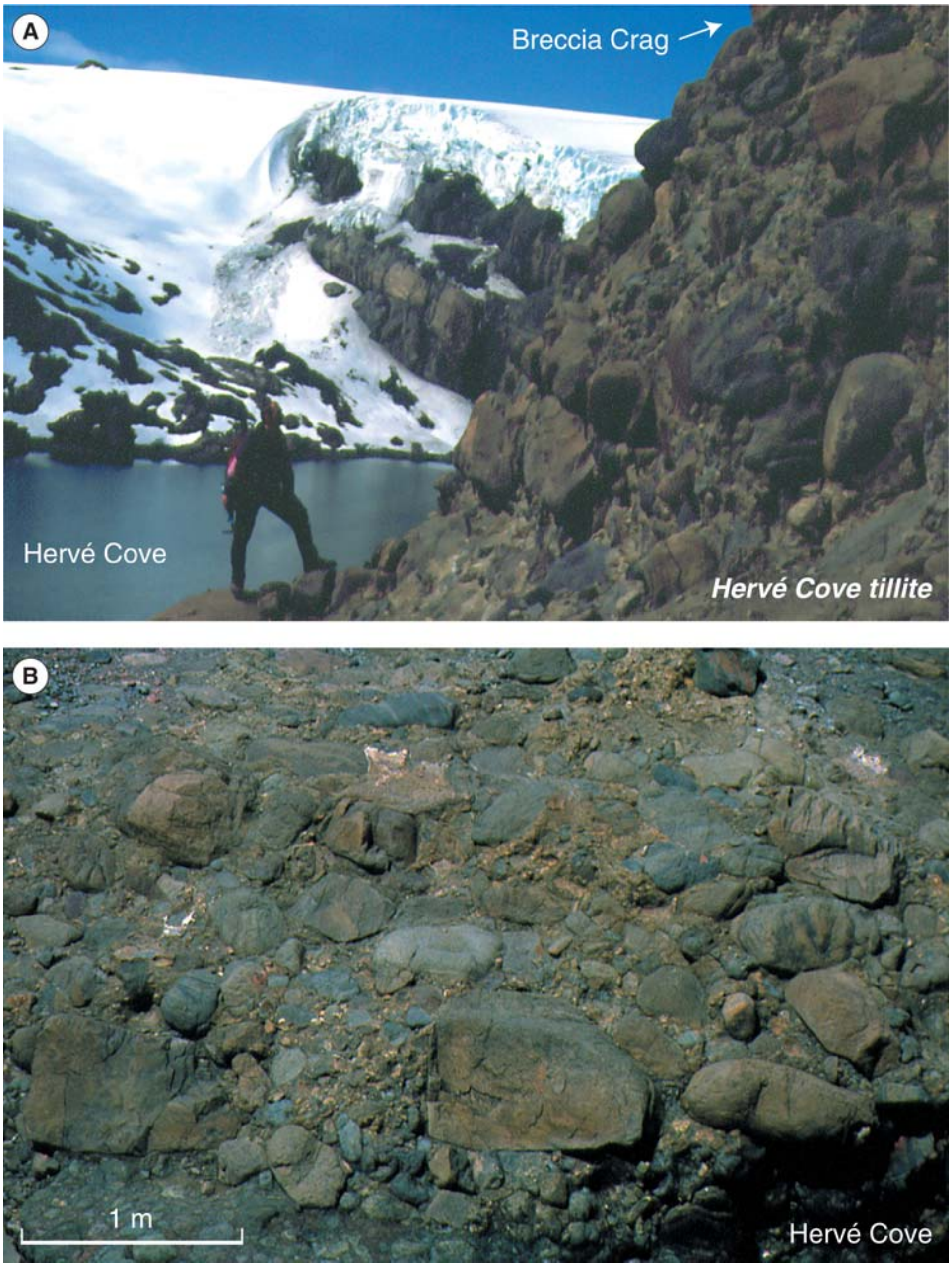

Fig. 4. Outcrops of Hervé Cove tillite at section BC-2 (**A**) and BC-3 (**B**). Note the unsorted nature of the diamictite dominated by boulders and debris of predominantly local rock material.

magmatic complex of the Outer Magmatic Arc of the South Shetland Islands (Birkenmajer 2001). The sequence contains many well-developed regolithic surfaces as well as fossil soil horizons with floral remains that record a gradual climatic cooling trend following the Early Eocene Climatic Optimum (Birkenmajer and Zastawniak 1989). A tillite horizon revealed at Hervé Cove and Breccia Crag (Ezcurra Inlet in Admiralty Bay) in the Point Thomas Fm provides direct evidence for the appearance of mountain glaciers during this climatic trend (Figs 1, 2). This is a valley-type tillite consisting mainly of coarse diamictite of varying thickness (10–65 m) that covers an uneven scoured surface developed on the lower basalt sequence of the formation (Figs 2, 3). Detrital components of the diamictite represent mostly local, unreworked volcanic material, though exotic boulders and debris are also noted (Fig. 4). Frost-splitting of boulders and associated clastic dykes as well as washing structures, erosional surfaces and fluvial sediments evidence seasonal cool and wet climatic conditions. Petrified *Nothofagus* wood fragments and volcanic bombs and tuffs found in the tillite suggest development of glaciers in a partly forested, active volcanic mountain range. Interfingering of diamictite layers and tuffs and lava flows of the lower basalt sequence observed at marginal parts of the tillite horizon suggests that it is close in age to its substratum. The tillite is covered by tuffs and thick lava flows of the upper basalt sequence of the Point Thomas Fm (see Figs 2, 3).

Radiometric dating

Samples of basaltic lavas directly under- and overlying the Hervé Cove tillite were taken along four sections at Hervé Cove and Breccia Crag for K-Ar dating (Figs 2, 3). The dating was performed at the Korea Polar Research Institute (Ansan). Samples BC1-1, BC2-1, and BC3-1 from basalts underlying the tillite gave ages of 38.1 (±1.4), 45.4 (±1.2), and 41.3 (±1.0) Ma, respectively. However, the analysis of thin sections indicates that the sample BC1-1 that yielded the age of 38.1 Ma is strongly altered, and therefore should be excluded from consideration. Samples BC1-3, BC2-3, and BC4-3 from basalts overlying the tillite gave ages of 28.6 (±0.9), 45.1 (±0.9), and 30.4 (±0.7) Ma, respectively. Thus the tillite is younger than 45–41 Ma and older than 45–29 Ma. Both age limits overlap at 45–41 Ma, and that value range is suggested as the most probable age of the Hervé Cove tillite.

Concluding remarks

Global deep-sea oxygen isotope curve suggests rapid development of Antarctic ice sheets close to the Eocene/Oligocene boundary (Zachos *et al.* 2001). This abrupt climatic event took place at the end of the 15 Ma-long cooling trend

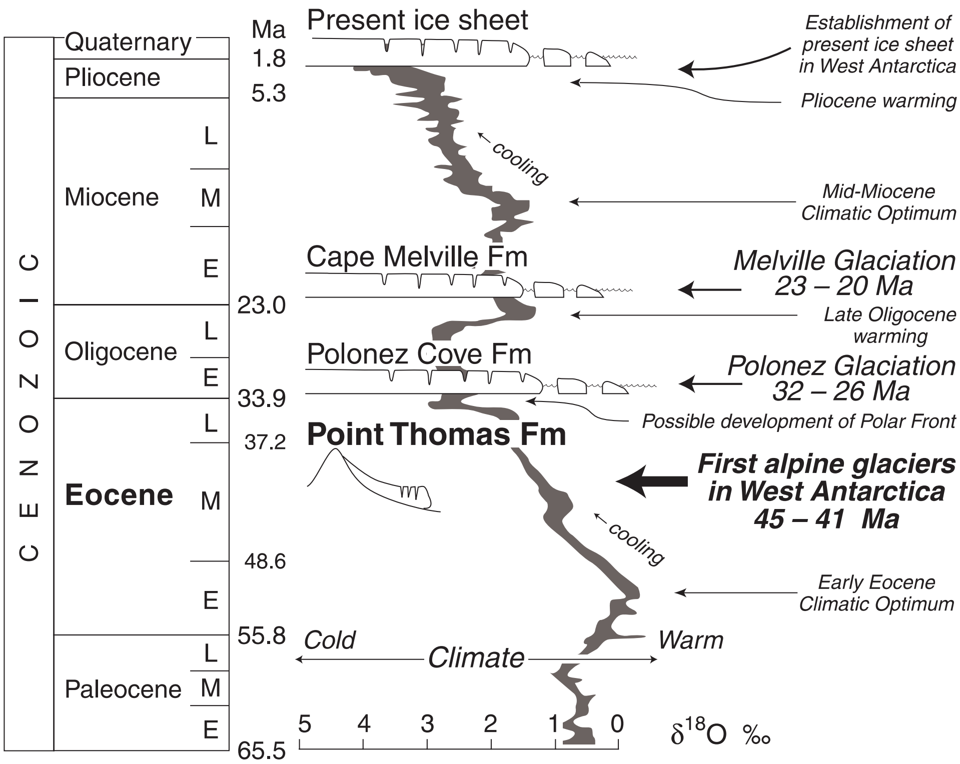

Fig. 5. Cenozoic climatic history of West Antarctica and main glacial events revealed from sedimentary record on King George Island. Global deep-sea oxygen isotope curve and climatic trends after Zachos *et al.* (2001). Geologic time scale after Gradstein and Ogg (2004).

following the Early Eocene Climatic Optimum (Fig. 5). Gradual deterioration of climate during this time interval is recorded in both the marine and terrestrial realms. Progressive decrease of sea water temperature can be deduced from geological data (sea-level changes, deposition of dropstones in open sea sediments), from geochemical proxies (stable oxygen isotope record, clay mineral composition) as well as from paleontological investigations (dinoflagellates, diatoms, radiolarians, foraminifers and molluscs) of deep-sea cores (Kennett and Warnke 1992, 1993). Important changes of the terrestrial ecosystem resulting in progradation of *Nothofagus*-dominated forests have been noted at lower latitudes on Seymour Island (Antarctic Peninsula) as well as at higher latitudes in McMurdo Sound in Antarctica (Case 1988; Doktor *et al*. 1996; Francis 1999, 2000; Pole *et al.* 2000). It is suggested by several authors that mountain glaciers might have developed in the forested Antarctic landscape inhabited by rich vertebrate faunas of marsupials and ratite birds (Prothero 1994; Tambussi *et al.* 1994; Reguero *et al*. 2002). However, there has been no direct evidence of such glacial activity re-

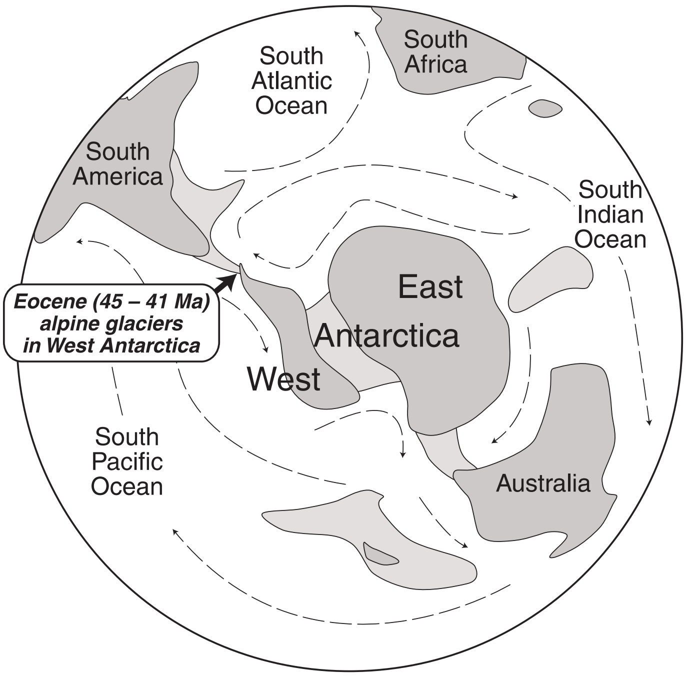

Fig. 6. Eocene paleogeographic and surface circulation reconstruction of the Southern Hemisphere and the location of first alpine glaciers in West Antarctica. Paleogeography and surface circulation after Lazarus and Caulet (1993).

ported. We document it here for the first time. Mountain glaciers occurred in the marginal zone of the Antarctic continent in the Middle Eocene (Fig. 6).

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