KRZYSZTOF BIRKENMAJER

OLIGOCENE-MIOCENE GLACIO-MARINE SEQUENCES OF KING GEORGE ISLAND (SOUTH SHETLAND ISLANDS), ANTARCTICA

(Plates 1—4)

BIRKENMAJER, K.: Oligocene-Miocene glacio-marine sequences of King George Island (South Shetland Islands), Antarctica. Palaeontologia Polonica, 49, 9—36, 1987.

King George Island (South Shetland Islands, West Antarctica) provides geological evidence for three Tertiary glaciations, post-dating Late Oligocene plant-bearing beds (Point Hennequin Group) intercalated in andesite lavas K-Ar-dated at about 24.5 Ma. The onset of continental glaciation (ice-sheet at sea level) in King George Island area was close to the Oligocene-Miocene boundary. There are two separate glacigenic successions, the Polonez Cove Formation (Chopin Ridge Group), and the Cape Melville Formation (Moby Dick Group) which contain material of Antarctic continent provenance, and a third one (Legru Bay Group) with locally derived tillites.

The Polonez Cove Formation includes lodgement till at the base followed by glacio-marine strata with numerous iceberg-rafted debris, rich in invertebrate fauna of the *Chlamys anderssoni* association. By comparison with the „*Pecten* Conglomerate" of Cockburn Island, NE Antarctic Peninsula, this fauna has been attributed to the Pliocene. The glacial event, termed the Polonez Glaciation, is considered to be the largest Cenozoic glaciation in West Antarctica. K-Ar dating of acidic lavas overlying glacio-marine strata yielded dates of more than 22.4 Ma and more than 23.6 Ma. Thus the Polonez Glaciation and its deposits pre-date the Oligocene-Miocene boundary. The geological age of this glaciation which post-dates the youngest non-glacial climate plant-beds of late Oligocene age, 24.5 Ma, appears thus to be latest Oligocene.

In the Moby Dick Group, shallow-marine deposits (Destruction Bay Formation) with pieces of carbonized wood (driftwood?), brachiopods of Early Miocene character, and recycled Cretaceous fossils, are followed by fossiliferous glacio-marine strata (Cape Melville Formation). These are crowded with ice-rafted debris, an evidence for the Melville Glaciation. A greater part of the fauna is Tertiary, there is moreover a considerable share of recycled Cretaceous fossils. Andesite dykes which cut through these strata yielded K-Ar ages of about 20 Ma. This, together with palaeontological dating of the underlying Destruction Bay Formation (Lower Miocene), indicates an Early Miocene age of the Melville Glaciation.

Key words: Late Oligocene, Early Miocene, glacio-marine deposits, palaeontological record, radiometric dating, Polonez Glaciation, Melville Glaciation, South Shetland Islands, West Antarctica.

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OLIGOCEŃSKO-MIOCEŃSKIE OSADOWE SUKCESJE LODOWCOWO-MORSKIE WYSPY KRÓLA JERZEGO (SZETLANDY POŁUDNIOWE), ANTARKTYKA

Streszczenie. — Obszar Wyspy Króla Jerzego w Szetlandach Południowych (Antarktyka Zachodnia) dostarczył dowodów geologicznych na trzy zlodowacenia trzeciorzędowe, młodsze od floronośnych osadów (grupa Point Hennequin) tworzących wkładki w kompleksie law andezytowych datowanych radiometrycznie na około 24,5 mln. lat. Początek kontynentalnego zlodowacenia w tym rejonie Antarktyki przypada blisko granicy oligocenu i miocenu. Wyróżnia się dwie niezależne sekwencje glacigeniczne, formację Polonez Cove (grupa Chopin Ridge) i formację Cape Melville (grupa Moby Dick), zawierające materiał okruchowy pochodzący z kontynentu antarktycznego i trzecią sekwencję (grupa Legru Bay) z tillitami lądowymi zawierającymi materiał lokalny.

Formacja Polonez Cove zaczyna się tillitami kontynentalnymi, nad którymi pojawiają się osady lodowcowo-morskie z licznymi okruchami skalnymi przyniesionymi przez dryfujące góry lodowe. Osady te obfitują w szczątki zwierząt bezkręgowych, zwłaszcza asocjacji z *Chlamys anderssoni*. Przez porównanie z tzw. „zlepieńcem pektenowym" Wyspy Cockburn, fauna ta została uznana za plioceńską. Zlodowacenie Polonez było największym kenozoicznym zlodowaceniem Antarktyki Zachodniej. Datowanie radiometryczne metodą potasowo-argonową kwaśnych law, spoczywających bezpośrednio nad osadami lodowcowo-morskimi formacji Polonez Cove, dało wiek tych law jako ponad 22,4 mln. i 23,6 mln. lat. Stąd też zlodowacenie Polonez i jego osady są starsze od granicy oligocen-miocen. Ponieważ omawiana epoka glacjalna nastąpiła po nie-glacjalnym okresie górnego oligocenu, w którym utworzyły się andezytowe lawy z wkładkami floronośnymi, datowane na 24,5 mln. lat, wiek zlodowacenia Polonez i jego osadów odpowiada najwyższemu oligocenowi.

W grupie Moby Dick nad płytkowodnymi morskimi osadami z kawałkami zwęglonego drewna, dolnomioceńskimi ramienionogami i redeponowanymi skamieniałościami kredowymi, (formacja Destruction Bay), spoczywają osady lodowcowo-morskie z bogatą fauną bezkręgowców (formacja Cape Melville), z dużą ilością materiału antarktycznego przyniesionego przez dryfujące góry lodowe (świadectwo zlodowacenia Melville). Znaczna część fauny kopalnej jest wieku trzeciorzędowego, część jest redeponowaną fauną kredową. Dajki andezytowe przecinające omawiane osady zostały datowane metodą potasowo-argonową na około 20 mln. lat. Ta data, wraz z paleontologicznym datowaniem niżej leżących osadów morskich (formacji Destruction Bay) wskazuje, że formacja Cape Melville i zlodowacenie Melville są wieku dolnomioceńskiego.

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BREAK-UP OF GONDWANALAND AND CENOZOIC ANTARCTIC GLACIATION

Palaeomagnetic evidence indicates that Antarctica, being part of the southern hemisphere supercontinent, Gondwanaland, occupied a high latitude polar or near-polar position since Late Palaeozoic (FRAKES 1979). The break-up of Gondwanaland commenced close to the Jurassic-Cretaceous boundary, some 135 Ma ago, and continued through the Cretaceous to final separation during Early Tertiary. The separation of Australia from Antarctica began in late Paleocene (CROOK 1981) or early Eocene (WEISSEL *et al.* 1977; KEMP 1981), and of South America from Antarctica in late Oligocene, by initial opening of the Drake Passage at about 29 Ma (KENNETT *et al.* 1975; BARKER and BURRELL 1977).

There is no indication of ice-cap formation on continental scale in Antarctica during Late Cretaceous. Lahar-type agglomerates recognized in the Late Cretaceous volcanic-sedimentary sequence of King George Island, South Shetland Islands (Birkenmajer 1985) may indicate the presence of local glaciation restricted to the highest volcanoes and mountain groups.

The separation of Antarctica from other southern hemisphere continents was a primary cause for cooling of its climate and appearance of continental ice-sheet. This cooling proceeded along with formation of Circum-Antarctic Current once the Drake Passage has been fully opened at about 25—22 Ma, and oceanic depths were achieved (Barker and Burrell 1977; Kennett 1977, 1980).

ANTARCTIC GLACIATION IN THE MARINE SEDIMENTARY RECORD

Quartz sand and silt grains interpreted as ice-rafted material of Antarctic origin, appear in deep-sea cores of the south-east Pacific beginning in Early Eocene (Margolis and Kennett 1970, 1971). Still there is no direct proof that they were ice-rafted, and other mechanisms may be evoked, such as plant-rafting, submarine currents, and wind transportation. Even in the case of ice-rafting, such fine quartz material may not necessarily be considered an evidence of glaciation in Antarctica, as coastal winter ice may pick and redistribute littoral sediment over large areas (see Spjeldnaes 1981).

Variation in quantity of presumably ice-rafted Antarctic debris from deep-sea cores around Antarctica, has provided some of the primary data for palaeoclimatic reconstructions of the area. Anderson *et al.* (1980) cautioned against using this kind of data as sole indicator of palaeoclimates, and report that sediment-laden icebergs are scarce in Antarctic waters today, most icebergs being barren of debris. The iceberg-related glacio-marine sedimentation is best evidenced by glacially striated and polished dropstones, often of considerable large dimensions (up to 2 m across), randomly distributed in the sediment (Birkenmajer, 1980*b*, 1982*a*, *b*, 1984).

EVIDENCES OF NON-GLACIAL CLIMATE TERRESTRIAL PLANT-BEARING DEPOSITION DURING PALEOCENE THROUGH LATE OLIGOCENE, ANTARCTIC PENINSULA SECTOR

The best information on Palaeogene palaeoclimatic conditions in the northern part of the Antarctic Peninsula sector, about 62—64 S (fig. 1) comes from fossil land-plant assemblages of terrestrial strata. Two areas of this sector deserve special attention: King George Island (South Shetland Islands), and Seymour Island (Antarctic Peninsula, NE part). A detailed account of these floras, their mode of occurrence and palaeoclimatic significance, has been presented elsewhere (Birkenmajer 1985). Below is a short summary of data bearing on dating the onset of continental glaciation in the Antarctic Peninsula sector.

King George Island

In King George Island, land-plant remains occur at numerous levels throughout a 2500 m thick stratiform pile of predominantly andesitic and basaltic lavas alternating with tuffs, breccias with lesser amounts of water-laid tuffites, shales and conglomerates (Barton 1961, 1964, 1965; Adie 1964*a*; Birkenmajer 1980*a*, 1985). These were distinguished as the King George Island Supergroup by Birkenmajer (*op. cit.*). As shown by radiometric dating (Birkenmajer *et al.* 1983*c*) the supergroup represents Late Cretaceous through Late Oligocene time span.

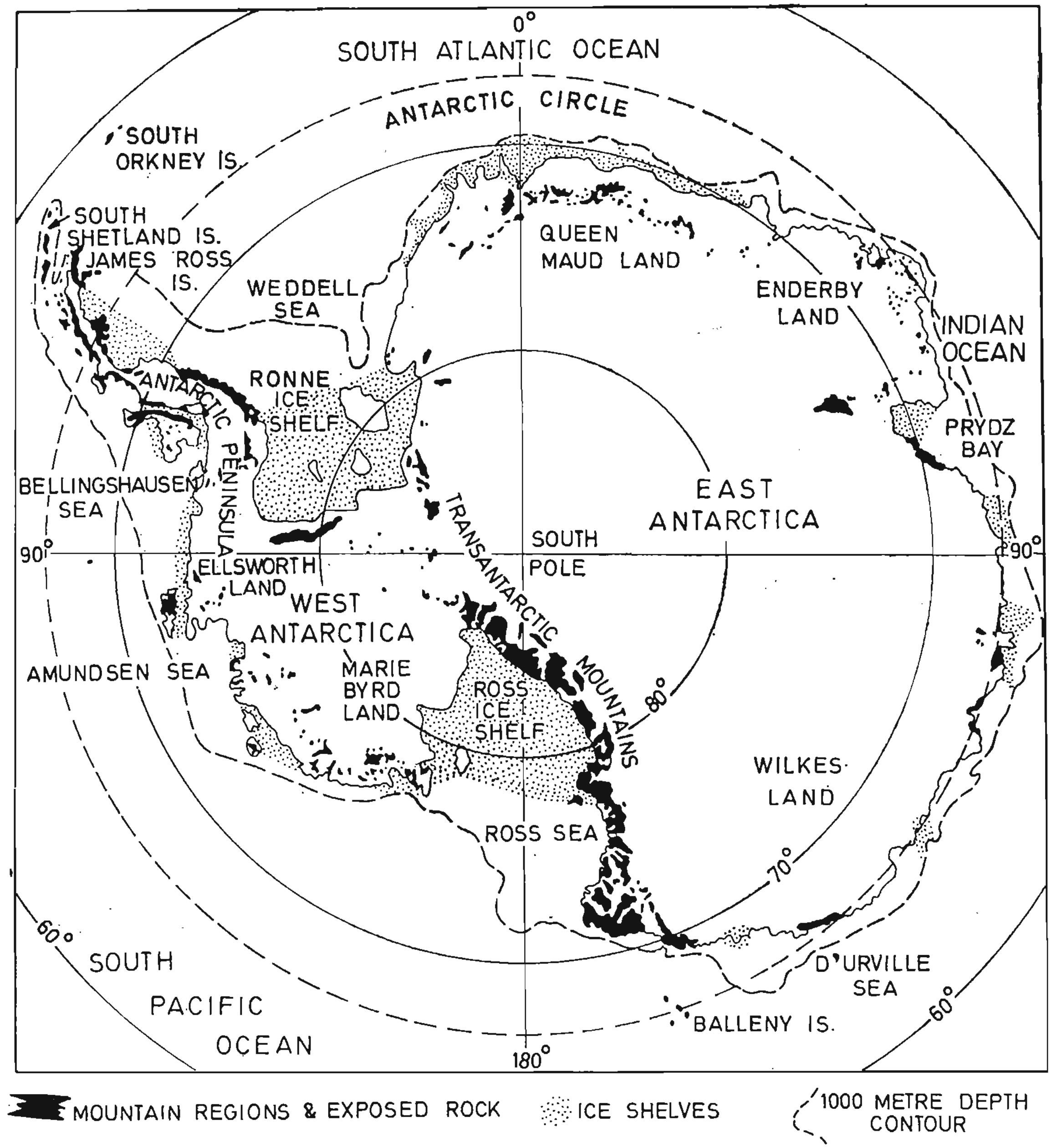


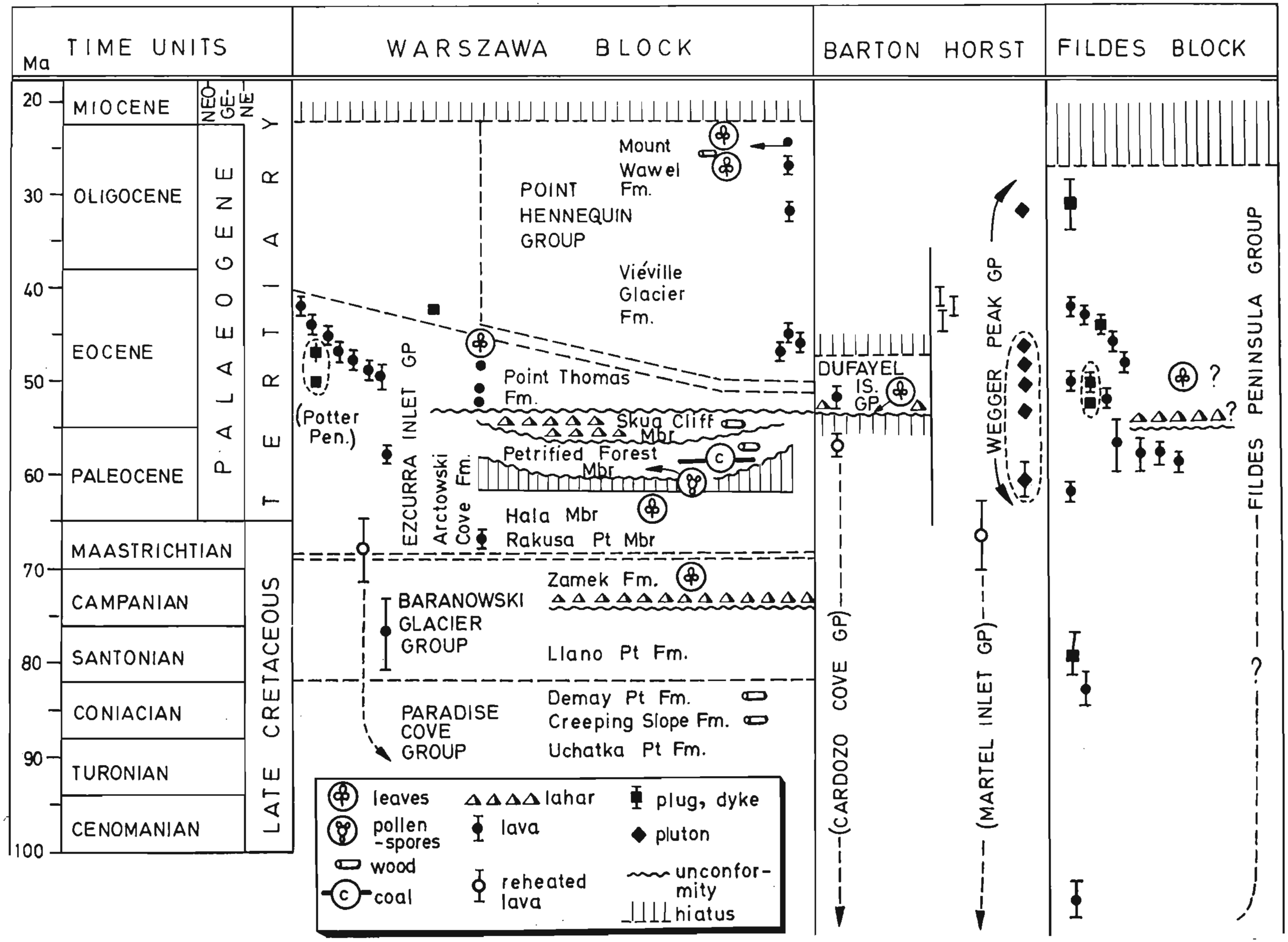
Fig. 1
Key map to Antarctica.

The position of fossil plant horizons within the King George Island Supergroup is shown in Table 1. The Palaeogene floras bearing on palaeoclimatic considerations regarding the onset of Cenozoic glaciation of the area, are known best from the Ezcurra Inlet and the Point Hennequin groups.

Ezcurra Inlet Group. The Ezcurra Inlet Group includes two formations. The lower Arctowski Cove Formation consists mainly of basaltic andesite lava flows, massive and thick in the lower part (Rakusa Point Member), and thinner, often scoriaceous flows with thin conglomerate and tuff-shale intercalations higher up (Hala Member). The basal lavas (Rakusa Point Mbr) represent a latest Cretaceous or Cretaceous/Palaeogene boundary volcanic event dated at 66.7±1.5 Ma (BIRKENMAJER *et al.* 1983c). The succeeding Hala Member lavas and sediments

Table 1

Stratigraphic position of fossil floras and lahars in the King George Island Supergroup at King George Island. Radiometric data from WATTS (1982), BIRKENMAJER *et al.* (1983*b*, *c*) and PANKHURST and SMELLIE (1983)



may thus be Paleocene in age. Fragments of petrified wood have been found in thin, well-rounded conglomerate intercalations in the lower part of this member.

The succeeding Petrified Forest Member (30—50 m thick) consists of fresh-water sediments infilling an erosional depression cut into underlying lavas. The succession of sediments (from bottom to top) consists of: clay-shale and tuff-sandstone; clay (with pollen-spore assemblages) containing a horizon of petrified wood fragments, some with annual growth-rings; an allochthonous charcoal-type coal layer; tuff-flake conglomerate with petrified wood fragments (with annual rings); top clay-shale.

The sporomorph spectrum from the lower part of the Petrified Forest Member includes 36 types of pollen and spores and represents a *Nothofagus*-Pteridophyta assemblage (STUCHLIK 1981). It suggests the presence of *Nothofagus* forests with well developed undergrowth in which ferns (also tree ferns) played the most important role. Rhamnaceae were also present. The abundance of pteridophyte spores and their high frequencies of occurrence indicate moist and warm climate conditions, comparable to those of the present frost-free Auckland Province lowlands (*op. cit.*).

The K-Ar dating of the Ezcurra Inlet Group lavas and associated plugs, suggests a Paleocene or Paleocene/Eocene boundary ages for the discussed flora (BIRKENMAJER 1985) — Table 1.

Petrified wood fragments which occur at two levels within the tuff-flake conglomerate of the Petrified Forest Member deserve special attention. They are represented by the genus *Araucaria* and a form intermediate between *Fagus* and *Nothofagus*, showing dense annual growth-rings (CORTEMIGLIA *et al.* 1981).

Another good fossil plant locality (not yet elaborated) is in the Point Thomas Formation at Cytadela Hill, Ezcurra Inlet. It yielded imprints of *Nothofagus* leaves and fern fronds preserved in a tuff intercalation between basaltic lavas. Its stratigraphic position probably corresponds to Eocene.

Point Hennequin Group. Well known plant-bearing horizons occur within the Point Hennequin Group, all in its upper unit called the Mount Wawel Formation (the lower unit, the Viéville Glacier Formation, consists mainly of lavas and fossil-free pyroclastics, radiometrically dated as Eocene) — Table 1.

The Mount Wawel Formation consists mainly of andesite lavas and pyroclastics, with three plant-bearing units in volcaniclastic water-laid sediment intercalations (BIRKENMAJER 1981; ZASTAWNIAK 1981; ZASTAWNIAK *et al.* 1984). The two lower units called the Dragon Glacier plant beds (first unit), and the Wanda Glacier plant beds (second unit), are known only from loose blocks in recent moraines. The upper (third) unit, called the Mount Wawel plant beds, has been recognized *in situ* between the lavas.

The Dragon Glacier plant beds consist of tuff, shaly siltstone and shale with numerous plant imprints reported mainly by DÍAZ and TERUGGI (1956), BARTON (1961, 1964, 1965), ADIE (1964*a*), BIRKENMAJER (1980*a*, 1981, 1985), ZASTAWNIAK (1981) and ZASTAWNIAK *et al.* (1985). This is a *Nothofagus*-Podocarpaceae assemblage (ZASTAWNIAK 1981) represented by imprints of deciduous leaves, shoots, seeds and fruits of conifers, moreover by infrequent imprints of horsetails and fern fronds. Among Podocarpaceae, the genera *Dacrydium* (*Dacrydioides*), *Acmopyle* and *Stachycarpus* are present. Among angiosperms, the genera *Nothofagus*, *Roophyllum*, *Rubus* and *Cupania* are characteristic.

The Wanda Glacier plant beds contain poorly preserved rootlets, impressions of conifer branches, and fragments of petrified wood.

The Mount Wawel plant beds, recognized *in situ* just above andesite lavas yielding a Late Oligocene K-Ar date of 24.5±0.5 Ma (BIRKENMAJER *et al.* 1983*c*), contained a plant assemblage very similar to that of the Dragon Glacier plant beds. It consisted mainly of leaf impressions of the genus *Nothofagus* (various types), and podocarpaceous conifer branches and rarer leaf impressions of aff. Araliaceae and ?Rhamnaceae. In both (Dragon Glacier and Mount Wawel plant beds), small leaf (microphyll and notophyll) classes are in excess of 95 per cent of that which corresponds with the values of the recent Australian Temperate (cool and warm) Rain Forest.

The above data indicate that during Palaeogene, Late Oligocene (24.5 Ma) inclusive, in the South Shetland Islands (about 62°S) there was no continental ice-cap the climate being warm during Paleocene-Eocene times, changing to temperate during the Oligocene.

James Ross Island Basin

The Palaeogene sediments distinguished as the Seymour Island Group at Seymour Island rest unconformably upon Upper Cretaceous Marambio Group (ELLIOT *et al.* 1975; ELLIOT and TRAUTMAN 1982; RINALDI *et al.* 1978; ZINSMEISTER 1982). The Seymour Island Group consists of two formations: the lower Cross Valley Formation and the upper La Meseta Formation.

Cross Valley Formation. This is a complex of non-marine sandstones and pebbly sandstones of deltaic character with large coalified logs (near the base), leaf impressions and coalified plant detritus (upper part of the formation). The leaf flora elaborated by DUSÉN (1908, see also remarks by ZASTAWNIAK 1981: 99—100) belongs to the richest among Palaeogene floras of Antarctica, the pollen spectra indicate a Paleocene age of the formation. Both the flora, and the appearance of a coal seam (1 m thick) in the upper part of the formation (FLEMING and ASKIN 1982; ASKIN and FLEMING 1982) provide gocd evidences of warm climate.

La Meseta Formation. This formation, at least 450 m thick, consists of unconsolidated marine sands with shell banks, facially corresponding to delta-shelf slope, tide-dominated environment, and lagoonal environment. Abundant marine fossils dominated by bivalves and gastropods (e. g., ELLIOT *et al.* 1975; ELLIOT and TRAUTMAN 1977; RINALDI *et al.* 1978; WELTON and ZINSMEISTER 1980; ZINSMEISTER 1982) indicate the ?Middle through Upper Eocene to ?Lower Oligocene ages for the formation. Besides molluscs, the formation also yielded shark teeth, vertebrae and teeth of teleost fish, reptile remains (i. a. turtle bones), bird remains (including penguins), sparse remains of large (probably marine) placental, and a jaw of primitive marsupial belonging to the extinct family Polydolopidae (WOODBURNE and ZINSMEISTER 1982). Most bones were collected from a beach-type setting at the top of the formation.

There is no indication of glacial climate throughout the whole La Meseta Formation. Coarser material in form of conglomerates with well-rounded gravel represents storm-lag gravels. No iceberg-rafted dropstones or any other evidences of glacial-control of sedimentation were found in these Eocene to ?Lower Oligocene strata.

Conclusion

The data summarized above give the following characteristics of the Palaeogene (Paleocene through Late Oligocene) climate of the Antarctic Peninsula sector: (1) warm to temperate, differentiated into summer and winter seasons, without evidences of prolonged winter snow cover; (2) rather rich in precipitation what resulted in extensive, lush vegetation cover, local accumulation of coal beds, and local development of restricted delta systems; (3) supporting snow-caps or ice-caps on tops of higher stratocones only, mainly during the Eocene (BIRKENMAJER 1985).

Calculations of surface palaeotemperatures of Pacific seawater off Antarctic Peninsula gave values of 14°C for late Eocene (FRAKES 1979: 193, fig. 7—2), but only 3°C for Oligocene (*op. cit.*, fig. 7—3). Such dramatic change in climatic conditions has not been recorded in Eocene through Late Oligocene floras of King George Island. Even the youngest, Late Oligocene (24.5±0.5 Ma) flora of the Mount Wawel plant beds grew in a climate much warmer than that corresponding to seawater surface palaeotemperature of 3°C. The latter palaeotemperature would be more probable for the Oligocene-Miocene boundary, resp. the latest Oligocene.

ONSET OF CENOZOIC GLACIATION IN WEST ANTARCTICA

Isolated centres of glaciation, initially restricted to higher mountains, mountain groups, highlands and elevated polar plateaus, had most likely already formed during Eocene and Oligocene, eventually merging into continental ice-cap at the end of Oligocene, close to Oligocene--Miocene boundary (BIRKENMAJER 1985). The coastal regions of Antarctica north of Antarctic Circle were vegetated persistently throughout Palaeogene (KEMP and BARRETT 1975; KEMP 1981), and Late Oligocene inclusively, especially in the Antarctic Peninsula sector (ZASTAWNIAK *et al.* 1985).

South of latitude 70°S

The onset of Cenozoic continental glaciation in Antarctica was probably a diachronous event, proceeding from south to north. In the Ross Sea sector (fig. 1) there is an evidence of glacio-marine iceberg-related sedimentation in the latest Oligocene (about 25 Ma), following a non-glacial climate marine deposition near sea level at about 26 Ma. Highly elevated Transantarctic Mountains in the Ross Sea sector may have been the site of significant ice development as early as Mid-Late Eocene, 44—45 Ma (WEBB 1983*a*, *b*). The late Oligocene glaciation extended into early Miocene (LECKIE and WEBB 1983) and further into mid-late Miocene and Pliocene-Pleistocene times (WEBB 1981, 1983*a*, *b*; WEBB *et al.* 1984; DENTON *et al.* 1984).

In Marie Byrd Land, the oldest basaltic hyaloclastites interpreted as products of eruption beneath continental ice-sheet gave a late Oligocene K-Ar date of 27±1 Ma (Le MASURIER and REX 1977).

A glaciated pavement of Miocene age was reported from Jones Mountains, Ellsworth Land (CRADDOCK *et al.* 1964; RUTFORD *et al.* 1968, 1972).

North of latitude 70°S

In the Antarctic Peninsula sector of West Antarctica including the South Shetland Islands and the James Ross Island Basin (fig. 1), the oldest evidence for land-ice development, probably in form of local ice-caps on tops of stratocones, is provided by late Cretaceous and early Tertiary (mainly Eocene?) lahars (Table 1). The latest Oligocene terrestrial plant-bearing strata, K-Ar dated at 24.5±0.5 Ma, indicate non-glacial climatic conditions at latitude 62°S in the South Shetland Islands up to the close of Palaeogene (BIRKENMAJER *et al.* 1983*a*; ZASTAWNIAK *et al.* 1985). Radiometric dating of volcanics associated with glacio-marine strata at King George Island, of the Polonez Glaciation and the Melville Glaciation, indicate the latest Oligocene and the earliest Miocene ages for these glaciations, respectively (BIRKENMAJER *et al.* 1985*b*, *c*). These glacio-marine strata thus provide evidence for the oldest glaciation at sea--level in the Antarctic Peninsula sector around the Palaeogene/Neogene boundary.

As a result of continental ice-cap expansion, the Late Oligocene refuges for coastal vegetation represented by tree-shrub communities of *Nothofagus* and Podocarpaceae (ZASTAWNIAK *et al.* 1985) were destroyed not only in the Antarctic Peninsula sector but also in the whole Antarctic continent.

There are also good evidences for another, Tertiary terrestrial glaciation in the South Shetland Islands, called the Legru Glaciation (BIRKENMAJER 1980*b*, *c*, 1982*a*).

LATEST OLIGOCENE AND EARLY MIOCENE GLACIALLY-CONTROLLED MARINE DEPOSITION IN KING GEORGE ISLAND

Glacial and glacio-marine characters of some Tertiary sedimentary sequences in King George Island have been recognized only recently (BIRKENMAJER 1980*b*, *c*, 1982*a—c*, 1983, 1984; BIRKENMAJER *et al.* 1983*a*, 1985*a*; BIRKENMAJER and WIESER 1985; TOKARSKI *et al.* 1981; PAULO and TOKARSKI, 1982) — fig. 2. As a result of geological work by the Polish Antarctic Expeditions of 1978—1981, the characteristics of sediments and the succession of the deposits and associated volcanics are known in considerable detail, the palaeontological studies are in fast progress, and the first radiometric dating has already been completed.

There are two major glacially-controlled successions in King George Island including glacio-marine strata, the Chopin Ridge Group, and the Moby Dick Group, giving evidences for the Polonez Glaciation and the Melville Glaciation, respectively. An interglacial-type succession (Wesele Interglacial) separates the Polonez Glaciation sequence from another glacially-controlled but non-marine succession of the Legru Glaciation. There are also isolated occurrences of Tertiary marine and glacio-marine strata, correlating either with Chopin Ridge or Moby Dick groups, or — partly — belonging to a separate succession.

Polonez Glaciation

The succession of glacially-controlled terrestrial and marine deposits of the Polonez Glaciation is represented by the Polonez Cove Formation, a part of the Chopin Ridge Group (pls 1, 2, figs 3, 4, Table 2), regarded from sparse palaeontological evidence to be Pliocene in age. Formal lithostratigraphic definitions of the units at group, formation and member levels are those introduced by BIRKENMAJER (1980*b—d*, 1982*a*).

Substratum. The substratum of the Polonez Cove Formation is represented by a volcanic effusive complex distinguished as the Mazurek Point Formation. It consists of basaltic lavas (type area — *op. cit.*), see figs 3, 4, or of a sequence of basaltic and andesitic lavas with tuff intercalations (in the area of Turret Point — Three Sisters Point, PAULO and TOKARSKI 1982). An imprint of indeterminable leaf has been found in the tuffs at the latter locality. The K-Ar dating of basalts (leucobasalts) at the type locality of the Mazurek Point Formation (at Polonez Cove) gave a late Cretaceous date 74^{+1}_{-7} Ma (BIRKENMAJER *et al.* 1985*c*).

There is an erosional unconformity and hiatus between the basalts and the overlying glacial and glacio-marine strata of Tertiary age. Strong weathering of basaltic lava sheet in its uppermost part just below glacigenic deposits, best visible at Polonez Cove, may have occurred under warm Palaeogene climate.

Basal tillites. The upper part of the Mazurek Point Formation lavas is often gouged in rather deep erosional furrows and depressions infilled with glacifluvial-type till (BIRKENMAJER 1980*b*, 1982*a*). Roches moutonnées and glacial grooves occur only in case of hard lava substratum under bottom moraine of the Polonez Glaciation at Three Sisters Point (TOKARSKI *et al.* 1981; PAULO and TOKARSKI 1982). They are however missing in the area of Polonez Cove where the basaltic substratum is strongly weathered and soft (BIRKENMAJER *op. cit.*).

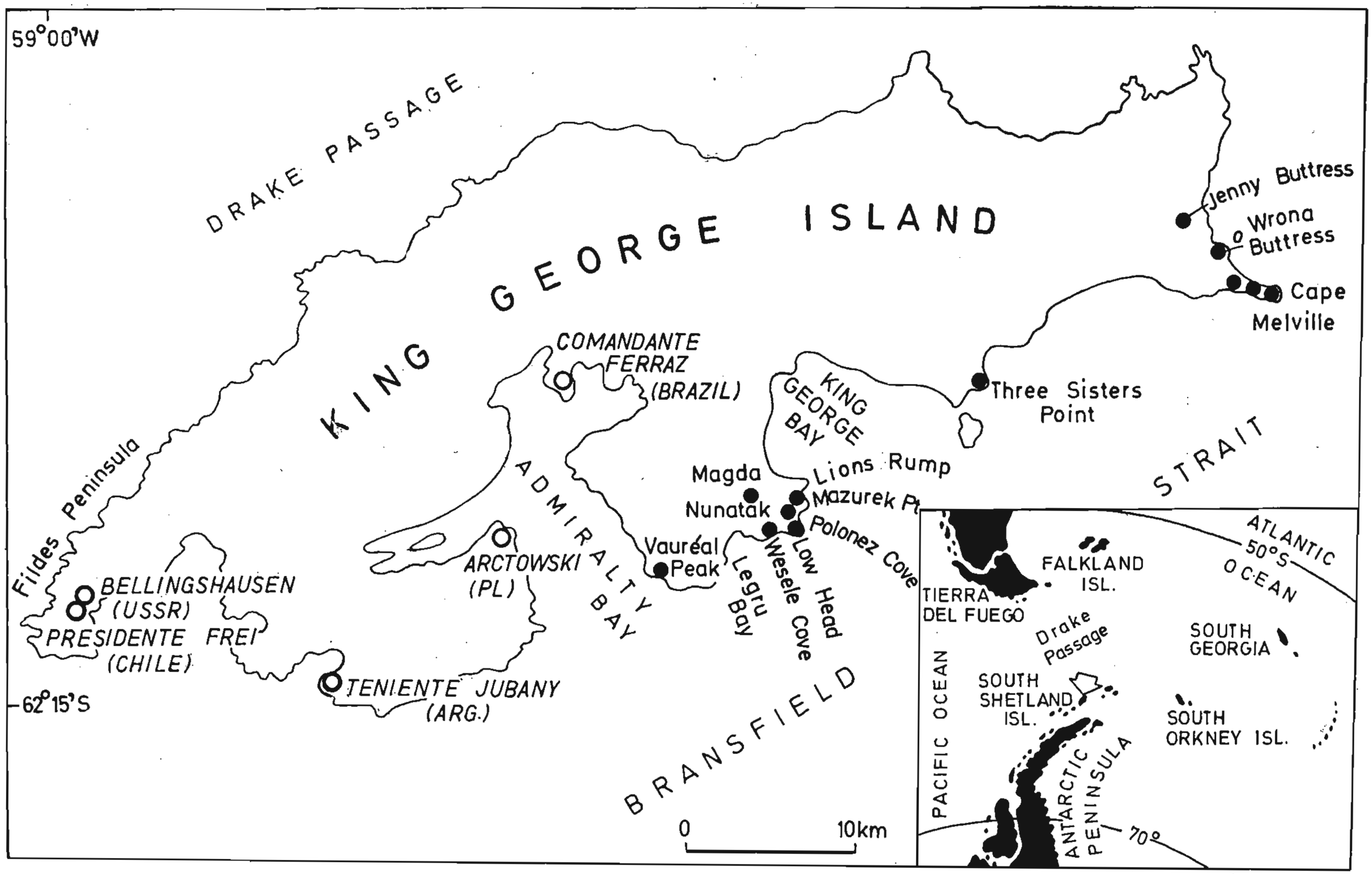


Fig. 2
Key map to sites of Tertiary glacial and glacio-marine deposits in King George Island (black dots). Inset shows position of the South Shetland Islands in the Antarctic Peninsula sector.

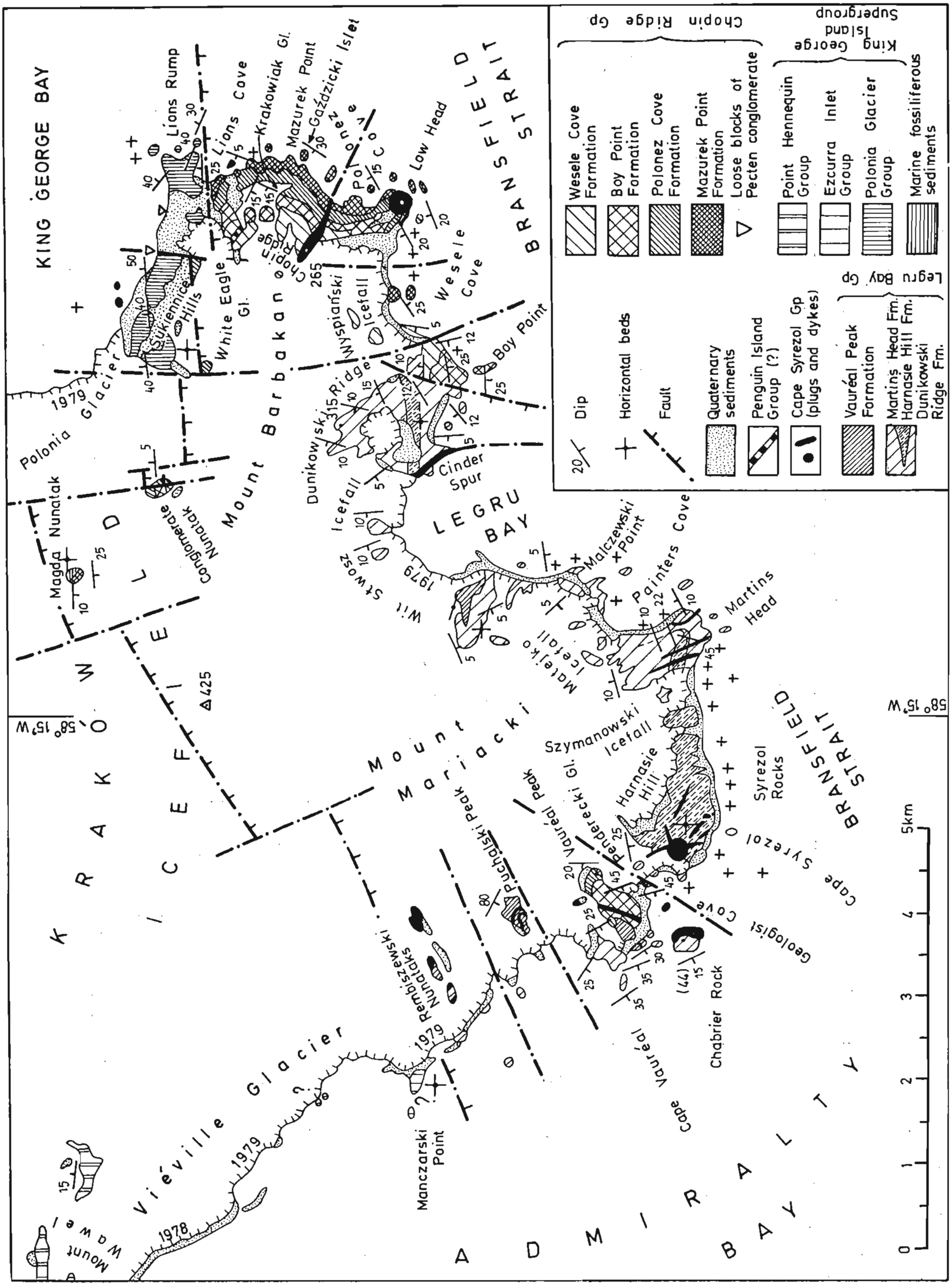


Fig. 3
Geological map of the Tertiary tillite-bearing sequences between Admiralty Bay and King George Bay, King George Island (after BIRKENMAJER 1982*a*).

Table 2
Lithostratigraphic standard of the Chopin Ridge Group

GROUP	FORMATION	MEMBER	LITHOLOGY	
LEGRU BAY			(volcanic-sedimentary succession with tillites and lahar-type agglomerates — c. 300m)	
CHOPIN RIDGE 300m+	WESELE COVE 75–100m		agglomerate, conglomerate, sandstone (mainly reworked Boy Point Formation)	
	BOY POINT 20–100m		acidic porphyritic lava flows alternating with tuff and agglomerate	
	POLONEZ COVE 5–65m	OBEREK CLIFF 10–30m	sandstone and conglomerate with marine fauna; rather frequent ice-rafted blocks	marine tillite
		SIKLAWA 2–10m	rhythmically bedded sandstones, siltstones and shales with marine fauna; scarce ice-rafted blocks	
		LOW HEAD 5–15m	basaltic conglomerate *(Pecten* conglomerate) with rich marine fauna; numerous ice-rafted blocks	
		KRAKOWIAK GLACIER 5–15m	tillite: ground-moraine and glacifluvial deposits (continental ice-sheet)	
	MAZUREK POINT 50m+		basalt lava flows, strongly brecciated and weathered in the upper part	

(base not exposed: under the sea)

The basal tillites distinguished as the Krakowiak Glacier Member are developed as lodgement till and glacifluvial deposits. The lodgement till is a massive mixtite with mainly angular blocks up to 2 m in diameter showing neither preferred orientation, sorting or grading. The glacifluvial deposits are represented by chaotic large-scale cross-bedded mixtite, with angular or poorly rounded blocks up to 2 m in diameter. The clastic fragments are poorly sorted and slightly oriented parallel to cross-sets. The erratic material, both in lodgement till and glacifluvial tillites, is mainly of Antarctic continent provenance. It indicates the source areas in the

Antarctic Peninsula, the Ellsworth Mountains, and the Pensacola-Theron Mountains (BIRKENMAJER *op. cit.*; BIRKENMAJER and WIESER 1985). The local material from the South Shetland Islands is less frequent. Glacial striae and glacially polished surfaces (facetted boulders) may often be recognized on erratic blocks.

Glacio-marine strata. There follows the succession of glacio-marine strata resting either upon basal tillites or directly upon basaltic substratum. They begin with basaltic conglomerate containing lenticular coquinas („tempestites" — GAŹDZICKI 1984) with *Chlamys anderssoni* (HENNIG): this is the Low Head Member of BIRKENMAJER (1980*b*, *c*, 1982*a*) corresponding more or less to the „*Pecten* Conglomerate" of BARTON (1965). Fine-grained sandstones, siltstones and shales occur in the middle Siklawa Member. Large-scale cross-bedded regressive conglomerates and sandstones included to the Oberek Cliff Member, terminate the Polonez Cove Formation (fig. 4).

Besides local basaltic material, the glacio-marine strata contain frequent iceberg-rafted dropstones up to 1.5 m in diameter, distributed at random within the sediment. These dropstones often reveal glacial striae and glacially polished surfaces (facetted boulders). The erratic spectrum is very similar to that of the basal tills indicating the same sources in Antarctica (BIRKENMAJER, *op. cit.*; BIRKENMAJER and WIESER 1985).

Fossils and palaeoenvironment. The glacio-marine sediments of the Polonez Cove Formation are rather rich in fossils. They contain (BŁASZYK and GAŹDZICKI 1980; GAŹDZICKI 1982, 1984; GAŹDZICKI and WRONA 1982*a*, *b*; GAŹDZICKI and PUGACZEWSKA 1984; GAŹDZICKI *et al.* 1982; BITNER and PISERA 1984; JESIONEK-SZYMAŃSKA 1984; GAŹDZICKA and GAŹDZICKI 1985), coccoliths (Tertiary), diatoms, chrysomonad cysts, rare planktonic foraminifera, numerous benthic foraminifera, tube worms, numerous bryozoans, infrequent brachiopods, numerous bivalves with dominating *Chlamys anderssoni* (HENNIG), moreover gastropods, crinoids, ophiuroids and echinoids. This assemblage generally corresponds to the so-called „*Pecten* Conglomerate" fauna first described by Andersson (1906) from Cockburn Island (James Ross Basin), and attributed to the Pliocene. As suggested by sedimentological investigation the whole faunal association confirms a very shallow, high-energy (predominantly) inner shelf environment of the Polonez Cove Formation.

Age by palaeontological data. Comparatively rich invertebrate fossil macrofauna collected from the Polonez Cove Formation and partially already described (see above), confirms Tertiary age of the fossil-bearing strata, particularly the Low Head Member („*Pecten* Conglomerate"). This fauna is, however, difficult to interpret in terms of detailed Tertiary stratigraphy, due to poor knowledge of Tertiary macrofaunas of Antarctica: most fossils are determined only at generic or dubious specific levels (prefixed with *conformis*). However, as no doubts have been raised as to the Pliocene age of the macrofaunal assemblage (see preceding section), the correlation of the Polonez Cove Formation with the „*Pecten* Conglomerate" of Cockburn Island was accepted. Until new light has been shed by the results of K-Ar dating of overlying lavas performed by Dr. H. KREUZER (BIRKENMAJER *et al.* 1985*c*) — see below.

There is a long discussion on the age of the „*Pecten* Conglomerate fauna" typified by *Chlamys anderssoni* (HENNIG) first described from Cockburn Island (James Ross Island Basin, NE Antarctic Peninsula) by ANDERSSON (1906), and originally considered by him on both faunal character and high position of the deposit above the sea, to be of Pliocene age. His view has been accepted by a majority of writers (e.g. ADIE 1962, 1964a, 1977; BARTON 1965; BIRKENMAJER 1980*b*, 1980*d*, 1982*a*) dealing with equivalent deposits of King George Island. HENNIG (1911), however, preferred a Pleistocene age of the conglomerate at Cockburn Island based on stratigraphic evaluation of the whole assemblage of fossils including brachiopods (BUCKMAN 1910), foraminifera (HOLLAND 1910), crustaceans, bivalves and bryozoans. This evaluation also forced ANDERSSON (in Addendum to BUCKMAN 1910) to reconsider his Pliocene assessment put forward in 1906, in view of the Pleistocene age as suggested by brachiopods (see also

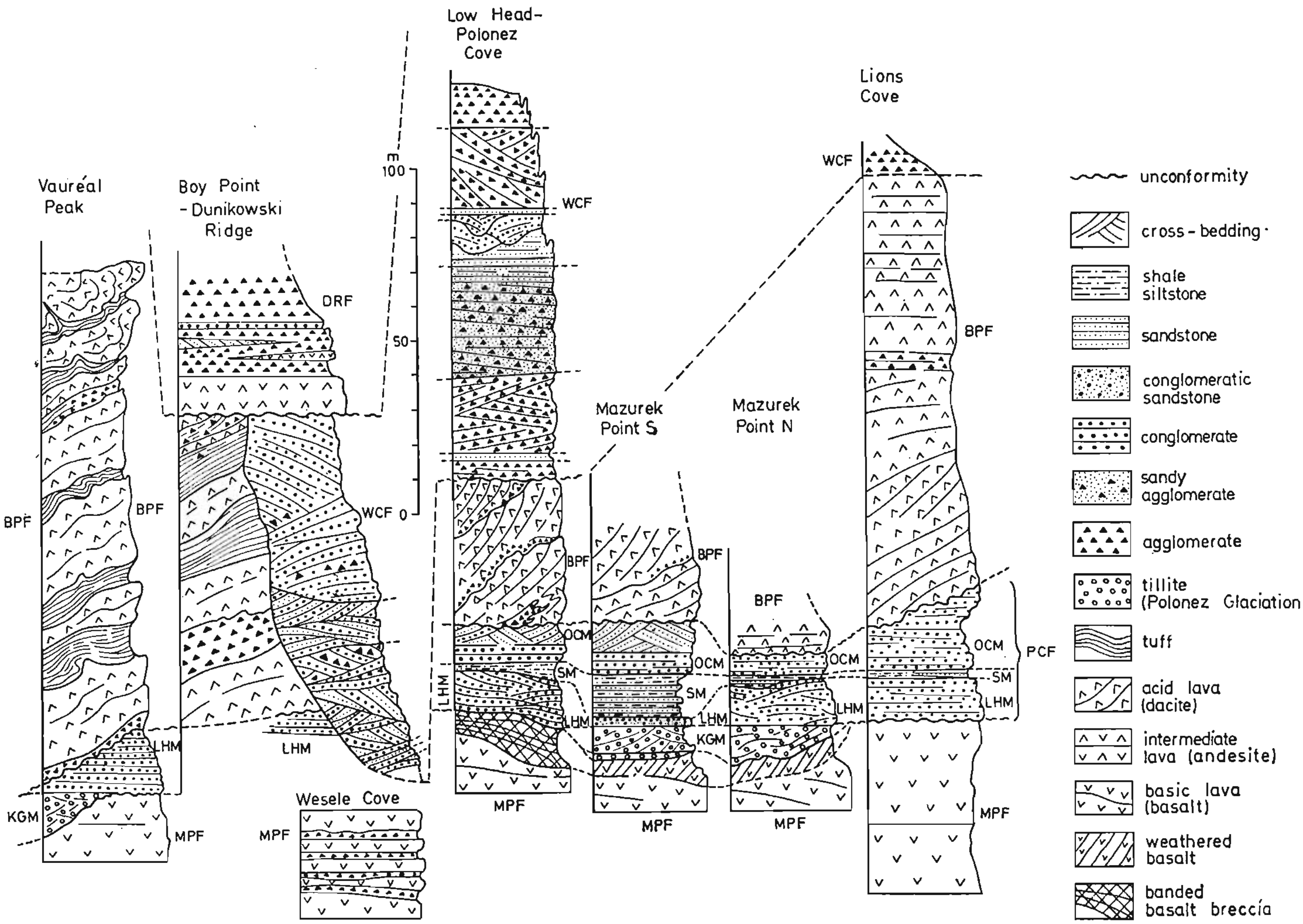


Fig. 4

Lithostratigraphic columns of the Chopin Ridge Group between Vauréal Peak and Lions Cove, King George Island (after BIRKENMAJER 1982*a*).

Chopin Ridge Group: MPF — Mazurek Point Formation; PCF — Polonez Cove Formation (KGM — Krakowiak Glacier Mbr; LHM — Low Head Mbr; SM — Siklawa Mbr; OCM — Oberek Cliff Mbr); BPF — Boy Point Formation; WCF — Wesele Cove Formation. Legru Bay Group: DRF — Dunikowski Ridge Formation.

THOMSON 1977). ADIE (1964*b*) and FLEMING and THOMSON (1979) attributed a closer unspecified Plio-Pleistocene age to the „*Pecten* Conglomerate" with fauna typified by *Chlamys anderssoni.* FAIRBRIDGE (1952 — *fide* ANDERSON 1965: 47) concluded that these deposits belong to a warm interglacial (Pleistocene) high sea level. ZINSMEISTER (1978) thought that since the „*Pecten* Conglomerate" stratigraphically overlies the Pliocene basalts of the James Ross Volcanic Group (radiometrically dated at 1—5 Ma), its age may be as young as Middle Pleistocene. ZINSMEISTER and WEBB (1982) suggest on comparison of volcanic successions of Seymour Island and Cockburn Island that the „*Pecten* Conglomerate" of the latter island can be no older than about 6 Ma.

The invertebrate macrofauna elaborated so far from the Polonez Cove Formation (GAŹDZICKI and PUGACZEWSKA 1984; BITNER and PISERA 1984; JESIONEK-SZYMAŃSKA 1984) is rather inconclusive with respect to the exact age of the glacio-marine deposits of the Polonez Glaciation. The majority of 49 bryozoan taxa show very wide stratigraphical ranges. Out of 27 taxa known from the seas of today, 2 are reported since Jurassic or Cretaceous, 1 since Tertiary, 5 since Eocene, 1 since Oligocene, 5 since Miocene, 3 since Pliocene (+4 taxa since Cockburn Island „Pliocene"), 2 since Pleistocene. The forms reported exclusively from the Tertiary are less frequent: 2 from Tertiary as a whole, 4 from Eocene and Eocene-Oligocene, 2 from Miocene, 3 from Miocene-Pliocene, and 2 from Pliocene. There are also 5 taxa reported from Quaternary only: 1 from Pleistocene and 4 recent ones. Six taxa are in common with the „*Pecten* Conglomerate" of Cockburn Island.

The bivalves are more consistently Tertiary in character. Out of 28 taxa determined, 1 genus (*Eburneopecten*) is reported from Late Cretaceous through Oligocene strata, 12 are from Tertiary as a whole, one from Oligocene, one from Miocene. Among taxa (usually determined at generic level) known from recent seas, 4 are reported since Paleocene or Eocene, one since Oligocene (*Pronucula*), one since Late Oligocene (*Timoclea*), 2 since Miocene, 2 since Pliocene. There are two taxa in common with the „*Pecten* Conglomerate" of Cockburn Island, one — *Chlamys anderssoni* (HENNIG) is diagnostic for the assemblage.

Out of 11 gastropod taxa determined, 8 species are exclusively Tertiary, one genus occurs since Eocene and one since Oligocene. Five species resemble those of the Tertiary (?Middle and Upper Eocene through ?Lower Oligocene) strata of Seymour Island, namely: *Polinices* cf. *subtenuis* IHERING, *Struthiolarella* (= *Antarctodarwinella*) cf. *nordenskjoeldi* WILCKENS, *Trophon* cf. *disparoides* WILCKENS and *Cyrtochetus* cf. *bucciniformis* WILCKENS.

Eleven nannoplankton (coccolith) taxa have been determined by GAŹDZICKA and GAŹDZICKI (1985). They were found attached to tests of planktonic foraminifers determined at generic level only as *Globigerina* and *Globorotalia*.

In Dr. J. DUDZIAK's opinion (personal communication) the calcareous nannoplankton described by GAŹDZICKA and GAŹDZICKI (1985) lacks Oligocene index forms. There is a co-occurrence of exclusively Eocene forms (*Chiasmolithus gigas*) with taxa of much wider age ranges (see: Additional References — Coccoliths):

Coccolithus pelagicus (WALLICH): Danian through Recent (REINHARDT 1970); since higher Paleocene (LORD *et al.* 1970);

Chiasmolithus altus BUKRY et PERCIVAL: Late Eocene through Late Oligocene in Australia (RADE 1977);

Coronocyclus nitescens (KAMPTNER) BRAMLETTE et WILCOXON: Oligocene through Miocene in Australia (RADE 1977);

Cyclicargolithus floridanus (ROTH et HAY) BUKRY: Late Eocene through Miocene in Australia (RADE 1977); Early Oligocene through Middle Miocene elsewhere (GARTNER 1977);

Ericsonia muiri (BLACK): Late Eocene through Early Miocene (BAUMANN 1970);

Reticulofenestra bisecta (HAY, MOHLER et WADE) n. comb. ROTH (1970) including *Dictyococcites dictyodus* MARTINI: Middle Eocene NP-14 zone through Late Oligocene NP-25 zone in the northern hemisphere (MÜLLER 1978); Middle Eocene through Late Oligocene (GARTNER 1977);

Reticulofenestra umbilica (LEVIN): Middle Eocene through Early Oligocene, up to the boundary of NP-22 and NP-23 zones (MARTINI 1971); higher Lutetian (Middle Eocene) through lower part of Early Oligocene (Rupelian) — GARTNER (1977). Recycled forms occur in sediments up to a middle part of Late Oligocene inclusively (MARTINI 1980);

Chiasmolithus gigas (BRAMLETTE et SULLIVAN) is known exclusively from the middle part of Lutetian (Middle Eocene) — GARTNER (1977); is restricted to lower part of NP-14 zone (Middle Eocene) — MÜLLER (1977).

The above age ranges indicate that many, if not all, of these coccoliths are recycled together with their host foraminifer tests. The youngest coccolith taxon (*Coronocyclus nitescens*) indicated only an Oligocene through Miocene age range of the assemblage.

In the present author's opinion, it should be taken into account that the coccoliths described by GAŹDZICKA and GAŹDZICKI (1985), together with their host foraminifer tests, were obtained only from a high-energy „tempestite" (coquina) of the Low Head Member. They have not been found in lower-energy fine-grained sediments of the Siklawa Member.

Age by radiometric dating. In order to solve the above palaeontological age uncertainties, K-Ar dating was performed on volcanic rocks associated with glacio-marine deposits of the Polonez Cove Formation. These deposits are capped by acidic (quartz-andesite to dacite) porphyritic lavas of the Boy Point Formation which yielded K-Ar ages in excess of 22 Ma: A-157 $> 23.6 \pm 0.3$ Ma, and A-162 $> 22.4^{+0.2}_{-0.4}$ Ma (BIRKENMAJER *et al.* 1985*c*). These dates clearly indicate that the glacio-marine deposits in question, and thus the Polonez Glaciation as well, are older than the Oligocene-Miocene boundary (22.5 Ma). A basaltic dyke (Cape Syrezol Group) which cuts through the Mazurek Point, the Polonez Cove, the Boy Point and the Wesele Cove formations at Chopin Ridge, Polonez Cove, has been dated at $> 21.8 \pm 0.6$ Ma (A-166) which is consistent with the results from the Boy Point Formation (*op. cit.*) — Table 4.

The base of the Polonez Cove Formation, represented by effusives of the Mazurek Point Formation yielded a late Cretaceous K-Ar age 74^{+1}_{-7} Ma (*op. cit.*). Thus, there is no direct evidence for the age of the base of the glacigenic deposits. This problem is discussed later in the last part of the paper.

Melville Glaciation

The succession of glacially-controlled marine deposits, attributed to the Melville Glaciation, is represented by the Cape Melville Formation, a part of the Moby Dick Group (pls. 3, 4, figs. 5—8, Table 3). Formal lithostratigraphic definition of units at group and formation levels was given by BIRKENMAJER (1982*b*, 1984).

Substratum. The substratum of marine and glacio-marine sediments of the Cape Melville — Melville Peninsula area is formed by olivine-augite basalts (leucobasalts) of the Sherratt Bay Formation. Only the top part of this formation consisting of terrestrial plateau-basalt sheet more than 60 m thick is exposed above sea level. The lava was subject to alteration (zeolitization) by hydrothermal solutions and by subsequent weathering. The K-Ar date > 18 Ma sets a minimum age of the basalts, which are possibly Palaeogene rather than late Cretaceous in age (BIRKENMAJER *et al.* 1985*b*). A stratigraphic hiatus has been recognized between the Sherratt Bay basalts and the overlying fossiliferous Miocene formations. Strong weathering of the upper part of the basalt lava pile could have occurred during Palaeogene under climatic conditions much warmer than at present.

Marine and glacio-marine strata. The next units, the Destruction Bay and the Cape Melville formations, are separated from one another by a slight unconformity. The Destruction Bay Formation (40—100 m thick) is developed best in the western part of the Melville Peninsula and at Wrona Buttress (fig. 5). It wedges out towards the east and is missing at Cape Melville (fig. 6). The formation consists of reworked basaltic material from the underlying Sherratt Bay Formation — tuffaceous and psammitic rocks, showing large-scale cross-bedding, with horizons rich in marine invertebrates (fig. 8).

The Cape Melville Formation (about 200 m thick) is represented by glacio-marine sediments: grey to greenish, brownish and black clay-shales and silty shales with subordinate intercalations of siltstone and fine-grained sandstone, and occasionaly thin marl. The formation often begins unconformably upon the Destruction Bay Formation with basal sandy conglomerate (western part of the area), and directly overlies the Sherratt Bay Formation basalts in the east. Numerous, usually angular erratics up to 2 m in diameter, randomly distributed in the clayey sediment, represent iceberg-rafted dropstones derived from the Antarctic continent (mainly Antarctic Peninsula, but also Ellsworth Mts. and Pensacola-Theron Mts.). They often show glacial striae and glacially polished facets, thus giving a primary evidence for continental

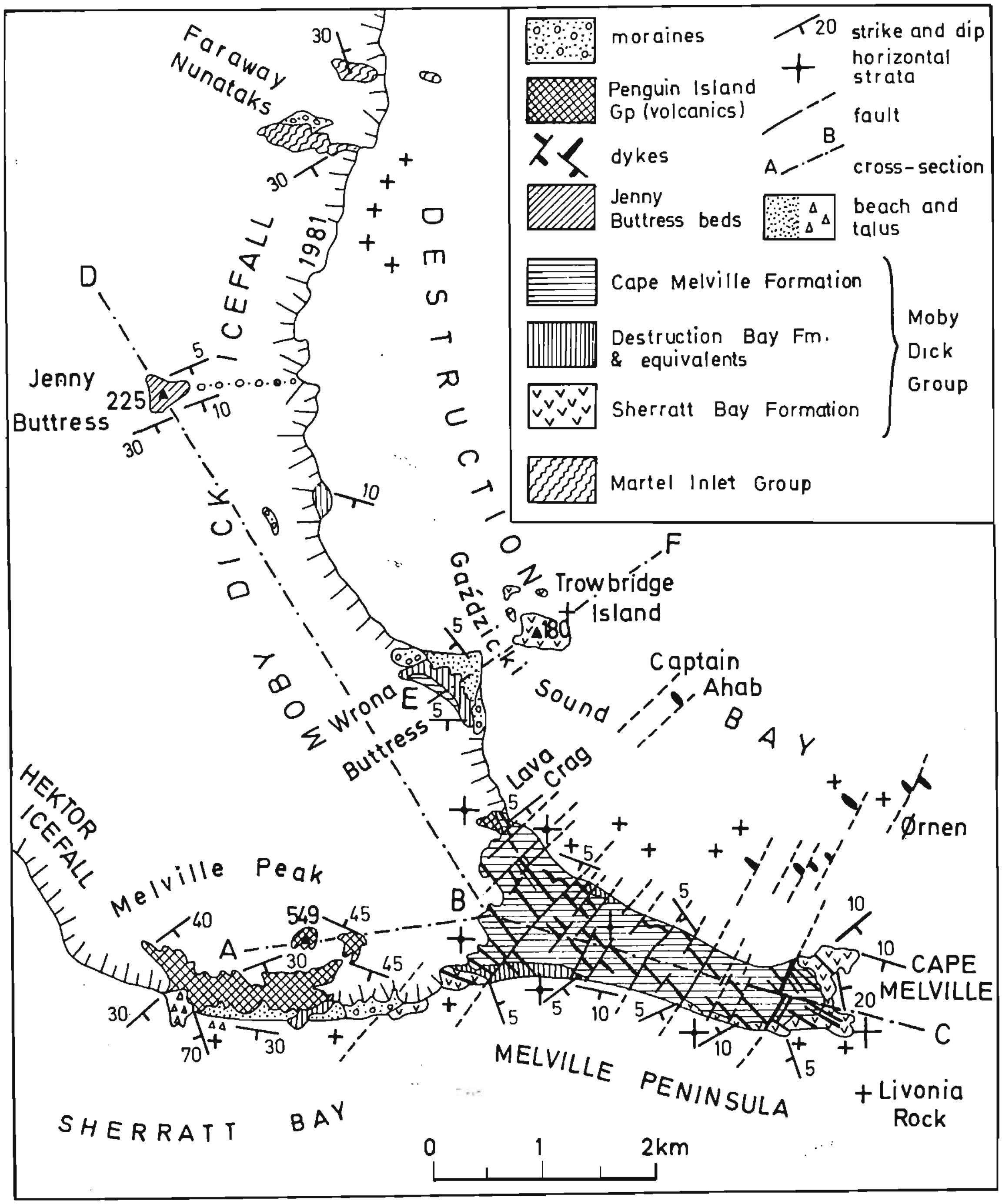


Fig. 5
Geological map of Tertiary glacio-marine sequence in the vicinity of Cape Melville, King George Island (after BIRKENMAJER 1984).

ice-sheet in Antarctica at sea level, called the Melville Glaciation (BIRKENMAJER 1982*b*, *c*). The erratic spectrum is very similar to that of the Polonez Glaciation one, apparently more enriched in Palaeozoic limestone fragments.

Fossils and palaeoenvironment. The Destruction Bay Formation yielded *in situ* bivalves, gastropcds, solitary corals and brachiopcds. The brachiopcds are represented by several species of the genera *Discinisca*, *Pachymagas*, *Neothyris*, *Rhizothyris*, *Magellania* and ?*Magella*

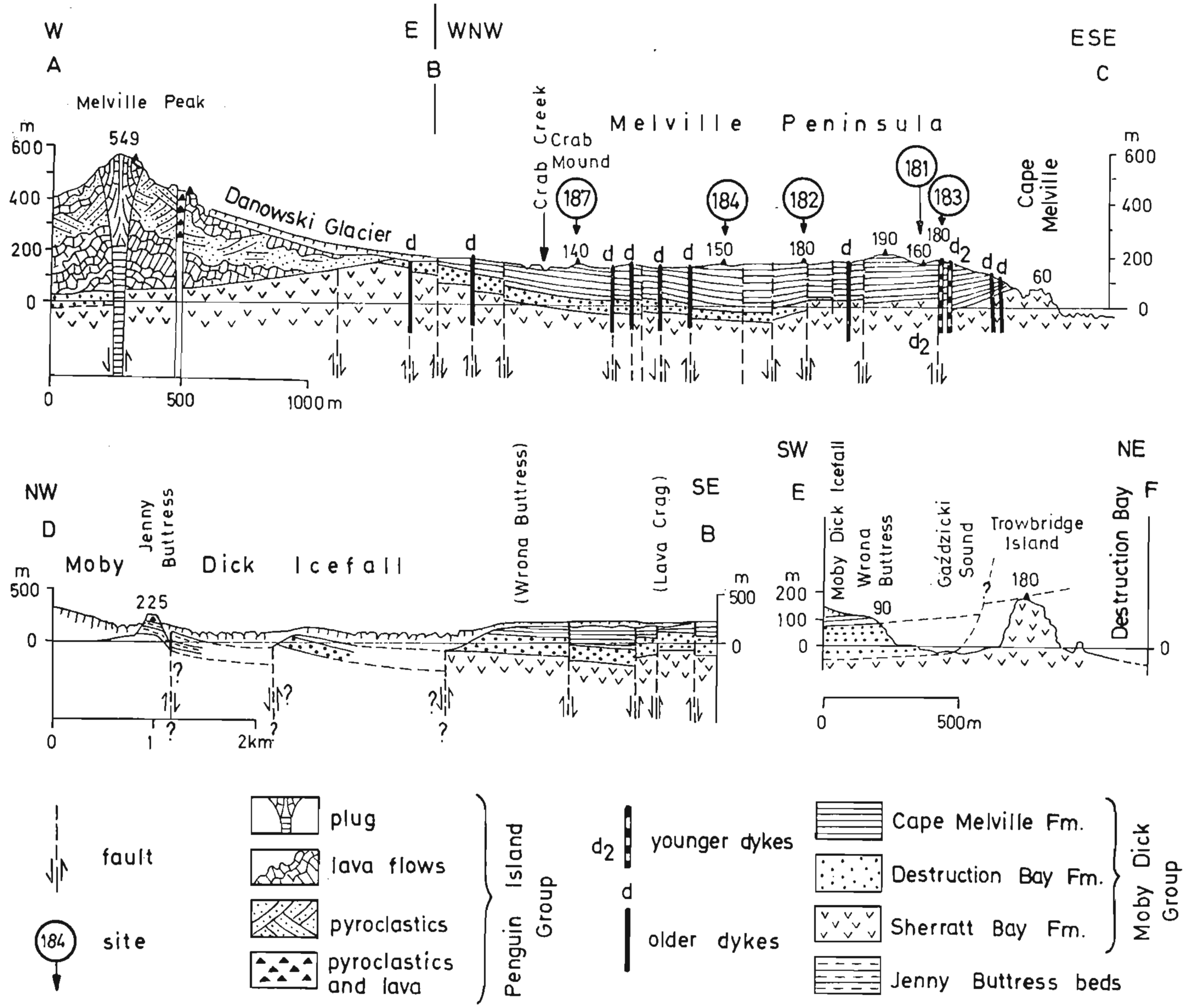
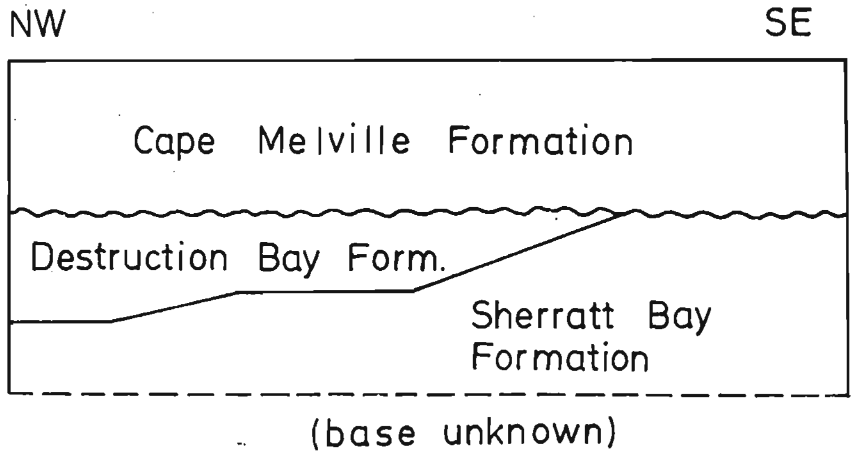


Fig. 6

Geological cross-sections of the Moby Dick Group and equivalent rocks between Cape Melville and Jenny Buttress (after Birkenmajer 1984). For localization of geological cross-sections see fig. 5. Circled numbers refer to selected fossil sites (see fig. 7).

analogous to those of the early Miocene assemblages of New Zealand (Biernat *et al.* 1985). There occur also recycled Cretaceous belemnites (fig. 8), recycled Cretaceous coccoliths and single Tertiary discoasters (Dudziak 1984; Birkenmajer 1984). The sediments of the Destruction Bay Formation were laid down in a shallow-neritic, rather high-energy marginal shelf zone of the Pacific Ocean. Rare conglomerate intercalations contain material of Antarctic continent characteristics. The pebbles do not show any glacial striae or other indications of glacial transport, thus they can not be treated as dropstones resulting from iceberg-rafting. The occurrence of recycled Cretaceous belemnites and coccoliths probably indicates the proximity of Upper Mesozoic marine sediment exposures at that time. Fragments of carbonized wood that occur in estuarine-type deposits of a part of the Destruction Bay Formation, may be either

Table 3
Subdivision of the Moby Dick Group



a vague evidence for forest cover in West Antarctica as late as early Miocene, or — more likely — they represent driftwood of distant origin.

The Cape Melville Formation is very rich in well preserved invertebrate marine fossils (BIRKENMAJER 1982*b*, *c*, 1984; GAŹDZICKI and WRONA 1982*a*, *b*; BIRKENMAJER *et al.* 1983*a*; and papers presented in this volume): solitary corals, polychaetes, bivalves, gastropods, scaphopods, crabs (and their feeding burrows), echinoids, asteroids, ophiuroids, which represent the Tertiary element *in situ*. There are also fish fragments. Microorganisms are represented by numerous benthic calcareous and arenaceous foraminifera, diatoms, chrysomonad cysts, silicoflagellates and sponge spicules. A part of these microorganisms may represent recycled Cretaceous or even Palaeogene material. Damaged calcareous nannoplankton consists exclusively of recycled Cretaceous coccoliths (DUDZIAK 1984; BIRKENMAJER 1984). Numerous recycled Lower Cretaceous belemnites have been collected (BIRKENMAJER *et al.* 1987, this volume). The character of sediments of the Cape Melville Formation and their benthic fauna, point to shallow-marine, quiet, low-energy environment (BIRKENMAJER 1982*b*, 1984), comparable with flat or gently sloping submarine plain of outer shelf or a more restricted basin, below wave base. Most of the sand-silt grade sediment probably derived from disintegrated basaltic rocks exposed along the coast. Numerous dropstones of all sizes up to about 2 m in diameter, often bearing impressive traces of glacial action (facets, glacial striae), are totally foreign to the environment. They were brought by drifting icebergs from the margins of the then glaciated Antarctic continent.

Age by palaeontological data. The invertebrate fossils, though numerous, are still too poorly known to determine the age of the glacio-marine strata (Cape Melville Formation) with much precision. The Cape Melville Formation yielded among its rich invertebrate fossil collection (see above), i. a. solitary corals of the genus *Flabellum* (Eocene — Recent), and foraminifera of the genera *Cyclammina*, *Pullenia* and *Uvigerina* (Eocene — Recent) — see GAŹDZICKI and WRONA 1982*b*, BIRKENMAJER *et al.* (1983*a*).

The brachiopod assemblage of the Destruction Bay Formation is indicative of a Lower Miocene age of this formation at Melville Peninsula (Wrona Buttress) and its equivalent strata at Jenny Buttress (Jenny Buttress beds). Calcareous nannoplankton of Tertiary age is scarce: at Jenny Buttress, the brachiopod-bearing beds yielded *Discoaster brouweri* Tan Sin Hok, reported to occur from the NN5 upper part (Mid-Miocene) through NN18 (Late Pliocene) nannoplankton zones (BIERNAT *et al.* 1985).

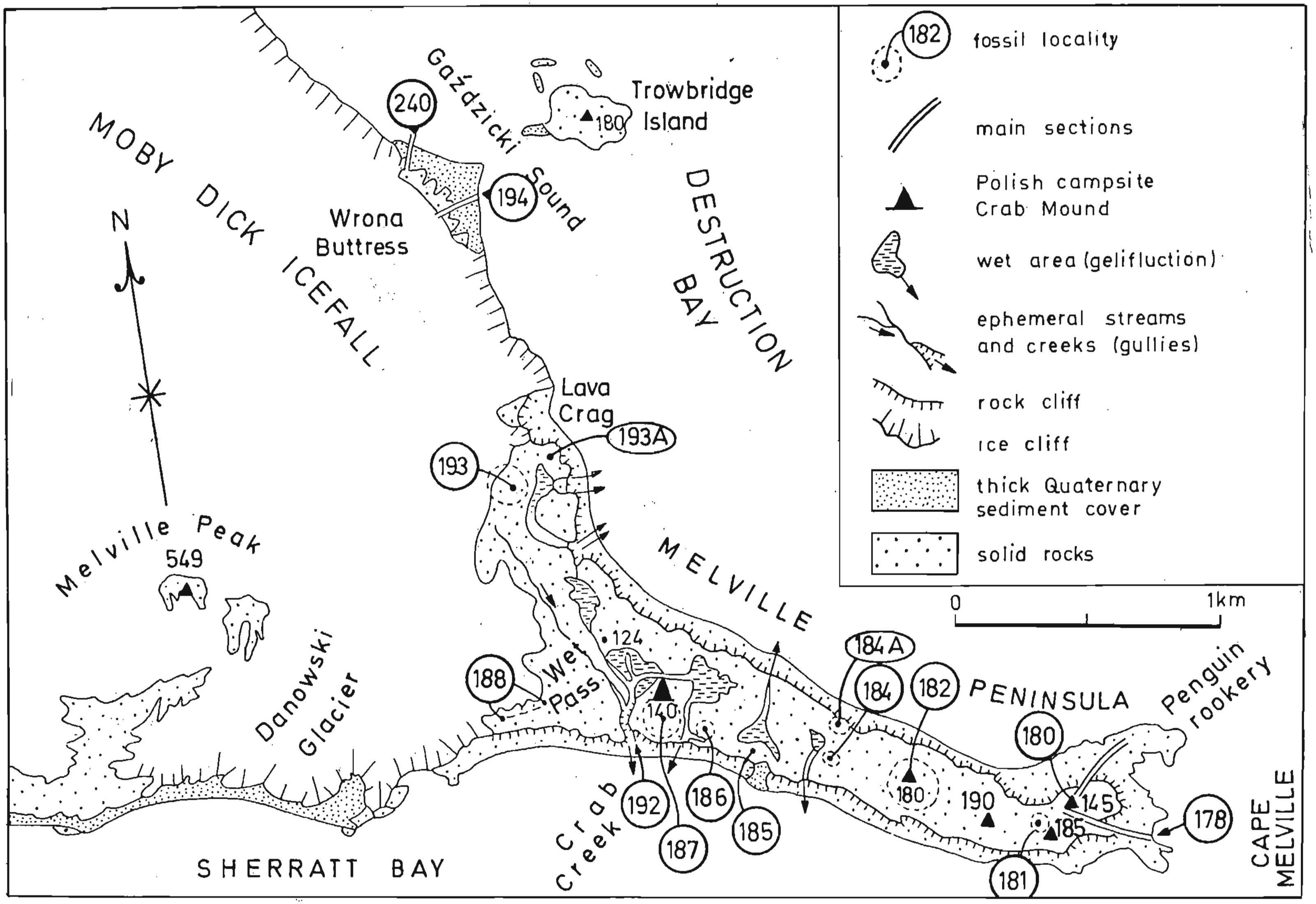


Fig. 7
Localities map of the Cape Melville area (after BIRKENMAJER 1984).

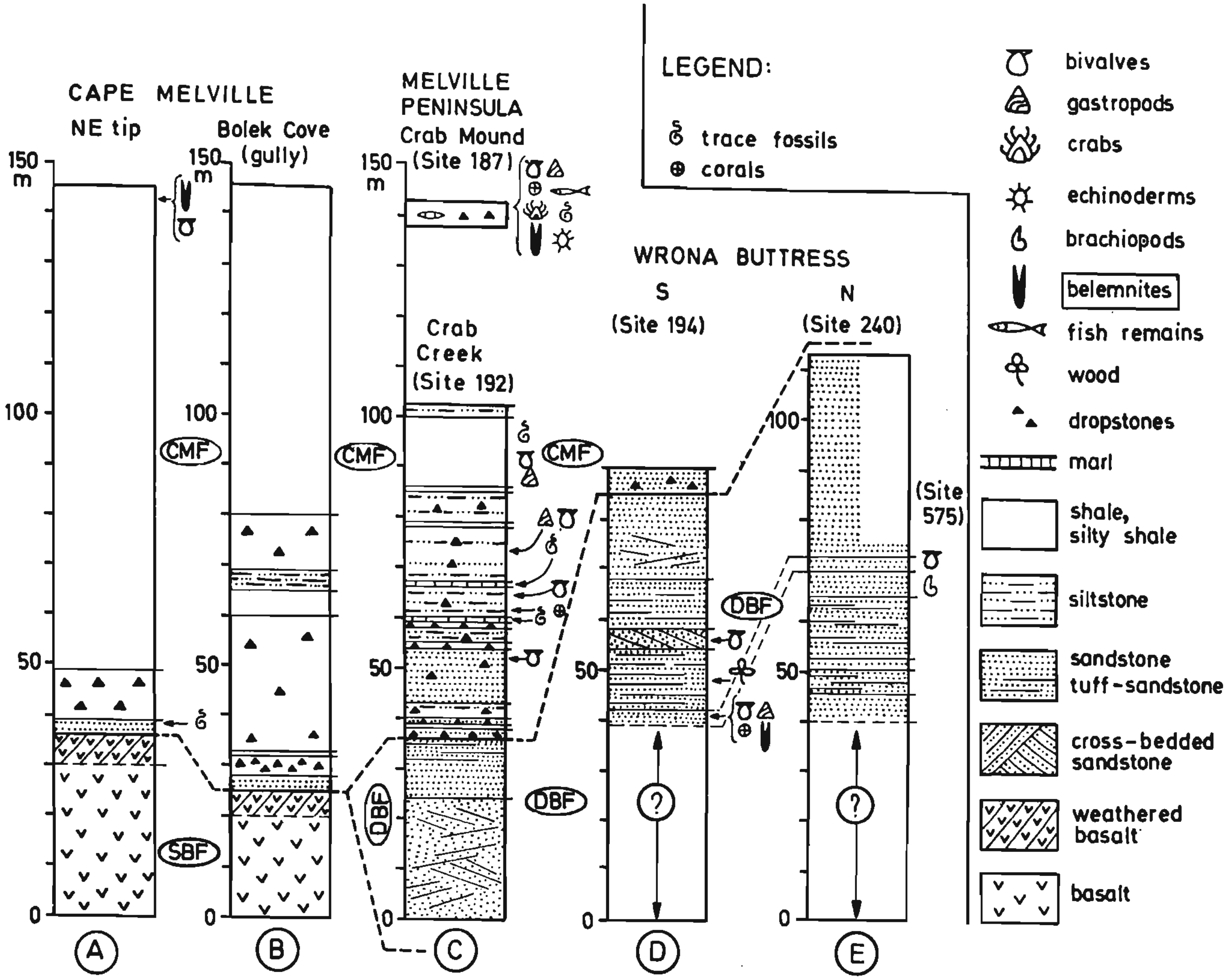


Fig. 8
Lithostratigraphic columns of the Moby Dick Group (A-E) between Cape Melville and Wrona Buttress (after BIRKENMAJER 1984). CMF — Cape Melville Formation; DBF — Destruction Bay Formation; SBF — Sherratt Bay Formation. For location of sites — see figs. 6, 7. Position of recycled belemnites shown.

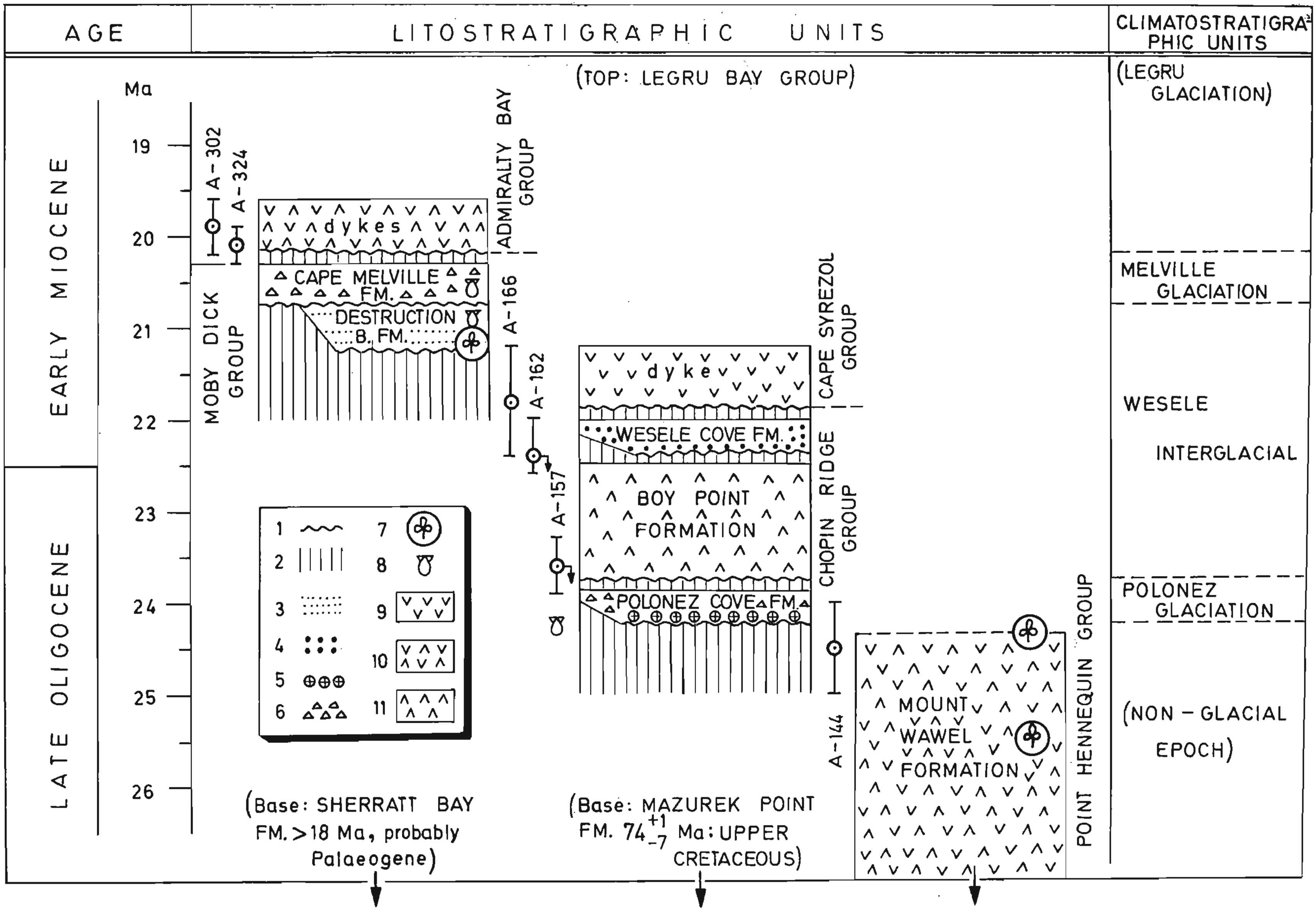
Age by radiometric dating. The whole Moby Dick Group is crossed by two generations of andesitic to basaltic dykes. Two older generation dykes yielded good early Miocene K-Ar ages: A-324 20.1±0.2 Ma and A-302 ⩾ 19.9±0.3 Ma (BIRKENMAJER *et al.* 1985*b*). Thus the geological age of glacio-marine strata (Cape Melville Formation) of the Melville Glaciation cannot be younger than Lower Miocene. As the Cape Melville Formation post-dates the Destruction Bay Formation which yielded early Miocene brachiopods, the most probable age for the Melville Glaciation and its deposits is Lower Miocene (BIRKENMAJER *et al.* 1985*b*).

Other glacio-marine strata

An isolated occurrence of glacio-marine sediments has been recognized at Magda Nunatak, King George Bay (TOKARSKI *et al.* 1981; BIRKENMAJER *et al.*, 1985*a*) — see fig. 3, pl. 2 : 1. These sediments yielded Tertiary bivalves and scaphopods (PUGACZEWSKA 1984), recycled Cretaceous coccoliths, and poorly preserved Tertiary discoasters (DUDZIAK 1984; BIRKENMAJER 1984). The rocks lithologically more closely resemble those of the Cape Melville Formation

Table 4

Probable stratigraphic positions and mutual spatial relations of tillite-bearing lithostratigraphic units on King George Island, based on radiometric dating of associated volcanics and selected palaeontological data. 1 — unconformity; 2 — hiatus; 3 — marine deposits; 4 — coarse terrestrial fresh-water deposits; 5 — continental tillite; 6 — marine tillite; 7 — land plants; 8 — marine fauna; 9 — basaltic rocks (dykes); 10 — andesitic rocks (lavas and dykes); 11 — acidic lavas



than the Polonez Cove Formation and, consequently, have been included in the Moby Dick Group. The overlying basaltic lavas and hyaloclastites intertonguing in the lower part with glacio-marine sediment, have been tentatively correlated with the Mazurek Point Formation (BIRKENMAJER 1982*a*, 1984; BIRKENMAJER *et al.* 1985*a*). In the light of radiometric dating of the Mazurek Point Formation at Polonez Cove, indicating a Late Cretaceous age for the latter (see above), the basaltic rocks at Magda Nunatak which overlie undoubtedly Tertiary glacio--marine strata, are incorrectly assigned to this formation. Radiometric dating of these lavas is now in progress.

CORRELATION AND CONCLUDING REMARKS

(1) The two main sequences of glacio-marine deposits on King George Island, the Polonez Cove and the Cape Melville formations, span the geological time from an undetermined part of late Palaeogene below the Oligocene/Miocene boundary (Polonez Cove Formation, top: > 23.6 Ma) through early Miocene (Cape Melville Formation: 20.1 Ma), some three millions of years or so (> 23—20 Ma) B. P. The onset of continental glaciation in the Antarctic Peninsula sector thus correlates with the base of the Polonez Cove and not Cape Melville Formation, as supposed previously (BIRKENMAJER 1985).

(2) The age of the base of the Polonez Glaciation is unknown as yet, because the underlying basaltic lavas are of Upper Cretaceous age by radiometric dating. It is suggested here that the age of the base of the Polonez Glaciation, and the Polonez Cove Formation as well, should not exceed 24.5 Ma. The latter date has been obtained from andesite lavas associated with the youngest plant-bearing unit (Mount Wawel plant beds) of the Point Hennequin Group, bearing no traces of glacial climate (BIRKENMAJER *et al.* 1983*b*; ZASTAWNIAK *et al.* 1985). This leaves a bracket of uncertainty of only about one million years and suggests that the onset of continental glaciation in the Antarctic Peninsula sector correlates with latest Oligocene: between 24.5 ± 0.5 and $> 23.6\pm0.3$ Ma.

(3) The development of glacio-marine sediments of the Polonez Cove Formation versus the Cape Melville Formation suggests different palaeobathymetric-palaeofacial zones, the former corresponding predominantly to high-energy, and the latter to low-energy environments. The sedimentological features, and the character of fossil assemblages, indicate that the Polonez Cove glacio-marine strata formed in littoral-shallow-shelf and those of the Cape Melville Formation — in deeper-water, outer shelf environments. Taking into account that both successions have bases undetermined as yet by radiometric dating, and that they pre-date volcanic events $> 23.6\pm0.3$ Ma (Polonez Cove Formation) and 20.1 ± 0.2 Ma (Cape Melville Formation) both very close to the Oligocene/Miocene boundary (22.5 Ma), one could argue that we deal here with only one instead of two (Polonez and Melville) glacial epochs in West Antarctica. The apparent age differences could be the result of inadequate number of dated samples. This problem will probably be solved by further investigations. At present, the author sees arguments in favour of treating the discussed glacio-marine sequences as separate ones, corresponding to two glacial epochs separated by an interglacial-type epoch, close to the Oligocene/Miocene boundary (Table 4).

Added in proof

1) The Lower Miocene age of glacio-marine strata of the Cape Melville Formation has been confirmed by foraminiferal study: BIRKENMAJER, K. and ŁUCZKOWSKA, E., 1987. Foraminiferal evidence for a Lower Miocene age of glacio--marine and related strata, Moby Dick Group, King George Island (South Shetland Islands, Antarctica). — *Stud. Geol. Polonica*, **90**, 81—123.

2) New K-Ar dating of the Legru Bay Group lavas which post-date the Chopin Ridge Group and its Polonez Cove Formation (glacio-marine sediments) at 25.7±1.3 Ma and 29.5±2.1 Ma (BIRKENMAJER, K., DELITALA, M. C., NARĘBSKI, W., NICOLETTI, M. and PETRUCCIANI, C., 1986. Geochronology of Tertiary island-arc volcanics and glacigenic deposits, King George Island, South Shetland Islands, West Antarctica. — *Bull. Polish Acad. Sci.*, Earth Sci., **34**, 257—273) confirmed the Oligocene age of the Polonez Glaciation. It appears now that this glaciation could pre-date the plant-bearing volcanigenic succession of the Point Hennequin Group (Mount Wawel Formation) dated at 24.5±0.5 Ma.

REFERENCES

ADIE, R. J., 1962. The geology of Antarctica. *In*: *Antarctic Research* (H. WEXLER, M. J. RUBIN and J. E. CASKEY, eds). — *Am. Geophys. Union, Geophys. Monogr.*, **7**, 26—39.

— 1964*a*. Geological history. *In*: *Antarctic Research* (R. PRIESTLEY, R. J. ADIE and G. de Q. ROBIN, eds.), 117—162. London.

— 1964*b*. Sea-level changes in the Scotia Arc and Graham Land. *In*: *Antarctic Geology* (R. J. ADIE, ed.), 27—32. North-Holland Publ. Co., Amsterdam.

— 1977. The geology of Antarctica: a review. — *Phil. Trans. Roy. Soc. Lond.*, B, **279**, 123—130.

ANDERSON, J. J., 1965. Bedrock geology of Antarctica. A summary of exploration, 1831—1962. — Ant. Res. Ser. (J. B. HADLEY, ed.), *Geology and Paleontology of the Antarctic*, 1—70.

ANDERSON, J. B., DOMACK, E. W. and KURTZ, D. D., 1980. Observations on sediment-laden icebergs in Antarctic waters: implications to glacial erosion and transport. — *Jour. Glac.*, **25** (93), 387—396.

ANDERSSON, J. G., 1906. On the geology of Graham Land. — *Bull. Geol. Inst. Upsala*, **7** (13—14), 19—71.

ASKIN, R. A. and FLEMING, R. F., 1982. Palynological investigations of Campanian to lower Oligocene sediments on Seymour Island, Antarctic Peninsula. — *Antarct. Jour. U. S.*, **17** (5), 70—71.

BARKER, P. F. and BURRELL, J., 1977. The opening of the Drake Passage. — *Mar. Geol.*, **25**, 15—34.

BARTON, C. M., 1961. The geology of King George Island, South Shetland Islands. — *Prel. Rept Falkd. Isl. Dep. Surv.*, **12**, 1—18.

— 1964. Significance of the Tertiary fossil floras of King George Island, South Shetland Islands. *In*: *Antarctic Geology* (R. J. ADIE, ed.), 603—609. North Holland Publ. Co., Amsterdam.

— 1965. The geology of South Shetland Islands, III. The stratigraphy of King George Island. — *Sci. Repts Brit. Antarct. Surv.*, **44**, 1—33.

BIERNAT, G. , BIRKENMAJER, K. and POPIEL-BARCZYK, E., 1985. Tertiary brachiopods fiom the Moby Dick Group o King George Island (South Shetland Islands, Antarctica). — *Stud. Geol. Polonica*, **81**, 109—141.

BIRKENMAJER, K., 1980*a*. Tertiary volcanic-sedimentary succession at Admiralty Bay, King George Island (South Shetland Islands, Antarctica). — *Ibidem*, **64**, 7—65.

— 1980*b*. Discovery of Pliocene glaciation on King George Island, South Shetland Islands (West Antarctica). — *Bull. Acad. Pol. Sci.*, Terre, **27**, 59—67.

— 1980*c*. Report on geological investigations of King George Island, South Shetland Islands (West Antarctica) in 1978—1979. — *Stud. Geol. Polonica*, **64**, 89—105.

— 1980*d*. A revised lithostratigraphic standard for the Tertiary of King George Island, South Shetland Islands (West Antarctica). — *Bull. Acad. Pol. Sci.*, Terre, **27**, 49—57.

— 1981. Lithostratigraphy of the Point Hennequin Group (Miocene volcanics and sediments) at King George Island (South Shetland Islands, Antarctica). — *Stud. Geol. Polonica*, **72**, 59—73.

— 1982*a*. Pliocene tillite-bearing succession of King George Island (South Shetland Islands, Antarctica). — *Ibidem*, **74**, 7—72.

— 1982*b*. Pre-Quaternary fossiliferous glacio-marine deposits at Cape Melville, King George Island (South Shetland Islands, West Antarctica). — *Bull. Acad. Pol. Sci.*, Terre, **29**, 331—340.

— 1982*c*. Report on geological investigations of King George Island and Nelson Island (South Shetland Islands, West Antarctica), in 1980—81. — *Stud. Geol. Polonica*, **74**, 175—197.

— 1983. Extent and course of the Pliocene glaciations in West Antarctica. — *Bull. Acad. Pol. Sci.*, Teıre, **30**, 9—20.

— 1984. Geology of the Cape Melville area, King George Island (South Shetland Islands, Antarctica): pre-Pliocene glaciomarine deposits and their substratum. — *Stud. Geol. Polonica*, **79**, 7—36.

— 1985. Onset of Tertiary continental glaciation in the Antarctic Peninsula sector (West Antarctica). — *Acta Geol. Polonica*, **35**, 1—31.

— and WIESER, T., 1985. Petrology and provenance of magmatic and metamorphic erratic blocks from Pliocene tillites of King George Island (South Shetland Islands, Antarctica). — *Stud. Geol. Polonica*, **81**, 53—97.

— GAŹDZICKI, A. and WRONA, R., 1983*a*. Cretaceous and Tertiary fossils in glacio-marine strata at Cape Melville, Antarctica. — *Nature* **303**, 56—59.

— NARĘBSKI, W., NICOLETTI, M. and PETRUCCIANI, C., 1983*b*. K-Ar ages of the „Jurassic Volcanics" and „Andean" intrusions of King George Island, South Shetland Islands (West Antarctica). — *Bull. Acad. Pol. Sci.*, Terre, **30** (3—4), 121—131.

—, —, —, — 1983*c*. Late Cretaceous through Late Oligocene K-Ar ages of King George Island Supergroup volcanics, South Shetland Islands (West Antarctica). — *Ibidem*, **30** (3—4), 133—143.

—, PAULO, A. and TOKARSKI, A. K., 1985*a*. Neogene marine tillite at Magda Nunatak, King George Island (South Shetland Islands, Antarctica). — *Stud. Geol. Polonica*, **81**, 99—107.

—, GAŹDZICKI, A. KREUZER, H. and MÜLLER, P., 1985*b*. K-Ar dating of the Melville Glaciation (Early Miocene) in West Antarctica. — *Bull. Polish Ac. Sci.: Earth Sc.*, **33**, 15—23.

— 1985. Pre-Neogene age of the Polonez Glaciation, West Antarctica, by K-Ar dating. — *N. Jb. Geol. Paläont. Mh.*, (in press).

—, —, PUGACZEWSKA, H. and WRONA, R. 1987. Recycled Cretaceous belemnites in Lower Miocene glacio-marine sediments (Cape Melville Formation) of King George Island, West Antarctica. *In*: A. GAŹDZICKI (ed.), Palaeont. Results Polish Antarctic Expeds. I. — *Palaeont. Polonica*, **49**, 49—62.

BITNER, M. A. and PISERA, A., 1984. Brachiopods from „*Pecten* conglomerate" (Polonez Cove Formation, Pliocene) of King George Island (South Shetland Islands, Antarctica). — *Stud. Geol. Polonica*, **79**, 121—124.

BŁASZYK, J. and GAŹDZICKI, A. 1980. Palaeontological studies in the King George Island during the IIIrd Polish Antarctic Expedition of the Polish Academy of Sciences, 1978—1979 (In Polish, English summary). — *Przegl. Geol.* **5**, 297—301.

BUCKMAN, S. S., 1910. Antarctic fossil Brachiopoda collected by the Swedish Polar Expedition, 1901—1903 (with an addendum by J. G. Andersson on the age of the brachiopod yielding beds of Cockburn Island). — *Wiss. Ergebn. Schwed. Südpolarexped.*, 3 (7), 1—43.

CORTEMIGLIA, G. C., GASTALDO, P., and TERRANOVA, R., 1981. Studio di piante fossili trovate nella King George Island delle Isole Shetland del Sud (Antartide). — *Atti Soc. Ital. Sci. Nat., Mus. Civ. Stor. Nat. (Milano)*, **122** (1—2), 37—61.

CRADDOCK, C., BASTIEN, T. W. and RUTFORD, R. H., 1964. Geology of the Jones Mountains area. *In*: *Antarctic Geology* (R. J. ADIE, ed.), 171—187. North-Holland Publ. Co. Amsterdam.

CROOK, K. A. W., 1981. The break-up of the Australian-Antarctic segment of Gondwanaland. *In*: *Ecological Biogeography of Australia* (A. KEARST, ed.), 3—13. W. Junk Publ., The Hague.

DENTON, G. H., PRENTICE, M. L., KELLOGG, D. E. and KELLOGG, T. B., 1984. Late Tertiary history of the Antarctic ice sheet: Evidence from the Dry Valleys. — *Geology*, **12**, 263—267.

DÍAZ, H. and TERUGGI, M., 1956. Contribución a la geológia de la Antártida Occidental. — *Publ. Inst. Antárt. Argent.*, **2**, 77—152.

DUDZIAK, J., 1984. Cretaceous calcareous nannoplankton from glaciomarine deposits of the Cape Melville area, King George Island (South Shetland Islands, Antarctica). — *Stud. Geol. Polonica*, **79**, 37—51.

DUSÉN, P., 1908. Über die tertiäre Flora der Seymour-Insel. — *Wiss. Ergebn. Südpolar Exped.* 1901—1903, **3**, 1—27.

ELLIOT, D. H. and TRAUTMAN, T. A., 1982. Lower Tertiary strata on Seymour Island, Antarctic Peninsula. *In*: *Antarctic Geoscience* (C. CRADDOCK, ed.), 287—297. Wisconsin Univ. Press, Madison, Wis.

— RINALDI, C., ZINSMEISTER, W. J., TRAUTMAN, T. A., BRYANT, W. A. and DEL VALLE, R., 1975. Geological investigations on Seymour Island, Antarctic Peninsula. — *Antarct. Jour. U. S.*, **10**, 182—196.

FLEMING, R. F. and ASKIN, R. A., 1982. Early Tertiary coal bed on Seymour Island, Antarctic Peninsula. — *Antarct. Jour. U. S.*, **17**, 67.

FLEMING, E. A. and THOMSON, J. W., 1979. *British Antarctic Territory Geological Map* 1 : 500 000: Northern Graham Land and South Shetland Islands (Ser. BAS 500 G, Sheet 2, ed. 1). Brit. Antarct. Surv.

FRAKES, L. A., 1979. *Climates throughout geological time.* 310 pp. Elsevier Publ. Co., Amsterdam.

GAŹDZICKA, E. and GAŹDZICKI, A., 1985. Oligocene coccoliths of the *Pecten* Conglomerate, West Antarctica. — *N. Jb. Geol. Paläont. Mh.*, 1985, 727—735.

GAŹDZICKI, A., 1982. Pliocene *Pecten* conglomerate of King George Island (South Shetland Islands, West Antarctica). *4th Int. Symp. Antarct. Earth Sci., (Adelaide), Abstr.*, 66.

— 1984. The *Chlamys* coquinas in glacio-marine sediments (Pliocene) of King George Island, West Antarctica. — *Facies*, **10**, 145—152.

— PUGACZEWSKA, H., 1984. Biota of the „*Pecten* Conglomerate" (Polonez Cove Formation, Pliocene) of King George Island (South Shetland Islands, Antarctica). — *Stud. Geol. Polonica*, **79**, 59—120.

— WRONA, R., 1982*a*. Palaeontological studies carried out during the Vth Antarctic Expedition of the Polish Academy of Sciences (In Polish, English summary). — *Przegl. Geol.*, 2, 57—61.
— 1982*b*. Late Cretaceous and Tertiary fossils from glacio-marine sediments of Melville Peninsula, King George Island, West Antarctica (In Polish, English summary). — *Ibidem*, 8, 399—404.
—, GRADZIŃSKI, R., PORĘBSKI, S. J. and WRONA, R., 1982. Pholadid *Penitella* borings in glaciomarine sediments (Pliocene) of King George Island, Antarctica. — *N. Jb. Geol. Paläont., Mh.*, 12, 723—735.
HENNIG, H., 1911. Le conglomérat pleistocène à *Pecten* de l'île Cockburn. — *Wiss. Ergebn. Schwed. Südpolarexped. 1901—1903*, 3 (10), 1—73.
HOLLAND, R., 1910. The fossil Foraminifera. — *Wiss. Ergebn. Schwed. Südpolarexp.* 1901—1903, 3 (9), 1—12.
JESIONEK-SZYMAŃSKA, W., 1984. Echinoid remains from „*Pecten* conglomerate" (Polonez Cove Formation, Pliocene) of King George Island (South Shetland Islands, Antarctica). — *Stud. Geol. Polonica*, 79, 125—130.
KEMP, E. M., 1981. Tertiary palaeogeography and the evolution of Australian climate. *In*: *Ecological Biogeography of Australia* (A. KEARST, ed.), 33—49. W. Junk Publ., The Hague.
— and BARRETT, P. J., 1975. Antarctic glaciation and early Tertiary vegetation. — *Nature* (Lond.), 258, 507—508.
KENNETT, J. P., 1977. Cenozoic evolution of Antarctic glaciation, the Circum Antarctic Ocean, and their impact on global paleoceanography. — *Jour. Geophys. Res.*, 82, 3843—3860.
— 1980. Paleoceanographic and biogeographic evolution of the Southern Ocean during the Cenozoic, and Cenozoic microfossil datums. — *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 31, 123—152.
—, HOUTZ, R. E., ANDREWS, P. B, EDWARDS, A. R., GOSTIN, V. A., HAJÓS, M., HAMPTON, M., JENKINS, D. G., MARGOLIS, S. V., OVENSHINE, A. T. and PERCH-NIELSEN, K., 1975. 44. Cenozoic paleoceanography in the Southern Pacific Ocean, Antarctic glaciation, and the development of the Circum-Antarctic current. — *Init. Repts DSDP*, 29, 1155—1169.
LECKIE, R. M. and WEBB, P. N., 1983. Late Oligocene — early Miocene glacial record of the Ross Sea, Antarctica: Evidence from DSDP Site 270. — *Geology*, 11, 578—582.
Le MASURIER, W. E. and REX, D. C., 1982. Volcanic record of Cenozoic glacial history in Marie Byrd Land and western Ellsworth Land: revised chronology and evaluation of tectonic factors: *In*: *Antarctic Geoscience* (C. CRADDOCK, ed.), 725—734. Univ. Wisconsin Press, Madison, Wis.
MARGOLIS, S. V. and KENNETT, J. P., 1970. Antarctic glaciation during the Tertiary recorded in Sub-Antarctic deep-sea cores. — *Science*. 170, 1085—1087.
— 1971. Cenozoic paleoglacial history of Antarctica recorded in Subantarctic deep-sea cores. — *Am. Jour. Sci.*, 271, 1—36.
PANKHURST, R. J. and SMELLIE, J. L., 1983. K-Ar geochronology of the South Shetland Islands, Lesser Antarctica: apparent lateral migration of Jurassic to Quaternary island arc volcanic. — *Earth Planet. Sci. Lettr.*, 66, 214—222.
PAULO, A. and TOKARSKI, A. K., 1982. Geology of the Turret Point — Three Sisters Point area, King George Island (South Shetland Islands, Antarctica). — *Stud. Geol. Polonica*, 74, 81—103.
PUGACZEWSKA, H., 1984. Tertiary Bivalvia and Scaphopoda from glaciomarine deposits at Magda Nunatak, King George Island (South Shetland Islands, Antarctica). — *Ibidem.*, 79, 53—58.
RINALDI, C. A., MASSABIE, A., MORELLI, J. and ROSENMAN, H. L., 1978. Geológia de la Isla Vicecomodoro Marambio. — *Contr. Inst. Antárt. Argent.*, 217, 1—44.
RUTFORD, R. H., CRADDOCK, C. and BASTIEN, T. W., 1968. Late Tertiary glaciation and sea-level changes in Antarctica. — *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 5, 15—39.
—, CRADDOCK, C., WHITE, C. M. and ARMSTRONG, R. L., 1972. Tertiary glaciation in the Jones Mountains. *In*: *Antarctic Geology and Geophysics* (R. J. ADIE, ed.), 239—243. Universitetsforlaget, Oslo.
SPJELDNAES, N., 1981. Ice-rafting, an indication of glaciation? — *Science*, 214, 687—688.
STUCHLIK, L., 1981. Tertiary pollen spectrum from the Ezcurra Inlet Group at Admiralty Bay, King George Island (South Shetland Islands, Antarctica). — *Stud. Geol. Polonica*, 72, 109—132.
THOMSON, M. R. A., 1977. An annotated bibliography of the paleontology of Lesser Antarctica and the Scotia Ridge. — *N. Zeal. Jour. Geol. Geophys.*, 20 (5), 865—904.
TOKARSKI, A. K., PAULO, A. and RUBINOWSKI, Z., 1981. Report on geological investigations of King George Island, South Shetland Islands (West Antarctica), in 1979—1980. — *Stud. Geol. Polonica*, 72, 133—140.
WATTS, D. R., 1982. Potassium-argon ages and paleomagnetic results from King George Island, South Shetland Islands. *In*: *Antarctic Geoscience* (C. CRADDOCK, ed.), 255—261. Univ. Wisconsin Press, Madison, Wisc.
WEBB, P. N., 1981. Late Mesozoic-Cenozoic geology of the Ross Sector, Antarctica (extended abstract). — *Jour. Roy. Soc. N. Z.*, 11 (4), 439—446.
— 1983*a*. A review of Late Cretaceous — Cenozoic stratigraphy, tectonics, paleontology and climate in the Ross sector, Antarctica. — *In*: *Antarctic Earth Sciences* (R. L. OLIVER, P. R. JAMES and J. B. JAGO, eds.), 545, Canberra.
— 1983*b*. Climatic, palaeo-oceanographic and tectonic interpretation of Palaeogene — Neogene biostratigraphy from MSSTS-1 drillhole, McMurdo Sound, Antarctica. *In*: *Antarctic Earth-Sciences* (R. L. Oliver, P. R. JAMES and J. B. JAGO, eds), 560. Canberra.

WEBB, P. N., HARWOOD, D. H., MCKELVEY, B. C., MERCER, J. H. and STOTT, L. D., 1984. Cenozoic marine sedimentation and ice-volume variation on the East Antarctic craton. — *Geology*, **12**, 287—291.

WEISSEL, J. K., HAYES, D. E. and HERRON, E. M., 1977. Plate tectonic synthesis: The developments between Australia, New Zealand and Antarctica since the Late Cretaceous. — *Mar. Geol.*, **25**, 231—277.

WELTON, B. J. and ZINSMEISTER, W. J., 1980. Eocene Neoselachians from the La Meseta Formation, Seymour Islands, Antarctic Peninsula. — *Contr. Sci. Nat. Hist. Mus. Los Angeles County*, **329**, 1—10.

WOODBURNE, M. O. and ZINSMEISTER, W. J., 1982. Fossil land mammal from Antarctica. — *Science*, **218**, 284—286.

ZASTAWNIAK, E., 1981. Tertiary leaf flora from the Point Hennequin Group of King George Island (South Shetland Islands, Antarctica). Preliminary report. — *Stud. Geol. Polonica*, **72**, 97—108.

—, WRONA, R., GAŹDZICKI, A. and BIRKENMAJER, K., 1985. Plant remains from the top part of the Point Hennequin Group (Upper Oligocene), King George Island (South Shetland Islands, Antarctica). — *Ibidem*, **81**, 143—164.

ZINSMEISTER, W. J., 1978. Biostratigraphic Datum-planes of Pacific Neogene. — *IGCP, Project* **114**, *3rd Work. Gp Meet.* (June 26—28, 1978). Stanford, Calif., 2 pp.

— 1982. Review of the Upper Cretaceous — Lower Tertiary sequence on Seymour Island, Antarctica. — *Jour. Geol. Soc.* (*Lond.*), **139**, 779—786.

— and WEBB, P. N., 1982. Cretaceous — Tertiary geology and paleontology of Cockburn Island. — *Antarct. Jour. U. S.* **17**, 41—42.

ADDITIONAL REFERENCES — COCCOLITHS

BAUMANN, P., 1970. Mikropaläontologische und stratigraphische Untersuchungen der obereozänen-oligozänen Scaglia im zentralen Apenin (Italien). — *Ecl. geol. Helvetiae*, **63**, 1133—1211.

GARTNER, S., 1977. Nannofossils and biostratigraphy: An overview. — *Earth-Sci. Rev.*, **13**, 227—250.

LORD, A. R. (ed.) *et al.*, 1982. A stratigraphical index of calcareous nannofossils. *Brit. Micropal. Soc. Ser. London.*

MARTINI, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. — *Proc. II Plankt. Confer.* (*Roma, 1970*). II, 739—777. Ediz. Tecnoscienza, Roma.

— 1980. Oligocene to Recent calcareous nannoplankton from the Philippine Sea, Deep Sea Drilling Project Leg. 59. — *Init. Repts DSDP*, **59**, 547—565. Washington, D. C.

MÜLLER, C., 1978. Remarks on biostratigraphic useful nannofossils in the Paleogene of the northern hemisphere. — *Newsletter Stratigr.*, **7**, 45—52.

RADE, J., 1977. Tertiary biostratigraphic zonation based on calcareous nannoplankton in eastern Australia nearshore basins. — *Micropaleont.*, **23** (3), 270—296.

REINHARDT, P., 1970. Synopsis der Gattungen und Arten der mesozoischen Coccolithen und anderer kalkiger Nannofossilien, Teil I. — *Freib. Forschungsh.*, **C 260**, 5—30.

ROTH, P. H., 1970. Oligocene calcareous nannoplankton biostratigraphy. — *Ecl. geol. Helvetiae*, **63**, 799—881.

EXPLANATIONS OF THE PLATES 1—4

PLATE 1

Polonez Cove and Chopin Ridge as seen from Low Head. Mazurek Point Formation (basalts) at sea level; prominent cliffs in the lower part of slope formed by the Polonez Cove Formation (glacio-marine strata); weathered lavas of the

Boy Point Formation above the cliffs; agglomerates and conglomerates of the Wesele Cove Formation — top left and right; basaltic dyke of the Cape Syrezol Group cutting through the whole Chopin Ridge Group — top middle part of photo.

photo: A. Gaździcki, 1979

PLATE 2

1. Palaeozoic limestone dropstone in conglomerates of the Low Head Member, Polonez Cove Formation.

photo: A. Gaździcki, 1979

2. Basaltic stacks of the Mazurek Point Formation at Three Sisters Point.

photo: A. Gaździcki, 1981

PLATE 3

1. Magda Nunatak: glacio-marine deposits exposed at the base of cliff just above talus (bottom, left); basaltic lava underlain by hyaloclastite forms the cliff.

photo: A. Gaździcki, 1981

2. Top platform, about 200 m a. s. l. of Melville Peninsula close to Crab Mound. Scattered dropstones weathered out of the Cape Melville Formation visible on the platform. Quaternary stratocone of Melville Peak in the background.

photo: R. Wrona, 1981

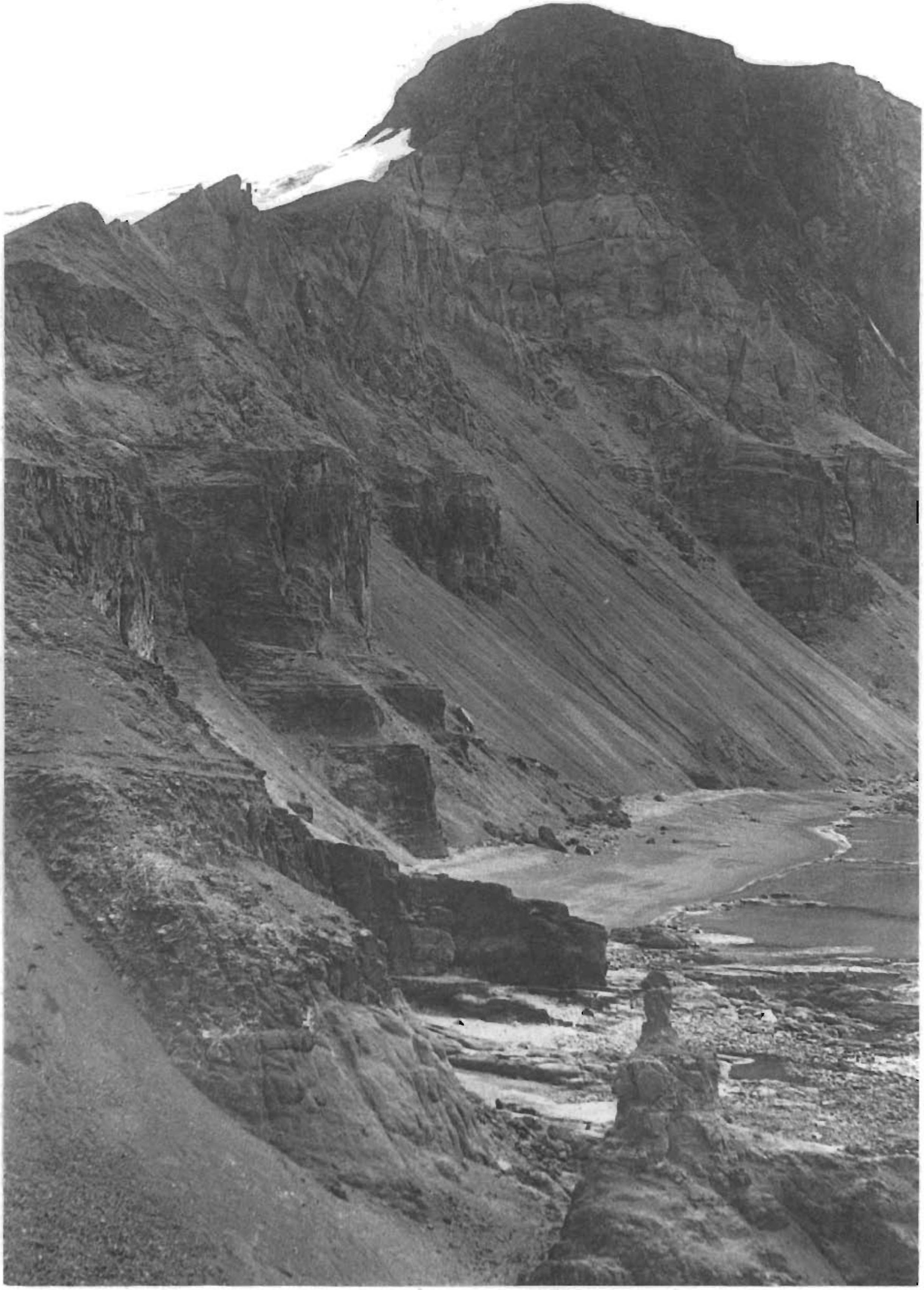
PLATE 4

1. Vertical northern cliff face of Melville Peninsula exposing about 200 m of well stratified, nearly horizontal Cape Melville Formation, cut by numerous thin vertical andesite dykes. Melville Peak (Quaternary stratcone) in the background.

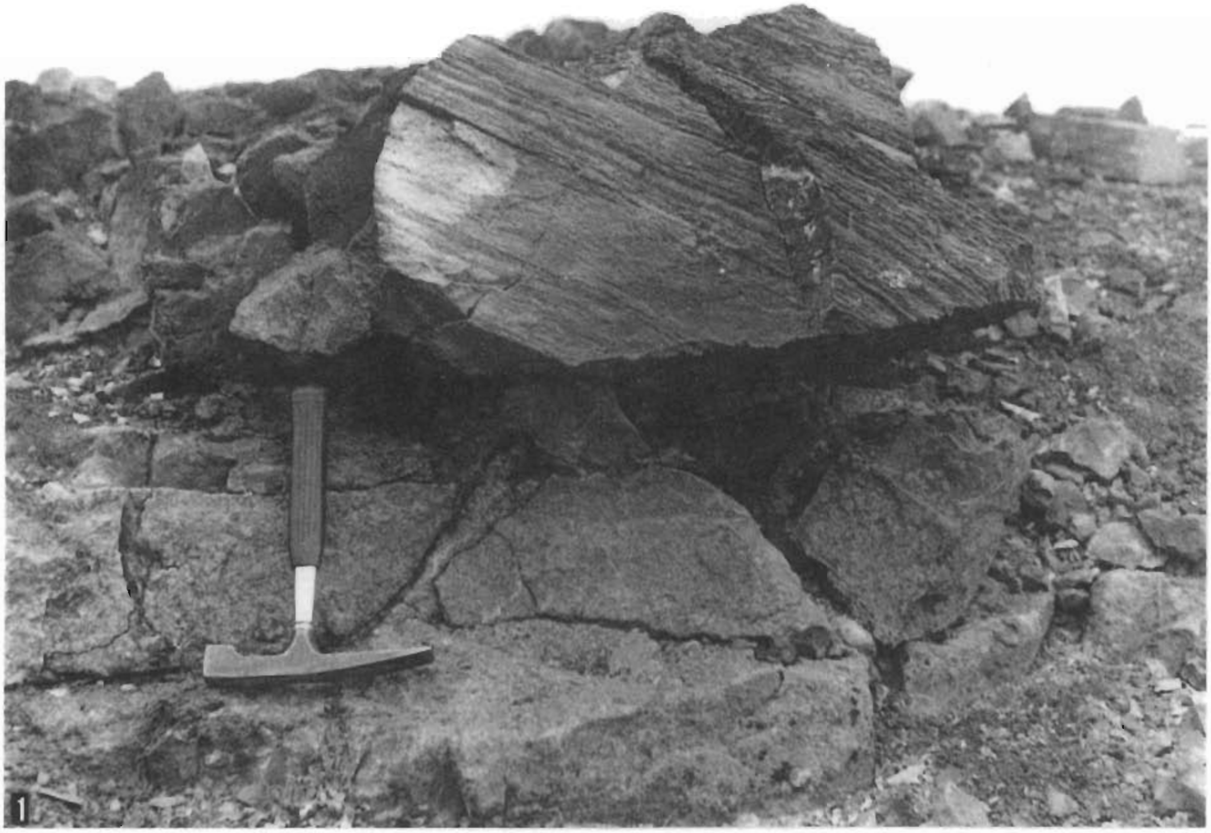
photo: A. Gaździcki, 1981

2. Wrona Buttress, exposure of the Destruction Bay Formation. Large-scale cross-sets visible in middle part of cliff.

photo: A. Gaździcki, 1981



K. Birkenmajer: Tertiary Sequences Of King-George Island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K. BIRKENMAJER: TERTIARY SEQUENCES OF KING-GEORGE ISLAND