Pliocene age of the oldest basaltic rocks of Penguin Island
(South Shetland Islands, northern Antarctic Peninsula)

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INTRODUCTION

The South Shetland Archipelago was separated from the
Antarctic Peninsula during the formation of the Bransfield
Strait and development of the Bransfield Rift presumably in the
Pliocene (about 4 Ma; Barker, 1982; Barker and Dalziel,
1983). Bransfield Strait was formed by rifting processes within
a continental magmatic arc (Lawver et al., 1995, 1996;
Galindo-Zaldivar et al., 2006). This extension is accompanied
most probably by trench roll-back at the South Shetland Trench
(Barker, 1982; Maldonado et al., 1994; Barker and Austin,
1998). Fretzdorff et al. (2004) classified the Bransfield Strait as
an actively extending marginal basin. Quaternary submarine and subaerial volcanism occurs
along the axis of the Bransfield Strait (Bridgeean Island, De-
ception Island, seamounts) and also lies off the rift axis on the
South Shetland Islands shelf (Weaver et al., 1979; Smellie,
1990; Keller et al., 1991; Smellie et al., 2002). Generally, the
volcanic rocks are compositionally transitional between island
arc basalts and mid-ocean ridge basalts (MORB; Fisk, 1990;
Keller and Fisk, 1992). The volcanic and geochemical varia-
tions are not systematic along the axis and do not reflect the
unidirectional propagation of rifting suggested by geophysical
data (Keller et al., 2002).

Penguin Island is situated north of the present axis of rifting,
close to King George Island being located between King
George Bay and Sherrat Bay (Fig. 1B). The small volcanic is-
land (1.84 km²; Fig. 1C, D) with about 180 m high basaltic
scoria cone (Deacon Peak) and a 350 m wide crater with a small
basaltic plug inside and radial dykes, measures between 1.4 and
1.8 km in diameter (Fig. 1A, E). The second principal vent on
Penguin Island is Petrel Crater maar (Fig. 1A, F) that was
formed during a phreatomagmatic eruption about 100 years
ago. Birkenmajer (1980) distinguished three lithostratigra-
phic units within the Penguin Island Group:
– the oldest basaltic lavas with intercalation of raised
beach deposits – the Marr Point Formation;
– the sequence of lava flows and pyroclastic rocks of cen-
tral scoria cone (stratocone) – the Deacon Peak Forma-
tion;
– the youngest pyroclastic rocks – the Petrel Crater
Formation.

The age of volcanic rocks from Penguin Island is still
poorly constrained. In the early 1960ies, Barton (1961, 1965)
and Hawkes (1961) concluded that the basaltic platform of
Penguin Island and lava flows from Lions Rump, Turret Point, Three Sisters Point, Melville Peak and Cape Melville (all on King George Island) are Pliocene to Recent in age. These ideas were subsequently reinterpreted and most of these outcrops are substantially older than, and unrelated to, Penguin Island (Birkenmajer, 1979, 1982; Smellie et al., 1984; Troedson and Riding, 2002; Troedson and Smellie, 2002). Birkenmajer (1982, 2001) suggested a late Pleistocene age for the basaltic platform (Marr Point Formation) on the Penguin Island. The Deacon Peak scoria cone and Petrel Crater maar have been dated using the lichenometry method (Birkenmajer, 1979). The formation of Deacon Peak was dated at about 300 years ago, whereas the eruption forming Petrel Crater maar was dated at about 1905 AD. These results were supported by anecdotal historical observations of whalers and seal hunters. More recently, investigations of radial dykes which cut the principal cone of the Penguin volcano were conducted by Kraus (2005), who determined Ar-Ar ages on plagioclase mineral separates. The obtained results suggest an improbable Tortonian age (8.8 ±2.4 Ma) for the dykes cutting the western slope of the scoria cone.

STUDY AREA
AND RESEARCH MATERIAL

The basaltic lavas alternating with beach deposits form the lowest unit of the Penguin Island Group and underlie the Deacon Peak scoria cone. They are covered by pyroclastic rocks (ashes, lapilli and bombs) deposited during the last eruptions. Birkenmajer (1979, 1982) suggested that the volcanic centre for the basal lavas lies to the north-east of the island. The sequence of lavas is up to 50 m thick and is mostly exposed as steep cliffs around the islands and in the inner slopes of Petrel Crater. The best and most easily accessible exposures of the basaltic platform are located along the northern margin of the island, especially close to the Gonzales Point where there are steep cliffs over 20 m high and about 300 m long (Fig. 1G). Locally, there is a noticeable contact between two lava flows emphasized by the presence of autobreccia between the two flows. Macroscopically, two main lithological and textural varieties of porphyritic basalts are visible: vesicular outer parts of the lava flow (carapace facies) and a massive core. The vesicles are commonly elongated in shape, rarely irregular, and exceed 1 cm in length. Their shape, if elongated, usually corresponds with a flow-banded texture. Locally, there is a noticeable flow folding. Moreover, due to shearing (Dadd, 1992), stretching and brecciation of flow-banded volcanic rocks are sporadically observed. The volcanic rocks are not altered. Veins and vesicles filled by hydrothermal minerals were not observed.

The dark grey basaltic lavas of the plateau display porphyritic, rarely glomeroporphyritic, interstitial or intergranular texture. Locally, they are scoriaceous. The studied rocks comprise olivine, plagioclase and clinopyroxene phenocrysts that may exceed up to 1.2 mm in length (Fig. 2). The groundmass contains plagioclase, olivine, clinopyroxene and chromite crystals and also glass. Plagioclase crystals occur as euhedral and subhedral phenocrysts sporadically showing zoning (Fig. 2) and as small (less than 0.3 mm in length), decussate laths in the groundmass. The core and the rims of plagioclase phenocrysts have a bytownite and labradorite compositions, respectively. Clinopyroxenes (Ti-augite; Fig. 2A) occur as euhedral, rarely twinned phenocrysts (~300 µm in length) and as groundmass, subhedral crystals (70 µm). The lavas contain two generation of olivine, which is the main mafic mineral. The phenocrysts (Fig. 2B-D), typically 600 µm in length, occur sporadically as glomerocrysts. Chromite occurs as a groundmass crystals (up to 200 µm in diameter; Fig. 2D) and as inclusions within olivine phenocrysts (50–100 µm in diameter; Fig. 2B).

All the analysed samples are low-potassium, calc-alkaline basalts containing ca. 50% of SiO₂ (Table 1). Weaver et al. (1979) suggested that the Penguin Island lavas are magnesian, mildly alkaline olivine basalts with up to 4% normative nepheline. In the total alkalis versus silica (TAS) classification diagram (Le Maitre et al., 1989), all the samples fall within the basaltic field. The rocks are enriched in large-ion lithophile elements and depleted in high field strength elements relative to N-MORB (Normal Mid-Ocean Ridge Basalt; Fig. 3A). The basalts are characterized by a relatively high concentration of elements such as Co, Cr and Ni. The absolute content of rare earth elements vary from 49.47 to 59.73 ppm for all the samples. Chondrite-normalized REE diagrams (Sun and McDonough, 1989) are relatively smooth and show steep patterns for LREE and MREE (Fig. 3B). The enrichment in LREE is clearly decipherable as the (La/Lu)⁰CN ratio ranges from 4.7 to 6.3. These rocks are also characterized by the lack of any Eu anomalies or, in some samples slight positive anomaly.

MATERIAL AND METHODS

The sample for whole-rock ⁴⁰Ar-³⁹Ar isotope dating and for palaeomagnetic study was selected from fresh, massive parts of the older lava after thorough examination of thin sections. The studied lava flow is exposed in cliffs, about 200 m

Fig. 1 A – location of the analysed sample (PING-3) on a geological map of the Penguin Island volcano (slightly modified after Birkenmajer, 1979, 1982); B – location of the Penguin Island volcano in the South Shetland Islands; C – geological cross-section of the Penguin Island volcano (based on Birkenmajer, 1979, 1982; modified); D–G – photographs of the Penguin Island volcano: D – Penguin Island (Deacon Peak), view from Turret Point; E – crater of principal cone with a small basaltic plug; F – Petrel maar, view towards Melville Peak; G – two lava flows of the basaltic plateau of the Penguin Island volcano with detailed location of the analysed sample.
The major oxides were determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES) at ALS Laboratory in Canada and reported in wt.% with total Fe as Fe₂O₃, whereas the trace elements, including REE, were measured by inductively coupled plasma mass spectrometry (ICP-MS) and reported in ppm.

The results of the ⁴⁰Ar-³⁹Ar whole rock age estimation are presented in Figure 4. The measurement data of mass spectrometry analysis are listed in Table 2. It is clearly visible that the Marr Point Formation lava yielded a statistically significant plateau age of 2.7 ±0.2 Ma. The five steps defining the plateaus correspond to about 50.5% of the ³⁹Ar released. The mean square weighted deviation (MSWD; calculated for n-1 degrees of freedom) for the plateau age is 1.66 and the corresponding ρ values is 0.16 (ρ – probability of occurrence based on Chi Square Tables).

MAGNETOSTRATIGRAPHY

All the specimens were strongly magnetised. The intensity of NRM ranged from 7.2 to 8.8 A/m. The NRM was demagnetised...
Fig. 2. Photomicrographs of basaltic rocks from Penguin Island (Marr Point Formation)

A – clinopyroxene phenocryst surrounded by groundmass of plagioclase laths, clinopyroxene olivine crystals and glass, crossed polars; B – BSE (back-scattered electrons) image of clinopyroxene, plagioclase and olivine phenocrysts with chromite inclusions; the groundmass containing plagioclase laths, clinopyroxene, olivine and also chromite crystals; C – olivine phenocrysts crossed polars; D – BSE image of olivine and chromite crystals; mineral symbols after Kretz (1983): Chr – chromite, Cpx – clinopyroxene, Pl – plagioclase, Ol – olivine; BSE images performed using Cameca SX 100 instrument in Polish Geological Institute – National Research Institute in Warsaw.

Fig. 3. N-MORB-normalised multi-element patterns (A) and chondrite-normalised REE patterns (B) for basaltic lavas from Penguin Island.

The normalisation values for N-MORB and chondrite are from Sun and McDonough (1989).
in an alternating field of amplitude up to 100 mT and more than 90% of the initial intensity of NRM was removed in a field not higher than 35 mT (Fig. 5A). Well-defined characteristic directions with steep negative inclinations group in the second quarter of the hemisphere. A normal magnetic polarity for the studied sample is therefore evident. The normal polarity of sample and the results of \(^{40}\text{Ar}^{39}\text{Ar}\) dating correspond well to the global polarity time scale GPTS (Gradstein et al., 2004) indicating that the rock studied is coeval with the upper part of the Magnetozone Gauss (Fig. 5B).

**CONCLUSIONS**

1. The new isotopic age presented here constrains the age of crystallisation and emplacement of basaltic magma forming the basal part of Penguin Island (Marr Point Formation) to the middle Pliocene (2.7 ±0.2 Ma). Combined \(^{40}\text{Ar}^{39}\text{Ar}\) and palaeomagnetic data imply a Piacenzian age for the basaltic plateau of Penguin Island.

2. The lava flows that built up the Penguin Island platform are more “primitive” than typical volcanic rocks from King George Island except for the Low Head lava dome (Smellie et al., 1998). The lavas are characterized by higher MgO, Cr, Ni and Co contents, than subduction-related lavas and they show some compositional characteristics of alkaline magmas.

3. Volcanism within Bransfield Strait is believed to have started in the Pleistocene at about 0.3 Ma (e.g., Birkenmajer and Keller, 1990; Keller et al., 1992). On the other hand, subduction-related magmatism is unknown after 9.8 Ma in the South Shetland Islands area (Smellie et al., 1984; Birkenmajer et al., 1986). Our new data indicate that the first signs of volca-

![Fig. 4. Stepwise argon release spectrum for a whole-rock lava sample from the Marr Point Formation of Penguin Island volcano](image)

**Table 2**

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<th>(^{39}\text{Ar}^{39}\text{Ar}) [%]</th>
<th>(^{39}\text{Ca}^{39}\text{Ar}) [%]</th>
<th>(^{39}\text{Ar}\times10^{-14})</th>
<th>% Step</th>
<th>Cum [%]</th>
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Integ. age = 5.4 ±0.3

(* Plateau age =

\[ \text{MSWD} = 1.66 \quad \rho = 0.16 \quad \text{steps 4–8} \]

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Codes for the column titles are as follows: step – number of heating steps; Pwr/T°C – degassing power (dot indicate plateau); Ca/K – element ratios; Mol \(^{39}\text{Ar}^{39}\text{Ar}\) \(\times10^{-14}\) – \(^{39}\text{Ar}^{39}\text{Ar}\) released at each step; % Step – % of total \(^{39}\text{Ar}\) released at each step; Cum [%] – cumulative \(^{39}\text{Ar}\) release; \(^{40}\text{Ar}^{39}\text{Ar}\) [%] – % of \(^{40}\text{Ar}\) released; errors are 2-sigma.
Fig. 5A – typical demagnetisation characteristics of the studied basaltic sample from the Penguin Island:
B – correlation of obtained normal magnetic polarity and Ar-Ar isotope age to the GPTS (Gradstein et al., 2004)

- a – stereographic projection of demagnetisation path; b – intensity decay curve; c – orthogonal plot; d – stereographic projection of line fit palaeomagnetic directions isolated from particular specimens with parameters of mean direction (D, I – mean declination and inclination; $\alpha_w$, K – Fisher’s statistics parameters, n – number of specimens; Irm – intensity of remanent magnetisation, Inrm – initial intensity of remanent magnetisation; open (closed) symbols denote upward (downward) pointing inclinations
nic processes that accompanied the opening of Bransfield Strait took place in the middle Pliocene.

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**REFERENCES**


