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Geology of Gerlache Strait, West Antarctica. I. Arctowski Peninsula

ABSTRACT: The rocks exposed along the western coast of Arctowski Peninsula and on offshore islands, Danco Coast (West Antarctica), represent the following lithostratigraphic units: the Trinity Peninsula Group metasediments (?Permian-Triassic); the Antarctic Peninsula Volcanic Group lavas, agglomerates and tuffs (Lower Cretaceous); the Andean Intrusive Suite, including adamellite, granite, granodiorite, diorite, tonalite and gabbro plutons (mid-Cretaceous), moreover basic and acid hypabyssal dykes (?Upper Cretaceous). The relationships between these rock–units are shown in geological map and sketches of field exposures.

Key words: West Antarctica, magmatic arc, Mesozoic.

Introduction

The present paper details geological observations made along the west coast of Arctowski Peninsula, Danco Coast (Antarctic Peninsula), from Orne Harbour in the north to Andvord Bay in the south, and on offshore islands (Figs 1 – 3). The field work was carried out by the present author during the 3rd Polish Geodynamic Expedition to West Antarctica 1987 – 88), organized by the Polish Academy of Sciences and led by Professor A. Guterch (Birkenmajer 1988).

The following rock-units have been distinguished: the Trinity Peninsula Group metasediments, TPG (?Permian-Triasic); the Antarctic Peninsula Volcanic Group, APVG (Lower Cretaceous); the Andean Intrusive Suite, including adamellite, granite, granodiorite, diorite, tonalite and gabbro plutons, AIS-1 (mid-Cretaceous), moreover basic and acid hypabyssal dykes, AIS-2 (?Upper Cretaceous).

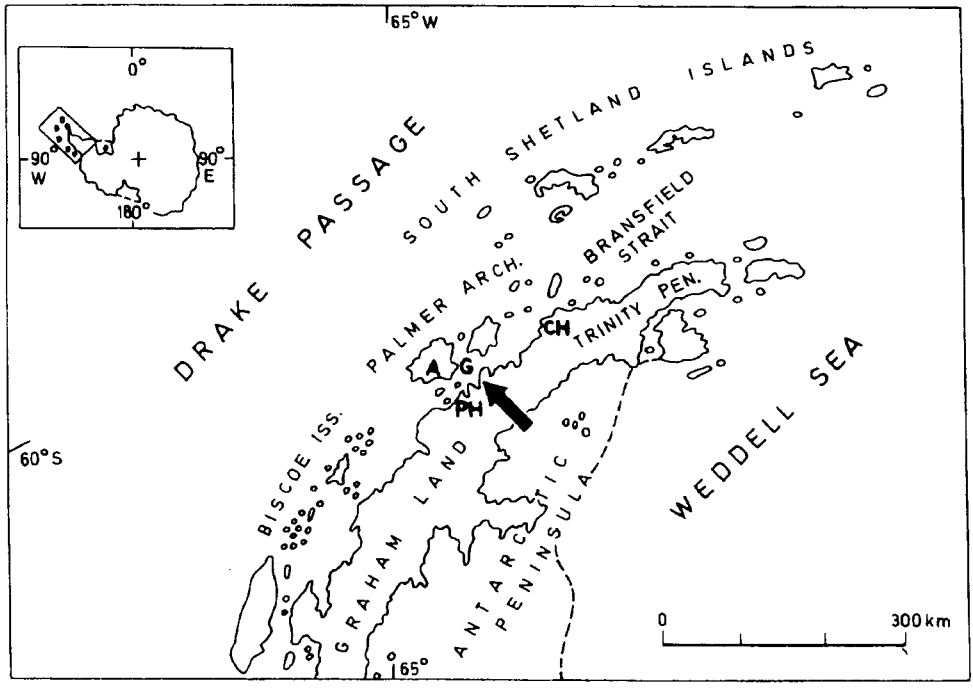


Fig. 1. Location of Arctowski Peninsula (arrowed) in Antarctic Peninsula and in Antarctica (inset). A — Anvers Island, CH — Cape Herschel, G — Gerlache Strait, PH — Paradise Harbour.

Trinity Peninsula Group (TPG)

The metasediments of the Trinity Peninsula Group crop out between Lester Cove and Henryk Cove in inner part of Andvord Bay (*see* West 1974, Fleming and Thomson 1979) — Figs 3, 5. They are difficult to reach and examine due to heavy ice conditions prevailing at Henryk Cove during the Austral Summer, and due to dangerous, steep slopes of the surrouding, highly glaciated mountains. An isolated exposure of the TPG rocks was also studied in the northern part of Danco Coast, at Cape Herschel (Fig. 4).

At Henryk Cove, Andvord Bay (Fig. 3), the TPG rocks are hard, often strongly thermally altered, grey to greenish, fine-grained sandstones in layers 0.5–1 m thick, alternating with similarly coloured shales in layers 2–20 cm thick. The ratio of sandstone to shale is from 10:1 to 20:1. The rocks dip at 55–60° towards the southeast.

The metasediments are crossed by white quartz veins 0.5–1 cm thick, and by two generations of thin dykes (AIS-2): the older melanocratic dykes and the younger leucocratic ones.

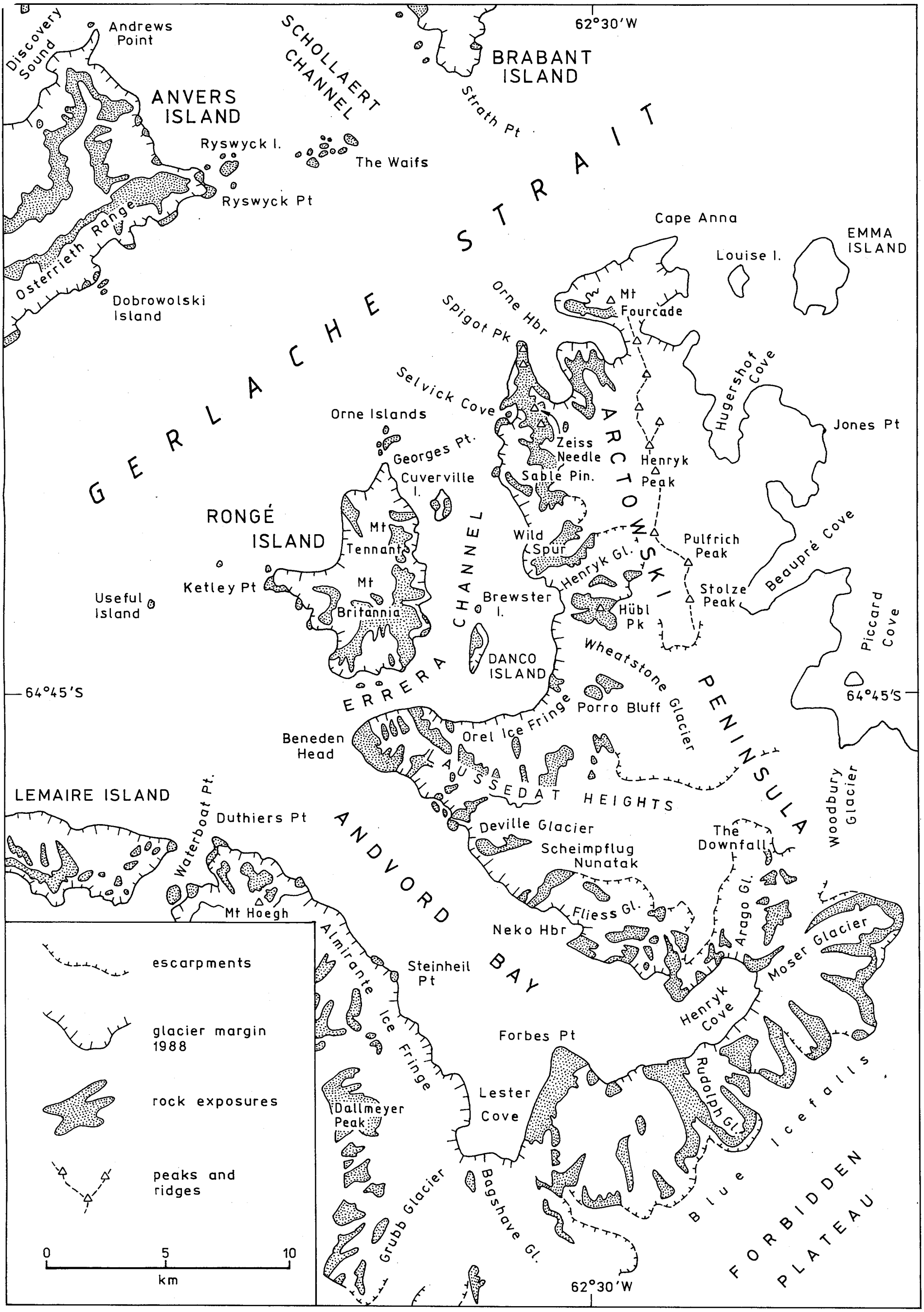


Fig. 2. Topographic features and location of place names on Arctowski Peninsula and its vicinity. Rock exposures shaded; glaciers blank.

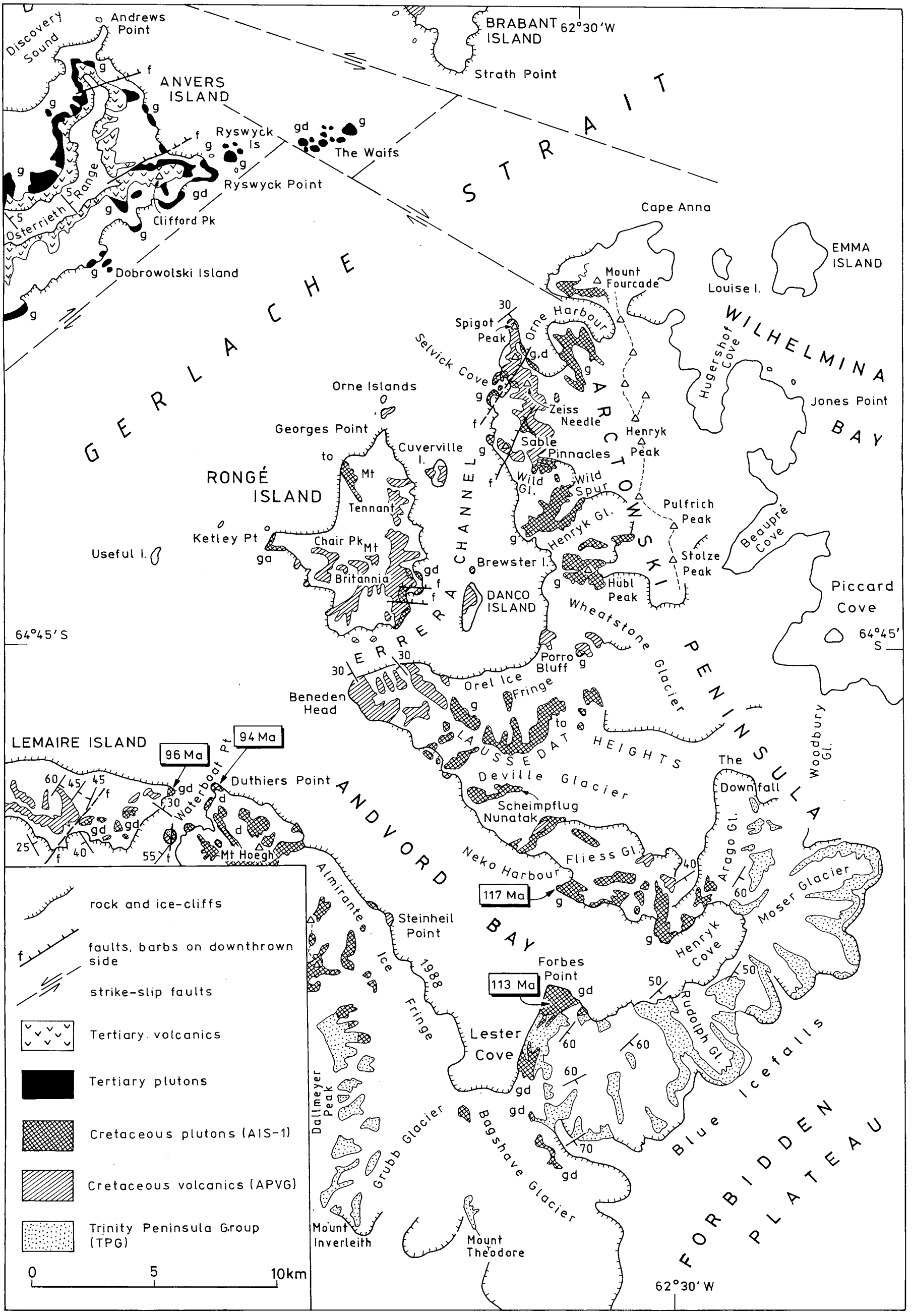


Fig. 3. Geological map of Arctowski Peninsula and its vicinity, as surveyed by the present author during the 1987/88 Austral Summer. Radiometric dates (after Pankhurst 1982 and Parada *et al.* 1992) in boxes. AIS-1 plutons: g — granite, granophyre; ga — gabbro; gd — granodiorite; d — diorite, quartz diorite; to — tonalite.

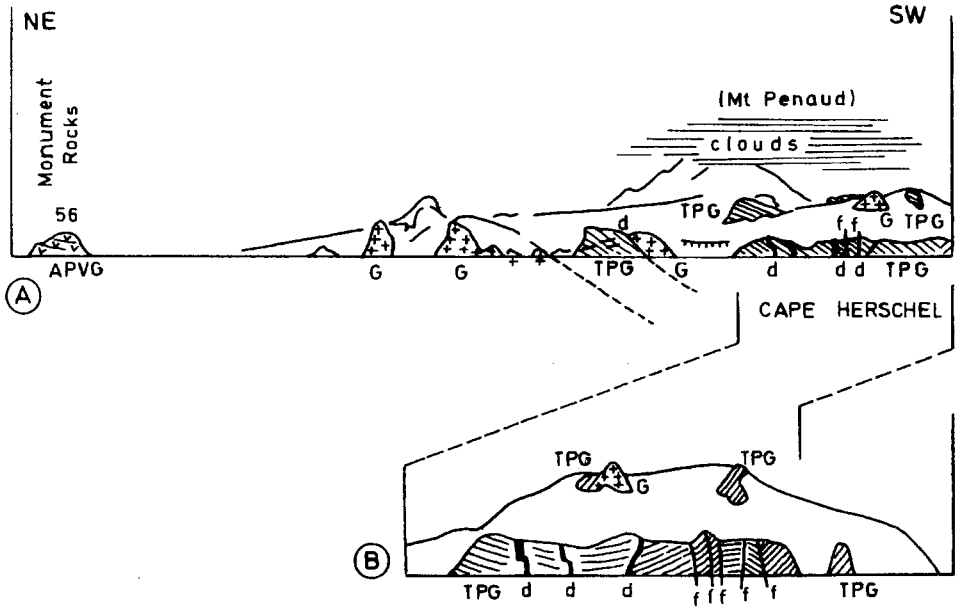


Fig. 4. Geological exposures at Cape Herschel (perspective sketch, Monument Rocks are 56 m high). d — melanocratic dykes (AIS-2); G — granitoid intrusions (AIS-1); APVG — Antarctic Peninsula Volcanic Group; TPG — Trinity Peninsula Group; f — faults.

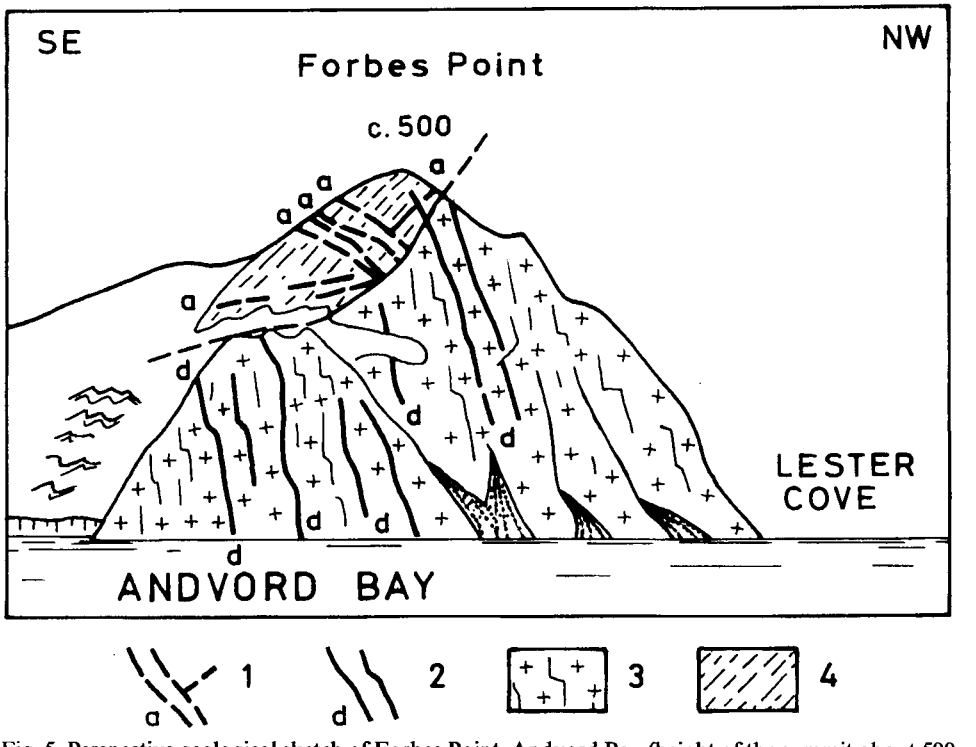


Fig. 5. Perspective geological sketch of Forbes Point, Andvord Bay (height of the summit about 500 m). 1 — leucocratic dykes (granite apophyses from the pluton); 2 — melanocratic dykes (AIS-2); 3 — granodiorite intrusion (AIS-1); 4 — Trinity Peninsula Group.

At Forbes Point (Andvord Bay), between Henryk Cove and Lester Cove (Figs 2, 3), the TPG metasediments become hornfelsic at the contact with a large granodiorite intrusion. Both the granodiorite and the TPG rocks are crossed by two systems of dykes, the older melanocratic dykes, and the younger leucocratic ones (Fig. 5).

At Cape Herschel, north of the *Primavera* Base (Argentine), northern Danco Coast (Fig. 1: CH), the TPG rocks consist of black metasediments (sandstone and shale) arranged in gentle folds (Fig. 4). The metasediments are vertically jointed, displaced by numerous vertical faults, intruded by a granite sill (AIS-1) and by numerous melanocratic dykes (AIS–2).

The TPG metasediments from Andvord Bay and Cape Herschel lithologically correspond to the lower unit of the Paradise Cove Formation (PCF), distinguished as the Almirante Brown Member (ABM). The type localities of both units are at Paradise Harbour, to the west of Andvord Bay (Birkenmajer 1992).

These rocks were included by Alarcón *et al.* (1976) and Hoecker and Amstutz (1987) to the "Bahía Charlotte formación" which is a younger synonym of the Trinity Peninsula Group (TPG). Fleming and Thomson (1979) distinguished the TPG metasediments at Andvord Bay as the "Trinity Peninsula Formation" (previously " Series": Adie, 1964).

Antarctic Peninsula Volcanic Group (APVG)

The TPG rocks form the base of the APVG lavas, as it was established at Paradise Harbour (Birkenmajer 1987, 1988, 1992, 1993, 1994). In the area described in the present paper, the basal basaltic volcanics with pillow lavas and cross-bedded tuffs, known from Paradise Harbour, have not been recognized. The contact of the APVG with the TPG along Arago Glacier, at Henryk Cove, was used by a granite intrusion (AIS-1). Its roof is formed by strongly altered APVG lavas (Fig. 3).

Alarcón *et al.* (1976) attributed the APVG rocks along the west coast of Arctowski Peninsula, and on offshore islands, to the "Canal Lautaro formación" (?Jurassic). Their view was shared by Hoecker and Amstutz (1987). However, this rock-unit is ill-defined from stratigraphic viewpoint, being practically useparable from the "Wiencke Island formación" (Cretaceous) of the same authors (*see* Birkenmajer 1993, p. 20). Therefore, a higher-rank lithostratigraphic name — the Antarctic Peninsula Volcanic Group (name introduced by Gledhill *et al.* 1982; *see also* Fleming and Thomson 1979; Thomson and Pankhurst 1983; Birkenmajer 1993, 1994), is preferred by the present author.

Occurrence

The main exposures of the monotonous effusive pile of the APVG were examined along the western coast of Arctowski Peninsula, from Spigot Peak (at

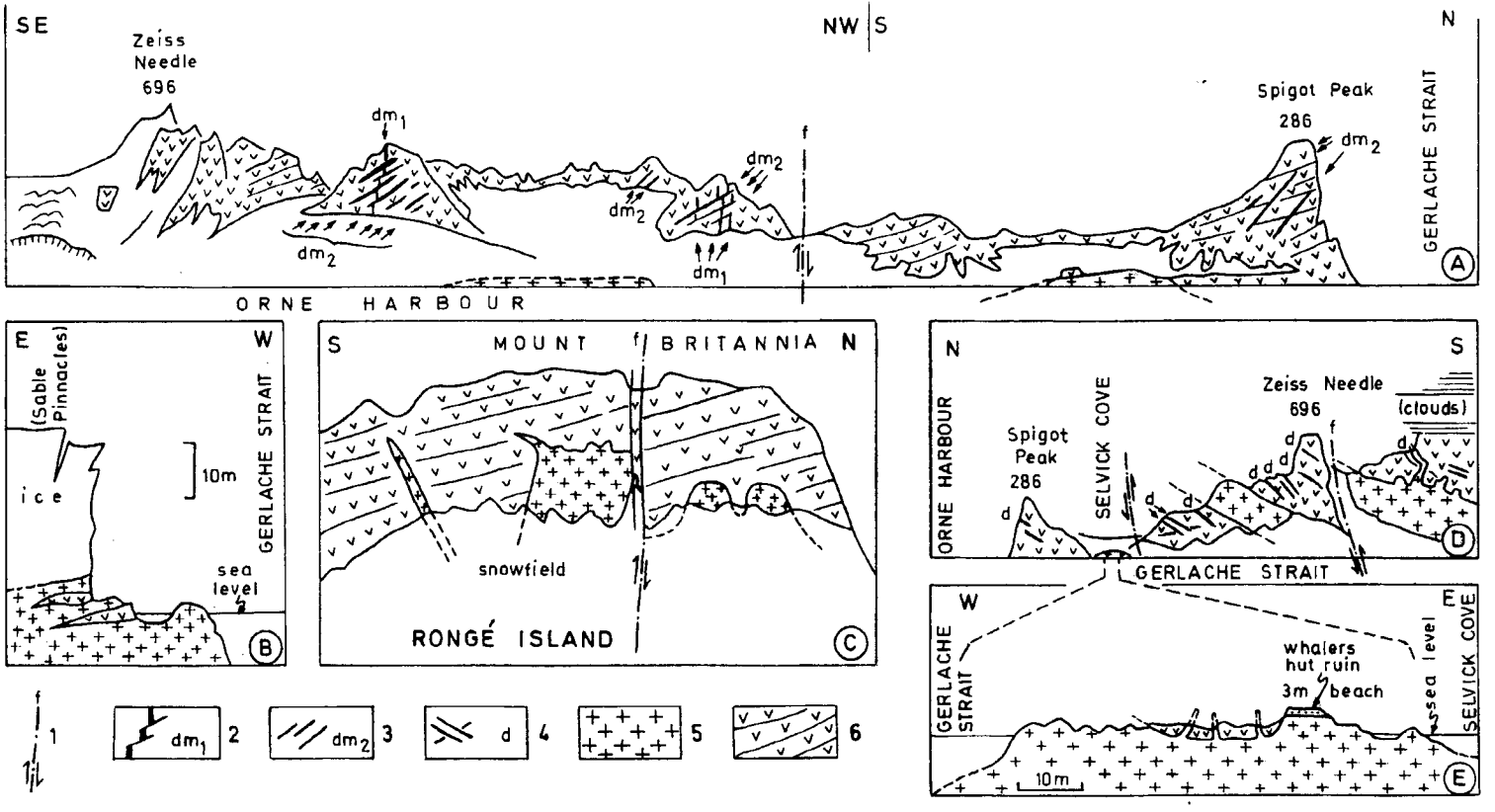


Fig. 6. Perspective sketches of geological exposures along the western coast of Arctowski Peninsula (scale indicated by scale bars or altitudes of peaks). 1 — faults; 2 — first-generation melanocratic dykes (AIS-2); 3 — second generation melanocratic dykes (AIS-2); 4 — melanocratic dykes, not differentiated (AIS-2); 5 — granitoid plutons (AIS-1); 6 — Antarctic Peninsula Volcanic Group (APVG).

Orne Harbour) to Beneden Head. The APVG pile crops out also on Rongé Island, Danco Island, Brewster Island and Cuverville Island (Figs 3, 6). The pile, more than 1000 m thick, consists of altered basalt, basaltic andesite and andesite lavas, with agglomerate and tuff interlayers, and with subordinate rhyolitic–dacitic lava intercalations. Its character is thus analogous to that described from the Paradise Harbour area (*see* Birkenmajer 1987, 1993, 1994).

At Orne Harbour, between Spigot Peak (286 m) and Zeiss Needle (696 m), there occur strongly jointed, hard, often hornfelsic, greenish basic APVG lavas dipping 40° SE. They are intruded by a granite-diorite pluton (AIS-1: Figs 3, 6A), considered by West (1974, fig. 3) to represent stratigraphic substratum of the APVG rocks. Numerous basic and acid dykes (AIS-2) 0.5–2 m thick cut the APVG rocks and the pluton.

At Danco Island, green basic lavas (APVG), alternating with green agglomerates, dip at 10–15° towards the south. They are traversed by two basic porphyritic dykes (AIS-2). The lavas are often strongly limonitized.

Petrography

Petrographic descritption of the APVG lavas by West (1974) includes basalt (at Rongé Island and Orne Islands), andesite (at Danco Island and Rongé Island), and green rhyolite (at Beneden Head). She also gives descriptions of andesite conglomerates (SW Beneden Head), augite-andesite tuff-breccias (southern Danco Island), rhyolite-tuff breccia with clasts of andesite, granite and sandstone (southern Rongé Island), moreover of lithic and lapilli tuffs with andesite and rhyolite clasts (Beneden Head; mainland to the east of Danco Island; Cuverville Island).

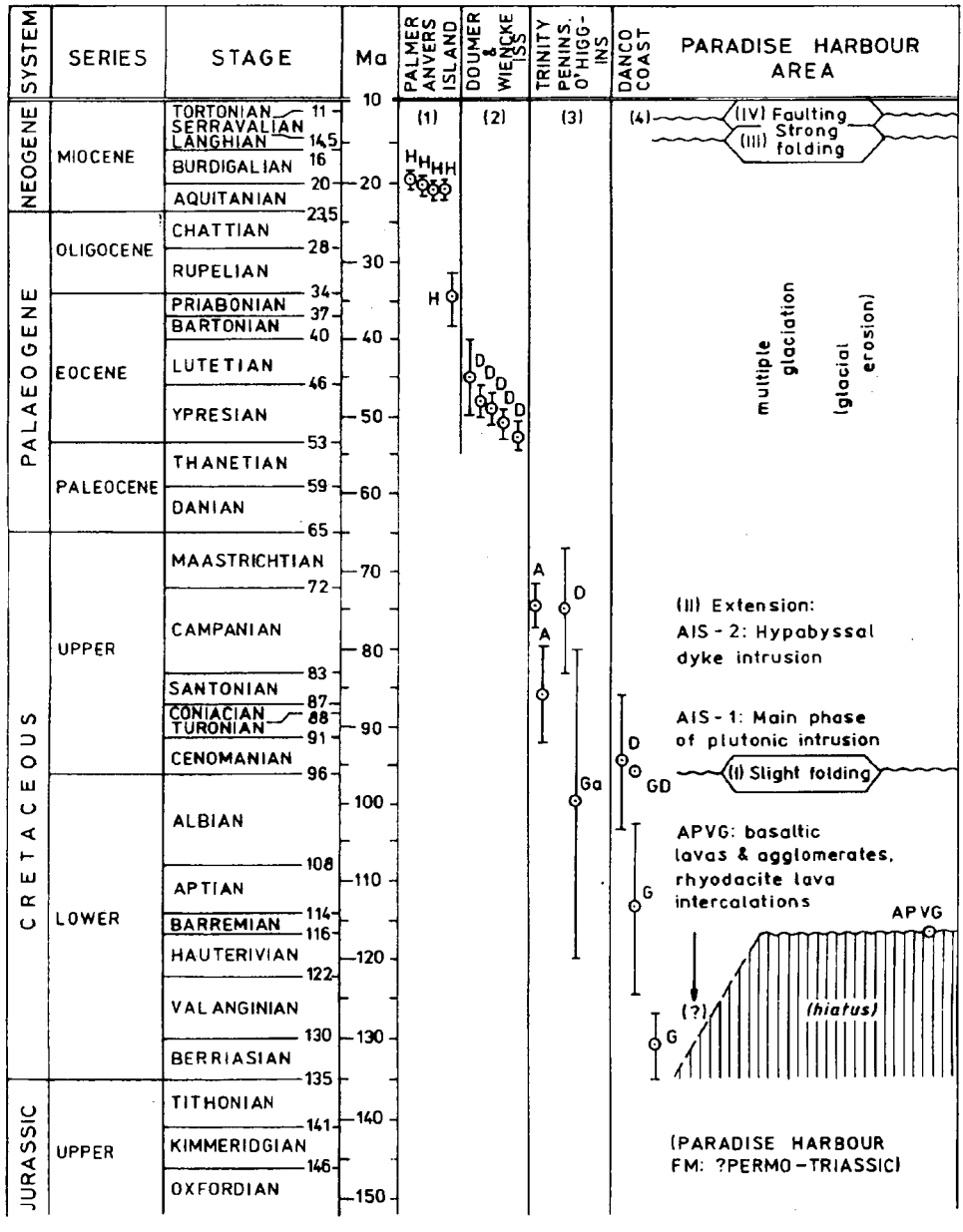
Age

The present author does not share the view expressed by West (1974) that a part of the granitoids represent "pre-volcanic plutonic rocks". The APVG lavas which form roofs of these plutons are baked and hornfelsed by hot magma intrusion, moreover traversed by apophyses issuing from the plutons (*see* below). The APVG effusive pile, as a whole, is older than the AIS-1 plutonic intrusions that penetrate the pile at different stratigraphic levels.

The APVG pile is thus older than the large adamellite-granite pluton which crops out along the south-western coast of Arctowski Peninsula, at Andvord Bay, and between Beneden Head and Henryk Cove. At Neko Harbour (Fig. 3), it yielded an Early Cretaceous Rb–Sr isochron date of 114±11 Ma (Pankhurst 1982). The APVG pile is there most probably of a Lower Cretaceous age. This is also suggested by the K–Ar date of 117 Ma (recalculated by Fleming and

TABLE 1

Succession of magmatic events and tectonic deformations at Paradise Harbour, south of Arctowski Peninsula, Danco Coast (*after* Birkenmajer, 1993, 1994). Chronostratigraphic scale after Odin and Odin (1990). A — andesite; D — quartz diorite; G — granite; Ga — gabbro; GD — granodiorite; H — hybrid pluton (with gabbro and tonalite). Radiometric dates with error limits: 1 — *after* Gledhill *et al.* (1982); 2 — *after* Scott (1965) and Rex (1976); 3 — *after* Halpern (1964); 4 — *after* Scott (1965), Grikurov *et al.* (1970), Fleming and Thomson (1979) and Pankhurst (1982)



Thomson 1979 from the original 120 Ma date of Grikurov *et al.* 1970) obtained from the base of the APVG lavas at Coughtrey Peninsula, Paradise Harbour (*see* discussion in Birkenmajer 1994, and Tab. 1).

Andean Intrusive Suite (AIS-1, 2)

The rocks of the Andean Intrusive Suite (name introduced by Adie 1964) occur as moderate-size to large-size plutons (AIS-1) of acid, intermediate and basic petrologic character (West 1974, Fleming and Thomson 1979). Their geological form corresponds to: subhorizontal sills (with bottom and top contacts exposed), often with apophyses issuing from their tops; stocks, with lateral and top apophyses; and batholiths, with top apophyses.

The second group is represented by smaller-size basic and acid hypabyssal dykes (AIS-2), postdating both the APVG rocks and the AIS-1 plutons.

Plutonic intrusions (AIS-1)

Plutonic intrusions, represented by adamellite, granite, granodiorite, diorite and tonalite, locally also gabbro (West 1974, Fleming and Thomson 1979), crop out over large areas of Arctowski Penisula, moreover to the south of Andvord Bay, and at Rongé Island (Figs 3, 5, 6). The roofs of the acid to intermediate plutons, formed by altered APVG lavas, are often penetrated by microgranite apophyses/dykes which issue from the plutonic bodies. Such roofs are recognizable in the southern part of Arctowski Penisula between Henryk Cove and Neko Harbour (Fig. 3), at Rongé Island (Figs 3, 6C), and in the northwestern part of Arctowski Peninsula from Sable Pinnacles to Orne Harbour (Figs 3, 6A, C, E).

At Zeiss Needle (696 m), a granophyre granite (West 1974) sill 100–150 m thick intrudes the APVG lava pile (Fig. 6D). This sill seems to be an offshot of a large adamellite-granite pluton (batholith) which occupies the middle part of Arctowski Penisula between Wild Spur and Wheatstone Glacier (Fig. 3). The base of the large pluton is not exposed.

At Orne Harbour, southeast of Spigot Peak (Fig. 6A), the top part of another pluton is exposed. Its inner part is formed by grey, medium-grained diorite traversed by thin, pink microgranite apophyses. The diorite passes laterally and upward into medium-grained granite which contains numerous xenoliths of grey diorite. The top contact of the pluton with the APVG lava roof is almost horizontal, the blocks of the APVG lavas are "floating" in pink granite. Both the diorite and granite are intruded by dark–green to black melanocratic dykes (AIS–2) about 1 m thick.

This pluton was considered by West (1974, fig. 3) to be older than the APVG tuffs and lavas. The present author's observations did not confirm her view: it is

well visible that the diorite-granite magma had intruded the already existing APVG complex

At Selvick Cove, south of Spigot Point (Fig. 3), the top contact of the same pluton crops out near ruins of an old whaling hut (Whalers Point — Fig. 6E). The roof of the red granite pluton is formed by black to green APVG lavas cut by thin apophyses of pink to red granite.

Below Sable Pinnacles, at sea level, the upper part of grey, medium-grained granophyric granite pluton (West 1974) contains lenticular xenoliths of green, altered APVG lavas (Fig. 6B).

At Mount Britannia, Rongé Island (opposite Danco Island), uneven roof of a granophyric granodiorite pluton (West 1974) is formed by altered APVG lavas. Some apophyses issuing from the pluton penetrate the lavas (Fig. 6C). Tonalite and gabbro intrusions were reported by West (1974) and Fleming and Thomson (1979) from the northern and western parts of Rongé Island, respectively.

Age of plutonic intrusions (AIS-1)

At Neko Harbour (Fig. 3), red to pink granite pluton (considered by West 1974 to predate the APVG lavas), yielded a Rb–Sr isochron date of 114 ± 11 Ma (Pankhurst 1982). The roof of the pluton is formed by the APVG lavas thermally altered by the granite magma. The pluton is intruded by basic dykes (AIS-2) 10 cm to 5 m thick.

At Forbes Point, Andvord Bay, the roof of a large granodiorite pluton (Fig. 5), likewise considered by West (1974) to be older than the APVG rocks, is formed by hornfelsic metasediments of the TPG. The metasediments are densely intruded by leucocratic, probably microgranitic (*cf.* West 1974), apophyses issuing from the pluton. The granodiorite pluton was K–Ar dated on biotite at 113 ± 3 Ma (Parada *et al.* 1992). It is penetrated by a dense swarm of subvertical melanocratic dykes that do also penetrate into the TPG roof.

In the inner part of Lester Cove, Andvord Bay (Fig. 3), subhorizontal apophyses issuing from a granodiorite stock, intrude finger-like the same TPG metasediments.

Hypabyssal dykes (AIS-2)

Two generations of hapabyssal melanocratic (basic) dykes, and one generation of leucocratic (acid) dykes have been distinguished in the area under study. They postdate both the APVG rocks and the AIS-1 plutons.

At Orne Harbour, between Spigot Point and Zeiss Needle (Figs 3, 6A), the older melanocratic dykes (dm_1) cut nearly vertically the APVG rocks; the

younger melanocratic dykes (dm_2) dip at angles 30–40° SW, traversing and displacing the older ones.

At sea level at Orne Harbour, the first generation basic dyke (dm_1), 2 m thick, cuts the APVG lavas, and dips 85° N. It is traversed by a leucocratic dyke 0.5 m thick dipping 75° NW. The second-generation basic dyke (dm_2), 2 m thick, dipping 85° ENE, cuts the APVG lavas and the APVG/AIS-1 (granite) contact nearby.

At Neko Harbour, Andvord Bay, the first-generation basic dykes (dm_1), 10 cm to 5 m thick, dipping 75–80° NE, cut red granite dated at 114 Ma (*see* above). Both the granite and the older basic dykes are traversed by a second-generation basic dyke (dm_2), 2 m thick, dipping 55° N.

At Henryk Cove, Andvord Bay, the TPG rocks are traversed by thin melanocratic dykes (older), and those by thin leucocratic dykes (younger).

At Forbes Point, leucocratic (microgranite — West 1974) dykes cut the granodiorite and penetrate as apophyses (dykes) its roof formed by altered TPG rocks. The granodiorite pluton is, moreover, cut by dense swarm of subvertical melanocratic dykes. Some of these are traversed by the leucocratic ones (Fig. 5).

Petrography and succession of hypabyssal dykes

West (1974, pp. 49–53) distinguished six groups of hypabyssal dykes, on the basis of the petrographical, chemical and field evidence:

(1) *Early microgranite dykes,* pale-green, often well-banded, were found to intrude the granodiorite (Forbes Point), adamellite and granite bodies (from Neko Harbour to Henryk Cove). At the latter sites, they show indistinct contact against to host granite. This possibly implies that the microgranites were intruded before the host rocks had completely crystallized.

At Neko Harbour, these dykes were found to be the oldest of several dyke phases (*i.e.* older than the dm_1 and dm_2 basic dykes of the present author — *see* above);

(2) *Early altered basic to intermediate dykes,* were found to be numerous, petrographically resembling the volcanic rocks (APVG of the present paper) which they often intrude. West argued that some of them were demonstrably older than the plutons, and metamorphosed by the "nearby extrusive granophyres". According to her, at Sable Pinnacles, the easterly dipping leucocratic hypabyssal rocks are "truncated by similar granophyre bodies";

(3) *Microgabbro dykes* were identified by West (1974) at southern Rongé Island where they were cutting sheared granite. Trough their coarse-grained texture, they resembled gabbros that occur at the western coast of this island;

(4) *Microgranite dykes.* This group of dykes was considered by West (1974) to be hypabyssal equivalents of granophyre-granite bodies that postdated the stratiform volcanic pile (=APVG). The dykes typically intruded the lava complex, moreover the granite and granodiorite bodies;

(5) *Altered basic to intermediate dykes,* were found to be younger than the "post-volcanic" (=post-APVG) microgranites, granophyres and tonalites (=AIS-1). Altered character of the dykes could imply that the "dyke emplacement occurred whilst the plutonic rocks were still hot";

(6) *Late microgabbro and microdiorite dykes,* intruded the "post-volcanic" (=post-APVG) plutonic roks (=AIS-1).

The above succession of the dykes is still insufficiently documented by geological field evidence. It seems that the first, third and fourth groups of the dykes are mainly intra-plutonic dykes, and extra-plutonic apophyses, directly related to the stages of intrusion and cooling of the Early Cretaceous AIS-1 plutons.

The second group of the dykes could be directly associated with the APVG phase of vulcanicity. Similar dykes, clearly predating the AIS-1 plutons, have also been found in the Paradise Harbour area (Birkenmajer 1994).

The fifth and sixth groups of dykes could correlate with the dm_1 and dm_2 melanocratic (basic) hypabyssal dykes, as distinguished in the present paper. A new phase of leucocratic (acid) dyke intrusion, between the dm_1 and dm_2 ones, recognised at Orne Harbour and Henryk Cove (*see* above), shows that the dyke succession is even more complicated than it was believed by West (1974).

Age of hypabyssal dykes (AIS-2)

No radiometric dates are so far available from the dykes of Arctowski Penisula and its vicinity. The dykes (AIS-2), both basic and acidic, are younger than the plutons of the Neko Harbour granite (dated at 117 Ma±11 Ma: Pankhurst 1982) and the Forbes Point granodiorite (dated at 113±3 Ma: Parada *et al.* 1992). By comparsion with the Paradise Harbour area (Birkenmajer 1993, 1994), the hypabyssal dykes might be of Upper Cretaceous age (*see* Tab. 1).

Tectonics

General remarks

The geological structure of Arctowski Peninsula and offshore islands is dominated by large plutons (AIS-1) intruded into the monotonous APVG effusive pile. The plutons are largely undeformed but locally they are faulted. The deformations in the APVG effusive pile are expressed as gentle, large-scale folds, and as gravity faults. The folding may be partly a result of compression generated during the Late Cretaceous in the Antarctic continental crust slab overriding the SE Pacific subduction zone (*cf.* Birkenmajer 1994). Locally, it

may be a result of updoming of the APVG complex by plutonic intrusions, during Early Cretaceous.

The geometric pattern of the hypabyssal dykes (AIS-2) has not been studied in detail due to restricted time available during field work. The investigations carried out further south, at Paradise Harbour (Birkenmajer 1993, 1994), indicate that this is a promising field of structural studies. At Paradise Harbour, extension caused by up-doming of the whole magmatic arc of Antarctic Peninsula produced a characteristic fracture pattern that was followed by hypabyssal dyke intrusion (AIS-2), probably during Late Cretaceous.

The TPG metasediments pose another tectonic problem. They were strongly folded and faulted already prior to the effusive phase of the APVG, probably close to the Triassic/Jurassic boundary. Strong folding and SE-vergent thrust faulting occurred at that time at Paradise Harbour (Birkenmajer 1992). Originally, the APVG/TPG contact was an angular unconformity (Birkenmajer 1987, 1992, 1993, 1994). At Henryk Cove, it is obliterated by the Early Cretaceous granitic intrusion (AIS-1).

Folding

The TPG rocks in the inner part of Andvord Bay, at Henryk Cove and Lester Cove, monoclinally dip southeast at 55–70° The APVG lavas, which form roof of the granite intrusion at Henryk Cove, between Arago Glacier and Fliess Glacier, dip 40° in the same direction. Elsewhere on Arctowski Peninsula, and on its offshore islands, the APVG lavas dip at 30° towards southwest (Beneden Head — Fig. 3), south (Rongé Island — Fig. 6C), or southeast (Orne Harbour — Fig. 6A). Locally (*e.g.*, at Orne Harbour), they lie nearly flat.

The lower dips might be an expression of original tilting of lava flows, the higher ones might partly result from up-doming by plutonic intrusion, but mainly they are associated with large-scale folding; locally, they are associated with faults.

Faulting

Faults are poorly recognizable in the area discussed in the present paper.

At Rongé Island, small gravity faults downthrow to the north the granite pluton and its APVG roof (Figs 3, 6C).

Between Spigot Point and Sable Pinnacles (Figs 3, 6D), several faults downthrow towards the west the APVG pile and the granitic-dioritic pluton. In this area, the melanocratic dykes of the first generation (Fig 6A: dm_1) seem to follow the SW–NE fracture pattern. They are often traversed by melanocratic dykes of the second generation (Fig. 6A: dm_2) which used fractures dipping

30–40° SE, that dissect both the APVG lavas and the first-generation dykes. The age of these faults should not be older than that of the second generation melanocratic dykes, probably corresponding to the Late Cretaceous extension (*cf.* Birkenmajer 1994).

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Streszczenie

W zachodniej części Półwyspu Arctowskiego (Ziemia Danco, Antarktyda Zachodnia) oraz na sąsiednich wyspach wyróżniono następujące jednostki litostratygraficzne: (1) metasedymenty grupy Trinity Peninsula (?permo-trias); (2) bazaltowe i andezytowe lawy, aglomeraty i tufy należące do grupy wulkanicznej Półwyspu Antarktycznego (dolna kreda); (3) intruzje plutoniczne (adamellit, granit, granodioryt, dioryt, tonalit, gabbro) starszej części grupy intruzji andyjskich (środkowa część kredy); (4) zasadowe i kwaśne dajki hypabyssalne młodszej części grupy intruzji andyjskich (górna kreda?). Mapa geologiczna i szkice odsłonięć obrazują wzajemne stosunki tych grup skalnych.