Journal of the Royal Society of New Zealand

ISSN: 0303-6758 (Print) 1175-8899 (Online) Journal homepage: https://www.tandfonline.com/loi/tnzr20

Precambrian rocks of the Ross Sea region

G. W. Grindley

To cite this article: G. W. Grindley (1981) Precambrian rocks of the Ross Sea region, Journal of the Royal Society of New Zealand, 11:4, 411-423, DOI: 10.1080/03036758.1981.10423331

To link to this article: https://doi.org/10.1080/03036758.1981.10423331

Published online: 09 Feb 2012.

© *Journal of the Royal Society of New Zealand,*
Volume 11, Number 4, pp. 411-423, 3 figs.

Precambrian rocks of the Ross Sea region

G. W. Grindley*

Precambrian rocks of at least two orogenic cycles form the basement of the Transantarctic Mountains between the Ross and Weddell Seas. Precambrian basement rocks also outcrop in Marie Byrd Land and in the intervening Ross Sea depression.

In the central Transantarctic Mountains, the Beardmore Group comprises folded metagreywackes overlying shallow-water calcareous and quartzitic metasediments. In the Queen Maud and Thiel Mountains, similar metagreywacke terrains underlie and are intruded by silicic ignimbrite and quartz porphyry. Folded metagreywacke associations in northern Victoria Land and in Marie Byrd Land are tentatively correlated on the basis of late Proterozoic acritarch assemblages. The Beardmore Group and southern equivalents were deformed, metamorphosed and intruded by granites before the deposition of shallow-water Lower Cambrian carbonate and clastic sequences.

Precambrian metamorphic complexes in the Transantarctic Mountains have undergone polyphase deformation and metamorphism. Migmatization is widespread and has given rise to late Precambrian – Ordovician anatectic granitoids. Both Rb/Sr and K/Ar radiogenic systems have remained open during the latest Precambrian and Cambro-Ordovician orogenic episodes, giving rise to numerous reset radiometric ages in the 700 – 450 m.y. interval.

An earlier Precambrian history is recognised in the Nimrod Group of the central Transantarctic Mountains, where an Archaean (c. 2800 m.y.) source terrain provided detritus to an early Proterozoic sedimentary suite.

The apparent eastward displacement of late Precambrian – Cambrian? metasediments from the McMurdo Sound region to the central Ross Sea has been interpreted as a result of transform faulting and spreading in the Byrd Basin during the separation of the Marie Byrd Land block of West Antarctica from East Antarctica.

INTRODUCTION

Precambrian rocks of at least two orogenic cycles form the exposed basement of the Transantarctic Mountains between the Ross and Weddell Seas, and the Ford and Fosdick Ranges of western Marie Byrd Land (Figs. 1 and 2). Geophysical data (Davey, this volume) and numerous radiometric age determinations have made it increasingly evident that both East and West Antarctica are underlain by Precambrian basement terrains. Drilling in Antarctic waters (DSDP Leg 28 – Ford and Barrett, 1975) has also led to the discovery of a submerged Precambrian or Cambrian metamorphic basement in the intervening Ross Sea depression.

Before 1956, the Transantarctic Mountains were commonly regarded as an upfaulted Precambrian basement block (the "Great Antarctic Horst" of the early expeditions) capped by the flat-lying cover of the Beacon Sandstone and intercalated dolerite sills. Erratics of Archaeocyatha-bearing limestone had been collected from moraines in the upper Beardmore Glacier, establishing the presence of an Early Cambrian sequence. Because of their lower metamorphic grade, the Cambrian limestones were generally considered an early marine phase of the Beacon Sandstone, and not a part of the metamorphic basement (Fig. 3).

* N.Z. Geological Survey, DSIR, Box 30-368, Lower Hutt, New Zealand.

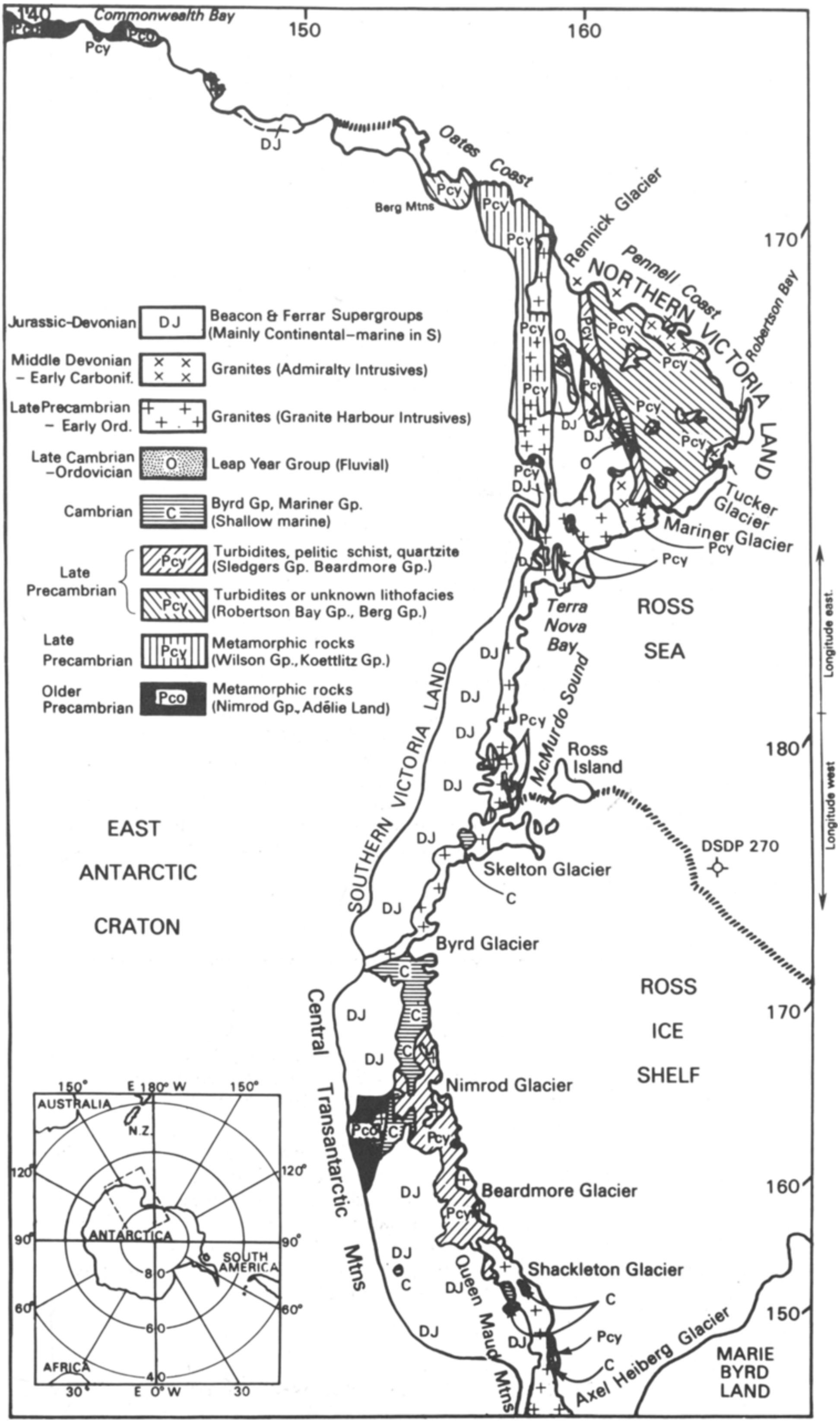

Fig. 1 — Generalised geological map of the western Ross Sea region showing distribution of Precambrian rocks.

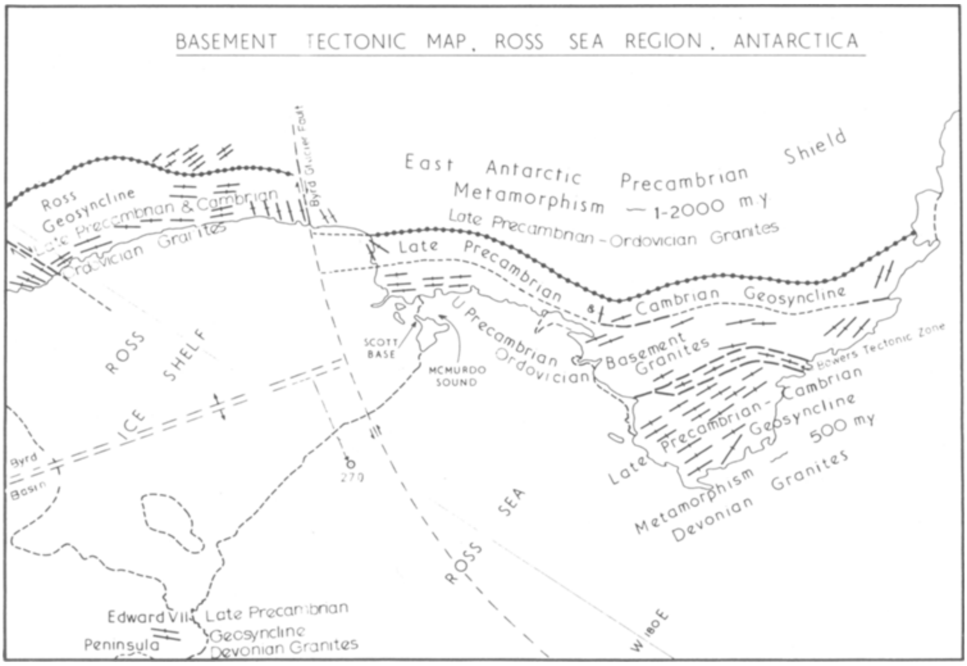

Fig. 2 — Basement tectonic map of the Ross Sea region showing late Precambrian — early Palaeozoic orogenic belts and their possible relationships to the East Antarctic Precambrian Shield. Generalized strike of tectonic structures indicated. Positions of possible Byrd Basin spreading ridge and Ross Sea transform fault from geophysical data (Davey, this volume).

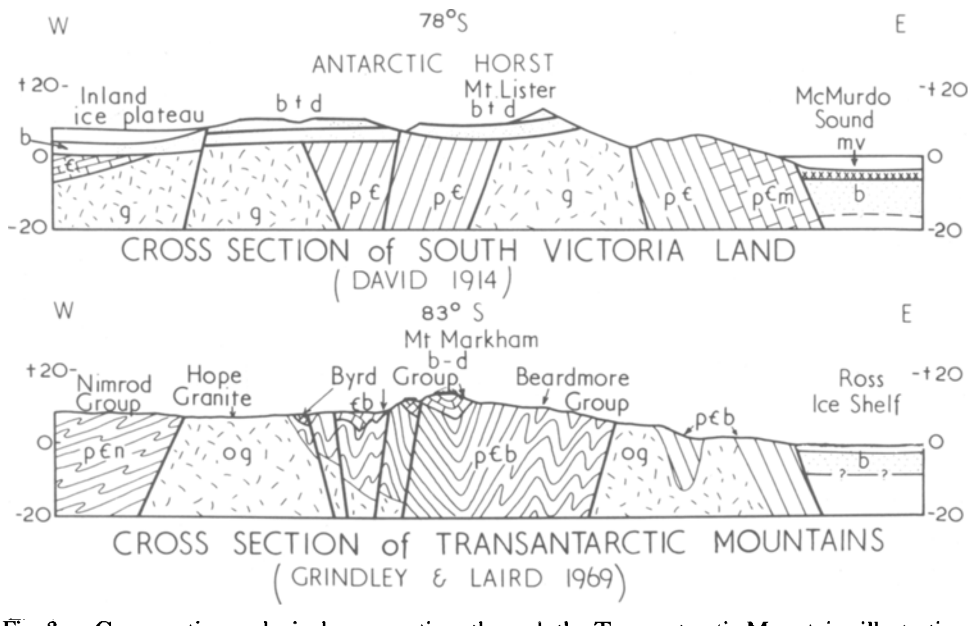

Fig. 3 — Comparative geological cross sections through the Transantarctic Mountains illustrating stratigraphic and structural concepts held during the early exploration phase (David and Priestley, 1914) and the later exploration phase (Grindley and Laird, 1969). b-d = Beacon Group + Ferrar dolerite. pcm = Precambrian marble. g = granite. og = Ordovician granite. pc = Precambrian. c = Cambrian. mv = McMurdo Volcanics. Scale in thousands of feet.

During and after the IGY the position of the Cambrian limestones as an integral part of the basement was firmly established in the Beardmore – Nimrod – Byrd region (Grindley and Laird, 1969, for references). An underlying sequence of unfossiliferous metagreywackes (Beardmore Group) was also recognised at this time and later shown to be unconformable below the Cambrian limestone sequence (Laird *et al.,* 1971). During the decade following the IGY late Precambrian metagreywackes were mapped throughout the Transantarctic Mountains, receiving a variety of local lithostratigraphic names. All were included in the Ross Supergroup of Grindley and Warren (1964) and appear on the series of 1:1 000 000 scale geological maps published by the American Geographical Society (Bushnell and Craddock, 1969). The Ross Supergroup also included the overlying Cambrian sequences and was defined as the deposits of a series of closely-linked geosynclinal basins of deposition that formed along the present site of the Transantarctic Mountains. The related term "Ross Geosyncline" has also been used with a similar but less formal connotation, (e.g., Harrington *et al.,* 1967).

The publication of the AGS geological maps in 1969 marked the end of the exploration phase in Antarctic geology. During the succeeding decade, New Zealand field parties in the Transantarctic Mountains and elsewhere (e.g. Marie Byrd Land) investigated the geology of critical areas in more detail. These areas include the McMurdo Sound region, northern Victoria Land and Marie Byrd Land. Geological understanding of the Ross Sea region has also benefited from U.S., British, Australian, Soviet and German investigations in adjoining regions such as the Ellsworth Mountains, Pensacola Mountains, Shackleton Range, Marie Byrd Land, Ellsworth Land, and the Pennell and Oates Coasts of northern Victoria Land.

YOUNGER PRECAMBRIAN SEQUENCES (Pcy)

Upper Proterozoic sediments were deposited mainly as turbidite fans from the continental margin of the East Antarctic craton, which was downwarped along the present trend of the Transantarctic Mountains. Although not all have been studied in detail, the rocks are broadly correlative on lithology, petrography, greenschist metamorphism and structural style, comprising thick units of quartzo-feldspathic metagreywacke, argillite, slate-phyllite with thinner units of quartzitic sandstone and rare limestone and volcanics, deposited on an unknown, probably continental, basement. Poorly-preserved acritarchs are described in some Russian publications (e.g. Iltchenko, 1972) as Vendian or upper Riphean. Radiometric K/Ar dating of phyllites and slates has generally provided early Palaeozoic ages corresponding to the Ross Orogeny (Adams, Gabites and Grindley, in press; Adams *et al.,* in press).

Central Transantarctic Mountains

The La Gorce Formation of the Scott Glacier region is a closely-folded sequence of metagreywacke, impure quartzite, black slate and phyllite with graded bedding, cross-bedding, flute and sole marks all indicative of turbidity current deposition in a deep-sea fan complex (Stump, in press). The steep-dipping bedding strikes east-northeast parallel to the trend of the Queen Maud Mountains. Closer to the coast between the Axel Heiberg and Shackleton Glaciers, the Duncan Formation is of higher metamorphic grade – high greenschist to amphibolite facies — due to proximity to the Queen Maud granitic batholith (McGregor, 1965). Sedimentary structures indicate a similar lithofacies. The La Gorce Formation has provided an Rb/Sr isochron of 710 ± 41 m.y. (Faure *et al.,* 1969).

At the mouth of Scott Glacier, on the small nunatak of O'Brien Peak (Katz and Waterhouse,. 1970b), a comparatively thin sequence (c. 300 m) of thin-bedded marbles, calc-schists and quartzites with concordant amphibolites and granites, is tentatively correlated with the Cobham Formation of the Nimrod Glacier region, but it could be younger, perhaps even Cambrian. Biotite and hornblende schist and gneiss with minor calc-silicates, 60 – 100 km along strike to the east of Leverett Glacier are also correlated with the Beardmore Group (Stump *et al.,* 1978).

The Goldie Formation of the Beardmore Group outcrops extensively between the Shackleton and Nimrod Glaciers (Fig. 1). It is a closely-folded, north-striking, metagreywacke-phyllite-slate sequence of turbidite facies (Gunn and Walcott, 1962) usually extensively hornfelsed by Ordovician granites. In the central Nimrod Glacier region (Laird *et al.*, 1971), it overlies the Cobham Formation, a 500 m+ sequence of thin-bedded marble, calc-schist, quartzite and biotite schist, lacking sedimentary structures but of shallow-water shelf-deposited facies. The Goldie Formation is overlain unconformably by the Early Cambrian Shackleton Limestone (Grindley and Laird, 1969).

Silicic volcanism and granite intrusion

Widespread silicic volcanism in the late Precambrian took place between the Thiel and Queen Maud Mountains, judging from the thick metavolcanic sequences associated with volcaniclastic sediments. The Wyatt Formation, at the head of Scott Glacier, has been mapped by Murtaugh (1969) in the Reedy Glacier and by Stump (1976) in the Amundsen Glacier. It is mainly younger than the La Gorce Formation though contacts may be faulted, or intrusive as well as conformable. At Ackerman Ridge, the Wyatt/La Gorce contact is vertical and apparently conformable (Katz and Waterhouse, 1970a), with the Wyatt Formation apparently younger than the La Gorce. A more recent re-examination has suggested the opposite (Stephen Self, Arizona State University, pers. comm.), i.e. that the La Gorce is younger than the Wyatt, but complex folding of the La Gorce Formation near the contact makes interpretation of stratigraphic superposition rather equivocal.

The Wyatt Formation elsewhere in the region intrudes the La Gorce metasediments (Murtaugh, 1969; Stump, 1976: 168) and passes gradationally into fine-grained porphyroblastic granite-gneiss forming part of the Wisconsin Range batholith (Murtaugh, 1969: 540).

The Wyatt Formation is dated at 620 ± 14 m.y. (Faure *et al.*, 1968), and <788 ± 14 m.y. (Faure *et al.*, 1979) by the Rb/Sr isochron method. Probably correlative silicic pyroclastics in the Thiel Mountains yielded an Rb/Sr isochron date of 660 ± 79 m.y., which is considered most reliable by Faure *et al.* (1979). The Wisconsin Range batholith provides similar latest Precambrian Rb/Sr isochron dates of 600 ± 13 m.y. in the Upper Amundsen Glacier and 615 ± 22 m.y. in the Upper Reedy Glacier. Relatively high initial $^{87}Sr/^{86}Sr$ ratios indicate both may be reset ages; alternatively they could be anatectic granites derived by crustal melting.

Northern Victoria Land

The Robertson Bay Group (Fig. 1) forms a thick sequence (6 km+) of quartzo-feldspathic metagreywacke and cleaved argillite in regular alternating beds up to 6 m thick. Graded bedding, cross-bedding and flute and load casts are locally abundant, indicating turbidity current deposition. Finer-grained beds are well-cleaved grey-green slates and phyllites, from which numerous K/Ar whole rock ages between 450 and 500 m.y. have been obtained (Adams *et al.*, in press). Mafic metavolcanics are known from the Mariner Glacier region (Riddolls and Hancox, 1968), and associated argillites contain Vendian acritarchs. Possibly, this part of the Robertson Bay terrain adjacent to the Bowers Trough in the southwest is transitional to or coeval with the Sledgers Group (Vendian – earliest Cambrian). On the Pennell Coast east of the lower Rennick Glacier, Riphean acritarchs have been obtained from phyllites and slates of the Anare and northern Bowers Mountains (D. S. Soloviev, pers. comm. 1970), but the stratigraphic relations with the Robertson Bay Group farther east and south are unknown. In the Tucker Glacier – Robertson Bay area, dark grey, simply-folded greywacke, phyllite and slate are contact-metamorphosed to cordierite-biotite-hornblende hornfels grade by plutons of the Upper Devonian Tucker Granodiorite (Harrington *et al.*, 1967). Palaeocurrent data indicate provenance of the sediments from the south (Wright, 1980).

West of the Bowers Tectonic Zone (Fig. 2), metagreywacke and phyllite of rather higher metamorphic grade but of similar lithofacies to the Robertson Bay Group form the basement of the Morozumi Range and the southern Daniels Range (Skinner, 1980; Tessensohn, this volume). About 250 km west of the Rennick Glacier mouth, metagreywacke, phyllite, calc-silicate schist and marble form a ridge of the Berg Mountains and have yielded Riphean acritarchs (Iltchenko, 1972).

Farther to the south, the Priestley Formation of the Terra Nova Bay area (Ricker, 1964; Skinner and Ricker, 1968) comprises a similar but more variable sequence of spotted slate, phyllite, quartzite and minor limestone, that is tentatively correlated with the Berg Group 500 km along strike to the northwest.

The age relationships of these various metagreywacke terrains cannot be determined directly. However, it may be significant that the Robertson Bay Group contains abundant tiny clasts of metagreywacke, slate, mafic volcanics and quartzite (Wright, 1980) probably derived in part from the Berg Group, Priestley Formation or other intracratonic low-grade metasedimentary terrains such as the greywackes of Cape Hunter, Commonwealth Bay, on the Adélie Coast (Stillwell, 1918). Metazoan trace fossils (Wright, 1980; Tessensohn, this volume) suggest a Vendian (latest Precambrian) age for at least part of the Robertson Bay Group.

Western Marie Byrd Land

Across the embayment of the Ross Sea, in the Rockefeller and Ford Ranges, late Precambrian metagreywackes are intruded by late Devonian and early Cretaceous granitoids. The metasedimentary Swanson Group, over 5 km in thickness, has been studied by several U.S. expeditions including the First and Second Byrd expeditions, and by a comprehensive helicopter-supported U.S. expedition in 1966-67 (references in Wade and Wilbanks, 1972). A New Zealand field party worked part of the Ford Ranges in the 1978-79 season (Andrews, Bradshaw and Adams, in prep.). Several U.S. 1:250 000 geological sheets cover the region; also, it is shown in the Marie Byrd Land 1:1 000 000 map sheet in the Antarctic Map Folio Series.

The Swanson Group mainly consists of grey, quartzose metagreywacke and argillite of a turbidite facies, commonly hornfelsed by granite intrusions, and comparable with the Beardmore and Robertson Bay Groups of the Transantarctic Mountains (see Wade and Long, in press, for comparisons). Upper units have structures indicative of shallow marine and beach environments while palaeocurrent measurements point to an easterly sloping depositional surface (Andrews *et al.*, in prep.). A simple pattern of west-northwest – east-southeast folds lines up with a similar northwest – southeast fold pattern in the Robertson Bay Group across the Ross Sea embayment.

The age of the Swanson Group is still uncertain. Late Precambrian (Upper Riphean) acritarchs were reported in samples collected by Soviet investigators (Iltchenko, 1972; Lopatin and Orlenko, 1972), while K/Ar dating of slates (Krylov *et al.*, 1970) indicates deformation of the sequence in the late Ordovician – early Devonian interval (410 - 450 m.y.).

PRECAMBRIAN METAMORPHIC COMPLEXES (Pco and Pcy)

Under this broad grouping are included Precambrian metasedimentary and metavolcanic sequences that have been reconstituted by metamorphism and partially migmatized by the invasion of granitic veins, dikes and schlieren produced by partial melting (anatexis) of the metamorphic sequence itself or of an underlying older basement. These complexes occur mainly in upfaulted blocks adjacent to major faults (northern Victoria Land and western Marie Byrd Land), as downfolded synclinal "keels" in late Precambrian – Cambrian granitic complexes (McMurdo Sound), and as basement to late Precambrian – Cambrian sequences (Miller Range). Stratigraphic, petrographic and structural analyses have been undertaken in few of these complexes, while the sparse radiometric age data commonly permits only the dating of the latest geological events – usually uplift to the near-surface — in their long and complex evolution.

Early (pre-IGY) geologic work on the metamorphic complexes of Victoria Land comprised field observations and petrology of rock samples collected during the Scott and Shackleton expeditions. Stratigraphic sequences in marbles and schists of the Koettlitz Group were recorded, and a general account of the Victoria Land basement was given by David Priestley (1914). Geologic work during the IGY and references to earlier work are given by Gunn and Warren (1962) and Harrington *et al.* (1967).

Central Transantarctic Mountains (Pco)

The Nimrod Group of the Miller and Geologists Ranges in the upper Nimrod Glacier region is a 2.5 km+ sequence of metasedimentary and minor metavolcanic rocks divided into five formations, all metamorphosed to the amphibolite facies (Grindley, 1972).

At the base, in the Miller Range, the Worsley Formation of marble, dolomite and schist underlies the Argosy Formation of semi-pelitic schist, quartzite, and minor calc-silicates. The overlying Aurora Formation of quartzo-feldspathic gneiss, augen-gneiss and migmatite with calc-silicate lenses is strongly tectonized beneath a major overthrust (Endurance Thrust) below the Miller Formation of marble, amphibolite and schist. Along the thrust are slivers of diorite and gabbro orthogneiss with boudins of quasi-eclogite (Argo Gneiss). A three-stage deformation history includes early overthrusting and recumbent folding with intrusion of "pre-tectonic" diorite and gabbro, coaxial refolding with migmatization and partial anatexis of tectonized and permeable layers, followed by post-metamorphic open folding, faulting, and intrusion of Ordovician granites and lamprophyre dikes. Outcrops of hornblende migmatite at the head of Reedy Glacier in the Wisconsin Range may be part of an older Precambrian basement underlying the La Gorce Formation (Murtaugh, 1969: 532).

Radiometric dating of the Nimrod Group is summarised by Adams, Gabites and Grindley (in press). Discordant U/Pb dates of relict detrital zircons in two paragneisses from the Aurora Formation (J. D. Gunner, pers. comm.) point to an Archaean cratonic source region (c. 2800 m.y.). Rb/Sr data on selected non-migmatized paragneiss and schist give an isochron at 1940 ± 77 m.y. that may be related to isotopic homogenization during lower Proterozoic sedimentation and diagenesis (Gunner and Faure, 1972). K/Ar data on amphibolites were originally interpreted as indicating isotopic closure at 1000 - 1100 m.y., but subsequent more detailed study (Adams, Gabites and Grindley, in press) indicates that isotopic closure was not achieved until the late Precambrian (Vendian – 580 - 620 m.y.) and that excess argon in amphiboles has produced older apparent ages up to 1100 m.y. The age of the Nimrod Orogeny (Grindley and McDougall, 1969) remains in doubt (see Table 1).

McMurdo Sound region (Pcy)

The oldest rocks of the basement complex are probably the highly deformed and metamorphosed sedimentary rocks of the Koettlitz Group. Blank *et al.* (1963) identified five formations in ascending order – Marshall Formation, Miers Marble, Garwood Lake Formation, Salmon Marble, Hobbs Formation. Reinterpretation of the sequence over the past five years (Findlay and Skinner, 1980) has shown that only one major marble unit is present (Salmon Marble) lying below pelitic, quartzitic, conglomeratic and amphibolitic schists with thin banded marbles (Hobbs Formation) and above dark semi-pelitic garnet-biotite schists with minor quartzitic, amphibolitic and calc-silicate layers (Marshall Formation). Amphibolite lenses, diorite and gabbro lie near the Salmon-Marshall boundary. Farther north in Ferrar, Taylor and Wright Valleys, a single lithologic unit (Asgard Formation) occupies synforms in weakly foliated granite and granodiorite (Larsen Granodiorite/Dais Granite) with an intervening strongly deformed migmatitic, border phase (Olympus Granite-gneiss). Asgard Formation, as presently defined, appears to include equivalents of all three formations to the south (Lopatin, 1972), but could be predominantly Hobbs Formation (Findlay and Skinner, pers. comm.).

This deformed late Precambrian – Cambrian? complex is intruded by undeformed Ordovician plutons (Irizar/Vida Granite, Theseus Granodiorite and unnamed granodiorite and diorite) and porphyry and lamprophyre dike swarms (Vanda Suite). Structural studies of the basement metasediments, included "pretectonic" augen-gneiss bands and the Olympus-Granite-gneiss have identified three phases of deformation – (F1) an early phase of recumbent isoclinal folding; (F2) a second phase of isoclinal refolding; and (F3) a late phase of moderately tight folds associated with pluton uprise of the Larsen (granodiorite) batholith and the formation of the bordering (Olympus) granite-gneiss zone (Smithson *et al.*, 1970, 1971, 1972; Williams *et al.*, 1971; Blattner, 1978; Findlay and Skinner, 1980). South of the Skelton Glacier, the similar Carlyon Granodiorite of the lower Darwin Glacier region includes pendants of pelitic and quartzitic metasediments and is also strongly deformed. The Carlyon Granodiorite is intruded by post-tectonic Ordovician granitoids (e.g. Hope Granite) and is probably late Precambrian or Cambrian in age. A Rb/Sr isochron of 568 ± 9 m.y. has recently been determined (Felder and Faure, 1980).

Radiometric dating in the basement complex has shown Rb/Sr isotopic homogenization of the Larsen Granodiorite at 489 ± 43 m.y., and the Irizar Granite at 471 ± 44 m.y. (Faure and Jones, 1974; 616, fig. 2), high initial $^{87}Sr/^{86}Sr$ ratios (0.71-0.72) suggesting anatectic melting or contamination by crustal source rocks rich in radiogenic Sr. An anomalous Rb/Sr isochron of 1000 ± 80 m.y. obtained by Deutsch and Webb (1964) on a Vanda porphyry dike (true age - 470 m.y.) has been explained by contamination with radiogenic Sr (Jones and Faure, 1967). A late Precambrian age of 610 ± 30 m.y. was obtained on a concordia plot of three zircon size fractions extracted from a diorite-gneiss band in the Asgard Formation of Victoria Valley (Allen and Gibson, 1962; Deutsch and Grögler, 1966). This is believed to be the age for the Olympus Granite-gneiss, Dais (= Larsen) Granodiorites (Faure and Jones, 1974) and the F3 deformation of the Koettlitz Group (Findlay and Skinner, 1980).

Precise correlation of the Koettlitz Group is not possible at this stage, pending further radiometric studies. However, it seems certain that at least parts of the Asgard and Marshall Formations are late Precambrian. The Salmon Marble was regarded formerly as Early Cambrian on the erroneous diagnosis of quartz rods as deformed Archaeocyatha (Blank *et al.*, 1963). Despite broad lithologic similarities of Salmon Marble with the early? Cambrian Anthill Limestone of the Skelton Group, and of the Hobbs Formation with associated and younger coarse volcanogenic clastics (Skinner, in press), correlation has not been clearly established during recent field mapping (D. Skinner, pers. comm.); both formations are presently considered late Precambrian or early Cambrian (Table 1).

Northern Victoria Land (Pcy)

Metamorphic and migmatitic rocks form the basement of the Wilson Hills and Usarp Mountains west of the Rennick Glacier and the Lanterman and Salamander Ranges to the east of the glacier adjacent to the Bowers Mountains. Originally described as Wilson Group from two localities in the northern Wilson Hills the name was subsequently extended to embrace all medium to high grade, regionally metamorphosed basement rocks of the Rennick Glacier region (Grindley and Warren, 1964; Dow and Neall, 1973). Slightly lower-grade metasediments in the upper Rennick Glacier were referred to the Rennick Group (Gair, 1967) or the Rennick schists of the Wilson Group (Sturm and Carryer, 1970). The granitic (anatectic) part was referred to the Granite Harbour Intrusives and migmatitic rocks to the Wilson gneisses (informal).

Most of the Wilson Group rocks are known only from rapid reconnaissance studies. The group consists mainly of pelitic and semi-pelitic schist, quartzo-feldspathic paragneiss, quartzite, and calc-silicate lenses, commonly intimately invaded by a network of granitic veins, dikes and schlieren to form granitic migmatites (Gair, 1967: fig. 5). Muscovite-biotite-garnet schist showing relict graded bedding is typical of the Rennick schists and strongly resembles the turbidite facies of the Robertson Bay Group (Gair, 1967; Skinner, 1980; Tessensohn, this volume). Andalusite, cordierite, sillimanite and K-feldspar are present in contact aureoles with younger granites. Marble is present at Sequence Hills in the upper Rennick Glacier and calc-silicate gneiss lenses containing diopside, actinolite and sphene are present at other localities. Amphibolite and hornblende schists have been recorded in the Lanterman Range (Dow and Neall, 1973) where a contact with metaconglomerate containing amphibolite clasts has been variously interpreted as faulted (Sturm and Carryer, 1970), unconformable but metamorphically gradational (Crowder, 1968), or unconformable with a metamorphic unconformity (Laird *et al.,* in press). The metaconglomerate (Husky Conglomerate) has been interpreted as a basal member of the Sledgers Group (Vendian — L. Cambrian) by Crowder (1968) and Laird *et al.* (in press) and as a part of the Wilson Group by Tessensohn (this volume). The Retreat Hills Schist at the head of the Mariner Glacier (Riddolls and Hancox, 1968) is a siliceous biotite schist with actinolite schist layers that

Table 1 — Provisional correlation chart of late Precambrian and Cambrian metasedimentary terrains and of the highly metamorphosed Precambrian complexes in the Ross Sea region. Arrows signify considerable uncertainty in age due to absence of unequivocal radiometric age data.

SCOTT GLACIER	NIMROD GLACIER	McMURDO SOUND	RENNICK GLACIER	MARIE BYRD LAND	PERIOD/EVENT	MA
* Felsic volcanics Leverett Formation	* BYRD GROUP Starshot Formation Shackleton Limestone Unconformable on B.G.	* SKELTON GROUP Volcaniclastics,schist Anthill Limestone (Salmon Marble?)	* MARINER GROUP Carbonate + clastics		ROSS OROGENY Volcanism CAMBRIAN Shelf Sediments	500
Unconformity inferred Lonely Ridge Granodiorite * 600±13 Rb-Sr(granod.) * 615±22 Rb-Sr(granod.) * 620±13 Rb-Sr(porphyry) * 660±79 Rb-Sr(porphyry) Wyatt Formation <788±14 * 710±41 Rb-Sr (metasediments) L.G.F.	*K-Ar 590±20 (N.G.) *Rb-Sr590±38 (N.G.) F2 deformation & metamorphism ? Argo Gneiss ?	* Carlyon Granodiorite *Rb-Sr 568±9 * Olympus granite gneiss U-Pb 610 ± 30. Augen-gneiss and foliated granodiorite.	Disconformity SLEDGERS GROUP Mafic volcanics,clastics carbonate,turbidite (acritarchs,tracefossils) ROBERTSON BAY GROUP Turbidite sequence of greywacke,argillite, minor mafic sills,calc-silicate lenses. (acritarchs,trace fossils)	SWANSON GROUP Turbidite sequence of greywacke,argillite, minor calc-silicates. (acritarchs,trace fossils)	Granites BEARDMORE OROGENY VENDIAN Volcanism UPPER	600 700
La Gorce Formation Turbidite sequence of greywacke,argill., quartzite, schist. O'Brien Peak Beds Pelitic schist,paragneiss marble,quartzite, meta conglomerate No exposed base	BEARDMORE GROUP Goldie Formation Turbidite sequence of greywacke,argillite, quartzite,calc-silicate Cobham Formation Pelitic schist,hornfels marble, quartzite meta conglomerate No exposed base	KOETTLITZ GROUP Pelitic schist, para-gneiss,marble, quartzite,amphibolite,migmatite,metaconglomerate.	Husky Conglomerate? *Rb-Sr 755±20 (pelitic schist) WILSON GROUP Pelitic schist, para-gneiss,calc-silicates, quartzite,migmatite, mafic dikes (Infrastructure of Robertson Bay Group)	FOSDICK METAMORPHICS Pelitic schist, para-gneiss, calc-silicates, quartzite,migmatite, mafic dikes (Infrastructure of Swanson Group)	PROTEROZOIC Turbidites U. RIPHEAN Shelf Sediments + Volcanism Uplift and marginal downwarp of craton	800 900 1000 1100
					L. RIPHEAN MIDDLE	1200 1300 1400
F2 deformation? Amphibolite facies metamorphism Amphibolite,diorite, migmatite F1 deformation ?	F2 deformation ? Amphibolite facies metamorphism ? NIMROD GROUP Argo Gneiss ? Diorite-gneiss,gabbro migmatite,augen-gneiss eclogitic lenses. F1 deformation ? (recumbent folding and thrusting)				PROTEROZOIC NIMROD OROGENY ?	1500 1600 1700
	NIMROD GROUP Miller,Aurora,Argosy and Worsley Formations (Head of Nimrod Glacier) *Rb-Sr 1940±77. Deposition of muddy, sandy and calcareous sediments. mafic volcanism				LOWER PROTEROZOIC Shelf Sediments + Volcanism	1800 1900 2000

is probably a more metamorphosed equivalent of the nearby Sledgers Group (or Robertson Bay Group).

Farther south in the Priestley Glacier and Terra Nova Bay, metasedimentary rocks are referred to the Priestley Formation (Skinner and Ricker, 1968; Nathan, 1971). Mineral assemblages range from quartz-albite-epidote-actinolite-hornfels to greenschist facies for the least altered rocks that are correlated with Berg Group or the Robertson Bay Group (~ Sledgers Group). Higher-grade cordierite, andalusite, hornblende and sillimanite schists and hornfels are placed in the hornblende-hornfels and amphibolite facies. However, the parent sediments – arkosic sandstone, quartzite, shale, minor limestone, conglomerate and mafic volcanics — do resemble the Sledgers Group of the Rennick Glacier area. At Terra Nova Bay, biotite-garnet schist and paragneiss are invaded by "pretectonic" gneissic quartz diorite and the "syntectonic" Larsen Granodiorite as well as a suite of post-tectonic granitoids ranging from melanogabbro through quartz-diorite to granodiorite and granite (Adamson, 1971; Skinner, 1972). Such detailed work as has been done on the "metamorphic complex" of Terra Nova Bay suggests that it may be a local equivalent of the Wilson Group (Skinner and Ricker, 1968, Table 1).

Structural studies of the Wilson Group have been undertaken only in limited areas. In the Lanterman Range, Bradshaw *et al.* (in press) have described polyphase deformation and metamorphism, an early synmetamorphic phase (F1) producing isoclinal northwest-striking folds and axial-plane schistosity followed by a second late metamorphic phase (F2) producing tight folds and a crenulate cleavage and lineation, while rotating the early F1 folds and lineations to a steep plunge (60-90° SE). Both fold phases are considered to predate formation of the overlying Husky Conglomerate. Post-metamorphic chevron-style open folds are developed towards the eastern fault boundary with the Sledgers Group. The precise ages of the fold episodes have yet to be determined, but F1 and F2 are both considered to be Vendian or pre-Vendian (if Husky Conglomerate is of that age). Structural studies have also revealed polyphase deformation of the Wilson Group in the Daniels Range (Skinner, 1980).

Radiometric dating of the Wilson (and Rennick) Groups has so far only yielded K/Ar minimum ages within the 450-550 m.y. range attributed to the thermal overprint of the Ross Orogeny and Granite Harbour Intrusives (Adams *et al.*, in press). A single Rb/Sr model age of 755 ± 20 m.y. (Faure and Gair, 1970) could be interpreted as evidence for Precambrian isotopic closure depending on whether one accepts the low initial $^{87}Sr/^{86}Sr$ ratio (0.704) chosen.

Western Marie Byrd Land

The Fosdick Metamorphic Complex in western Marie Byrd Land (Table 1) has been interpreted as a basement to the Swanson Group (Klimov, 1967; Lopatin and Orlenko, 1972; Grikurov and Lopatin, 1974; Wade and Long, in press), and as an "infrastructure" of deep-seated metamorphosed and migmatized Swanson Group sediments (Wilbanks, 1972; Andrews *et al.*, in prep.). The Fosdick Metamorphics are exposed in the Fosdick Mountains to the north of the Ford Ranges, but relationships with the Swanson Group and the late Devonian Ford Granodiorite and early Cretaceous Byrd Coast Granite plutons are not seen. Late Tertiary olivine basalt and tuff cover the eastern part of the complex. Two units are distinguished: a lower unit of migmatized garnet, cordierite and sillimanite gneiss, feldspathic quartzite and minor amphibolite, and an upper unit of migmatized biotite–plagioclase gneiss and schist alternating with amphibolite. Wilbanks (1972) recognised the following phases of deformation and metamorphism:

D1	Emplacement of metabasite dikes.
F1 + M1	Folding along NE axes, crystallization of early "paleosome" garnet enclosing older sillimanite fabric.
D2	Emplacement of metabasite dikes.
F2 + M2	Folding along WNW axes, crystallization of quartzofeldspathic "neosome" with garnet, sillimanite, etc.
F3	Uplift of range, block-faulting, basalt volcanism.

Rb/Sr data on the Fosdick metamorphics has not provided any obvious isochrons, the data points scattering over a field between two limiting isochrons at about 100-120 m.y. and 400-450 m.y. Total rock – mica pairs all give reset ages ranging from 90-100 m.y. with $^{87}Sr/^{86}Sr$ initial ratios as high as 0.725 (Halpern, 1972).

Ross Sea Embayment

Metamorphic basement rocks were drilled in DSDP hole 270 in the central Ross Sea, at the base of a mid-Upper Cenozoic marine and glaciomarine sequence (Ford and Barrett, 1975). The basement rocks consist of marble, calc-silicate schist and biotite (chlorite) schist, metamorphosed to the amphibolite facies (diopside + wollastonite are index minerals), followed by retrogression to the greenschist facies. The metamorphic rocks are strikingly similar to the marbles and calc-silicate gneisses of the Koettlitz Group (Salmon Marble, etc.) of the McMurdo Sound region 500 km to the west.

The presence of continental basement rocks shows that the Ross Sea Embayment is unlikely to be a volcanic rift-zone floored by oceanic crust, although some local rifting and a general thinning of the continental crust is probable. The absence of Devonian–Triassic (Beacon) continental sediments also indicates that a simple horst-graben structure for the Transantarctic Mountains and Ross Sea depression is an oversimplification (see Fig. 3). The presence of Koettlitz Group metamorphic basement 500 km to the east of McMurdo Sound across the strike of the orogenic belt is also curious and could be interpreted as a result of c. 300 km of sinistral strike-slip displacement along a major transform fault extending from Byrd Glacier northward along the eastern margin of Iselin Bank to the Pacific-Antarctic Ridge (Davey, this volume). This postulated transform lines up with the Byrd Glacier Fault (Grindley and Laird, 1969) across which major dextral displacement of the Ross orogenic belt may have occurred (Fig. 2). Southeast of the proposed transform fault, a spreading ridge below the Ross Ice Shelf and Byrd Basin could have produced the proposed strike-slip displacements and also led to the separation of the Precambrian blocks of East and West Antarctica.

ACKNOWLEDGEMENTS

I am grateful to the N.Z. National Committee for Antarctic Research for the invitation to write this review paper and to other Antarctic geologists for their support and encouragement. Drs D. N. B. Skinner and P. B. Andrews pointed out various inconsistencies, supplied unpublished information, and suggested additional references. Mrs F. Tonks typed the manuscript, and DSIR Cartographic Section draughted Figure 1.

REFERENCES

Adams, C. J.; J. E. Gabites; G. W. Grindley. In press Orogenic history of the central Transantarctic Mountains: new K-Ar age data on the Precambrian – Early Paleozoic basement. Craddock (in press).

Adams, C. J.; J. E. Gabites; A. Wodzicki; J. D. Bradshaw; M. G. Laird. In Press. Potassium-argon geochronology of the Precambrian–Cambrian Wilson and Robertson Bay Groups and Bowers Supergroup, north Victoria Land, Antarctica. Craddock (in press).

Adamson, R. G. 1971. Granitic rocks of the Campbell-Priestley divide, northern Victoria Land. *N.Z. Journal of Geology and Geophysics* 14(3): 486-503.

Adie, R. J. (Ed.). 1972. *Antarctic Geology*. North-Holland: Amsterdam.

Allen, A. D., and G. W. Gibson. 1962. Geological Investigations in Southern Victoria Land, Antarctica. Part 6 — Outline of the Geology of the Victoria Valley Region. *N.Z. Journal of Geology and Geophysics* 5(2): 234-242.

Blank, R.; R. A. Cooper; R. M. Wheeler; I. A. G. Willis. 1963. Geology of the Koettlitz Blue Glacier Region. Southern Victoria Land. Antarctica. *Transactions of the Royal Society of N.Z. Geology* 2(5): 79-100.

Blattner, P. 1978. Geology and geochemistry of Mt Dromedary Massif, Koettlitz Glacier area, southern Victoria Land — Preliminary Report. *N.Z. Antarctic Record* 1(2): 16-19.

Bradshaw, J. D.; M. G. Laird; A. Wodzicki. In press. Structural style and tectonic history in Northern Victoria Land. Craddock (in press).

Bushnell, , and C. Craddock. 1969. Geologic Map of Antarctica. 1:1 000 000. Antarctic Map Folio Series. American Geographic Society: New York.

Craddock, C. (Ed.). In press. *Antarctic Geoscience.* University of Wisconsin Press: Madison.

David, T. W. E., and R. E. Priestley. 1914. Glaciology, physiography, stratigraphy and tectonic geology of South Victoria Land with short notes on paleontology by T. Griffith Taylor. *British Antarctic Expedition 1907-9. Reports of Scientific Investigations Geology 1.* 319 pp. 95 pls. 67 figs. panorama.

Deutsch, S., and N. Grögler. 1966. Isotope age of Olympus Granite-gneiss (Victoria Land — Antarctica). *Earth and Planetary Science Letters* 1(2): 82-84.

Deutsch, S., P. N. Webb. 1964. Sr/Rb dating on basement rocks from Victoria Land; evidence for a 1000 million year old event. Adie 1972: 557-562.

Dow, J. A. S., and V. E. Neall. 1973. Geology of the Lower Rennick Glacier northern Victoria Land, Antarctica. *N.Z. Journal of Geology and Geophysics* 17(3): 659-714.

Faure, G., and H. S. Gair. 1970. Age determinations of rocks from Northern Victoria Land, Antarctica. *N.Z. Journal of Geology and Geophysics* 13(4): 1024-1025.

Faure, G., and L. M. Jones. 1974. Isotopic composition of strontium and geologic history of the basement rocks of Wright Valley, southern Victoria Land, Antarctica. *N.Z. Journal of Geology and Geophysics* 17(3): 611-625. Appendix: Petrological notes by L. B. Owen: 626-627.

Faure, G.; R. Eastin; P. T. Ray; D. McLelland; C. H. Schulz. 1979. Geochronology of igneous and metamorphic rocks, central Transantarctic Mountains. *In* B. Laskar and C. S. Raja Rao (Eds.), *Fourth International Gondwana Symposium* Vol. II. Hindustan Publishing Company: Delhi. Pp. 805-811.

Felder, R. P., and G. Faure. 1980. Rubidium-strontium age determination of part of the basement complex of the Brown Hills, central Transantarctic Mountains. *Antarctic Journal of the U.S.* 15(5): 16-17.

Findlay, R. H., and D. N. B. Skinner. 1980. Early structural evolution of part of the Gondwana Craton: the structural evolution of the Ross Orogen at McMurdo Sound, Antarctica. Abstracts. Fifth International Gondwana Symposium: Wellington, New Zealand.

Ford, A. B., and P. J. Barrett. 1975. Basement Rocks of the South-Central Ross Sea, Site 270, DSDP Leg 28. *In* D. E. Hayes *et al.* (Eds), *Initial Reports of the DSDP* 28: 861-868.

Gair, H. S. 1967. The Geology from the Upper Rennick Glacier to the Coast, Northern Victoria Land, Antarctica. *N.Z. Journal of Geology and Geophysics* 10(2): 309-344.

Gair, H. S.; A. Sturm; S. J. Carryer; G. W. Grindley. 1969. Sheet 13, Northern Victoria Land. Geologic Map of Antarctica. 1:1 000 000. *Antarctic Map Folio Series. Plate XII, Folio 12 — Geology.* American Geographical Society, New York.

Grikurov, G. E., and B. G. Lopatin. 1975. Structure and Evolution of the West Antarctic part of the Circum-Pacific Mobile Belt. *In* K. S. W. Campbell (Ed.), *Gondwana Geology.* Proceedings, Third Gondwana Symposium, Canberra. Pp. 639-650.

Grindley, G. W. 1972. Polyphase Deformation of the Precambrian Nimrod Group, central Transantarctic Mountains. Adie 1972: 313-318.

Grindley, G. W., and M. G. Laird. 1969. Sheet 15, Shackleton Coast. Geologic Map of Antarctica. 1:1 000 000. *Antarctic Map Folio Series. Plate XIV, Folio 12 — Geology.* American Geographical Society, New York.

Grindley G. W., and M. McDougall. 1969. Age and correlation of the Nimrod Group and other Precambrian rock units in the Central Transantarctic Mountains, Antarctica. *N.Z. Journal of Geology and Geophysics* 12(2-3): 391-411.

Grindley, G. W., and G. Warren. 1964. Stratigraphic nomenclature and correlation in the western Ross Sea region. *In* R. J. Adie (Ed.), *Antarctic Geology.* North Holland: Amsterdam. Pp. 313-333.

Gunn, B. M., and R. I. Walcott. 1962. The Geology of the Mt Markham Region, Ross Dependency, Antarctica. *N.Z. Journal of Geology and Geophysics* 5(3): 407-426.

Gunn, B. M., and G. Warren. 1962. Geology of Victoria Land between the Mawson and Mulock Glaciers, Antarctica. *N.Z. Geological Survey Bulletin 71.* 157 pp.

Gunner, J., and G. Faure. 1972. Rubidium-strontium geochronology of the Nimrod Group, central Transantarctic Mountains. Adie 1972: 305-311.

Halpern, M. 1972. Rubidium-Strontium Total Rock and Mineral Ages from the Marguerite Bay Area, Kohler Range, and Fosdick Mountains of West Antarctica. Adie 1972: 197-204.

Harrington, H. J.; B. L. Wood; I. C. McKellar; G. J. Lensen. 1967. Topography and Geology of the Cape Hallett – Tucker Glacier District, Antarctic. *N.Z. Geological Survey Bulletin 80.* 100 pp.

Iltchenko, L. N. 1972. Late Precambrian acritarchs of Antarctica. Adie 1972: 599-602.

Jones, L. M., and G. Faure. 1967. Age of the Vanda Porphyry dikes in the Wright Valley, Southern Victoria Land, Antarctica. *Earth and Planetary Science Letters* 3: 321-324.

Katz, H. R., and B. C. Waterhouse. 1970a. Geological reconnaissance of the Scott Glacier area Southeastern Queen Maud Range, Antarctica. *N.Z. Journal of Geology and Geophysics* 13(4): 1030-1037.

———; ———. 1970b. Geologic Situation at O'Brien Peak, Queen Maud Range, Antarctica. *N.Z. Journal of Geology and Geophysics* 13(4): 1038-1049.

Klimov, L. V. 1967. [Some results of geological investigations in Marie Byrd Land in 1966-1967.] *Information Bulletin 65 Soviet Antarctic Expedition* 6(6): 555-559.

Krylov, A. Ya.; B. G. Lopatin; T. I. Maxina. 1970. Age of rocks in the Ford Ranges and on the Ruppert Coast (western part of Byrd Land). *Information Bulletin 80 Soviet Antarctic Expedition* 8(2): 64-66.

Laird, M. G.; G. D. Mansergh; J. M. A. Chappell. 1971. Geology of the Central Nimrod Glacier Area, Antarctica. *N.Z. Journal of Geology and Geophysics* 14(3): 427-468.

Laird, M. G.; J. D. Bradshaw; A. Wodzicki. In press. Stratigraphy of the Late Precambrian and Early Palaeozoic Bowers Supergroup, northern Victoria Land, Antarctica. Craddock (in press).

Lopatin, B. G. 1972. Basement complex of the McMurdo "oasis", south Victoria Land. Adie 1972: 287-292.

Lopatin, B. G., and E. M. Orlenko. 1972. Outline of the Geology of Marie Byrd Land and the Eights Coast. Adie 1972: 245-250.

McGregor, V. R. 1965. Geology of the area between the Axel Heiberg and Shackleton Glaciers, Queen Maud Range, Antarctica. Part 1 — Basement complex, structure and glacial geology. *N.Z. Journal of Geology and Geophysics* 8(2): 314-343.

Murtugh, M. J. 1969. Geology of the Wisconsin Range batholith, Transantarctic Mountains. *N.Z. Journal of Geology and Geophysics* 12: 526-550.

Nathan, S. 1971. Geology and petrology of the Campbell — Aviator divide, northern Victoria Land, Antarctica. Part 2 — Paleozoic and Precambrian rocks. *N.Z. Journal of Geology and Geophysics* 14(3): 564-596.

Ricker, J. 1964. Outline of the Geology between Mawson and Priestley Glaciers, Victoria Land. Adie 1972: 265-275.

Riddolls, B. W., and G. J. Hancox. 1968. The geology of the Upper Mariner Glacier region, North Victoria Land, Antarctica. *N.Z. Journal of Geology and Geophysics* 11(4): 881-899.

Skinner, D. N. B. 1972. Differentiation source for the mafic and ultramafic rocks ('Enstatite-peridotites') and some porphyritic granites of Terra Nova Bay, Victoria Land. Adie 1972: 299-303.

——— 1980. Ganovex '79. *N.Z. Antarctic Record* 3(1): 15-24.

——— In press. Stratigraphy and Structure of lower grade metasediments of Skelton Group, McMurdo Sound. Does Teall Greywacke really exist? Craddock (in press).

Skinner, D. N. B., Ricker, J. 1968. The geology of the region between the Mawson and Priestley Glaciers, North Victoria Land, Antarctica. Part I — Basement metasedimentary and igneous rocks. *N.Z. Journal of Geology and Geophysics* 11(4): 1009-1040.

Smithson, S. B.; P. R. Fikkan; D. J. Murphy; R. S. Houston. 1972. Development of augen-gneiss in the ice-free valley area, south Victoria Land. Adie 1972: 293-298.

Stillwell, F. L. 1918. The metamorphic rocks of Adélie Land. *Scientific Report Australasian Antarctica Expedition 1911-14* A, 3(1): 1-230.

Stump, E. 1976. On the Late Precambrian — Early Paleozoic metavolcanic and metasedimentary rocks of the Queen Maud Mountains, Antarctica, and a comparison with rocks of similar age from Southern Africa. *Institute of Polar Studies Report 62,* 212 pp. Ohio State University Research Foundation: Columbus.

——— In press. The Ross Supergroup in the Queen Maud Mountains. Craddock (in press).

Stump, E.; P. M. Lowry; G. M. Heintz-Stocker; P. V. Colbert. 1978. Geological investigations in the Leverett Glacier area. *Antarctic Journal of the U.S.* 13(4): 3-4.

Sturm, A., and S. J. Carryer. 1970. Geology of the region between the Matusevitch and Tucker Glaciers, North Victoria Land, Antarctica. *N.Z. Journal of Geology and Geophysics* 13(2): 408-435.

Wade, F. A., and D. R. Long. In press. The Swanson Formation, Ford Ranges, Marie Byrd Land — evidence for direct relationship with Robertson Bay Group, northern Victoria Land. Craddock (in press).

Wade, F. A., and J. R. Wilbanks. 1972. The Geology of Marie Byrd and Ellsworth Lands, Antarctica. Adie 1972: 207-214.

Wilbanks, J. R. 1972. Geology of the Fosdick Mountains, Marie Byrd Land. Adie 1972: 277-286.

Williams, P. F., B. E. Hobbs; R. H. Vernon; D. E. Anderson. 1972. The structural and metamorphic geology of basement rocks in the McMurdo Sound Area, Antarctica. *Journal of the Geological Society of Australia* 18(2): 127-142.

Wright, T. O. 1980. Sedimentology of the Robertson Bay Group, northern Victoria Land, Antarctica. *Antarctic Journal of the U.S.* 15(5): 6-8.

Received, 1 May 1981