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Polish geological research on King George Island, West Antarctica (1977–1996)

ABSTRACT: The Polish geological research on King George Island, South Shetland Islands (West Antarctica), during the two past decades (1977–1996) included: stratigraphy, radiometric dating, petrology and geochemistry, sedimentology and palaeoenvironmental studies, volcanology, tectonics, structural geology, Quaternary geology, palaeobotany and palaeozoology. The major scientific achievements were: (1) the establishment of formal lithostratigraphic standards for radiometrically-dated Upper Cretaceous through Tertiary magmatic rock sequences and intercalated sediments; (2) the discovery of four Tertiary glaciations and three interglacials, spanning some 30 Ma from Early/Middle Eocene through Early Miocene; (3) the discovery and systematic elaboration of rich terrestrial and marine biota of Late Cretaceous through Early Miocene ages; (4) the reconstruction of changing Late Cretaceous and Tertiary terrestrial and marine palaeoenvironments in a mobile volcanic-arc setting; (5) the determination of age and structural evolution of the island's two Quaternary volcanoes; (6) the reconstruction of the Late Cretaceous through Recent evolution stages of the South Shetland magmatic arc and its backarc Bransfield Basin and Rift, based on tectonic and structural studies.

Key words: Antarctica, King George Island, magmatic arc, Cretaceous–Tertiary.

Introduction

The paper presents main Polish research directions and achievements in geological sciences on King George Island, South Shetland Islands (West Antarctica) since 1977. This research was an integral part of the programmes of multidicipline scientific expeditions organized by the Polish Academy of Sciences: from 1977 to 1986 to the Polish *H. Arctowski* Station on King George Island (Birkenmajer 1978, 1979, 1980e, f, h, 1982f, g, 1983c; Błaszyk and Gaździcki 1980; Gaździcki and Wrona 1982a, b, 1986; Gaździcki 1987a, b, 1996; Tokarski 1986, 1987b; Tokarski *et al.* 1981, 1982); and from 1984 to 1991, as a part of the Polish West Antarctic Geodynamic Expeditions operating from chartered ships (Birkenmajer 1987a, 1988a, 1991a). In 1994, some additional studies were also carried out within the programme of the Brazilian geological expedition (Birkenmajer 1995a–c).

A complete list of papers published between 1978 and 1990, referring to the Polish geological research on King George Island, is presented in a bibliography of the Polish Antarctic research (Earth-sciences) compiled by Birkenmajer and Gaździcki (1991). More recent publications are included in the reference list attached to this paper. Lists of new place names introduced by the Polish geologists on King George Island were published separately (Birkenmajer 1980j, 1984b; Tokarski 1981b).

Lithostratigraphic standards

A need for formalization of lithostratigraphic standard applicable to magmatic and sedimentary successions of King George Island, part of the magmatic arc of the South Shetland Islands (Fig. 1), became apparent already during the first field season (1977/78) of the Polish geological research on the island. The existing informal standard including only a few rock-units of lithostratigraphic group rank (Hawkes 1961; Adie 1964; Barton 1965) proved to be insufficient for detailed geological mapping and site description. A number of new, formally described rock-units of the supergroup, group, formation and member ranks had therefore been distinguished and successively introduced, and the existing informal ones redefined and formalized or rejected (Birkenmajer 1980a, b, g, i, 1981c, d, 1982a, c, d, 1984). The new lithostratigraphic standard covers the Upper Cretaceous through Tertiary stratiform terrestrial volcanic pile more than 3.5 km thick, its intercalated terrestrial and marine sediments, and associated hypabyssal plugs and dykes, and moderate-size plutons.

Recognition of four major tectonic blocks bounded by the NE-SW-running strike-slip faults parallel with the island axis (Fig. 2), helped explain great differences in geological age and succession of strata over King George Island (Birkenmajer 1983b). These tectonic blocks probably represent terranes displaced with respect to one another at a considerable distance.

Palaeontological versus radiometric dating

Rich fossil plant assemblages found in terrestrial strata intercalated in the volcanic piles (Stuchlik 1981; Zastawniak, 1981, 1990, 1994; Zastawniak *et al.* 1985; Birkenmajer and Zastawniak 1986; Tokarski *et al.* 1987) had appeared to be of restricted stratigraphic value (Birkenmajer and Zastawniak 1986,

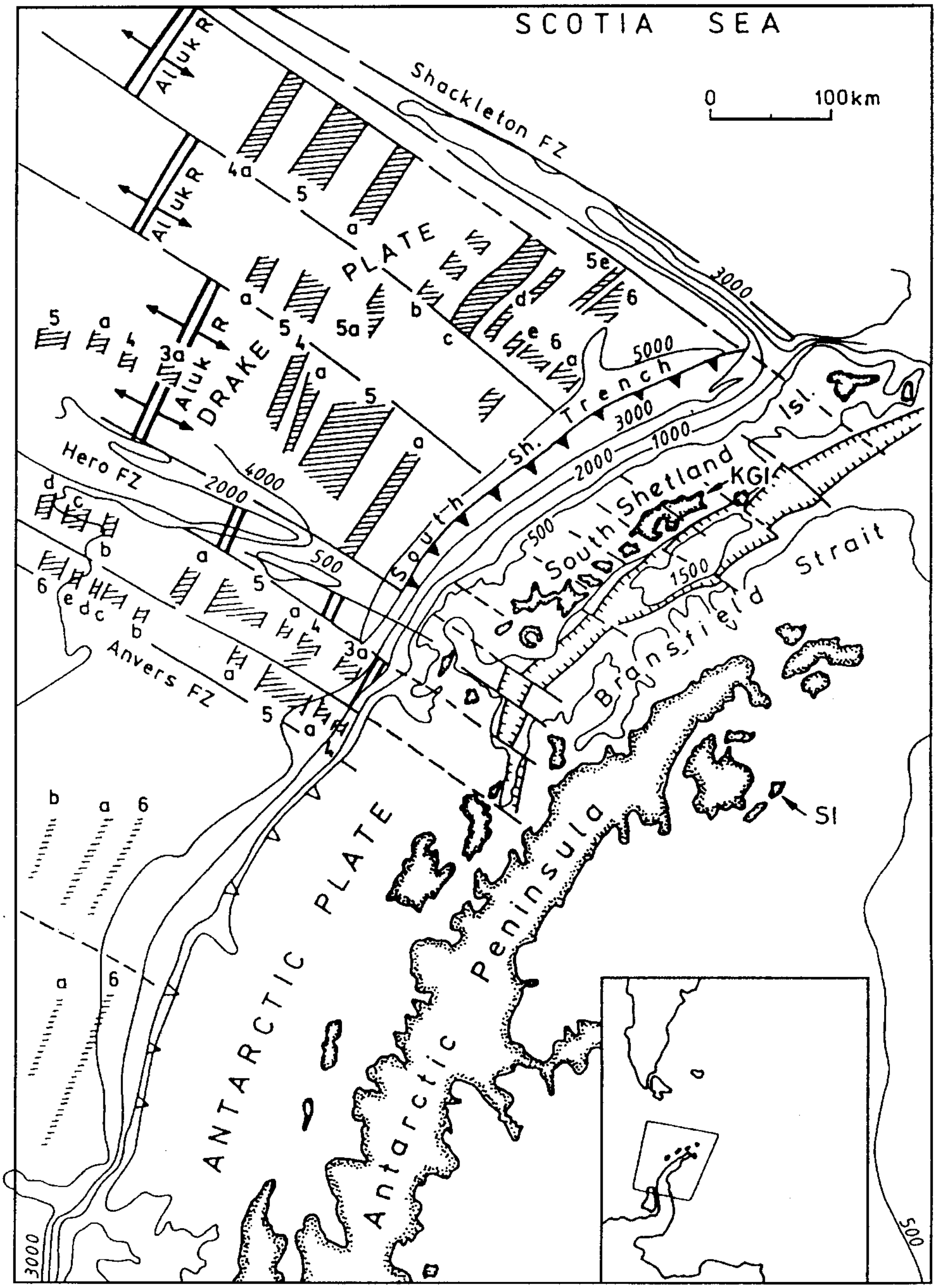

Fig. 1. Plate tectonic setting of the northern Antarctic Peninsula and the South Shetland Islands (KGI — King George Island, SI — Seymour Island). Bransfield rift barbed; convergent plate boundary marked by heavy barbs; spreading ridge divergently arrowed; fracture zones (FZ) dashed; magnetic anomalies obliquely shaded and numbered (adapted from British Antarctic Survey, Tectonic Map of the Scotia arc, 1985 and Meissner *et al.* 1988).

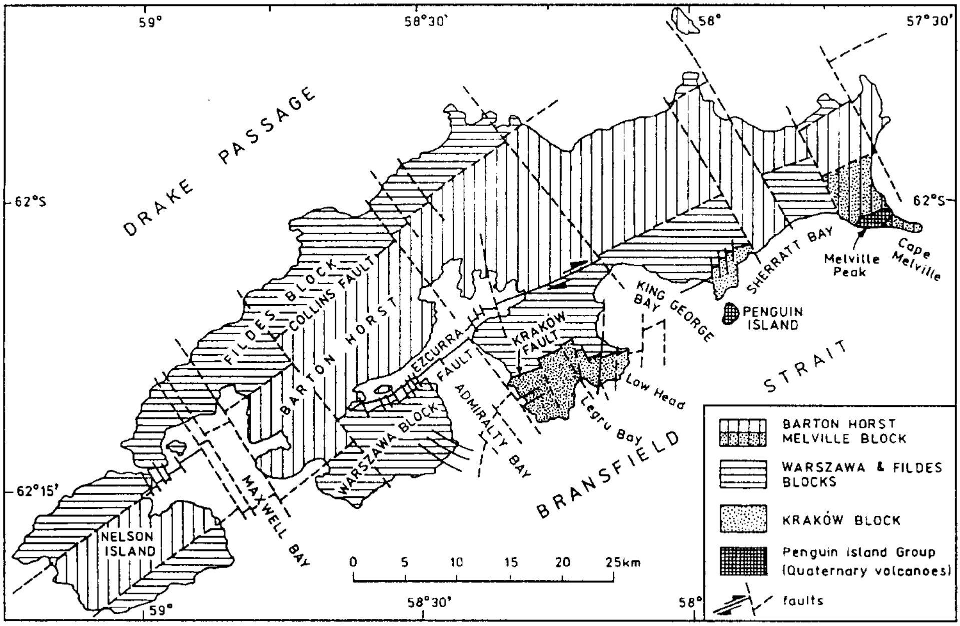

Fig. 2. Tectonic blocks of King George Island (after Birkenmajer 1983b).

1989a, b). On the other hand, fossil invertebrate and coccolith spectra obtained from the Tertiary glacio-marine strata often showed contamination by older (recycled) fossils — a result of glacial processes and iceberg-rafting (Birkenmajer *et al.* 1983a, 1987; Dudziak 1984; Birkenmajer and Dudziak 1990). Moreover, those marine fossils which were believed to occur *in situ* did often show wide or uncertain stratigraphic ranges (*cf.* Gaździcki and Pugaczewska 1984; Birkenmajer 1987b; Pugaczewska 1984). Direct stratigraphic dating of the Tertiary marine and glacio-marine deposits by fossil assemblages was possible only in a few cases (Biernat *et al.* 1985; Birkenmajer and Łuczkowska 1987a, b).

In the light of the above, the radiometric dating of volcanic and plutonic rocks on King George Island proved to be of primary importance for determination of geological ages of the associated fossiliferous deposits. It had also helped determine duration of particular palaeoclimatic and magmatic cycles as well as reconstruction of geological history of the island as part of the South Shetland Islands arc.

An extensive K-Ar dating programme was carried out, involving close cooperation of the Italian, German and Brazilian geochronological laboratories (Birkenmajer *et al.* 1983b, c, 1985a, 1986a–c, 1990b; Birkenmajer and Gaździcki 1986; Birkenmajer 1988b, 1989b). Radiometric dating by other authors (*e.g.*, Smellie *et al.* 1984) had also been used to refine geological ages of particular formations in the new lithostratigraphic standard (Birkenmajer 1988b, 1989a–c, 1991b).

A problem of reliability of the K-Ar dating for geological age determination of some volcanic successions exposed along the southern coast of the island was considered (Birkenmajer *et al.* 1990b). A considerable dispersal of the K-Ar dates and their error limits was sometimes stated within the same lithostratigraphic unit. This could be a result of reheating by successive intrusions and/or by raised geothermal gradient in the active volcanic arc of the South Shetland Islands. Recently, a more reliable $^{40}Ar/^{39}Ar$ method was applied with good results to volcanic rocks along the northern coast of King George Island (Hu *et al.* 1995).

Geochemistry and petrogenesis

The magmatic suites of King George Island originated as a result of the Late Cretaceous through Tertiary subduction of the SE Pacific oceanic crust under the Antarctic Peninsula–South Shetland Islands continental crustal wedge. A well expressed calc-alkaline trend is shown by the majority of magmatic rock sequences of that age on King George Island, and in the Admiralty Bay area in particular (*e.g.*, Birkenmajer and Narębski 1981; Birkenmajer *et al.* 1981, 1985b, 1991a; Smellie *et al.* 1984; Birkenmajer 1994a, 1995d; Zheng and Birkenmajer 1996).

The stratiform, mainly terrestrial, pile of lavas, tuffs and volcanic agglomerates of Late Cretaceous through Early Tertiary age, more than 3 km thick at Admiralty Bay, shows the presence of several successive volcanic cycles starting with basaltic andesites, followed by basalts, andesites, and terminating with rhyodacites (Birkenmajer and Narębski 1981; Birkenmajer *et al.* 1981). Hydrothermal processes were responsible for widespread zeolitization (Birkenmajer *et al.* 1989b) and pyrite mineralization. The latter is either stratabound or is associated with quartz veins (Birkenmajer 1982d; Paulo and Rubinowski 1987).

Tertiary glaciations and interglacials

Four Tertiary glaciations and three interglacial-type stages have been distinguished on King George Island (Fig. 3). They span about 30 Ma, from Early/Middle Eocene, ca 50 Ma, through Early Miocene, ca 20 Ma (Birkenmajer 1980b, 1982a, c, 1983a, 1984a, 1987b, 1988b, 1989c, 1990, 1991b, 1992a, 1994c). An extensive Polish research of this subject included:

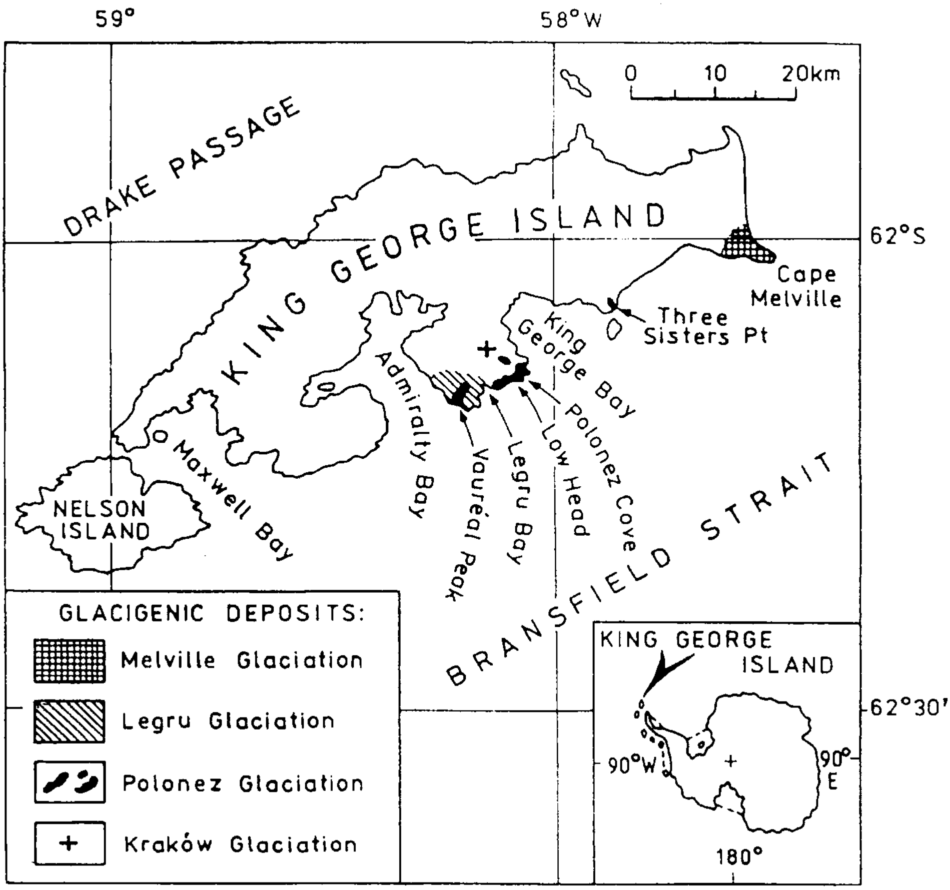

Fig. 3. Distribution of Tertiary glacial and glacio-marine deposits on King George Island.

(1) Sedimentological studies of the Eocene, Oligocene and Lower Miocene glacial and glacio-marine strata (Birkenmajer *et al.* 1985d, 1991c; Porębski and Gradziński 1987, 1990; Birkenmajer 1995a, b);

(2) Mineralogical study of a regolith formed during warm interglacial-type Tertiary climatic stage (Birkenmajer and Łydka 1990), and a petrological study of Tertiary brown coals (Birkenmajer *et al.* 1991b);

(3) Petrological and structural studies of lavas and hypabyssal intrusions forming base of the Oligocene glacigenic strata (Paulo and Tokarski 1982);

(4) Petrological studies of rock fragments occurring as erratic boulders in lodgement tills and as dropstones in glacio-marine strata (Birkenmajer 1980b, 1982a, c, 1983a, 1984a; Birkenmajer and Wieser 1985; Birkenmajer and Butkiewicz 1988);

(5) Elaboration of taxonomy of plant remains from terrestrial preglacial and interglacial strata, evaluation of their geological age, palaeoenvironment and

palaeoclimatic requirements (Stuchlik 1981; Zastawniak 1981, 1990, 1994; Zastawniak *et al.* 1985; Birkenmajer and Zastawniak 1986, 1989a, b; Tokarski *et al.* 1987);

(6) Elaboration of taxonomy, assessment of stratigraphic value (*e.g.*, problem of glacial recycling), geological age and palaeoenviromental requirements of marine fossil assemblages from glacial and glacio-marine strata (*e.g.*, Birkenmajer *et al.* 1983a; Dudziak 1984; Pugaczewska 1984; Gaździcki *et al.* 1982; Gaździcki 1984, 1987b, 1988, 1996; Gaździcki and Pugaczewska 1984; Gaździcki and Stolarski 1992; Biernat *et al.*, 1985; Gaździcka and Gaździcki 1985; Birkenmajer and Łuczkowska, 1987a, b; Birkenmajer and Dudziak 1990; Hara 1992);

(7) Radiometric (K-Ar) dating of lavas, tuffs, hypabyssal dykes and plugs associated with the Tertiary glacial and glacio-marine strata (see above: Palaeontological versus radiometric dating).

Tertiary palaeoclimatic and palaeoenvironmental changes in a mobile volcanic arc setting

Multidisciplinary approach to the problems of palaeoclimatic and palaeoenvironmental changes on King George Island during the Tertiary (see above), allowed to establish the succession of geological events and their regional correlation in the mobile volcanic arc setting of the northern Antarctic Peninsula region (Fig. 4).

(1) The oldest Kraków Glaciation (Early/Middle Eocene, about 50 Ma) is represented by fossiliferous shallow-marine clastics with iceberg-rafted dropstones, grading upward into marine basaltic hyaloclastites alternating with lava flows. The sedimentary environment was that of an inner shelf of a marginal sea. The centre of glaciation was situated somewhere in Antarctic Peninsula.

(2) The Arctowski Interglacial (Middle Eocene–Early Oligocene, 50–32 Ma) was characterized by primitive terrestrial environments which hosted rich vegetation typical of warm and moist climate. Ice-caps had formed on tops of higher volcanoes.

(3) During the Polonez Glaciation (late Early Oligocene, 32–30 Ma), continental ice-cap of West Antarctica expanded over Bransfield Strait and reached King George Island. Basal lodgement tills laid down by this ice-cap are followed by stratified submarine diamictites deposited under floating shelf ice, and those by fossiliferous shallow-marine strata with iceberg-rafted dropstones. Active basaltic volcanoes supplied lava and clastics to the marine basin. The sources of iceberg-rafted dropstones were located partly in the South Shetlands, but mainly in continental Antarctica (Antarctic Peninsula, Ellsworth Mts, possibly also Pensacola-Theron Mts).

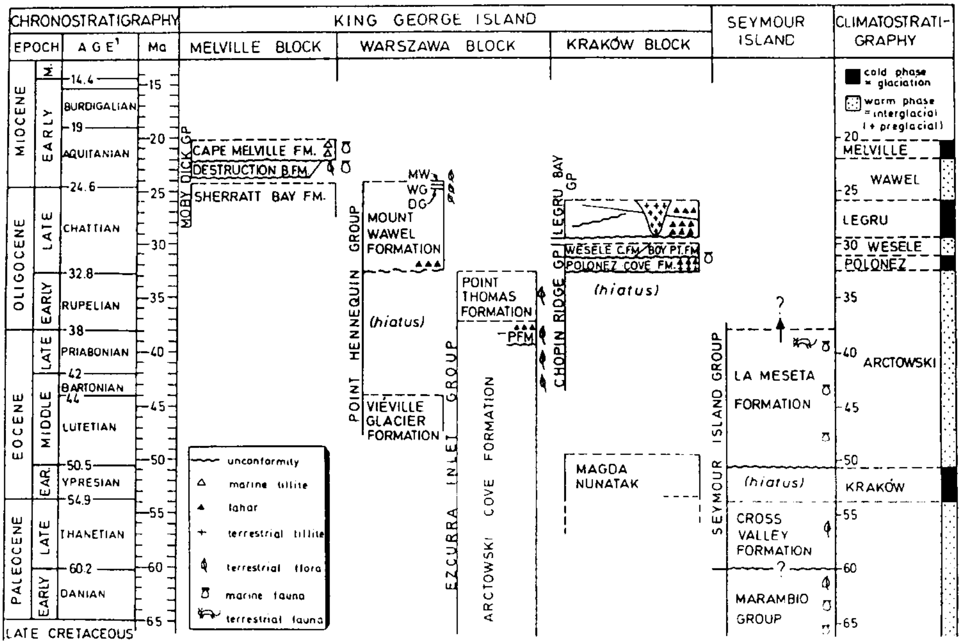

Fig. 4. Stratigraphic position of Tertiary glacial deposits, terrestrial flora and fauna, and marine fauna, in particular tectonic blocks of King George Island (*cf.* Figs 1, 2) and correlation with Seymour Island (after Birkenmajer 1988b). DG — Dragon Glacier plant beds, WG — Wanda Glacier plant beds, MW — Mount Wawel plant beds. Tertiary stratigraphy of Seymour Island after Zinsmeister (1982) and Feldmann and Woodburne (1988).

(4) During the Wesele Interglacial (mid-Oligocene, ca 30 Ma), King George Island and the adjoining part of Bransfield Strait were dry land undergoing dissection by a primitive river system. Scarce fluvial and slope deposits are confined to buried valleys. No fossils have been found in terrestrial strata.

(5) During the Legru Glaciation (Late Oligocene, 30–26 Ma), a thick sequence of subaerial laharic agglomerates alternating with andesitic and basaltic lavas had formed. Glaciers radiating from a local ice-cap on King George Island had deposited bottom tills in narrow buried valleys.

(6) At the beginning of the Wawel Interglacial (Oligocene/Miocene boundary, 26–22 Ma), temperate (cool and warm) rain forests covered slopes of andesitic volcanoes. A shallow-marine incursion occurred at the end of this epoch.

(7) During the Melville Glaciation (Early Miocene, 22–20 Ma), King George Island was at least partly inundated by a marginal sea. Inner to outer shelf/upper slope environments were rich in benthic invertebrate fauna. The marine deposits contain numerous, often large iceberg-rafted clasts, mainly of Antarctic continent provenance, comparable to those found in the Polonez Glaciation.

There is a lack of stratigraphic record on King George Island from the mid-Late Miocene to the Pliocene epochs.

Quaternary glaciation

The studies in Quaternary geology included: (1) mapping of Quaternary (mainly Holocene) moraines and related glacial features, and age determination of glacier retreats and surges, with the use of the lichenometric method (Birkenmajer 1980d, 1994b, 1995c; Birkenmajer *et al.* 1988a); (2) measurements of altitudes and description of raised marine features/beaches formed during the Holocene and pre-Holocene times (Birkenmajer 1981a, b). The lichenometric method was applied in some cases to date the raised marine beaches, but the results were not always convincing (Birkenmajer 1981b). Radiocarbon dating of a subfossil peat resting on a marine-abrasion ledge 45 m a.s.l. cut into an old moraine, gave 4950±140 yrs B.P. This coincided with a major post-Pleistocene retreat of glaciers in Admiralty Bay during mid-Holocene (Birkenmajer *et al.* 1985c).

Volcanological studies

Detailed studies of the two Quaternary volcanoes on King George Island were carried out. Penguin Island — a dormant volcano, was geologically re-mapped, its several rock-units of formation rank were formally described and illustrated. The age of particular formations and volcanic features was determined with the use of lichenometric method: they had formed between the late XVIIth century and 1906 A. D. (Birkenmajer 1980c, 1982e).

The Melville Peak — an extinct volcano, was geologically mapped, its structure and evolution elaborated in considerable detail, new formal lithostratigraphic units were described and illustrated (Birkenmajer 1982b). The age of the oldest lavas was K-Ar-dated at between 296,000±27,000 and 72,000±15,000 years indicating a Pleistocene age of the volcano (Birkenmajer and Keller 1990).

These two volcanoes are located on the continental crustal block of the South Shetland Islands, along the Penguin Line which runs SW-NE subparallel to the Bransfield Rift (Birkenmajer 1992b).

Structural stages of magmatic arc evolution

Structural studies were carried out in Upper Cretaceous through Lower Tertiary lavas, tuffs and minor intrusions. They concentrated on brittle deformation which resulted mainly in strike-slip faults and tension gashes. Three sets of extensional joints and dykes, parallel to the respective orientations of the main principal stresses, correspond to three deformation stages (Tokarski 1981a, 1984, 1987a, c, 1988, 1991): (1) the development of joints and dykes of set I is attributed to the eastward subduction of the ancient Pacific Ocean crust (up to about 23 Ma); (2) the development of set II joints and dykes, reflecting clockwise rotation of the main principal stress up to its recent orientation, is attributed to the main plate reorganization which resulted in cessaction of subduction and opening of the Scotia Sea; (3) the development of the set III joints and dykes was related to the opening of the Bransfield Strait.

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odkrycie czterech zlodowaceń trzeciorzędowych rozdzielonych trzema interglacjałami, reprezentującymi łącznie okres około 30 milionów lat, od wczesnego/środkowego eocenu po wczesny miocen włącznie; (3) odkrycie i opracowanie bogatych zespołów flory i fauny kopalnej wieku od późnej kredy po wczesny miocen włącznie; (4) rekonstrukcję zmieniających się środowisk lądowych i morskich w czasie od późnej kredy po wczesny miocen włącznie, w warunkach mobilnego subdukcyjnego łuku wulkanicznego; (5) określenie wieku i opracowanie ewolucji struktur dwóch czwartorzędowych wulkanów; (6) rekonstrukcję stadiów ewolucji strukturalnej magmowego łuku Szetlandów Południowych i jego załukowego basenu i ryftu Bransfielda.