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Pre-Quaternary glaciations of West Antarctica: evidence from the South Shetland Islands*)

ABSTRACT: Three major pre-Quaternary glaciations have been recognised on King George Island. South Shetland Islands (West Antarctica). The oldest is the Melville Glaciation evidence by fossiliferous glaciomarine sediments. Presence of numerous belemnites and Cretaceous calcareous nannoplankton suggested at first a late Cretaceous age. However three is an increasing evidence that these Cretaceous fossils are recycled and occur in late Tertiary (?Miocene) strata.

Two glaciations separated with an interglacial have been recognised in a thick Pliocene sequence of laves and sediments. The older Polonez Glaciation is represented by continental-type tillites succeeded by glaciomarine sediments with **Chlamys anderssoni** fauna. Acidic volcanic activity, coarse-clastic sedimentation and subaerial erosion characterise a mid-Pliocene Wesele Interglacial succeeding the Polonez Glaciation. Andesitic laves and lahars cut by glacially eroded valleys with strongly diagenesized tillites represent the youngest, late-Pliocene Legru Glaciation.

Key words: Antarctica, pre-Quaternary glaciations.

1. Introduction

Much record of Cenozoic climatic history of Antarctica is hidden under continental ice-sheet. Apart from Transantarctic Mountains, it is mainly along narrow ice-free margins of the continent and of island groups adjucent to it that Tertiary tillites and other scattered evidences of past glaciations

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emerge. The South Shetland Islands (Figure 1) occupy a privileged position in this respect abounding in evidence of three separate late Cenozoic glacial epochs preceding the Quaternary glaciation: the oldest Melville Glaciation, the Polonez Glaciation, and the youngest Legru Glaciation (Birkenmajer, 1980b, 1982a-c, 1983). Moreover, lahr-type agglomerates present in the ?Eocene through Miocene sequence (King George Island Supergroup) may, at least partly, be regarded as evidences for local ice-caps on tops of larger stratocones (Birkenmajer, 1980a), preceding a major continental glaciation.

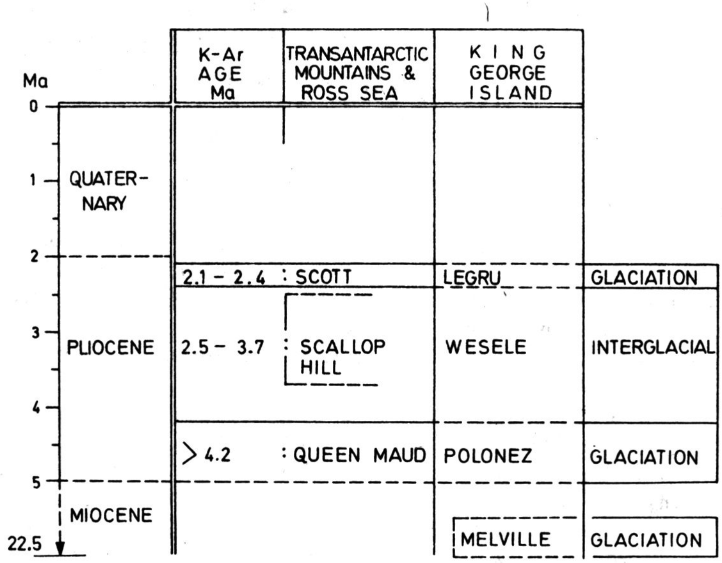

Fig. 1. Location of pre-Quaternary glacial and glaciomarine deposits on King George Island

2. Pre-Pliocene glacial event

2.1. Melville Glaciation

The oldest fossiliferous glaciomarine sediments have been recognised at Cape Melville, King George Island (Birkenmajer, 1982b, c, 1983), in a complex previously described as layered volcanics (Barton, 1961, 1965) containing poorly preserved bivalve **Malletia** sp. showing affinities to Miocene species of southern South America (Zinsmeister, 1978). The whole succession underlying Quaternary volcanics (Penguin Island Group), has been distinguished as the Moby Dick Group and subdivided in three formations (Birkenmajer, 1982a, c, 1983) — Figure 2. The lower Sherratt Bay Formation consists of olivene-augite basalt lava sheet more than 60 m thick, extruded under subaerial conditions. The middle Destruction Bay Formation consists of reworked basaltic material in form of large-scale cross-badded tuffs and psammites, sometimes with horizons rich in marine invertebrates: bivalves (abundant, often in life position), gastropods, solitary corals, and brachiopods **in situ,** and with belemnites [recycled?]. Channelling and megaripple arrangement of cross-stratified sets are indicative of near-shore environment, scarce conglomerate intercalations contain pebbles of Antarctic continent provenance. The formation is between 40 and 110 m thick, wedging out towards the east to null. No indications of glacial climate were found, while occurrence of carbonized wood fragments in cross-stratified units may indicate climatic conditions favourable for vascular plant growth on Antarctic continent.

2.1.1. Glaciomarine strata

The Cape Melville Formation, about 200 m thick, represents mainly glaciomarine sediments, with the exception of discontinuous conglomeratic sandstone at its base. The formation rests conformably but without transition upon the Destruction Bay Formation in the western part of the area, coming into direct contact with weathered basalt of the Sherratt Bay Formation on the east (Figure 2). The Cape Melville sediments consist

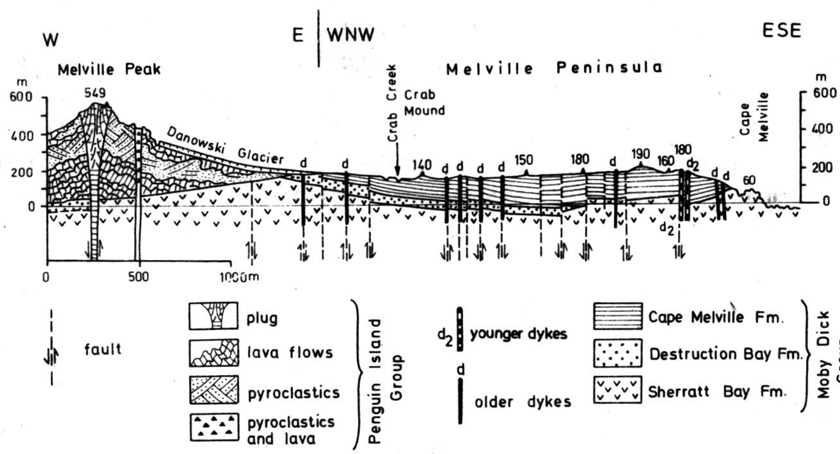

Fig. 2. Geological cross-section of the Cape Melville area

of grey to green, brownish and black shale and silty shale, with subordinate siltstone, fine-grained sandstone and thin marl intercalations. Usually unworked, often glacially-striated blocks up to 1.5 m in diameter are randomly scattered within the sediment. These magmatic, metamorphic and sedimentary blocks resemble rocks known from Antarctic Peninsula, Ellsworth Mountains and Pensacola-Theron Mountains. They have been interpreted as dropstones iceberg-rafted from the Antarctic continent during the Melville Glaciation (Birkenmajer, 1982b, c, 1983).

2.1.2. Fossils

The Cape Melville Formation is rich in marine fossils, predominatly invertebrates (Birkenmajer, **op. cit.**, Gaździcki & Wrona, 1982a, b), not yet fully elaborated. The macrofossils are represented by solitary corals of the genus **Flabellum** (abundant, usually in life position), serpulids, polychaetes (genera **Glycera** and **Ophryotrocha**), bivales (abundant, often in life position), gastropods (common), scaphopods, crabs of the family Majidae (abundant, often very well preserved) and crab-made burrows, echinoids and asteroids, bryozoans, and belemnites (common, especially in an upper part of the formation). Vertebrates are represented by fish fragments preserved in crab burrows.

Microfossils include calcareous and arenaceous foraminifers, i.a. large tests of the genus **Cyclammina**, moreover small foraminifera of the genera **Pullenia**, **Uvigerina** etc., scacre diatoms (mainly of the genus **Conscinodiscus**), chrysomonad cysts and silicoflagellates (e.g., of the genus **Distephanus**).

Calcareous nannoplankton (Dudziak, 1982; Gaździcki & Wrona, 1982a, b) is represented by poorly preserved Cretaceous forms: **Cribrosphaerella ehrenbergi** (Arkhangelsky), **Kamptnerius magnificus** Deflandre, **Discorhabdus biradiatus** (Worsley), **Marthasterites furcatus** Deflandre, **M. inconspicuus** Deflandre, **Rucinolithus irregularis** Thierstein, **Tetralithus malticus** Worsley, **T. pyramidus** Gardet, **T. obscurus** Deflandre, **T. gothicus** Deflandre, **Corollithion exiguum** Stradner, **C. achylosum** (Stover), **Hayesites albiensis** Manivit, **Prediscosphaera cretacea** (Arkhangelsky) etc.

2.1.3. Age

The presence of Cretaceous nannoplankton together with belemnites would indicate a Cretaceous (late Cretaceous) age of the Cape Melville Formation, and the Melville Glaciation as well, in case these fossils were **in situ** (Birkenmajer, 1982b, c; Gaździcki & Wrona, 1982a). However there is a growing suspicion that these two fossil groups are recycled, supplied to the Cape Melville Formation basin from an unknown source by ice-rafting during a Tertiary glaciation (Birkenmajer, 1983). There occur some foraminifer genera in our sediment which do not appear prior to base Tertiary, and some comparable glaciomarine deposits on King George Island contain poorly preserved Tertiary discoasters together with Cretaceous coccoliths (Dudziak, 1983; Birkenmajer, 1983). Moreover, Miocene affinities of some specimens of bivalve genus **Malletia** from our deposits have been suggested (Zinsmeister, 1978).

It should be also remembered that neither marine Upper Cretaceous (Campanian — Maastrichtian) Marambio Group (Rinaldi **et al.**, 1978; Del Valle & Medina, 1980), nor Paleocene — Lower Oligocene Seymour Island Group sediments (Elliot **et al.**, 1975; Elliot & Trautman, 1977; Rinaldi **et al.**, 1978) in the James Ross Island Basin supplied any evidence for contemporaneous glaciation in West Antarctica.

The sediments of the Melville Glaciation pre-date those of the Pliocene Polonez Glaciation (Birkenmajer, 1982a, 1983). Considering the fact that the maximum West Antarctic glaciation occurred during the latest Miocene and early Pliocene time (e.g., Kennett **et al.**, 1975; Craddock & Hollister, 1976; Kennett, 1977, 1978), and that erratic spectra of both the Melville and Polonez glaciations are very similar suggesting similar drift-paths and denudation level in mainland Antarctica, a Miocene age for the former glaciation should seriously be considered (Birkenmajer, 1983).

3. Pliocene glacial and interglacial events

3.1. Polonez Glaciation

Tillites and fossiliferous glaciomarine strata (with "**Pecten** conglomerate") of the Polonez Cove Formation, well exposed along the southern coast of King George Island (Figure 1) supply good evidence for a Pliocene Polonez Glaciation (Birkenmajer, 1980b, 1982a, b, d).

3.1.1. Substratum

The substratum of glacigenic deposits is formed by basaltic-andesitic lava sheet of the Mazurek Point Formation (**op. cit.**), sometimes with poorly preserved leaf imprints in intervening tuffs (Paulo & Tokarski, 1982). Upper surface of volcanic complex immediately below the overlying matrine conglomerate of the Polonez Cove Formation (Low Head Member) is usually strongly weathered and brecciated — Figure 3. Deep erosional sculpturing of basaltic lava occurs below glacifluvial tillites (Birkenmajer, 1980b, 1982a), **roches moutonnées** and glacial grooves have been found below ground moraine tillites in case of hard basalt substratum (Tokarski **et al.**, 1981; Paulo & Tokarski, 1982) but are absent in case of soft weathered basalt bottom (Birkenmajer, 1980b, 1982a).

3.1.2. Tillites.

Ground moraine and glacifluvial-type tillites occur discontinously at the base of glaciomarine strata of the Polonez Cove Formation. The first

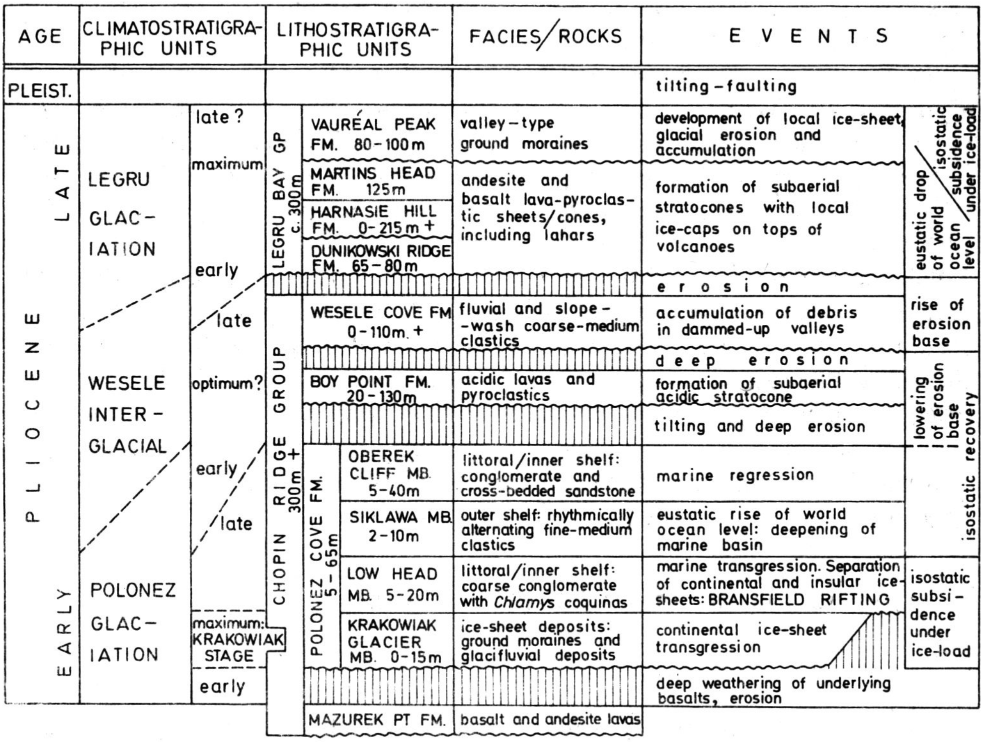

Fig. 3. History of Pliocene glaciations and interglacial epoch on King George Island

type is a massive mixtite lacking preferred orientation, sorting and grading of mainly unworked blocks which are up to 2 m in diameter. The second-type tillite is a stratified mixtite predominantly with poorly roundded blocks up to 2 m across, showing poor sorting and indictinct preferred orientation in large-scale, rather chaotic cross-sets. Both tillites usually show predominance of erratic material of distant origin, derived from Antarctic continent (Antarctic Peninsula, Ellsworth, Pensacola and Theron Mts), which often shows glacial striae and facetted surfaces, over local material.

3.1.3. Glaciomarine strata

The glaciomarine strata begin with coarse basaltic conglomerate (Low Head Member) often with **Chlamys** coquinas ("**Pecten** conglomerate" of Barton, 1961, 1965) which is followed by finer-grade sandstone, siltstone and shale (Siklawa Member), and by regressive large-scale cross-bedded conglomerates and sandstones (Oberek Cliff Member). Presence of numerous, largely unworked erratic blocks of distant origin (derived from Antarctic continent) in form of randomly distributed ice-rafted dropstones up to 1.5 m across, often glacially striated and facetted, is a good evidence of glaciomarine character of the deposits.

3.1.4. Fossils

The fossils occur in the whole glaciomarine succession of the Polonez Cove Formation, being most common in its basal Low Head Member. It yielded (Goździcki & Pugaczewska, 1983): coccoliths of the genus **Discoaster** (single), single diatoms of the genus **Coscinodiscus**, chrysomonad cystts (rare), scarce planktonic foraminifers of the genera **Globigerina** and **Globorotalia**, abundant benthonic foraminifera of the families Miliolidae (mainly genus **Pyrgo**), Nodosariidae (genera **Nodosaria** and **Lagena**), Glandulinidae (mainly genus **Parafissurina**) and Elphidiidae (genus **Parellina**), frequent worms (genera **Serpula** and **Spirorbis**), abudant bryozoans represented by 49 species belonging mainly to the genera **Heteropora**, **Cellaria**, **Sertella**, **Holoporella** and **Pasythea**, rare brachiopods (genera **Cryptopora**, **Neothyris**, **?Magellania** resp. **?Lithyrella**), abundant bivalves represented by 28 species with the most common **Chlamys anderssoni** (Hennig), **Venus newtoni** Wilckens and the genera **Limopsis** and **Panopea**, frequent gastropods represented by 11 species with the most common **Nassa**, **Acteon** and **Polinices**, frequent ostracods (genera **Kangarina**, **Bradleya**, **Buntonia** and **Idiocythere**), frequent crinoids, rare ophiuroids, and rare ephiunoids (genera **?Notocidaris** and **?Sterechinus**).

3.1.5. Age

The fauna listed above resembles to great extent that of Andersson's (1906) "**Pecten** conglomerate" from Cockburn Island, and seems to confirm a Pliocene (Gaździcki & Pugaczewska, 1983) and not Pleistocene (Hennig, 1911) age of the sediment. A pre-Quaternary age of glaciomarine sediments is also suggested by their strong lithification, and by high altitudes of occurrence — up to about 300 m above the sea. Lower position of other exposures, down to sea level, is due to downfaulting of Pliocene strata in the direction of Bransfield Strait during Quaternary (Birkenmajer, 1982a).

3.1.6. Wesele Interglacial

Glaciomarine sediments of the Polonez Cove Formation are capped by acidic lavas and pyroclastics of the Boy Point Formation, and those by a complex of fluvial, large-scale cross-bedded edgewise conglomerate, agglomerate and psammite, with boulder lag concentrates and channel-fill structures. These deposits have formed during a warmer climatic epoch called the Wesele Interglacial after the Wesele Cove Formation. Their clastics derived from immediate substratum.

The fluvial deposition had been preceded by short, very intense erosion resulting in deeply incised V-shaped valleys cutting through underlying volcanics down to the Polonez Cove Formation (Birkenmajer, 1980b, 1982a, d).

3.1.7. Legru Glaciation

The whole Legru Bay Group formed under glacial conditions during a late Pliocene (resp. late Pliocene — ?early Pleistocene) glacial epoch called the Legru Glaciation. The group consists of andesitic, subordinately basaltic lavas and pyroclastics, alternating with coarse, lahar-type agglomerate and edgewise conglomerate. This stratiform complex is dissected by narrow U-shaped valleys radiating from a local centre in southern part of King George Island. The valleys are filled with very coarse, strongly diagenesized tillites with blocks of local provenance, showing numerous evidences of contemporaneous glacial climate: ice-wedges, frost-split blocks etc. This was a valley-type insular glaciation of the South Shetland Islands separated from the continental ice-sheet by the Bransfield Strait (Birkenmajer, op. cit.).

4. Correlation

Contrary to fossiliferous glacigenic deposits of the Melville and the Polonez glaciations, there are no palaeontological data available from the deposits of either the Wesele Interglacial or the Legru Glaciation. These climatostratigraphic units are belived to represent mid-Pliocene and late-Pliocene (resp. late Pliocene — ?early Pleistocene) events respectively (Figure 3).

Figure 4 presents an attempt at correlating Pliocene glacial and interglacial epochs between the Transantarctic Mountains — Ross Sea sector and the King George Island area. Two pre-Pleistocene glaciations recognised in Transantarctic Mountains, the older Queen Maud Glaciation and the younger Scott Glaciation (Mayewski, 1975) may correlate with the Polonez Glaciation and the Legru Glaciation respectively. The Wesele Interglacial may correlate with the Scallop Hill Interglacial represented by "**Pecten** gravels" with **Chlamys tuftsensis** (Webb, 1972; Bull & Webb, 1973; Calkin & Bull, 1974).

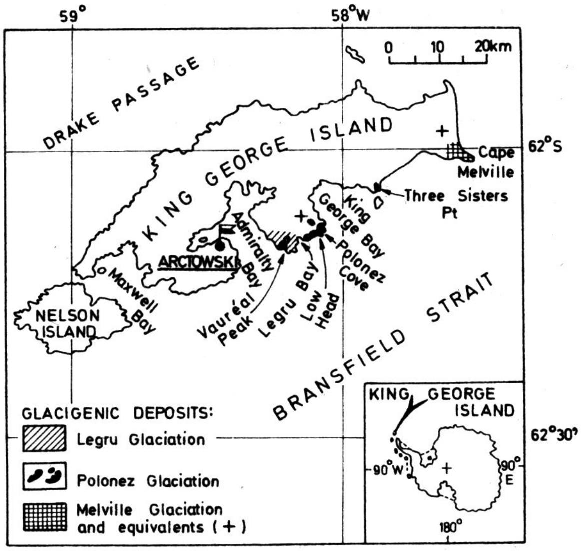

Fig. 4. Tentative correlation of Tertiary glacial-interglacial epochs of King George Island and Transantarctic Mountains — Ross Sea area

5. Резюме

На острове Кинг Джордж на южных Шетландах (западная Антарктика) установлено три крупных дочетвертичных оледенения. Наиболее древнее оледенение — это мельвиль, во время которого образовались гляциально-морские отложения, заключающие богатую фауну. Наличие многочисленных белемнитов и мелового известкового наннопланктона заставляла предполагать позднемеловой возраст отложений. Однако дальнейшие исследования указывают, что меловые окаменелости залегают на вторичном ложе, а заключающие их отложения могут быть отнесены к поздне-третичному (миоценовому?) времени.

Два оледенения разделенные межледниковьем, обнаружены в мощном комплексе лав и плиоценовых отложений. Более древнее оледенения полонез представлено тиллитами континентального типа. Над ними появляются ледниково-морские отложения с фауной комплекса Chlamys anderssoni Во время межплиоценового межледниковья веселе отлагались кислые лавы и континентальные крупнообломочные осадки, шла интенсивная эрозия под воздействием текущих вод. Андезитовые лавы и селевые отложения, расчлененные гляциальными долинами, которые заполнены тиллитами, образовались во время наиболее молодого позднеплиоценового оледенения легру.

6. Streszczenie

Na Wyspie King George w Szetlandach Południowych (Zachodnia Antarktyka) wyróżniono trzy większe zlodowacenia przedczwatrorzędowe. Najstarszym jest zlodowacenie Melville, w czasie którego utworzyły się osady morsko-glacjalne z bogatą fauną głównie bezkręgowców. Obecność licznych belemnitów i kredowego nannoplanktonu wapiennego sugerowała początkowo wiek późnokredowy tych osadów. Dalsze badania wskazują jednak, że skamieniałości kredowe występują na wtórnym złożu, a same osady glacigeniczne mogą być wieku młodotrzeciorzędowego (mioceńskiego?).

Dwa zlodowacenia rozdzielone okresem interglacjalnym rozpoznano w grubym kompleksie law i osadów wieku plioceńskiego. Starsze zlodowacenie Polonez reprezentują tillity typu kontynentalnego, nad którymi pojawiają się osady morsko-glacjalne z fauną bezkręgowców zespołu z **Chlamys anderssoni**. W czasie śródplioceńskiego interglacjału Wesele tworzyły się kwaśne lawy i osady lądowe gruboklastyczne, zachodziła też na dużą skalę erozja pod wpływem wód płynących. W czasie najmłodszego, późnoplioceńskiego zlodowacenia Legru, utworzyły się pokrywy law andezytowych i laharów rozcięte przez doliny glacjalne wypełnione tillitami.

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