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by

I.R.McLeod and D.S.Trail

Papers Submitted to the SCAR International Symposium on Antarctic Geology, September, 1963.

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I.R. McLeod and D.S. Trail

INTRODUCTION

The papers in this Record contain the results of geological investigations carried out by geologists of the Bureau of Mineral Resources attached to the Australian National Antarctic Expeditions.

These papers were presented at the SCAR Symposium on Antarctic Geology held in Cape Town, South Africa, from 16th to 20th September, 1963, and they will probably be published in the Proceedings of this Symposium. They are issued as Record 1963/130 of the Bureau of Mineral Resources so that they may sooner be made available to workers in the field of Antarctic Geology.

ABSTRACTS

Paper 1 :

An Outline of the Geology of the Sector from 45°E to 80°E, Antarctica.

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Australia

The rocks of the sector of Antarctica between 45°E and 80°E and north of 75°S latitude are predominantly metamorphic and can be divided into two major units, one of high-grade the other of low-grade metamorphic rocks.

The low-grade rocks occur in the southern Prince Charles Mountains and consist of quartzite, quartz-mica schist, marble, and amphibolite in the greenschist facies of metamorphism. Their general strike is about east-west. They have been intruded by large granite bodies.

High-grade metamorphic rocks occur throughout the rest of the sector. They can be broadly divided into rocks with charnockitic affinities (particularly common along the coast from the Robinson Group, east of Mawson, west to Edward VIII Gulf, and in the Framnes Mountains, and in the Napier and Tula Mountains); biotite-quartz-feldspar gneisses which are migmatised in places (common in the northern Prince Charles Mountains); and garnet-quartz-feldspar gneisses (common along the east side of Prydz Bay). Each of these broad groups contains numerous mineralogical and textural variants, and the groups are not mutually exclusive in any one area. Evidence is widespread that a metamorphism of quite high grade was superimposed on the pre-existing metamorphic rocks.

In the area extending for 100 miles to the west and south of Mawson the general strike of the high grade gneisses is about north-south. Elsewhere, with few exceptions it is about east-west. Dolerite dykes are very common in the Vestfold Hills. Isolated dykes of dolerite or basalt were seen at several places in Enderby and Kemp Lands and in the Prince Charles Mountains.

Permian sediments occur in situ at the south-west corner of the Amery Ice Shelf. Fragments of siltstones containing Glossopteris were found 270 km to the south of this in moraine of the Fisher Glacier.

Paper 2:

Schist and Granite in the southern Prince Charles Mountains

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Australia.

The Prince Charles Mountains extend south from 70°S for about 600 kilometres between longitudes 60°E and 70°E. The northern mountains are formed by the high-grade metamorphic rocks typical of East Antarctica. A large area in the southern mountains contains nunataks formed by sediments metamorphosed under greenschist facies conditions, and by large bodies of granite.

Quartzite, quartz-mica schist, marble, ferruginous rocks, and amphibolite, comprise the metamorphosed sediments. They are mainly altered sandstone, limestone, and silty and limy mudstone. The ferruginous rocks may be metamorphosed chert. Some amphibolites are metamorphosed basic igneous rocks.

Some rocks near granite have been metamorphosed under albite-epidote hornfels or hornblende hornfels conditions.

Large bodies of biotite granite with accessory tourmaline and fluorite crop out within the metamorphosed sediments. Quartz veins and reefs and tourmaline-bearing pegmatites in the southern mountains are probably related to these granites.

In the sediments a first phase of deformation is represented by isoclinal folds and recumbent folds. Axial plane schistosity of these folds is plicated by a second phase of deformation. Granite and adjacent metamorphics at Mount Bayliss have a marked cataclastic foliation.

The sediments were first regionally metamorphosed under greenschist facies conditions. A period of widespread thermal metamorphism followed, possibly with mild deformation, during which biotite and perhaps cordierite crystallised. This metamorphism accompanied the emplacement and cataclasis of the Mount Bayliss granite and probably the emplacement of the other granite bodies.

The undeformed nature of the metamorphosed basic intrusions suggests emplacement between the regional and thermal periods of metamorphism.

The regional metamorphism may be the same event as the metamorphism dated between 500 and 650 million years on the Mac-Robertson Land and Kemp Land coast. The emplacement of the granites may be a post-kinematic feature of this metamorphism.

Paper 3 :

Geological Observations in Oates Land

I.R. McLeod, M.Sc.

Australia

The geology of several localities near the coast of Oates Land between longitudes 157°E and 166°E is described. The rocks of the western Wilson Hills and Magga Peak (several miles further west) are fine-grained banded biotite-quartz-feldspar gneiss containing numerous small migmatitic veins. The veins generally are of granitic composition, but show a wide range in texture and in the proportions of constituent minerals. Adamellite containing numerous inclusions occurs in part of the eastern Wilson Hills.

Near Cape Williams, micaceous schists of the almandine-amphibolite facies have undergone a later thermal metamorphism. No igneous rocks were found in the vicinity, but adamellite occurs on a large island 15 miles to the north-west.

The rocks of the Cape North area are sediments which have been tightly folded, and metamorphosed under greenschist facies conditions. Massive biotite granodiorite which occurs at several places to the north-east and south-east of Cape North is probably younger than the metasediments.

Potassium/argon dates indicate Lower Palaeozoic metamorphism and igneous intrusion in the region.

Paper 4 :

The Saline Lakes of the Vestfold Hills, Princess Elizabeth Land

I.R. McLeod, M.Sc.

Australia.

The Vestfold Hills, one of the "Antarctic Oases", is an area of bare rocky hills with numerous lakes.

Some of the lakes are very saline. Surface water samples have been collected at irregular intervals over a period of six years from four of these lakes which occur in an east-west trending valley. Samples collected at different times from the same lake show a considerable range in the content of total dissolved solids, due probably to the inflow of water from melted snow. The content of total dissolved solids may be as great as 27 percent; the predominant ions are sodium and chloride.

The surface of all four lakes is below present sealevel. Molluscan remains, of species still living around the Antarctic coast, are common in places around them.

The valley in which the lakes occur was originally an arm of the sea. The lakes were probably isolated by a eustatic fall in sealevel and subsequently concentrated by evaporation.

Paper 5 :

The Glacial Geology of the Prince Charles Mountains

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Australia.

The Prince Charles Mountains, extending 600 kilometers south from the Amery Ice Shelf between longitudes 60°E and 70°E, are exposed in a 2000-meter-deep depression in the continental ice cap apparently caused by the rapid drainage of inland ice to the sea by way of the Lambert Glacier and adjacent glaciers.

The higher mountains rise between 1000 and 2500 meters above sea level and about 1000 meters above the ice surface. In the south most nunataks have broad summit plateaux; in the north many high nunataks have small summit areas. A few nunataks have flanking rock benches; all have cirques, most of which are abandoned.

The glacial deposits are sub-divided according to their surfaces:

Unpatterned moraine lacks a regularly patterned surface; it is lateral moraine on active ice cap glaciers, abandoned lateral moraine adjacent to ice cap glaciers, and terminal moraine of extinct or receding mountain glaciers.

Hillocky moraine has a surface of steep irregular hillocks and probably lies on stagnant ice.

Patterned moraine has a surface of regularly spaced and similar, subconical mounds. It blankets most flat or gently sloping rock surfaces up to 1000 meters above the ice surface and extends beneath the ice surface. In places hillocky moraine and unpatterned moraine lie on patterned moraine.

Patterned moraine extends on gentle slopes from summit plateaux and benches to the floors of abandoned cirques. The cirques, benches, and summit plateaux were formed before the deposition of this moraine.

Nunataks with small summit areas, which are generally lower than neighbouring nunataks with broad summit plateaux, appear to have been formed before the vertical maximum of the ice cap by the enlargement and convergence of cirques cutting into broad summit plateaux.

Several cirques have cut into and through one prominent bench. The summit plateaux and some benches appear to pre-date the cirques and may be pre-glacial features representing not a peneplain, but a landscape of rolling hills and broad valleys.

The glacial history is apparently simple. First mountain glaciers cut cirques in rolling hills and coalesced to form valley glaciers which over-deepened the central parts of valleys, leaving the margins as benches. The early ice cap covered and protected the summit plateaux of the southern mountains while cirque erosion and frost weathering reduced the northern mountains. Later the ice cap buried almost all mountains, then withdrew below its present level leaving a blanket-like deposit of moraine on which a pattern developed.

Since the formation of the pattern, renewed mountain glacier activity cut small valleys in the patterned moraine and the ice cap rose 50 or 100 meters above its present level.

Through the glacial period the ice cap glaciers have continued to deepen their valleys, and the downward recession of ice from the Prince Charles Mountains will continue until the glaciers reach some base level and a stage of glacial maturity results.

PAPERS

Paper 1 :

An Outline of the Geology of the Sector from 45°E to 80°E, Antarctica

I.R. McLeod, M.Sc.*

Australia

INTRODUCTION

This paper is a summary of the results of geological work by the Australian National Antarctic Research Expeditions (ANARE) in the sector 45°E to 80°E, as far south as 75°S. The work has been in progress since the establishment of Mawson early in 1954, with the object of working out the geology of the region on a broad reconnaissance scale before the commencement of more detailed mapping. A detailed account of the results of the early stages of the work is given by Crohn (1959); a similar account of subsequent work is being prepared. The geology of the southern Prince Charles Mountains has been briefly described by Trail (1963a).

A map giving an interpretative outline of the geology of the region is presented as Figure 1 of this paper.

PHYSIOGRAPHY

Rock exposures are common along parts of the coast between Edward VIII Gulf and Mawson, around Amundsen and Casey Bays, along the eastern side of Prydz Bay, and in parts of the interior of the sector. They are estimated to make up about one percent of the sector between the coast and 75°S. The remainder is occupied by the continental ice cap, which reaches a maximum altitude of more than 3000 metres in the interior of Enderby Land before falling to a height of 2000 metres at the head of the Fisher Glacier. The areas of concentrated outcrop in the interior of the sector are south and east of Casey Bay (Nye, Raggatt and Scott Mountains), inland from Amundsen Bay in the Enderby Land Peninsula (Tula and Napier Mountains) and the Prince Charles Mountains, a system flanking the huge Lambert Glacier and its major tributary, the Fisher Glacier, between 70°S and 75°S. No outcrops are known south of about 69°S in that part of the sector between 45°E and 60°E.

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The coastal exposures are mostly islands or rocky headlands, and with few exceptions do not rise to a great height. An old erosion surface falling from 125 metres at Edward VIII Gulf to 35 metres at Mawson has been recognised, and in the Vestfold Hills and Larsemann Hills, which are extensive rocky coastal exposures with deeply indented coastlines indicative of recent submergence, remnants of two old erosion surfaces appear to be present at 125 and 30 metres altitude (Crohn, 1959). Numerous lakes are a feature of the Vestfold Hills. Several of these are highly saline, containing up to 27 percent total solids (mainly sodium chloride). Their surfaces are well below present sealevel. Probably these saline lakes were originally connected with the sea, and were concentrated by evaporation after they were isolated from it (McLeod, 1963).

The mountains around Amundsen and Casey Bays and in the interior of Enderby and Kemp Lands, and the Framnes Mountains inland from Mawson, are very rugged and deeply dissected, with jagged ridges and sharp peaks. The topography of these features is largely the result of sculpture by ice movement and nivation. On the other hand, the Prince Charles Mountains are characterised by extensive flat-topped massifs, some many square kilometres in extent. Thick deposits of moraine have blurred the topography of the underlying bedrock, and features such as cirques have extensively modified the bedrock surfaces, but even so it is apparent that the summits of these massifs represent an old erosion surface. In most of the Prince Charles Mountains, this surface stands at heights ranging from 1000 to 2600 metres, whereas around the Amery Ice Shelf similar flat-topped exposures have summits only 60 to 200 metres above sealevel.

Moraine occurs on many of the inland rock exposures at heights up to several hundred metres above the present surface of the ice sheet.

Raised beaches have been found in Amundsen Bay and in the Vestfold Hills at a height of about 9 metres. Molluscan remains on these beaches are all of forms still living around the Antarctic coast, as are most of the microfossils (Crespin, 1960).

Deposits of mirabilite occur in depressions in coastal outcrops, and around saline lakes.

REGIONAL GEOLOGY

The rocks of the sector can be divided into four main categories: the high-grade metamorphic rocks of the Precambrian shield, which form most of the outcrops; sediments metamorphosed high in the greenschist facies (Turner and Verhoogen, 1960), which have been found only in the southern Prince Charles Mountains; large granite bodies, also known only in the southern Prince Charles Mountains; and the unaltered Permian sediments of the Amery Formation, which have been found in situ only at Beaver Lake in the north-east Prince Charles Mountains. In addition, basic dykes (some of them metamorphosed) and pegmatite veins are widespread.

High Grade Metamorphic Rocks.

Rocks metamorphosed in the top subfacies of the almandine-amphibolite facies or in the granulite facies (Turner & Verhoogen, 1960) occur throughout the region, except in the southern Prince Charles Mountains. There is little doubt that they are part of the Precambrian shield despite the apparent Lower Palaeozoic age found for rocks of this category in the Mawson area (Starik et al., 1960). These comparatively young ages probably represent the impress on the rocks of one or more metamorphic episodes later than their initial metamorphism. Evidence for more than one metamorphic episode in the region is described below.

On a broad lithological basis, the high-grade metamorphic rocks can be divided into four types, viz: rocks with charnockitic affinities; metasedimentary gneisses; granitic-textured gneiss; and garnet-quartz-feldspar gneiss. Types which do not fit into these are referred to as undifferentiated metamorphics. The author emphasises that the names used for each of these divisions are terms applied for convenience of reference, and do not have any genetic connotation or stratigraphic significance. The relative ages of the various divisions are not known. Each of the broad divisions contains numerous textural, mineralogical and petrological variants, and members of one division quite commonly occur in minor proportions in an area predominantly occupied by rocks of another division. The distinctive characteristics of each type are presumably a result of a combination of the original overall compositional differences, the grade and conditions of metamorphism, and the subsequent metamorphic history of the area.

Rocks with charnockitic affinities

Rocks with charnockitic affinities are the most widespread in the region. They occupy most of the sector from Mawson to Casey Bay; other exposures have been found in the north-eastern Prince Charles Mountains and on the eastern side of the Amery Ice Shelf. With few exceptions they are in the pyroxene granulite sub-facies of metamorphism. They can be subdivided into three units, which are referred to here as charnockite, banded gneiss with charnockitic affinities, and quartz-feldspar gneiss. The names given to these units are those of the predominant rock type in each. They must be regarded only as a convenient means of reference, and have no genetic connotation. The banded gneiss with charnockitic affinities and the quartz-feldspar gneiss are similar in many respects, and further work may show that they are equivalent. The charnockite and banded gneiss with charnockitic affinities along the coast of Mac-Robertson Land and Kemp Land are described in some detail elsewhere in this Symposium (McCarthy and Trail, 1963).

The charnockite is best developed around Mawson and in the Framnes Mountains. Typically it is a uniform fine-grained to medium-grained granulitic-textured rock, with the dark colour in the hand specimen which is typical of charnockites. It contains hypersthene, quartz, potash and plagioclase feldspar, and rare garnet and biotite. In thin section, many specimens appear to have been recrystallised after intense granulation. Elongated inclusions are common; most are fine-grained and rich in biotite or hypersthene or both. In the vicinity of Mawson, and in parts of the Framnes Mountains, the rock contains a high proportion of coarse tabular crystals of perthitic potash feldspar. A poorly defined foliation is imparted to the rock by the parallel orientation of these feldspar crystals and the elongated inclusions.

A charnockite with large feldspar crystals, very similar to the rock at Mawson, occurs at Mount Loewe in the north-eastern Prince Charles Mountains. At Jennings Promontory, on the eastern side of the Amery Ice Shelf, the rock is also similar, but here contains relatively abundant hornblende and biotite in addition to the hypersthene; the hornblende is somewhat ophitic, replacing the hypersthene.

Rocks of the unit referred to in this paper as "banded gneiss with charnockitic affinities" are best known along the Kemp Land coast (McCarthy and Trail, 1963); the inclusion in this unit of the coastal rocks near the western border of Enderby Land is tentative, because they have not been examined in the same detail. The unit is referred to as having charnockitic affinities because of the occurrence almost everywhere of orthopyroxene as the predominant mafic mineral, and because most specimens have a granulitic texture. Some of the bands are not unlike the charnockite occurring further to the east. The rocks of the unit consist in the main of regularly alternating bands of light-coloured quartz-feldspar gneiss and dark coloured feldspar-pyroxene gneiss. The thickness of each band is generally less than a metre, although bands 10 metres thick have been found; overall, the feldspar-pyroxene gneiss forms about 20 to 30 percent of the unit.

The quartz-feldspar gneiss is medium-grained and generally foliated. It consists predominantly of quartz and plagioclase, with potash feldspar in places; the feldspars generally have a perthitic structure. Dark minerals occur in only minor amount : pyroxene (predominantly orthopyroxene with some clinopyroxene) and hornblende are generally present, and garnet and biotite may or may not be present.

The feldspar-pyroxene gneiss is generally a dark-coloured medium grained rather massive rock containing pyroxene, plagioclase and minor hornblende, and in places, minor biotite, garnet and potash feldspar. As in the quartz-feldspar gneiss, both orthopyroxene and clinopyroxene are generally present, with the former predominant; and both the feldspars commonly have a perthitic structure. In places the Enderby Land rocks show the effects of retrograde metamorphism from the pyroxene-granulite facies to the almandine-amphibolite facies - the pyroxene has been partly replaced by hornblende, and much of the feldspar has a corroded look.

Quartz-feldspar gneiss is the characteristic rock of the Tula and Scott Mountains. It is composed of blue or brown quartz and brown strongly perthitic feldspar in various proportions, with rare garnet, pyroxene and plagioclase. The rock is medium-grained and commonly has a good foliation; it is generally banded, with bands a few millimetres wide composed almost entirely of quartz alternating with similar-sized bands composed of quartz and feldspar. Although the mineral composition is similar to the charnockite, and the blue quartz and brown feldspar are typical of charnockites, the quartz-feldspar gneiss differs from them in hand specimen in having neither the granulitic texture nor the dark colour of charnockite.

Interbedded with the quartz-feldspar gneiss are layers, from a few centimetres to several metres thick, of medium-grained, equigranular, rather massive feldspar-pyroxene gneiss containing antiperthitic oligoclase, orthopyroxene and clinopyroxene. A few layers of white, fine-grained garnet-quartz-feldspar gneiss and of bluish-coloured quartzite also occur. Bands of black, medium-grained hypersthenite up to about 3 metres thick are interbedded with the gneisses; some of these bands are almost pure pyroxene, while others contain small amounts of feldspar.

At the McLeod Nunataks, south-east of the Tula Mountains, parts of the quartz-feldspar gneiss have a granulitic texture reminiscent of the charnockite. As typical charnockite (with a low pyroxene content) occurs further south at the Knuckey Peaks, it is likely that the quartz-feldspar gneiss and the charnockite are related, the difference between them being the degree of metamorphism they have undergone.

Garnet-quartz-feldspar gneiss

The garnet-quartz-feldspar gneiss can be subdivided into two types, depending on their textural appearance. The first of these types occurs on the eastern side of Prydz Bay. The rocks are light-coloured, fine-grained to medium-grained, and commonly have an almost granitoid texture (especially in the Rauer Group of islands). They are predominantly quartz and feldspar; biotite is commonly present, garnet occurs in minor amount, and sillimanite, amphibole and pyroxene occur rarely. In places the gneiss possesses a poorly-defined banding due to differences in grain size or texture or concentration of the biotite flakes. Straight, parallel veins of coarse-grained massive granite several metres thick are a feature of the Larsemann Hills. These are absent from the Rauer Group, but the gneiss here contains irregular quartz-feldspar veins with a granitic or pegmatoidal texture. In parts of the Larsemann Hills both the gneiss and the granitic veins are rich in magnetite; amphibole, biotite and magnetite-rich lenses which occur in the Larsemann Hills may be of metasomatic origin.

The second type of garnet-quartz-feldspar gneiss occurs in the Leckie Range and Mount Channon in Kemp Land; examination of air photos suggests that a similar rock forms the Arnell Bluffs, 20 km south of the Leckie Range. This type of gneiss also consists of feldspar, quartz and minor biotite and garnet. It is distinguished from the first type by being generally finer grained, and possessing a well-defined large-scale banding (due to concentration of biotite and/or garnet) which can be discerned from a distance of a kilometre or more. It also contains bands of charnockite up to two or three metres wide. The gneiss at the Leckie Range has a strong lineation. Here too, thin quartz-feldspar veins along the foliation of the gneiss are intersected by metamorphosed basic dykes which do not have a macroscopic lineation. These dykes are in turn invaded by thin, pink granite veins.

Metasedimentary gneiss

Gneissic rocks originally of sedimentary origin are abundant along about 20 kilometres of the coast in the Taylor Glacier area. They also occur in parts of the Framnes Mountains and are of widespread occurrence in the northern Prince Charles Mountains.

The unit is made up of a variety of rock-types, but the rocks are predominantly medium-grained garnet-biotite-quartz-feldspar gneiss and garnet-quartz-feldspar-gneiss of the almandine-amphibolite or granulite facies. They are well foliated and generally distinctly banded; the thickness of most bands is about a metre, but bands up to 15 metres thick have been found. The proportion of biotite varies greatly, ranging from accessory amounts to more than 10 percent of the rock; some thin bands are predominantly biotite. Garnet is mostly present in moderate amount, sillimanite is a constituent of the rock at many places, and cordierite is locally abundant.

A feature of these gneisses, particularly in the Taylor Glacier area, is the great number of large and small bodies of pink or red pegmatitic or granitic rock in them. These bodies are generally concordant with the foliation of the gneiss, and range in width from less than a metre to 20 metres; the largest seen is about one and a half kilometres long and half a kilometre wide. The granitic rock is medium-grained and generally massive, but is foliated parallel to the gneiss in some exposures. It consists of potash feldspar, quartz, biotite, minor plagioclase, and,rarely, garnet. Veins of aplite and feldspar-rich pegmatite are also a feature of these gneisses.

Granitic-textured gneiss

Granitic-textured gneiss of the almandine-amphibolite facies is predominant in the north-east Prince Charles Mountains and at the Clemence Massif and Grove Nunataks. The term "granitic-textured" is chosen for this unit to indicate the overall appearance in the field of the predominant rock in it, and does not have any genetic connotation. The unit contains also greater or lesser amounts of banded biotite-quartz-feldspar gneiss (with or without garnet) very similar to the garnet-biotite-quartz-feldspar gneiss of the metasedimentary gneiss. The two units are probably closely related; indeed, in this paper the distinction between them is made mainly on the relative proportions, on a large scale, of the granitic-textured gneiss and the finer-grained banded biotite-quartz-feldspar gneiss.

The granitic-textured gneiss is generally medium-grained, roughly equigranular (although parts contain large crystals of potash feldspar), and consists essentially of pink or red feldspar, quartz and biotite, with garnet in minor amount in places. Both potash and plagioclase feldspar occur, and either may be predominant; perthitic structure is common in them. Biotite ranges from common to rare. The rock is mostly well-foliated, and in some places displays a poorly-defined banding due to variations in the relative proportions of the principal minerals.

Small amounts of biotite-quartz-feldspar gneiss are generally present, interbanded with the granitic-textured gneiss, such as in parts of the northern Prince Charles Mountains, or forming small remnants within it, such as at the Clemence Massif. At the Grove Nunataks, foliated granite gneiss is cut by numerous veins of massive granite. Granitic-textured gneiss at Fram Peak, a few miles north of the Hansen Mountains, appears to have been partly recrystallised.

The evidence at present is not conclusive for either a metamorphic or igneous origin for the granitic-textured gneiss.

Undifferentiated metamorphics

The rocks classed as undifferentiated metamorphics are those which, as a whole, do not readily fit into the types described above. The areas shown as such on the accompanying map (Figure 1) are quite distinct from one another and have no apparent lithological or structural relation to each other.

The rocks of this category which occur around Casey Bay appear to have been predominantly medium-grained garnet-pyroxene-quartz-feldspar rocks, probably of the granulite facies. However, many now show the effects of retrograde metamorphism to the almandine-amphibolite facies, with, in some places at least, accompanying cataclasis. The pyroxene and garnet have been partly replaced by hornblende and biotite, and sillimanite and a second generation of feldspar and quartz have formed.

The geology of the outcrop on the western side of the Amery Ice Shelf is known only from specimens collected by a glaciological field party. The specimens are medium-grained equigranular garnet-quartz-feldspar gneiss; biotite or pyroxene are present in amounts ranging from accessory to common. In texture and mineral composition, some are not unlike parts of the garnet-quartz-feldspar gneiss occurring in the Leckie Range, but not enough is known about their relationships for a definite correlation to be made.

Garnet-quartz-feldspar gneiss occurs also at Mount Caroline Mikkelsen, but here the grain sizes of the constituent minerals range from fine to coarse and the gneiss contains fine-grained bands and lenses made up of plagioclase, quartz and orthopyroxene. Some of these specimens also are not unlike rocks occurring at the Leckie Range, but once again, insufficient is known about them to allow correlation with the Leckie Range rocks.

The Vestfold Hills consist of a variety of gneisses. These include pyroxene-quartz-feldspar gneiss, garnet-quartz-feldspar gneiss, garnetiferous quartzite, and pyroxenite; pyroxene-quartz-feldspar rocks appear to be the predominant variety. Although many of the gneisses are counterparts of those in the categories described above, no particular type seems to be predominant, so the rocks of the Vestfold Hills area are, for the time being, regarded as "undifferentiated metamorphics". The dolerite dyke swarm which intrudes these gneisses is a notable feature of the area.

The rocks in the southern Prince Charles Mountains classed as undifferentiated metamorphics generally are biotite-hornblende-quartz-feldspar gneiss, garnetiferous in places; staurolite was found in one specimen. They appear to have undergone synkinematic metamorphism followed by a regional heating without deformation, and now have a metamorphic grade in the lower part of the almandine-amphibolite facies. What appear to be metamorphosed basic dykes are a feature of all the exposures visited, especially at the southern end of the Mawson Escarpment. The dykes still retain their original form, and hence were probably intruded between the synkinematic metamorphism and the regional reheating. The regional relationships of the gneisses are not known; their metamorphic grade is higher than that of the quartzites and quartz-mica schists flanking the Fisher Glacier, but lower than that of the gneisses of the northern Prince Charles Mountains. Possibly they represent rocks similar to the quartzites etc, which have been metamorphosed past the greenschist facies by the regional heating. It is not known whether these biotite-hornblende-quartz-feldspar gneisses grade into the greenschist facies rocks along the Fisher Glacier on the one hand, and/or into the high-grade gneisses of the northern Prince Charles Mountains on the other. The whole of the Mawson Escarpment has been tentatively included in this category, because aerial inspection indicated that the rocks were similar along the whole of their length.

Rocks of the Greenschist Facies

Rocks high in the greenschist facies of metamorphism (Turner and Verhoogen, 1960) form the large massifs flanking the Fisher Glacier in the southern Prince Charles Mountains. These occurrences are described only briefly here; a more detailed account is given elsewhere in this Symposium (Trail, 1963b). The rocks are predominantly quartzite and quartz-mica schist; chloritoid-quartz schist is common in places. Bands of actinolite amphibolite occur at some massifs. Marble was found near granite bodies at Mount Dummett and Mount Bayliss, and in moraine at Mount Rymill and the Goodspeed Nunataks. Goethite-rich schists occur in moraine at Mount Rymill and crop out in the contact zone of the granite at Mount McCauley; hematite and quartz-hematite rock occur in moraine at Mount McCauley.

At several places, the metamorphic grade has been increased to the hornblende-hornfels facies by the emplacement of large bodies of granite; at others, the rocks appear to have been thermally metamorphosed, but no granite was found in the vicinity. Rocks such as quartz-hornblende amphibolite are common; the more calcic hornfels contains minerals such as epidote, scapolite and calcite along with the hornblende, quartz and feldspar.

Granite

The only large granitic bodies which have been found are in the southern Prince Charles Mountains, near the Fisher Glacier (Trail, 1963b). The size and shape of these bodies is not known (except at Mount Bayliss).

At Mount Dummett and Mount McCauley a massive, medium-grained two mica granite contains small concentrates of garnet. Sheared augen-gneiss containing feldspar, quartz, biotite, hornblende and epidote which occurs at Mount Bloomfield may originally have belonged with this unit. Granite was not found in situ at the Goodspeed Nunataks, but moraine near the northernmost nunatak consists almost entirely of boulders of massive granite. The low-grade metamorphic rocks at Mount Bayliss, south of the Fisher Glacier, contain a sub-horizontal, sill-like body of biotite granite 150 metres thick, which exhibits a marked sub-horizontal foliation. Late stage minerals such as fluorite and tourmaline are relatively abundant in the granite at Mount Bayliss and in some of the specimens collected at the Goodspeed Nunataks.

Basic Dykes

Dolerite dykes are very numerous in the Vestfold Hills, forming a well displayed dyke swarm. Most of the dykes strike about north-south; other minor sets trend east -west, north-west to south-east, and north-east to south-west. Members of all these sets appear to have been emplaced more or less contemporaneously. Single dolerite dykes were found at several places in Enderby and Kemp Lands; most of these trend approximately north - south. All the dolerites are essentially plagioclase-pyroxene rocks; olivine has not been found in them.

The age of the dolerites is not definitely known. They do not seem to have been affected by the Lower Palaeozoic metamorphism which is so widespread in East Antarctica; by analogy with similar rocks in the Ross Sea region and other parts of Antarctica, they are assigned a Jurassic age.

Basalt dykes were seen in several places in the Tula and Prince Charles Mountains. In the former area they occur in or near zones of shearing. These basalts may be related to the dolerites, but they could represent a younger, possibly Tertiary, igneous episode.

Specimens of deformed and altered olivine rock and olivine-pyroxene cataclasite were collected from a locality in the north-east Vestfold Hills by N.T. Lied, weather observer in the 1961 expedition. The field relations of these specimens are not known.

Metamorphosed basic dykes occur along the coast of, and in the interior of, Enderby and Kemp Lands, and in the Prince Charles Mountains. Although widespread, they are not numerous and have been found mainly as isolated occurrences, not as groups. They still distinctly have the form of dykes - they cut sharply across the foliation of the gneiss, and have well-defined margins; some, however, can be seen to pinch out along their strike, and a few have a faint foliation parallel to their margin. The original rock, which was probably basalt or dolerite, has been wholly or partly recrystallised to feldspar, pyroxene, amphibole, quartz, magnetite, and in some cases, biotite or garnet. The rock in which the dykes were emplaced was clearly high-grade gneiss; both gneiss and dyke rock have since been altered by a later metamorphism.

Pegmatites

Coarse-grained, pegmatoidal rocks were found in most of the outcrops examined, except those of the Amery Formation. They can be divided into two types.

The most numerous are coarse-grained, discontinuous veins, irregular in width and direction, composed mainly of quartz and feldspar with accessory pyroxene, biotite, amphibole or garnet. Graphic intergrowths of the constituent minerals are rare in this type. Most veins seem to be very coarse-grained variants of the rocks in which they occur, and were probably formed by the same metamorphic or metasomatic processes.

Less common, but widespread, are very coarse-grained, straight, parallel-sided pegmatite veins ranging up to 5 metres in width; the wider ones are commonly zoned. They contain mainly pink perthite and quartz (commonly graphically intergrown), with large biotite plates and some plagioclase; small amounts of garnet and minerals such as tourmaline and sphene may also be present. Most of these veins have had no macroscopically observable effect on the adjacent rock, but in a few cases, although the edge of the pegmatite is quite sharply defined, the enclosing rock has been granitised for a distance of a metre or two from the pegmatite.

Veins of this type are relatively common in the southern Prince Charles Mountains and here can be correlated with the granites described above. They have also been found at many other places in the region, such as the interior of Enderby and Kemp Lands, where no batholithic granite masses are known to occur.

Sediments

Sediments of the Amery Formation crop out along the western and southern sides of Beaver Lake in the north-east Prince Charles Mountains. On their western margin they are downfaulted against metamorphic rocks along the Amery Fault; their relation to the high-grade metamorphic rocks between Beaver Lake and the Amery Ice Shelf is not known. The area of sediments not covered by ice is thought to be about 450 square kilometres, but most of this is buried under deposits of moraine. The thickness of the sedimentary sequence is estimated to be at least 500 metres.

The rocks of the formation have a striking lithological resemblance to parts of the Beacon Sandstone of the McMurdo Sound area. They are mainly current-bedded feldspathic sandstones, calcareous in part, made up of rather angular, only moderately sorted grains of quartz and feldspar in a clay matrix. Carbonaceous shale, coal seams and beds of massive, reddish-brown or grey mudstone also occur. The coal is intermediate in rank between brown and black coal. No identifiable macrofossils have been found, but palynological work by Balme and Playford (1958) indicates an upper Artinskian or Kungurian age for samples from near the top of the sequence. The attitude of current bedding in the sediments indicates that their source was to the west of Beaver Lake. Along the edge of Beaver Lake the sediments are almost horizontal, but dips of 20° to 30° to the east have been observed near the Amery Fault.

Boulders of siltstone containing remnants of Glossopteris (White, 1962) were found in moraine at Mount Rymill, 250 km south of Beaver Lake. The siltstone is brick-red in colour and is soft and fissile. Some boulders include bands of sandstone, which does not contain any fossils. The source of the boulders is not known.

The very presence of the Lambert Glacier suggests a major depression in the underlying rock. The occurrence in this depression of the only Beacon Group equivalents known in East Antarctica other than in the Ross Sea - Weddell Sea region and in the Horn Bluff area may be coincidental. But it is attractive to speculate that the topographic depression is also a structural depression of long standing - possibly a graben - which was a locus of sedimentation in upper Palaeozoic times.

STRUCTURE

Along the coast from Mawson to Stefansson Bay, and south to the Stinear Nunataks, the regional strike of the metamorphic rocks is roughly north-south. Elsewhere, with few exceptions, it is about east-west, both in the high-grade gneisses and the rocks of lower grade along the Fisher Glacier. Dips are generally steep, and folds with amplitudes up to several hundred metres can be seen in many places. The degree of folding ranges from quite open to very tight; a large-scale recumbent fold has been noted at Depot Peak.

Small-scale faults, with an apparent displacement of a few metres, are fairly common, but large-scale faults have been seen at only a few places. Some of the large faults are marked by zones of mylonite up to 10 metres wide; basalt dykes occur in or near some of these zones.

Although the fault has not been seen on the ground, the sediments of the Amery Formation are undoubtedly downfaulted against high-grade metamorphic rocks by the north-south trending Amery Fault. Near the fault, the sediments dip eastwards at 20° to 30°, whereas further east they are nearly horizontal. The surface of the sediments, and of the high-grade metamorphic rocks on the eastern side of Beaver Lake, has a maximum altitude of about 200 metres, while the height of the mountains west of the fault is about 1000 metres. The fault scarp can be seen in places, but it is largely masked by the blanket of moraine piled up against it. The only limits which can be placed on the age of this fault are that movement took place along it after the deposition of the Permian Amery Formation and before the maximum of the glaciation.

The complete change in rock type from the Vestfold Hills to the Rauer Group, 10 km to the south, and the absence from the Rauer Group of the dolerite dykes which are so common in the Vestfold Hills, indicates a major structural break between these two places.

Crohn (1959) on physiographic grounds has suggested that block faulting has played a considerable part in determining the present configuration of the Prince Charles Mountains. The topography of many of the large rock exposures is suggestive of fault scarps. However, the same features could have been formed by erosion of a landscape of moderate relief by ice-cap glaciers when the surface of the ice-cap was at a higher level. The larger ice-streams, such as the Lambert Glacier and its tributaries, must have profoundly deepened the pre-glacial valleys and so formed the long, straight rock faces which are features of many of the large massifs and ranges of the Prince Charles Mountains. It is quite possible that extensive faulting has occurred in the area, but little direct evidence of this is available at present.

METAMORPHIC HISTORY

Tectonically, the sector is made up of two units: the high-grade metamorphic rocks of the Precambrian Shield, and a zone of largely quartzose sediments which have undergone low-grade metamosphism accompanied by widespread shearing and emplacement of large granite masses. The rocks of intermediate metamorphic grade in the southern Prince Charles Mountains are tentatively included with the latter unit.

Evidence, more-or less conclusive, has been found at many places in the region that more than one metamorphic episode has affected the high-grade metamorphic rocks. The most obvious evidence is that of the metamorphosed basic dykes which cut across the foliation of the gneisses. Although the gneiss may be quite strongly foliated (and, at the Leckie Range, lineated also), the texture of the metamorphosed dykes is either massive or poorly foliated in a direction parallel to the walls of the dykes. This indicates that the gneiss acquired the foliation before emplacement of the dykes, and that deformation was not important in the later metamorphism.

Mineralogical evidence of retrograde metamorphism from the pyroxene granulite facies to the almandine-amphibolite facies is best displayed in the Casey Bay and Edward VIII Gulf areas. Mineralogically, the main effect of the second metamorphism is replacement of pyroxene by hornblende or, rarely, biotite. In a few places feldspar has been altered to sericite.

Detailed mineralogical examination of rocks from the Mawson area and the Framnes Mountains indicates that many have been granulated and then partly recrystallised and possibly metasomatised. The measured ages of 490 to 650 my for rocks from Mawson (Starik et al, 1960), most probably represent an effect of more than one metamorphic episode; on regional grounds it would seem highly unlikely that rocks of the

Antarctic Shield were first crystallized as late as the Lower Palaeozoic. Further, the range in measured ages (490, 535, 555, 650 my) for specimens from the same place suggests differential argon loss resulting from metamorphism of pre-existing metamorphic rocks.

In places, as in the Mawson - Framnes Mountains area and parts of Casey Bay, the later metmaorphism was accompanied by or preceded by cataclasis of the gneiss. In other places, such as parts of the Kemp Land coast and the interior of Enderby Land, deformation was unimportant, because the form of basic dykes was not affected.

It is not known whether the later periods of metamorphism were contemporaneous in the different parts of the sector. Nor is the date of metamorphism of the low-grade rocks of the southern Prince Charles Mountains known in relation to the metamorphic history of the high-grade rocks.

The history of the region is obviously complex. Nevertheless, a general outline can be very tentatively summarised as follows :

1. Metamorphism to the granulite or almandine-amphibolite facies of a succession of sedimentary and igneous rocks, and their incorporation into the Antarctic Shield. This metamorphism probably occurred at different times in different parts of the region, and some parts may have been affected by more than one metamorphism.

2. Intrusion of basic dykes.

3. Further metamorphism at the almandine-amphibolite facies grade. This metamorphism may have occurred at different times in different parts of the region but it could have been contemporaneous - the widespread distribution of rocks with a measured age of 480 my (Picciotto and Cappez, 1963) indicates a widespread metamorphic event at this time. This could also have been the event which metamorphosed the greenschist facies rocks of the southern Prince Charles Mountains, accompanied by granite emplacement and perhaps the emplacement of parallel-sided pegmatite dykes throughout the region.

4. These metamorphic events were followed by deposition of freshwater sediments, possibly in a downfaulted basin, in lower Permian times, and the widespread injection of basic dykes, probably during the Jurassic.

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Petrographic descriptions and interpretations of many rocks from the sector were prepared by W.R. McCarthy of Australian Mineral Development Laboratories, Adelaide; detailed petrographic work on other specimens was done by P.W. Crohn or myself.

The paper is presented with the permission of the Director, Bureau of Mineral Resources, Geology and Geophysics, Canberra.

REFERENCES

BALME, B.E., and PLAYFORD, C., 1958 - Samples from the Prince Charles Mountains, Antarctica. Univ.W.Aust.Palynol.Rep. (25)(unpubl.).

CRESPIN, I., 1960 - Some recent foraminifera from the Vestfold Hills, Antarctica. Sci.Rep. Tohoku Univ.Second Ser.,Spec.Vol.4, 19-31.

CROHN, P.W., 1959 - A contribution to the geology and glaciology of the western part of Australian Antarctic Territory. Bur.Min.Resour.Aust.Bull. 52.

McCARTHY, W.R., and TRAIL, D.S., 1963 - The high-grade metamorphic rocks of the Mac-Robertson Land and Kemp Land coast. This Symposium.

McLEOD, I.R., 1963 - The saline lakes of the Vestfold Hills, Princess Elizabeth Land. This Symposium.

PICCIOTTO, E., and COPPEZ, A., 1963 - Bibliographie des mesures d'ages absolus on Antarctique. Ann.Soc.Geol.Belg. 85(8), B263-B308

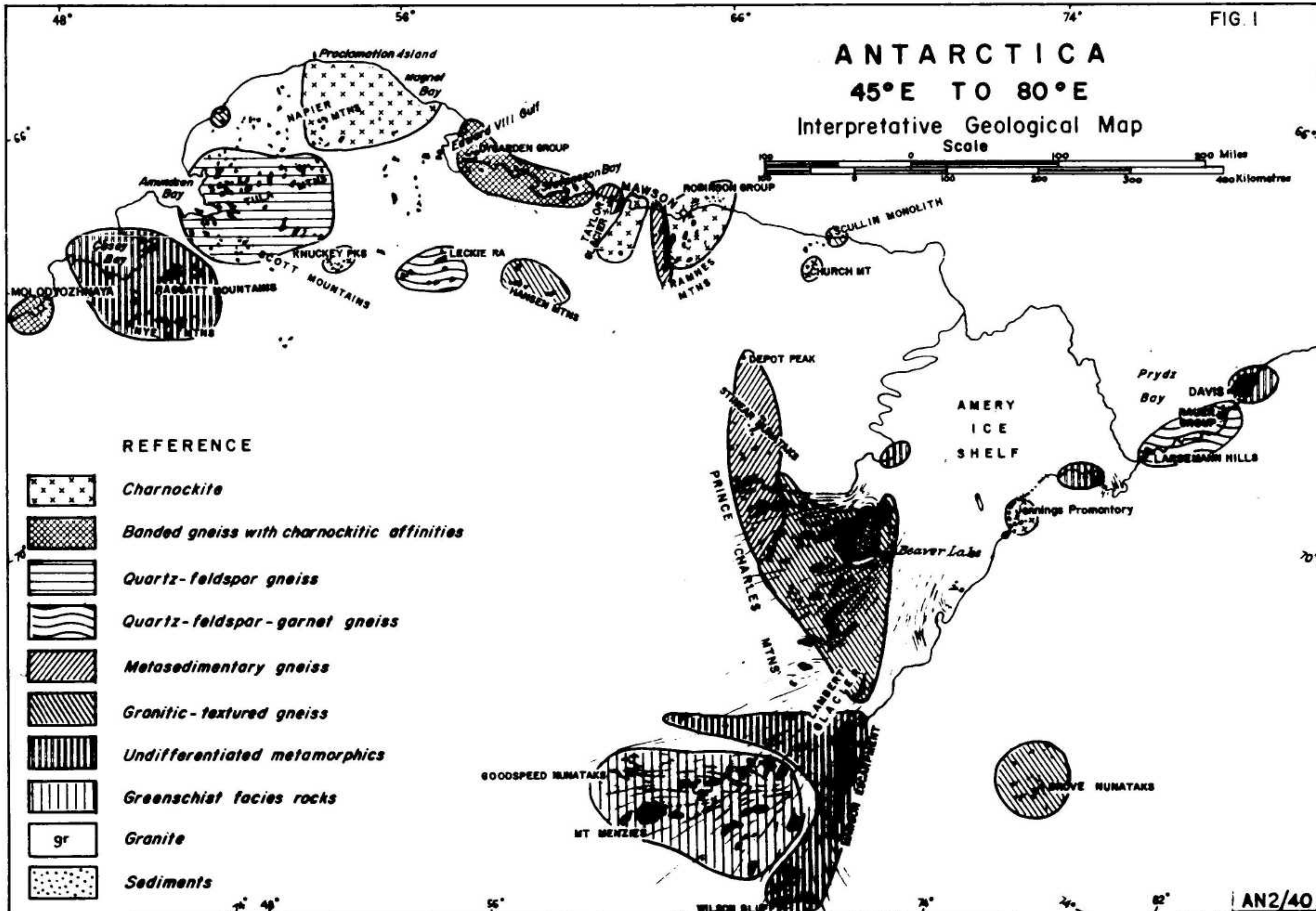
STARIK, I.E., RAVICH, M.C., KRYLOV, A.Y., SILIN, Y.I., ATRASHENOK, L.Y., and LOVTSYUS, A.V., 1960 - New data on the absolute age of rocks of the eastern Antarctic continent. Dok.Acad.Sci. U.S.S.R. 134(6), 1441-1443.

TRAIL, D.S., 1963a - Low-grade metamorphic rocks from the Prince Charles Mountains, East Antarctica. Nature, 197 (4867), 548-550.

TRAIL, D.S., 1963b- Schist and granite of the southern Prince Charles Mountains. This Symposium.

TURNER, F.J., and VERHOOGEN, J., 1960 - IGNEOUS AND METAMORPHIC PETROLOGY 2nd ed. McGraw Hill, New York.

WHITE, Mary, E., 1962 - Permian plant remains from Mount Rymill, Antarctica. In Report on 1961 plant fossil collections. Bur.Min.Resour.Aust.Rec. 1962/114 (unpubl.).



Bureau of Mineral Resources, Geology and Geophysics

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PAPER 2:

Schist and Granite in the Southern Prince Charles Mountains

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SUMMARY

The southern Prince Charles Mountains, between 60°E. and 70°E., and 73°S. and 74½°S., are composed of rocks metamorphosed in the greenschist facies (quartzite, quartz schist, marble, ferruginous schist, and amphibolite), or in the almandine amphibolite facies (biotite-feldspar-quartz gneiss, mica-quartz schist with andesine, augen gneiss, and metamorphosed basic dykes), by hornfels (quartz-hornblende amphibolite and others), and by granite, pegmatite and quartz veins.

Recumbent and isoclinal folding, and cataclastic foliation are evident.

The greenschist facies rocks were deposited as quartz-rich sediments, ferruginous sediments, chert, and limestones.

Regional metamorphism and severe folding was followed by emplacement of granite and basic dykes, mild deformation (severe cataclastic deformation locally) and a predominantly thermal, second metamorphism accompanied or closely followed by potash metamomatism, and the emplacement of granite, pegmatite, and quartz veins.

Metamorphic grade increases towards the coast, but the relationship of these rocks to the high-grade metamorphics typical of East Antarctica is unknown. The rocks of the southern Prince Charles Mountains were possibly metamorphosed in the widespread event dated at 480 m.y.

INTRODUCTION

The Prince Charles Mountains are located in East Antarctica south of the central part of the Indian Ocean between longitudes 60°E. and 70°E., and latitudes 69½°S. and 74½°S.(Fig. 1). They are a group of large and small nunataks extending about 600 kilometres inland from the Amery Ice Shelf. The Australian National Antarctic Research Expeditions investigated the geology of these mountains between 1954 and 1961.

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Trail (1963) has described briefly rocks metamorphosed under greenschist facies conditions, which crop out in the southern Prince Charles Mountains. These low-grade metamorphics differ from the high-grade metamorphics, typical of East Antarctica, which form the northern Prince Charles Mountains. This paper describes and discusses the known geology of the southern Prince Charles Mountains, the geological history of this area, and its regional setting.

McLeod (1959), Ruker (in prep.) and Trail (in prep.) record the geological investigation of the southern Prince Charles Mountains. Information on the northern Prince Charles Mountains has been obtained from Crohn (1959), Stinear (1956), and McLeod (1959).

W.R. McCarthy of Australian Mineral Development Laboratories, Adelaide, has described the petrography and the metamorphic history of all rocks collected by Ruker and Trail from this area and has given me a great deal of information and advice on the presentation of this paper.

GEOLOGY

The southern Prince Charles Mountains are composed of rocks metamorphosed in the greenschist facies (nunataks around the Fisher Glacier) and of rocks metamorphosed in the almandine amphibolite facies (Binders Nunataks, Mount Creswell, Wilson Bluff and the southern part of the Mawson Escarpment). Large bodies of granite have been emplaced in the greenschist facies rocks, and some rocks adjacent to the granite are metamorphosed in the albite-epidote hornfels or hornblende hornfels facies.

Fig. 2 shows the distribution of the known rocks by lithology and by metamorphic facies as described by Fyfe, Turner, and Verhoogen (1958).

Rocks of the Greenschist Facies

Quartzite and quartz schist are probably the most abundant of the greenschist facies rocks.

Isoclinally folded quartzite, at least 1500 metres thick, makes up the bulk of Mount Menzies. It is a massive, fine-grained rock containing 90 to 97 percent quartz, and is composed of white, pink, green, or black bands from 1 metre to 100 metres thick. Accessory chloritoid colours the green bands; the white bands contain accessory muscovite and sericite; the black bands appear to be stained by iron; the pink bands were not sampled. One quartzite sample contains 1 percent garnet, probably spessartite, and a sample from moraine contains 5 percent magnetite. Bands, a few metres thick, of mica-quartz schist and chloritoid-quartz schist occur within the quartzite; one band contains some cordierite.

Green quartzite forming the lower part of Mount Bayliss (Fig. 3) is composed of 85 percent quartz and 15 percent biotite, muscovite, and sericite. Where weathered, it resembles an unaltered sandstone.

At Mount McCauley and Mount Rymill, quartzite containing feldspar and mica is interbanded with biotite-feldspar-quartz schist and biotite-sericite-quartz schist; at Mount Seddon calcite-sericite-quartz schist is interbanded with biotite-quartz schist (Ruker, in prep.).

Quartzite from moraine at the Goodspeed Nunataks is described by McLeod (1959) as a mosaic of quartz grains containing muscovite, magnetite, zircon, tourmaline, and sphene.

Marble occurs in moraine at the Goodspeed Nunataks and magnesian marble in moraine at Mount Rymill. Small outcrops of marble lie near granite at Mount Dummett and Mount Bayliss.

Ferruginous schist occurs in moraine at Mount Rymill as stilpnomelane-goethite-quartz schist, and goethite-tremolite-muscovite-stilpnomelane schist crops out in the contact zone of the granite at Mount McCauley. Moraine on the north and east sides of Mount McCauley contains large boulders of hematite (in which magnetite occurs as rounded inclusions) and fragments of jaspilite (Ruker, in prep.).

Amphibolites form a few thin concordant bands within the quartzite at Mount Menzies. The only specimen collected contains 85 percent actinolite, 12 percent quartz, and 1 percent feldspar.

Rocks of the Almandine Amphibolite Facies

Biotite-feldspar-quartz gneiss is the most abundant of the almandine amphibolite facies rocks which form Binders Nunataks, Mount Creswell, and the south end of the Mawson Escarpment (Ruker, in prep.). The feldspar is andesine or labradorite; some gneisses also contain garnet and green hornblende.

Mica-quartz schist forming most of Wilson Bluff contains biotite , some muscovite, cummingtonite, and plagioclase in the range andesine-labradorite; garnet and tourmaline occur in places (McLeod, 1959). At the south end of the Mawson Escarpment, muscovite-staurolite-quartz schist is interbanded with hornblende-bearing quartz gneiss (Ruker, in prep.).

Augen gneiss which forms much of Mount Bloomfield is composed of epidote, hornblende, biotite, quartz, augen of plagioclase, and augen of microcline (McCarthy in Ruker, in prep.).

Basic dykes described by Ruker (in prep.) at Binders Nunataks and the Mawson Escarpment (Fig. 4) are hornblende amphibolites with andesine and garnet or quartz.

Hornfels

These rocks are found adjacent to granite emplaced within the greenschist facies rocks; they have been metamorphosed under albite-epidote hornfels facies or hornblende hornfels facies conditions.

Quartz-hornblende amphibolite (hornblende 60 to 75 percent, quartz 20 to 35 percent, andesine 1 percent in some) is abundant as boulders in moraine on the summit plateau of Mount Bayliss. Airphoto interpretation and distant observations suggest that dark rocks exposed in the northern and southern cliffs of the mountain are also amphibolite, overlying a granite sheet (Fig. 3). A fifteen-metres-thick zone of calcite-biotite-epidote-microcline-quartz-hornblende amphibolite lies under the granite sheet, between it and the quartzite described above. Epidote-microcline-quartz-hornblende amphibolite forms much of the eastern part of Mount Dummett; the western part is granite.

Other hornfelsed rocks are scapolite-biotite-calcite-epidote rock, exposed between granite and marble in a small nunatak at the west end of Mount Bayliss, and a variety of rocks found by Mellor (in McLeod, 1959) among moraine covering one of the Goodspeed Nunataks, near a moraine deposit composed almost exclusively of granite. These rocks are: recrystallised sandstone with accessory muscovite, magnetite, zircon, tourmaline, and sphene; calcite-pistacite-quartz rock; and magnetite-biotite-sericite-quartz rock.

Intrusive and Other Rocks.

Some rocks described here as granite have not been examined microscopically. They may not be granite in terms of their feldspar content, but their mode of occurrence and hand-specimen appearance suggest the name.

Granite made up of quartz, feldspar, biotite muscovite, and small concentrations of garnet, forms large outcrops at Mount McCauley and Mount Dummett which may be parts of the same body (Ruker, in prep.). Granite from moraine at the Goodspeed Nunataks is a coarse massive rock composed of perthite, plagioclase, quartz, biotite, and accessory lepidolite, fluorite, beryl, tourmaline, zircon, muscovite, and magnetite (McLeod, 1959). At Mount Bayliss (Fig. 3), a 150-metres-thick, sub-horizontal body of granite has a marked cataclastic foliation and is, in places, an augen gneiss. The rock is composed of quartz, microcline, and biotite, with accessory fluorite, orthite, sphene, and rare zircon.

Pegmatites composed of quartz, feldspar (microcline and albite in two specimens), biotite, garnet, and tourmaline, cut almandine amphibolite facies rocks forming Mount Creswell and Wilson Bluff. Quartz-feldspar pegmatites also occur at Mount Bloomfield, and at Mount Dummett they extend outwards from the granite mass(Ruker, in prep.).

Quartz veins and a few small quartz reefs occur in schist or hornfels near granite at Mount Bayliss, Mount McCauley, and Mount Dummett. Quartz veins are common in schists at Mount Menzies and Wilson Bluff, and in augen gneiss at Mount Bloomfield.

STRUCTURE

McLeod (1959) describes small recumbent folds in schist at Wilson Bluff and illustrates large-scale folding at Patrick Point (Fig. 5).

At Mount Menzies, schistosity in the quartzite and interbanded schist is developed parallel to the steeply dipping axial planes of isoclinal folds with amplitudes up to 1000 metres.

Cataclastic foliation is developed in granite and contact rocks at Mount Bayliss, in augen gneiss at Mount Bloomfield, and in marble from moraine at the Goodspeed Nunataks (McCarthy in Trail, in prep. & in Ruker, in prep.).

GEOLOGICAL HISTORY

Sedimentation

The greenschist facies rocks were probably deposited as sedimentary quartzite, impure quartz-rich sediments, ferruginous sediments, chert, and pure and impure limestone.

The rocks of the almandine amphibolite facies probably originated as quartz-rich sediments which may or may not have been deposited in the same environment as the greenschist facies rocks.

Deformation, Metamorphism, and Igneous Activity

Both greenschist facies rocks and almandine amphibolite facies rocks show the effects of two episodes of metamorphism. The first was one of regional metamorphism in which schistosity or foliation developed, presumably during the deformation which produced the isoclinal and recumbent folds.

The second episode was apparently one of thermal metamorphism, indicated by the growth of large crystals with no preferred orientation (chloritoid and biotite in the greenschist facies rocks, and biotite and hornblende in the almandine amphibolite facies rocks).

In a plicated schist from Mount Menzies, crystals of cordierite in the axial areas of the plications apparently began to grow in these structurally favourable locations towards the end of the phase of mild deformation which plicated the schistosity. In hornfels and quartzite from Mount Bayliss, large crystals of biotite, microcline, and quartz, appear to have grown after the development of the marked cataclastic foliation in these rocks and in the overlying granite (Fig. 3). In the augen gneiss at Mount Bloomfield, biotite, microcline, and quartz, together with sericite, epidote, green uralitic hornblende, and sphene, also form a second generation of metamorphic minerals which appear to have grown during a phase of dynamic metamorphism (McCarthy in Trail, in prep. and in Ruker, in prep.).

The plication of the cordierite-bearing schist of Mount Menzies, and the cataclastic deformation of the granite of Mount Bayliss and the augen gneiss of Mount Bloomfield, appear to represent localised deformation accompanying the predominantly thermal, second phase of metamorphism. The formation of microcline at Mount Bayliss and Mount Bloomfield suggests that potash metasomatism also occurred during the second metamorphism.

The Mount Bayliss granite and the metamorphosed basic dykes appear to have been affected only by the second metamorphism, and they were probably emplaced between the two metamorphic episodes.

The granite exposed at Mount McCauley and Mount Dummett, the granite from moraine at the Goodspeed Nunataks, the pegmatites, and the quartz veins, are not evidently metamorphosed. They may have been emplaced during or after the predominantly thermal second phase of metamorphism.

The history of metamorphism and igneous activity in the rocks of the southern Prince Charles Mountains may be tentatively summarised as follows :

1. Regional metamorphism involving severe folding.
2. Emplacement of Mount Bayliss granite and of basic dykes.
3. Mild deformation, with severe cataclastic deformation locally.
4. Widespread thermal metamorphism probably accompanied or closely followed by potash metasomatism, emplacement of granites, pegmatites, and quartz veins.

Resemblances between the Mount Bayliss granite and the undeformed granites and pegmatite (the presence of fluorite and microcline) strengthen the possibility that events 2, 3, and 4, constitute three stages in one comprehensive episode of thermal metamorphism and granite emplacement.

REGIONAL SETTING

Handspecimens of greenschist facies schist or quartzite and of almandine amphibolite facies gneiss are strikingly different, but their mineralogies indicate that the difference in metamorphic grade between the two groups is not great.

The garnet-bearing and cordierite-bearing rocks of Mount Menzies were metamorphosed under highest greenschist facies conditions, possibly not far short of the conditions which produced the staurolite-quartz schist of the Mawson Escarpment, typical of the lowest subfacies of the almandine amphibolite facies.

Similarities in the metamorphic histories of the two groups also suggest that they were metamorphosed at the same time. They are probably not separated by the tectonic discordance which I previously postulated (Trail, 1963).

The metamorphic history of the rocks of the Antarctic coast north of the Prince Charles Mountains is complex (Crohn, 1959), (McCarthy and Trail, 1963). Perhaps several metamorphic episodes have followed an original, regional metamorphism under granulite facies conditions.

The intervening rocks of the northern Prince Charles Mountains, described by Stinear (1956), Crohn (1959), and McLeod (1959), appear to lie mostly in the sillimanite-almandine subfacies of the almandine amphibolite facies, or in the hornblende granulite subfacies of the granulite facies.

The increase in metamorphic grade from the southern Prince Charles Mountains towards the coast may be gradual, or it may be sudden, across a metamorphic unconformity yet to be located.

The age of the rocks of the southern Prince Charles Mountains is unknown. They are probably, but not necessarily younger than the granulitic rocks of the coast. The latest metamorphic event in the southern Prince Charles Mountains is tentatively correlated with the event dated at 480 m.y. which Picciotto and Coppez (1963) describe as widespread in East Antarctica.

Future systematic sampling for age determination, particularly of the granites, in the southern Prince Charles Mountains should add very valuable data to the geochronology of East Antarctica.

ACKNOWLEDGEMENTS

I acknowledge very gratefully the assistance of W.R. McCarthy, of the Australian Mineral Development Laboratories who has provided almost all the petrographic detail and interpretation on which this paper is based, who has read and critically discussed the manuscript with me, and who has given freely of his time and thought to its preparation. I thank I.R. McLeod who has given much information and who has critically read the paper, and I thank R.A. Ruker for information.

My colleagues and I are very grateful to men of the Australian National Antarctic Research Expeditions for their support for geologists in the field. In particular I thank my field companions, D.O. Keyser and J. Seavers for their patience and determination.

This paper is presented with the permission of the Director, Bureau of Mineral Resources, Geology and Geophysics, Australia.

REFERENCES

CROHN, P.W., 1959 - A contribution to the Geology and Glaciology of the Western part of the Australian Antarctic Territory. Bur.Min.Resour.Aust.Bull. 52.

FYFE, W.S., TURNER, F.J., and VERHOOGEN, J., 1958 - Metamorphic Reactions and Metamorphic Facies. Mem.geol.Soc.Amer. 73.

McCARTHY, W.R., and TRAIL, D.S., 1963 - The high-grade metamorphic rocks of the Mac-Robertson Land and Kemp Land Coast. This Symposium.

McCARTHY, W.R., in prep. - Appendix in Ruker, in prep.

McCARTHY, W.R., in prep. - Appendix in Trail, in prep.

McLEOD, I.R., 1959 - Report on Geological and Glaciological Work by the 1958 Australian National Antarctic Research Expedition. Bur.Min.Resour.Aust.Rec.1959/131 (unpubl.).

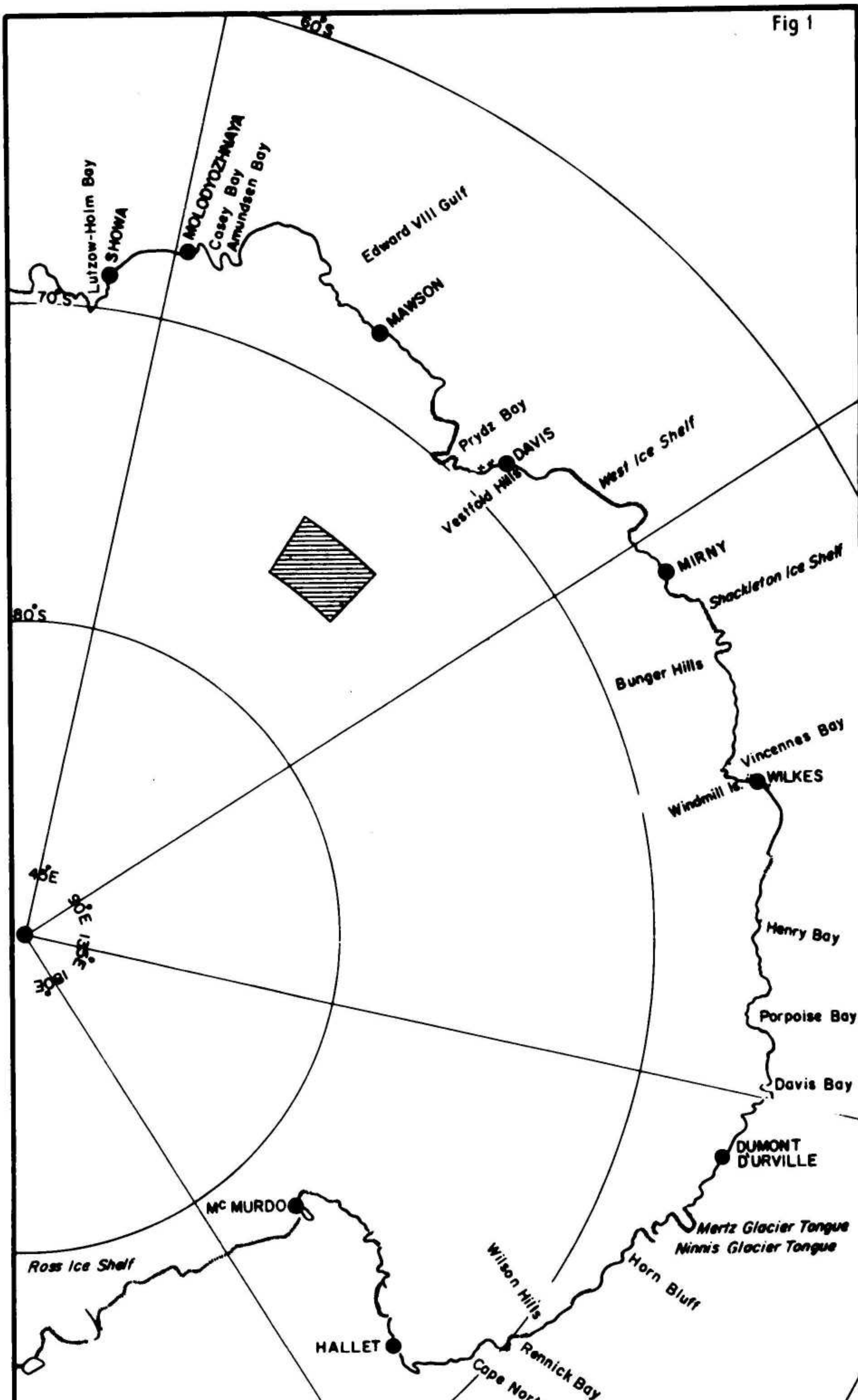
PICCIOTTO, E., and COPPEZ, A., 1962 - Bibliographie des mesures d'ages absolus en Antarctique. Ann.Soc.geol.Belg. 85, 8.

RUKER, R.A., in prep. - Geological Reconnaissance in Enderby Land and Southern Prince Charles Mountains, Antarctica. Bur.Min.Resour.Aust.Rec. in preparation.

STINEAR, B.H., 1956 - Preliminary Report on Operations from Mawson Base, Australian National Antarctic Research Expedition 1954-55. Bur.Min.Resour.Aust.Rec. 1956/44 (unpubl.).

TRAIL, D.S., in prep. - The 1961 geological reconnaissance in the southern Prince Charles Mountains, Antarctica. Bur.Min.Resour.Aust.Rec. in preparation.

TRAIL, D.S., 1963 - Low grade metamorphic rocks from the Prince Charles Mountains, East Antarctica. Nature, 197, 548-550



LOCATION OF

SOUTHERN PRINCE CHARLES MOUNTAINS ANTARCTICA

RECONNAISSANCE GEOLOGICAL MAP OF THE SOUTHERN PRINCE CHARLES MOUNTAINS ANTARCTICA

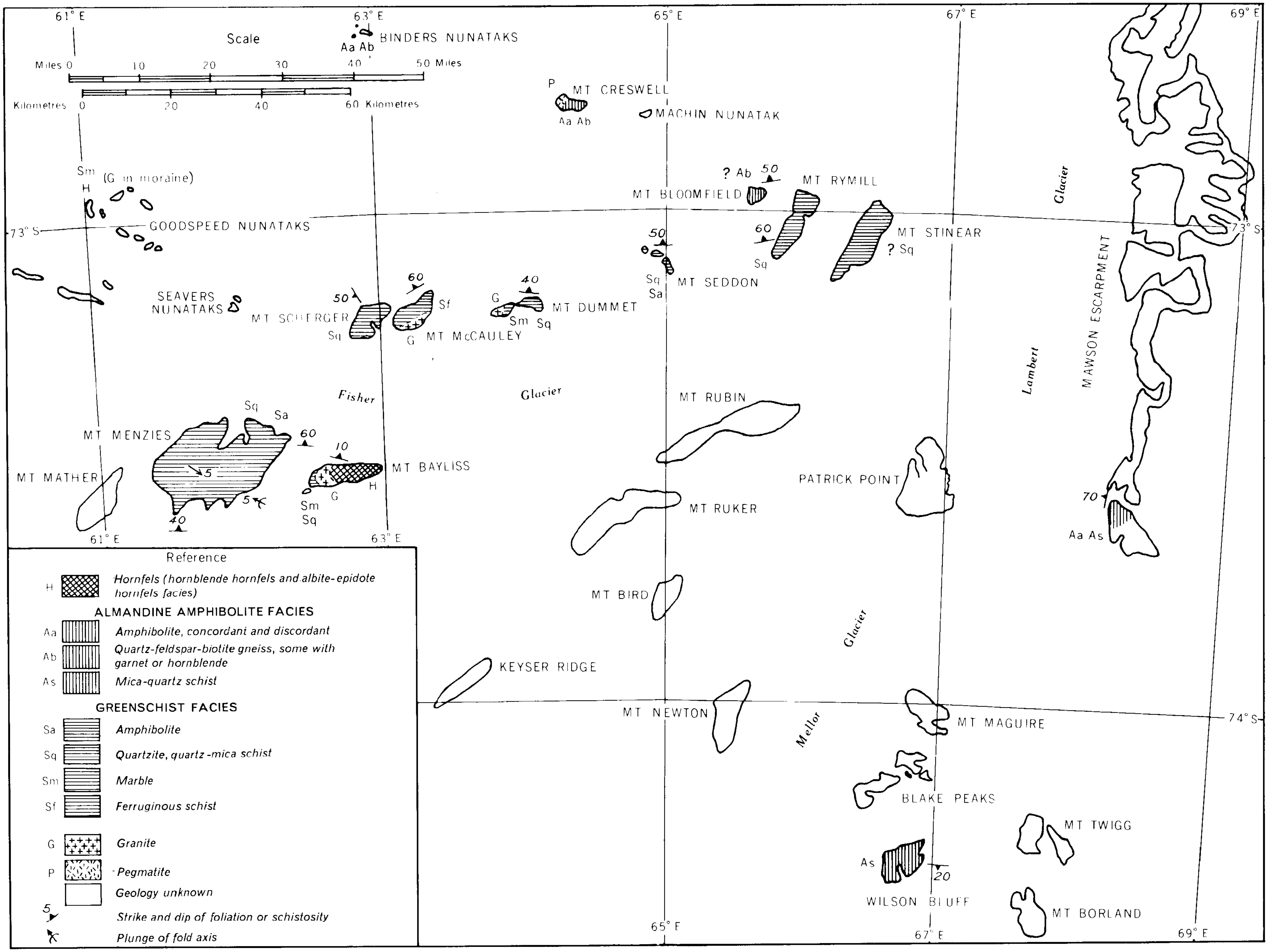


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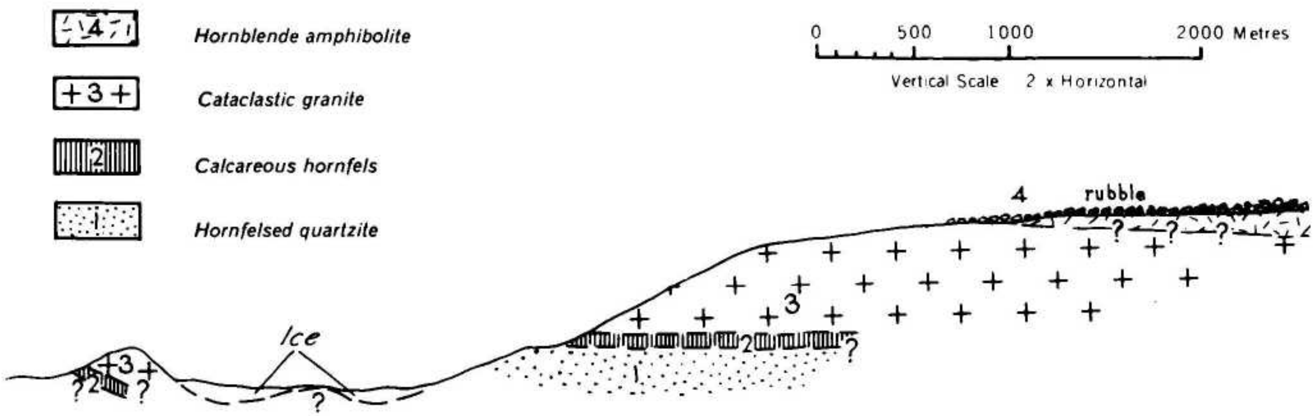
FIG. 3



DIAGRAMMATIC SECTION OF MOUNT BAYLISS, WEST END

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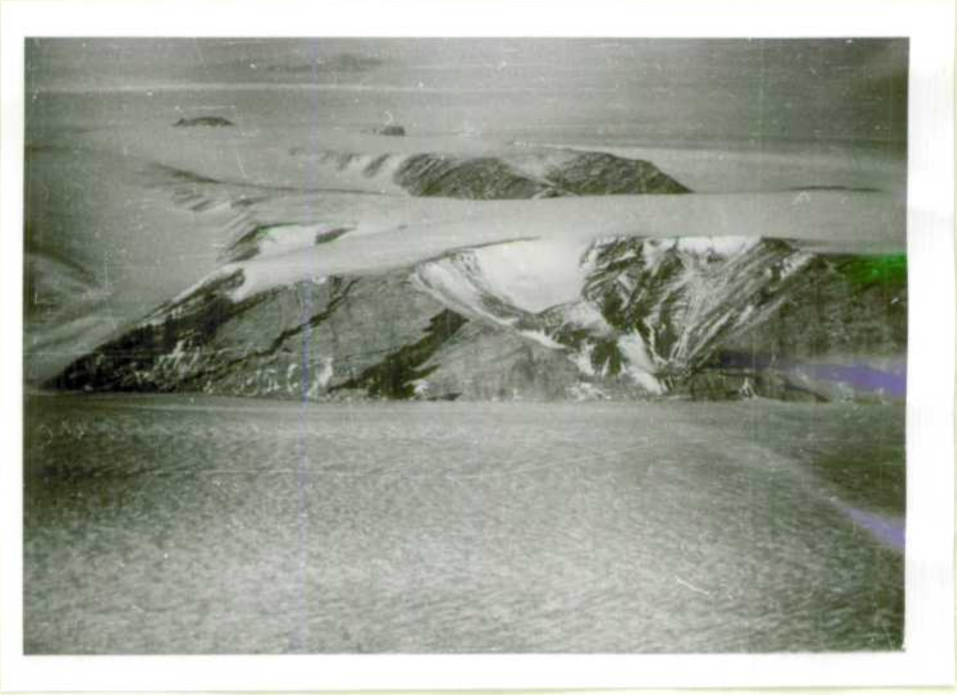
(Photo by R.A. Ruker)

Fig.4: Metamorphosed basic dykes at the south end of the Mawson Escarpment.



(Photo by I.R. McLeod)

Fig. 5: Large-scale folding at Patrick Point. The cliff is about 1000 metres high.

PAPER 3 :

Geological Observations in Oates Land

I.R. McLeod, M.Sc.*

Australia.

INTRODUCTION

This paper summarizes the geological investigations by the Australian National Antarctic Research Expeditions (ANARE) in Oates Land, between 157°E and 166°E. These expeditions, led by Phillip Law, visited several localities in the summers 1958-59, 1960-61, and 1961-62 and geological investigations on a broad reconnaissance scale were made by J. Hollin, the writer, and C.M. Gregory in those respective seasons. A detailed account of the results of the work is being prepared. (McLeod & Gregory, in prep.).

Other places in the same sector were visited by the Soviet Antarctic Expedition early in 1958 (Klimov & Soloviev, 1958).

REGIONAL GEOLOGY

The geological relationships between the localities visited are not known, because of the distances separating them. In this account, therefore, each of the areas visited is described separately, in order from west to east. These places are shown in Fig. 1. The geological setting of the region is briefly discussed in a following section.

Magga Peak (69°09'S, 157°08'E).

Magga Peak is a nunatak about 250 metres high on the coast at the western edge of the Pennell Glacier.

The rocks of the peak are fine-grained biotite-quartz-feldspar gneisses, banded in parts and containing thin feldspar and quartz-feldspar veins, some of them ptygmatic. Pink garnet is present in places. The general strike of the gneisses is north-north-west.

Numerous granite veins occur in the biotite-feldspar gneiss. These are either parallel to the banding of the gneiss or cut across it. The composition of the veins is variable. In general, quartz and feldspar are always present; biotite may be an important constituent, or may be present in only small amount. Some veins contain large ophitic hornblende crystals, others small irregular masses of magnetite.

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One fine-grained porphyritic dolerite dyke, striking about north-north-west, was seen.

Western Wilson Hills

Several places in the western part of the Wilson Hills were visited, viz. Stanwyx Ridge (69°19'S, 158°14'E), Cook Ridge (69°21'S, 158°23'E), Parkinson Peak (69°34'S, 158°41'E), and the nearby Aviation Islands (69°15S, 158°30'E).

Fine-grained biotite-quartz-feldspar gneiss is the predominant rock at all these places except Cook Ridge, where it is present in only minor amount. In most of the gneiss, concentration of the biotite along layers produces a banded structure, with the bands only a millimetre or two thick. Plagioclase generally forms about half the gneiss, and is mostly andesine, although it is more sodic in some specimens; it forms porphyroblasts in places. Biotite makes up about 5 percent of most specimens, but is more common in parts.

Although the gneiss is predominantly feldspar, quartz, and biotite, small amounts of other minerals may be present. These are mainly garnet, sillimanite (especially in the Aviation Islands) and muscovite, as well as the accessories zircon and apatite.

The banded gneiss on one of the Aviation Islands contains a discordant massive lens-like body about 3 metres wide, with straight, well-defined edges. It has a similar mineral composition to the enclosing gneiss (plagioclase, quartz and biotite), but quite a distinctive texture - the rock is more massive than the banded gneiss, and is not banded. In outcrop it resembles a dyke metamorphosed along with the enclosing rocks but neither the field nor the petrographic evidence is conclusive in this respect.

The strike of the banded gneiss varies from place to place, and parts are intensely folded. The general strike is east to south-east and dips are mostly steep to the south.

Migmatitic, predominantly quartzo-feldspathic veins and masses with a more-or-less granitic texture are very common in the banded gneiss. Indeed, at Cook Ridge, the only banded gneiss is small remnants within the quartzo-feldspathic rock. The veins are very irregular in size and shape. Most are short, with a length of only a few metres; their width ranges from a few centimetres to a metre or more. Branching and anastomosing of the veins is very common. Many are parallel to the banding of the gneiss, but others cut sharply across it.

The grain size and mineral composition of the veins are also very variable. The grain-size ranges from medium to coarse, and may change from one to the other within a distance of 10 cm. Specimens may be either even-grained or porphyritic, with large crystals of feldspar or biotite. The relative proportions of the predominant minerals (plagioclase, potash feldspar, and quartz) may change rapidly within a short distance. Biotite is mostly present, the proportion ranging from less than 1 percent up to about 10 percent of the rock. Garnet (probably almandite), usually associated with biotite, is common in parts, and rare in others. Both the biotite and the garnet tend to form aggregates of small flakes or grains rather than to occur uniformly through the rock. Muscovite and magnetite occur in places, and fibrolite is common in some of the veins on the Aviation Islands. In some cases, veins cut sharply across other veins with contrasting texture, grain size and mineral composition.

The presence of garnet and sillimanite and the texture in thin section of specimens of the veins suggests that they are metamorphic or metasomatic rather than igneous in origin, but the genesis could not be resolved from the specimens collected.

Several straight, parallel-sided dykes of biotite granodiorite occur on Parkinson Peak, and two of adamellite on Cook Ridge. These dykes are quite different in appearance to the other veins, and the field evidence suggests that they are igneous. Petrographic examination confirms that the dykes on Cook Ridge are probably igneous. The dykes on Parkinson Peak have some petrographic characters suggesting a metamorphic origin, and they may have been formed by rheomorphism.

Only one basic dyke was seen, a narrow dyke on Cook Ridge, striking south-east.

No direct evidence of major faulting was seen in the Wilson Hills. However, between the Pennell and Tomlin Glaciers at least, step-faulting on lines parallel to the coast (i.e. trending south-east), is indicated by distinct stepped increases in the heights of the rock ridges which here trend at right angles to the coast. The respective breaks in altitude on several ridges are approximately collinear. From the coast inland, at least three stages can be distinguished, at heights of approximately 150, 600, 1000 metres. Aerial photographs of the area east of the Tomlin Glacier show two distinct scarps in the surface of the ice sheet, trending south-east and about 30 km. long; these scarps probably reflect fault-scarps in the underlying rock.

<u>Eastern Wilson Hills</u>

The only point visited here was Mount Ellery, (69°54'S, 159°39'E). This is composed of grey biotite adamellite containing numerous inclusions which make up about 25 percent of the rock. These inclusions have an average diameter of about 5 cm. and are composed of foliated biotite (mostly altered to chlorite), and muscovite, quartz, calcic andesine and rare epidote. The inclusions have poorly defined boundaries, and contain unoriented, coarser biotite and feldspar, suggesting that the inclusions were partly incorporated into the adamellite by granitization. The adamellite contains also a few more massive biotite-rich xenoliths with a maximum diameter of about 70 or 80 cm.

<u>Cape Williams.</u>

Several outcrops were visited in the Cape Williams area, viz. Cape Williams itself (70°33'S, 164°05'E), Platypus Ridge (70°46'S, 163°43'E), and an island shown on Russian maps as "Sputnik Island" (70°20'S, 163°30'E).

"Sputnik Island" had previously been visited by the Soviet Antarctic Expedition (Klimov & Soloviev, 1958) and only the north-eastern part was examined by ANARE. The rocks here consist of massive, grey, medium-grained biotite adamellite. The plagioclase is andesine and shows both normal and reversed zoning. The adamellite contains a few small biotite-rich xenoliths.

The rocks on Cape Williams and Platypus Ridge are schists of the almandine-amphibolite facies. They are fine-grained, well bedded and well cleaved. Thin quartz veins are numerous. Mica, both biotite and muscovite, is a very common constituent, making up 75 percent of some specimens. It forms two generations, one very well foliated, the other unoriented and occurring as aggregates, single crystals and poikilitic grains. Other common minerals are quartz, feldspar, and andalusite (which commonly forms small porphyroblasts). The schists contain small pods made up of actinolite, diopside, labradorite, and quartz. The schists strike at 140°, and dip uniformly to the south-west at 50°.

The second generation of unoriented biotite, and the occurrence of probable chloritoid in some specimens, point to a late synkinematic or post-kinematic thermal metamorphism which has produced an incipient hornfels texture. The most obvious cause of this thermal metamorphism is the adamellite which crops out on "Sputnik Island".

Cape North

Several places in this area were visited, viz. Cape North (70°41'S, 165°46'E), Nella Island (70°36'S, 166°04'E) Thala Island (70°37'S, 166°05'E), Gregory Bluffs (70°42'S, 165°52'E) and Arthurson Bluff (70°45'S, 166°05'E).

Cape North itself consists of sediments metamorphosed to the greenschist facies. The rocks are thin-bedded to medium-bedded slate, greenstone, and recrystallized arkose, greywacke and lithic sandstone. Most specimens have a moderate to good cleavage. Mica (predominantly sericite, but including biotite, chlorite, and stilpnomelane) is common, and quartz and plagioclase occur in most of the specimens; calcite is present in some, forming 40 percent of one specimen (a greenstone). Accessory minerals include opaques, zircon, sphene and tourmaline.

These metasediments are folded into a series of quite tight folds plunging south-east at approximately 30°. At the time of the visit, these folds were picked out by snow along the ledges formed by the bedding planes on cliff exposures. This feature made the metasediments readily recognizable at a distance.

Nella Island, Thala Island, Gregory Bluffs and Arthurson Bluff are all composed of medium-grained massive biotite granodiorite. The plagioclase is andesine and shows excellect reversed zoning. The granodiorite contains about 2 percent xenoliths, which are up to about 1 metre in diameter. These xenoliths consist predominantly of sub-rounded to irregularly shaped fragments of biotite-quartz diorite. Sub-rounded xenoliths of porphyritic microgranite occur rarely. Dykes of alaskite up to 4 metres thick are common.

No contact was seen between the granodiorite and the metasediments. It is probable that the granodiorite is the later of the two units, because no sign of the dynamic metamorphism which has affected the metasediments was seen in it.

AGE MEASUREMENTS

The age of four specimens from Oates Land was determined by the Department of Geophysics, Australian National University. Details of these measurements are given elsewhere in this Symposium (Webb, McDougall & Cooper, 1963). In summary, ages of 417 my and 451 my were found for gneiss from the western Wilson Hills, and 344 my and 365 my for adamellite from the Cape North area.

REGIONAL CONSIDERATIONS

A feature of the high-grade metamorphic rocks of the western Wilson Hills (in those areas which have been examined, at least) is the absence of calcareous rocks. The country rocks are monotonously plagioclase-quartz-biotite gneisses, indicating an essentially non-calcareous composition for the parent material, which was probably a thick sequence of argillaceous and perhaps greywacke-type sediments.

The measured ages, 417 my and 451 my, have counterparts in many other parts of Antarctica. Present knowledge of the geological history of the region is not sufficient to decide whether the ages represent the time at which the rocks were metamorphosed and migmatized, or whether they represent the effect of a metamorphic episode (for instance, the one which affected the rocks of the Cape North area) superimposed on pre-existing metamorphic rocks.

The gneiss of the western Wilson Hills may be part of the Antarctic Shield, or may be equivalent to the metasediments of the Ross System. At the present state of knowledge, petrographic correlations are of doubtful value. Metamorphic rocks of the almandine-amphibolite facies are widespread in the shield, and occur also in parts of the Ross System in Victoria Land. Age measurements are of little help - many rocks of the shield bear the impress of a widespread early Palaeozoic metamorphism and have apparent ages of about 450 my.

Gravity and magnetic observations near the coast indicate a major structural break roughly coincident with longitude 155°E, about 50 miles west of the Wilson Hills (Ushakov, 1960), and this break may mark the transition from the shield area of East Antarctica to the Caledonian(?) fold zone bordering the Ross Sea.

The low-grade metamorphic rocks of the Cape North area can be fairly confidently correlated with the Moubray Group in the Hallett area, 170 miles to the south-east. There the Moubray Group is an argillite-greywacke assemblage, with minor limestone (Hamilton, 1958), but without the prominent schistosity which the rocks of the Cape North area display.

The relationships of the metamorphic rocks of the Cape Williams area are at present in doubt. The metamorphic grade is higher than at the Cape North area, but a good cleavage is present at both places. Because the rocks at Cape Williams possess this cleavage, and because they do not resemble in the least the migmatites of the Wilson Hills, they can probably be regarded as a relatively highly metamorphosed part of the Moubray Group.

The adamellite and granodiorite of the Cape Williams and Cape North areas appear to be the youngest rocks in the region (except perhaps, for the few basic dykes, which are probably Jurassic). At both places, the evidence suggests that they are younger than the nearby metamorphic rocks. Further, the granodiorite of the Cape North area has the youngest (Upper Devonian, according to the time scale of Kulp, 1961) age of any granitoid rock yet reported from Antarctica. It belongs to a later tectonic episode than the one to which the Granite Harbour Intrusive Complex is related (Gunn & Warren, 1962). The Complex is truncated by the Kukri Peneplain which is overlain by the Lower Devonian beds at the base of the Beacon Group, whereas an Upper Devonian age is indicated for the granodiorite of the Cape North area, and hence possibly also for the massive granitoid rocks elsewhere in northern Victoria Land and Oates Land.

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The petrographic descriptions of the specimens from Oates Land were prepared by W.R. McCarthy of the Australian Mineral Development Laboratories, Adelaide.

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REFERENCES.

GUNN, B.M., and WARREN, G., - 1962 - Geology of Victoria Land between the Mawson and Mullock Glaciers Antarctica. N.Z. geol.Surv.Bull. 71.

HAMILTON, W.M., 1958 - Geological and survey work (in Ross Dependency). Ann.Rep.N.Z.Dep.sci.ind. Res. for year ended 31st March 1958. 14-16.

KLIMOV, L.V., and SOLOVIEV, D.S., 1958 - Preliminary information about geological observations in the East Antarctic. Inf.Bull.Soviet Antarctic Exped. 1, 27.

KULP, J.L., 1961 - Geologic time scale. Science 133 (3459), 1105-1114.

McLEOD, I.R., and GREGORY, C.M., (in prep.) - Geological investigations along the Antarctic coast between longitudes 108°E and 166°E, 1960, 1961 and 1962. Bur.Min.Resour.Aust.Rep.

USHAKOV, S.A., 1960 - Some features of the structure of King George V Coast and Oates Coast according to geophysical data. Inf.Bull. Soviet Antarctic Exped. 18, 11.

WEBB, A.W., McDOUGALL, I., and COOPER, J.A., 1963 - Potassium-argon dates from Vincennes Bay Region and Oates Land, East Antarctica. (this Symposium).

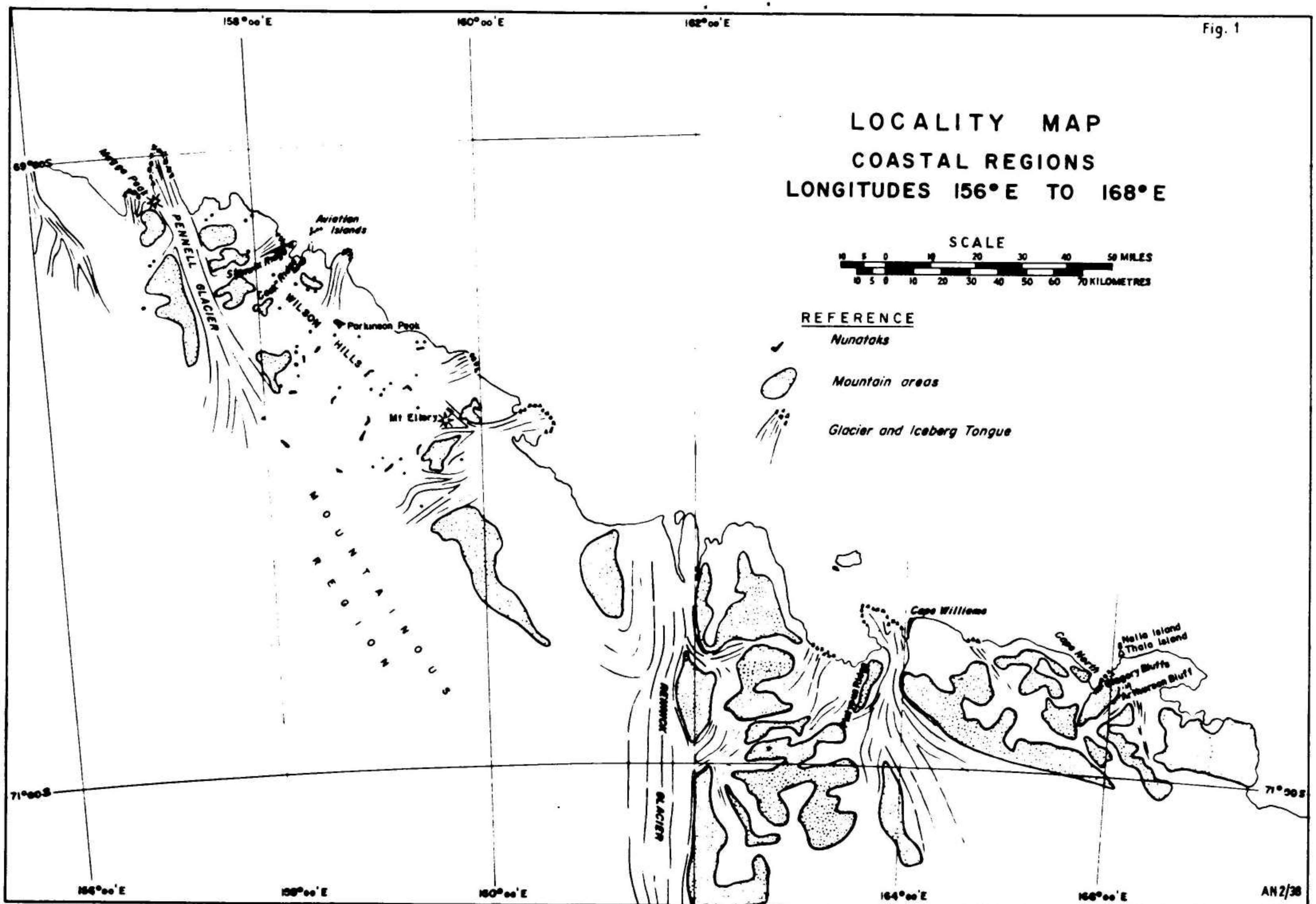

Fig. 1

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PAPER 4 :

The Saline Lakes of the Vestfold Hills, Princess Elizabeth Land

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Introduction

The Vestfold Hills, one of the "Antarctic oases" is an area of bare, rocky hills and islands on the north-east coast of Prydz Bay, Princess Elizabeth Land. A party of the Australian National Antarctic Research Expeditions (ANARE) which landed early in 1955 found that the water in some of the lakes in the hills was distinctly salty (Law, 1959 p.37). After the establishment in 1957 of the ANARE station at Davis (68°35'S, 77°57'E) at the western edge of the hills, samples were collected from four saline lakes (Lake Dingle, Lake Stinear, Deep Lake and Club Lake) by the station personnel, who also found that the surfaces of these lakes were below sealevel. The four lakes have been sampled at irregular intervals in the succeeding years, and other lakes have been sampled also. This paper describes the geographic setting of the four lakes named above, summarizes the results of the water sampling, and gives conclusions as to the origin of the lakes.

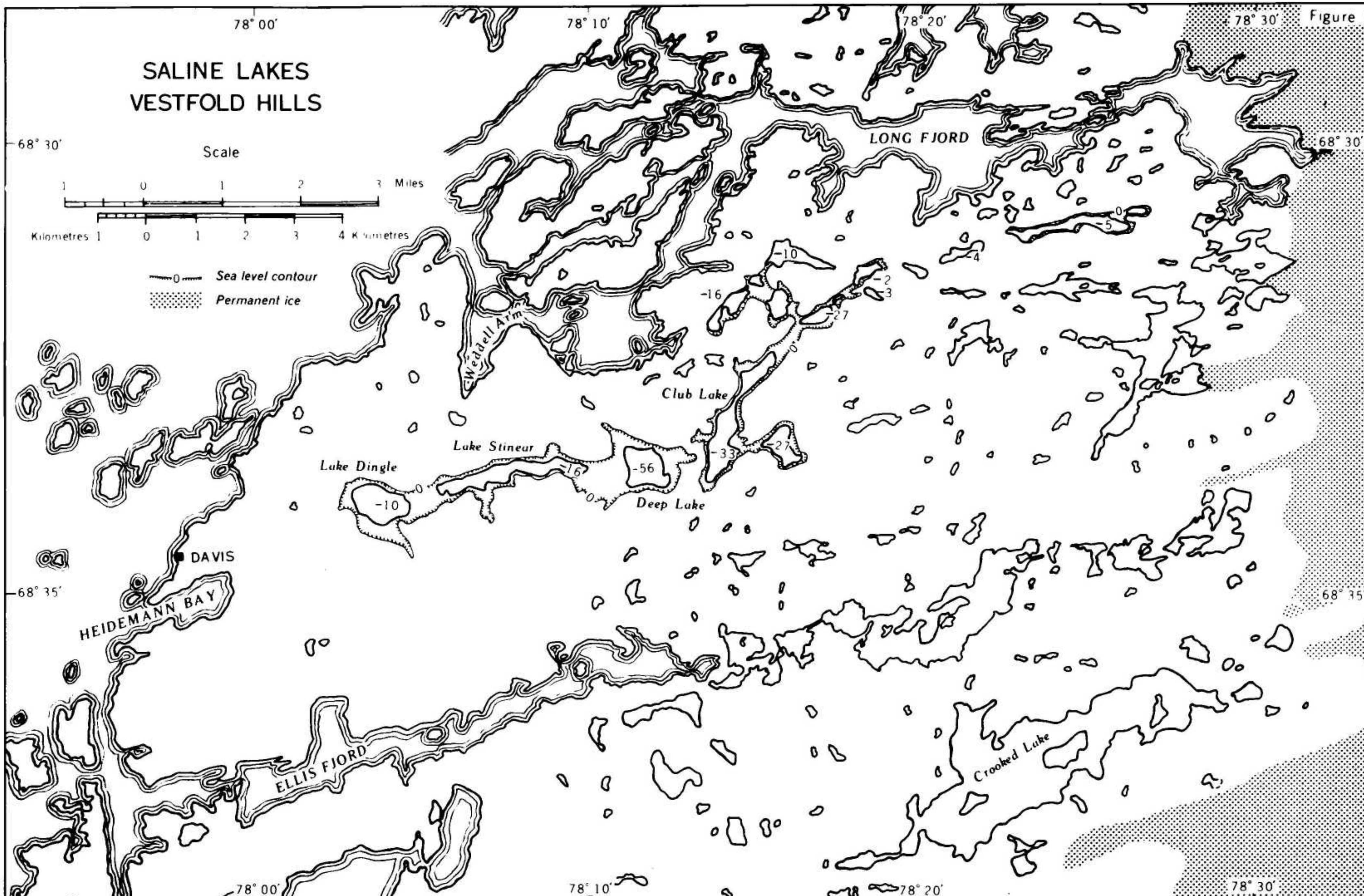
The Vestfold Hills

The Vestfold Hills and associated islands occupy a roughly triangular area. The base of the triangle, (the southern margin of the area), is about 30 km long, and its extent from south to north is also about 30 km. The coastline has numerous deep indentations and myriad islands.

The relief of the area is moderate, consisting of hummocky ridges and hills separated by narrow valleys floored by moraine. Numerous lakes ranging in maximum extent from a few metres to several kilometres, occur in these valleys. The general altitude, ruggedness and degree of relief of the hills increases from west to east, i.e. towards the continental icecap - the hills are less rounded, and the valleys deeper and narrower. The highest parts of the hills are about 160 metres above sealevel.

The ablation rate during the warmer parts of the year is extremely high. During winter, although the hills remain free of snow, large drifts build up against hill slopes. By midsummer the snow has disappeared from the hills, except for an irregular zone a kilometre or two wide adjoining the icecap; the only snow remaining elsewhere is in a few small drifts against steep, south-facing slopes.

FIG. 1



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The Setting of the Lakes

Lake Dingle, Lake Stinear and Deep Lake (Figure 1) occur along a roughly east-west line in a valley which can be traced eastwards from Heidemann Bay to a lake east of Club Lake; beyond this lake, the continuity of the valley is lost in the jumble of hills and valleys. The valley crosses the southern part of Club Lake, but the main topographic control for this lake is a very prominent north-north-east trending valley between Long Fiord and Ellis Fiord. The sides of Club and Deep Lakes are steep to precipitous, except for a few small beaches at the mouths of valleys opening into them (Figure 3). The sides of Lake Stinear are less rugged, especially along the southern margin, where several valleys enter it, while the margins of Lake Dingle are still more open. The surface of all four lakes is below sealevel: Lake Dingle, - 10 metres; Lake Stinear, - 16 metres; Deep Lake, - 56 metres; and Club Lake, - 33 metres.

A well-defined boulder-strewn terrace breaks the line of cliffs around Deep Lake and around Lake Stinear (Figure 4). A similar terrace can be discerned in places around Lake Dingle. The altitude of these terraces is a little above sealevel, and their width ranges from one to several metres. The lowest parts of the divides between the lakes are at about the same level as the terraces, and are likewise flat and boulder-strewn. Traces of terraces below the conspicuous one can be seen around Lake Stinear, but these lower terraces are very fragmentary - in many parts they consist of a line of boulders along the contour rather than an actual terrace.

The floor of many of the larger subsidiary valleys opening into the lakes consists of unconsolidated coarse sand. In some, fine, unconsolidated yellowish-green silt occurs at a depth of 20 cm or more. At the time of visits by the writer (in February 1959 and February 1960) some of the valleys on the south side of Lake Stinear contained small trickles of water derived from melting snow drifts further up the valley. The water of some of these small streams was quite brackish. A small shallow pool on the divide between Deep Lake and Lake Stinear was almost as salt as seawater to the taste. As the ground around all the lakes appeared to be impregnated with salt a sample of green silty material was collected from a valley at the south-west corner of Deep Lake, and analysed for soluble salts. The sample (on an air-dried basis) contained a total of 12.19 percent water-soluble salts, made up of the following percentages of ions : Ca^{++}+Sr^{++}, 0.12; Mg^{++}, 0.83; Na^{+}, 3.29; K^{+}, 0.12; HCO_3^-, 0.17; SO_4^{--}, 0.19; Cl^-+Br^-, 7.47.

Deposits of mirabilite ($Na_2SO_4 \cdot 10H_2O$) are present in the lower parts of some of the valleys. The largest deposit seen, in the valley off the south-west corner of Deep Lake, was about 10 metres long, 5 metres wide, and at least a metre thick (Figure 3). Encrustations of salts occur on the rocks adjoining the water. These are predominantly sodium sulphate. Halite has been found in and around some small pools, and would have precipitated at a higher temperature (owing to solar heating of the pool and surrounding rocks) than that prevailing in the lakes.

Shell remains are very common on the terraces and in the sand and silt of the subsidiary valley floors. The remains are obviously not very old; most show their original colouring, and many still retain parts of the nacreous interior surface. Specimens collected by B.H. Stinear and the writer from the shores of Lake Dingle and Lake Stinear, and Deep Lake respectively were identified by Dr. McMichael of the Australian Museum, Sydney, (pers.comm.) as :

Pelecypoda

Laternula elliptica King and Broderip

Lima hodgsoni Smith

Malletia pellucida Thiele

Pecten colbecki Smith

Thracia meridionalis Smith

Gastropoda

Nacella depressa Hedley

and also worm tubes bearing a small vermetid gastropod, possibly *Stoa*.

All the gastropods are rather worn, so that identification is very doubtful.

All these forms are still in existence around the Antarctic coastline. Some have also been recorded from Quaternary deposits at McMurdo Sound (Speden, 1962).

More than 30 species of Foraminifera have been recognised in samples from the terraces on the south side of Lake Dingle, and from several places around Deep Lake. Some of these have been described by Crespin (1960).

Mummified Adelie penguin carcasses and seal remains (including the carcase of a juvenile leopard seal) occur on a small beach on Deep Lake. Remains have also been found on the shore of Lake Stinear.

Water Levels

Variations in the levels of the surfaces of the four lakes were noted at intervals in the spring of 1959 and summer of 1959-60 by means of a graduated stake set in each lake near the shore. The variations (in inches) are shown in Table 1. Because of the possibility of errors in reading due to the usual wind-ruffled surface, the figures can only be regarded as approximate.

Date 1959	Lake Dingle	Lake Stinear	Deep Lake	Club Lake
23 Sept.	N.R.	N.R.	0	0
14 Oct.	N.R.	0	$\frac{1}{4}$	$\frac{1}{2}$
26 Oct.	N.R.	0	$\frac{1}{2}$	$\frac{1}{2}$
15 Nov.	0	0	N.R.	N.R.
25 Nov.	-1	*	$\frac{3}{4}$	$\frac{3}{4}$
8 Dec.	0	0	$\frac{3}{4}$	$\frac{1}{2}$
1960				
5 Jan.	$1\frac{3}{4}$	1	$2\frac{1}{4}$	0
22 Jan.	$2\frac{1}{4}$	$1\frac{3}{4}$	$2\frac{1}{4}$	0
1 Feb.	2	$2\frac{1}{2}$	$2\frac{1}{4}$	$-\frac{1}{2}$

N.R. Not read

* On this date the stake was found to have been moved by ice floes. It was reset on the 8/12/59.

It is apparent that a slight rise in water level occurred in all except Club Lake during December, i.e. when the melting of the snow on the surrounding hills was most intense. It also seems likely that the net change in volume of the lakes over a year is very small. The volume of water added to the lakes each year by precipitation and inflow of melted snow must be considerable. But in extensive, low-lying rocky areas such as the Vestfold Hills, the relative humidity is very low and this, coupled with the moderately high winds speed , must, despite the low temperatures, make for a high rate of evaporation. Under present climatic conditions, the balance between inflow (and precipitation) and evaporation is probably about even.

<u>Water Temperatures</u>

The surface water temperatures of Lakes Dingle and Stinear were measured at intervals during 1958, and of all four lakes in 1959 and 1962. Measurements were not made at regular intervals; the observations available suggest that the surface water reaches a minimum of about -20°C in July and August, and a maximum of about 8°C during the summer, although in summer the surface temperature fluctuates considerably.

Water temperature measurements of the deeper parts of the lakes were made on all except Club Lake in August, 1962, and January 1963 using ordinary thermometers lagged with cotton wool and suspended at the appropriate level for 30 minutes before reading. The results obtained are shown in Table IV. The figures show that while there is little temperature stratification during the winter, a considerable temperature differential may exist between the surface and bottom of the lakes during the summer. The surface temperature in summer is presumably dependent on the cloud cover and wind speed in addition to the air temperature.

Irregular observations have also been made on the amount of ice on the lakes. Deep Lake and Club Lake have not been observed to freeze over, except for narrow strips of ice a few inches wide which form in sheltered places around their edges when the water temperature is less than about -15°C. Lake Dingle is usually completely frozen from July until November; the ice cover disappears in late November and early December as the water temperature approaches 0°C. An ice thickness of 75 cm was measured on Lake Dingle in late September, 1959. Lake Stinear usually freezes completely a couple of weeks after Lake Dingle; as on Lake Dingle, the ice cover disappears in November or early December. The maximum measured ice thickness on Lake Stinear was 35 cm in September, 1959. The ice cover on the lakes is not always solid ice. On many occasions, it was found to consist of a slushy mixture of ice crystals and snow 10 cm or more thick. In some years, both lakes have been observed to be free of ice at times during the July to November period.

Lake Depths

Two lines of soundings, one about east-west and one about north-south,were run across Deep Lake, using a dingy flown in by helicopter. Bathymetric form lines drawn from these soundings are shown in Figure 2. Most of the soundings encountered a firm bottom, such as would be formed by sand.

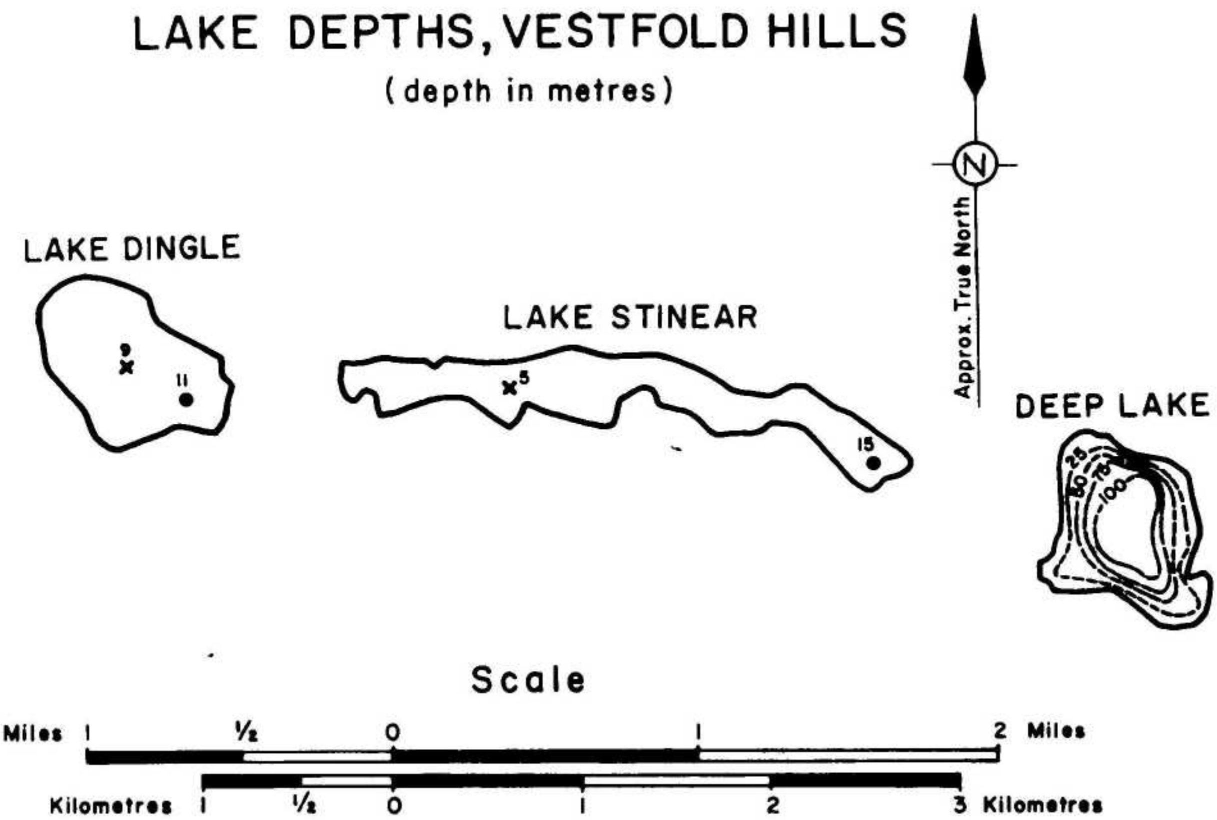
The only information available on the depths of Lakes Stinear and Dingle are two isolated soundings in each. These also are shown in Figure 2.

Composition of the Lakes.

Samples of surface water have been collected at the lake edges at irregular intervals from 1957 onwards, and analysed by the Bureau of Mineral Resources, Geology and Geophysics. The total soluble salts (in grams per litre) for each sample are shown in Table III.

Water samples were collected away from the shores of Lakes Dingle and Stinear in August 1962, and from these two and Deep Lake in January 1963. At these times, samples were collected from the surface, and near the bottom of each lake, and from a level half way between these two. The compositions of the samples are shown in Table IV. The compositions of these samples are representative of those of surface samples collected in earlier years (except that potassium in Deep and Club Lakes is higher than usual in the August 1962 and January 1963 samples). The relative proportions of the various ions are nearly constant, regardless of the total salt content of the sample.

FIG. 2.



Bureau of Mineral Resources, Geology and Geophysics. July 1963. **AN2/37** EJ

To accompany Record No 1963/130

A feature of Table III is the variation in time of the salinity of surface waters of the lakes, especially Lake Dingle. The sampling has not been regular enough to establish any points of maximum or minimum salinity but in all cases, the decrease in salinity occurs in spring and summer, so is most likely due to incomplete mixing between the highly saline lake water and inflowing fresh water from melting snow on the surrounding hills. The fresh water would tend to form a layer on the denser lake water, and mixing would be gradually brought about by wave action and currents. This factor of incomplete mixing is well illustrated by the Lake Dingle samples collected in January 1963, and also by the differences in temperature at the various levels. The lower salinity of the surface samples collected in August from Lakes Dingle and Stinear is due in part at least to contamination of the sample by ice slush.

Because of this factor of incomplete mixing, the composition of the surface water can differ from place to place on the same lake. Samples collected on a calm, sunny day at short intervals at three places on the edge of Club Lake (which had no ice cover at the time) had the compositions shown in Table II. These compositions are representative of surface samples collected from Club Lake in earlier years.

TABLE II

Surface water compositions, Club Lake, 21 August 1962 (g/litre)

	Cl	SO_4	HCO_3	Br	Ca	Mg	Na	K	Sr	T.D.S.
Club Lake: 21.8.62										
I (Edge)	170	2.31	0.30	0.81	2.12	15.0	78.7	4.71	0.08	273.0
II (Edge)	170	2.31	0.20	0.68	2.16	14.61	78.7	4.71	0.08	274.1
III (Edge)	170	2.28	0.30	0.69	2.12	14.88	78.7	4.71	0.08	275.7

Because of the variations resulting from incomplete mixing, the compositions of the surface water cannot be taken as an accurate indication of the bulk composition of the lakes. No trend can be inferred from the few samples collected to date from the deeper parts of the lakes. Despite the variation shown from time to time in the surface water composition of the lakes, no overall change is evident for the six years in which samples have been collected.

Origin of the Lakes

It is clear that the salts in the lakes could not have originated from the surrounding rocks or from volcanic exhalations - the rocks in the area are all high-grade metamorphic rocks (such as pyroxene-quartz-feldspar gneiss and garnet-quartz-feldspar gneiss) and dolerite dykes. In general, the composition of the lakes is similar to but far more concentrated than seawater, so it seems likely that the salts originated from seawater. This could not have been windblown sea-spray, because lakes nearer the sea are quite fresh. Further, the remains of marine organisms around the lakes prove that the lakes were once connected to the sea. The topography of the environs of the lakes and the salt content of the ground between the terraces and the present lake surfaces support this conclusion.

The obvious explanation for the origin of the lakes is that the valley in which they occur was once a long, narrow arm of the sea, and that the lakes were isolated by a relative fall of sealevel and subsequently concentrated by evaporation. The proportions of some of the ions in the lake waters are not the same as in seawater, suggesting deposition of certain salts during this concentration.

In the concentration of seawater by evaporation, bromine does not separate out before the final stages of evaporation, so that, assuming no loss of bromine, it is possible to calculate the proportionate volumes of seawater that, when concentrated by evaporation, would be required to produce saline waters with the composition of each of the lakes and to determine the salts deposited in the process. This calculation gives an approximate concentration ratio (the volume of seawater which, when reduced to unit volume with deposition of certain salts, would be equivalent to the present lake waters) for each of the lakes as follows: Lake Dingle, 6; Lake Stinear, 7; Deep Lake, 11; and Club Lake, 11. The principal salt deposited is sodium sulphate in all lakes plus sodium chloride in Deep and Club Lakes, and small amounts of calcium carbonate and calcium sulphate.

The age of the lakes is not known; they were certainly formed after the retreat of the icecap from the Vestfold Hills. Their isolation from the sea could have been a result either of a eustatic fall in sealevel or of isostatic uplift following removal of the ice sheet, or a combination of both.

Acknowledgments

I am deeply indebted to the ANARE personnel at Davis over the years for the effort and time they expended in collecting water samples and making other observations on the lakes in addition to their normal station duties.

Discussions which I had with D. Haldane, of the Bureau of Mineral Resources, Geology and Geophysics, were of considerable assistance in the preparation of the paper.

The paper is presented with the permission of the Director, Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia.

References

CRESPIN, Irene, 1960 - Some recent foraminifera from Vestfold Hills, Antarctica. Sci.Rep.Tohoku Univ.Second Ser. Spec. Vol. 4, 19-31.

LAW, P.G., 1959 - The Vestfold Hills. ANARE Rep.Ser.A, 1.

SPEDEN, I.C., 1962 - Fossiliferous Quaternary marine deposits in the McMurdo Sound region, Antarctica. N.Z.J.Geol.Geophys.5(5), 746-777.

TABLE III

Total dissolved salts in lake water samples (g/litre).

Date	Lake Dingle	Lake Stinear	Deep Lake	Club Lake
1957				
14 Mar.	-	245	-	-
19 Apr.	224	-	271	-
26-27 June*	226	242	-	-
28 Sept.	180	240	261	262
1958				
2-4 Jan.+	221	230	261	270
23Dec.	202	230	260	-
1959				
30 Jan.	-	-	268	-
30 Aug.	-	237	268	-
23 Sept.	-	-	-	269
15 Nov.	105	-	-	-
1960				
5 Jan.	200	226	248	270
1 Feb.	200	226	266	270
1962				
21 Aug. x	-	-	273	274
27 Aug.	221	245	-	-
1963				
21 Jan.	209	245	273	-

* 26th June, Lake Stinear; 27th June, Lake Dingle

\+ 2nd Jan. Lake Stinear, Deep Lake, Club Lake; 4th Jan., Lake Dingle.

x Mean of 3 samples, Club Lake; see Table II.

TABLE IV

Composition profiles (g/litres)

	Cl	SO_4	HCO_3	Br	Ca	Mg	Na	K	Sr	T.D.S.	Water Temp. °C
Lake Dingle :											
27.8. 62											
Surface	137	2.86	0.30	0.42	2.22	9.41	66.6	2.61	0.04	221.0	-17.3
22 feet	139	2.91	0.30	0.42	2.24	9.84	69.3	2.70	0.05	227.1	-17.1
45 feet	140	2.91	0.30	0.43	2.24	9.87	70.6	2.70	0.05	229.1	-16.8
21.1.63											
Surface	125	2.98	0.30	0.38	1.99	8.56	67.0	2.61	0.04	209.0	- 3.9
17 feet	143	2.93	0.30	0.41	2.26	9.86	71.0	2.70	0.05	232.0	1.6
34 feet	145	2.94	0.30	0.43	2.27	9.85	71.5	2.70	0.05	235.7	5.0
Lake Stinear:											
27.8.62											
Surface	148	2.62	0.25	0.43	2.10	10.10	78.6	2.61	0.04	245.0	-19.4
7 feet	151	2.64	0.25	0.43	2.18	10.60	78.6	2.61	0.04	249.0	-17.9
15 feet	152	2.70	0.25	0.45	2.14	10.50	78.6	2.62	0.04	248.7	-18.0
21.1.63											
Surface	148	2.78	0.25	0.43	2.06	10.05	78.6	2.62	0.04	245.1	- 6.7
22 feet	151	2.61	0.20	0.45	2.14	10.45	78.6	2.62	0.04	248.6	- 2.8
44 feet	153	2.67	0.30	0.44	2.18	10.50	78.6	2.62	0.04	251.0	4.7
Deep Lake :											
21.1.63											
Surface	169	2.47	0.30	0.84	2.28	14.95	78.8	4.71	0.08	273.0	- 7.7
25 feet	169	2.47	0.30	0.70	2.28	14.98	78.8	4.71	0.08	273.3	4.7
50 feet	169	2.55	0.30	0.84	2.28	14.95	78.8	4.71	0.08	273.4	4.7

[illegible]ure 3: Beach at mouth of gully at south-west corner of Deep Lake. The white patches at left foreground, and at the base of the rocks on the right, are mirabilite deposits. Mirabilite also fringes the rocks around the water.

Figure 4: Looking east along Lake Stinear. A prominent terrace can be seen along the northern side of the lake, and to a lesser degree, on the southern side.

PAPER 5

The Glacial Geology of the Prince Charles Mountains

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INTRODUCTION

The Prince Charles Mountains are located in East Antarctica south of the central part of the Indian Ocean (Fig.1). They lie in Mac-Robertson Land between latitudes 69½°S. and 74½°S. and longitudes 60°E. and 70°E., a group of nunataks extending 600 kilometres south and 300 kilometres west from the head of the Amery Ice Shelf (Fig.2).

This paper describes the forms of these nunataks and the glacial deposits found among them; from these features I attempt to derive the glacial history of the Prince Charles Mountains. In addition to my field observations, for information I have drawn freely on published and unpublished reports by Australian National Antarctic Research Expeditions geologists B.H. Stinear (1956), P.W. Crohn (1959), I.R. McLeod (1959), and R.A. Ruker (in prep.). Information has also been obtained from air photographs taken by the Royal Australian Air Force Antarctic Flight and from maps compiled by the Antarctic Mapping Branch of the Division of National Mapping, Commonwealth of Australia.

Few heights in the Prince Charles Mountains have been very accurately measured. Most are obtained from aircraft radar altimeter runs, from barometric measurements, or from photogrammetry. The heights are sufficiently accurate for this general study.

Glacial Setting

The Prince Charles Mountains are exposed in a great trough in the continental ice cap, apparently caused by the rapid flow of inland ice to the sea in a most effective drainage system comprising the Lambert Glacier (400 kilometres long and 50 to 100 kilometres broad), its tributaries, and smaller independent glaciers feeding the Amery Ice Shelf.

The bottom of the ice trough, (the surface of the Lambert Glacier) rises only about 100 metres in 150 kilometres south of its junction with the Amery Ice Shelf; 300 kilometres south of this margin the bottom of the trough has risen about 1000 metres. The western side of the ice trough rises gently to an altitude of about 2500 metres, between 200 and 300 kilometres from the Lambert Glacier. The eastern side of the trough is higher and steeper, since the westward flow of ice from Princess Elizabeth Land is considerably hindered by the 120-kilometre-long rock barrier of the Mawson Escarpment.

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Few nunataks in the Prince Charles Mountains exceed 2500metres in altitude; but for the depression in the ice cap the Prince Charles Mountains would not be exposed.

NUNATAKS

The many large nunataks range from a few square kilometres to a few hundred square kilometres in area. High nunataks rise between 500 and 1000 metres above the ice surface, and most of them reach altitudes between 1000 and 2500 metres. Mount Menzies, in the southern Prince Charles Mountains, is exceptionally high, 3300 metres above sea level and between 1500 and 2000 metres above the ice surface.

The summits of the nunataks, the benches on the flanks of the nunataks, and the cirques in the nunataks are in particular the features used to elucidate the glacial history of the mountains.

Summits, in form, divide the nunataks into two types; nunataks with broad summit plateaux, and nunataks with small summit areas.

South of latitude 72°, in the southern Prince Charles Mountains, most nunataks between 1200 and 2500 metres in altitude have broad summit plateaux (Fig. 3), ranging from 10 to 100 square kilometres in area, though Mount Menzies has a small summit area. Most of these summit plateaux are partly bounded by cliffs or steep slopes between 50 and 800 metres high. From some plateaux gentle slopes extend down to ice level.

Crohn (1959) records many flat-topped nunataks in the northern mountains. However, air photographs and maps reveal that the proportion of broad summit plateaux to small summit areas among high nunataks (over 1000 metres altitude), decreases fairly steadily northwards through the Prince Charles Mountains (Fig. 4) to the Stinear Nunataks, which have no broad plateaux (Stinear, 1956). Along the eastern side of the Amery Ice Shalf, rock outcrops, below 500 metres in altitude, have broad summit plateaux.

Nunataks with small summit areas are mostly complexes of narrow aretes separating cirques; some are thin, simple ridges; a few are matterhorn peaks.

Benches occur on many nunataks as flat or gently sloping rock platforms up to several hundred metres wide, at levels between 100 and 1000 metres below the summits. Benches are common on nunataks with broad summit plateaux (Fig. 3) and some benches exist on nunataks with small summit areas (Fig. 5).

Cirques are developed in almost all nunataks over 1000 metres in altitude. Many of the cirques are small, less than 1 kilometre across, particularly on nunataks with broad summit plateaux (Fig.6). Nunataks with small summit areas generally have several large cirques; one cirque on the north side of Mount Menzies is about 8 kilometres across and about 1200 metres deep at its back wall (Fig. 5).

Most cirques contain no flowing ice; some are partly buried in the continental ice cap; a few are partly or wholly occupied by active mountain glaciers.

GLACIAL DEPOSITS

Almost all gently sloping or flat rock surfaces, including the broad summit plateaux, the benches, and the floors of abandoned cirques, are partly or wholly covered by a blanket-like deposit of moraine ranging in thickness from a few metres to 50 metres or more. Smaller, discrete accumulations of moraine lie on or adjacent to stagnant or flowing ice fringing many nunataks.

The glacial deposits are sub-divided by three distinct types of surface to unpatterned moraine, hillocky moraine, and patterned moraine (Fig. 7).

Unpatterned moraine has a sloping or undulating surface which lacks a regularly repeated pattern. It is composed of sub-angular and angular rock fragments ranging up to 3 or 4 metres across. Most fragments are between 1 centimetre and 50 centimetres across; fragments less than 1 millimetre across are rare.

Unpatterned moraine forms the lateral moraines of active glaciers. On some nunataks it occurs up to 50 metres above present ice levels as long and low sinuous ridges elongated parallel to the present ice flow direction. Similar accumulations occur rarely several hundred metres above the present ice surface.

In abandoned mountain-glacier valleys, unpatterned moraine forms straight, steep-sided mounds up to 5 metres high, elongated across the valleys. They are presumably terminal moraines marking steps in the recession of the mountain glaciers.

Hillocky moraine in the Prince Charles Mountains has been identified only from distant observations and from air photographs; it has not been closely examined. The surface of this moraine appears to be formed by irregularly spaced, steep-sided hillocks ranging from less than 1 metre to more than 15 metres in height. Adjacent hillocks commonly differ in height by several metres. Some of the depressions between hillocks are occupied by "ponds" of flat ice up to several metres in diameter.

On air photographs the texture of hillocky moraine suggests that it contains a much higher proportion of small fragments (probably less than 1 centimetre across) than either unpatterned moraine or patterned moraine contains.

Hillocky moraine occurs on the floors of some abandoned cirques and on the gently sloping sides of nunataks, adjacent to stagnant ice. Nowhere does it occur far above the present ice surface, and it is probably formed on the surface of stagnant, moraine-charged ice. The small fragments in this moraine may be cemented in a matrix of ice and thus protected from removal by wind.

<u>Patterned moraine</u> has a surface consisting of regularly spaced, similar sub-conical mounds of rock fragments. It resembles the type of patterned ground defined by Washburn (1956) as unsorted nets. The patterned moraine of the Prince Charles Mountains has not been excavated, and only its surface can be described. Crohn (1959) first described this material in this area.

Most of the rock fragments forming the mounds range from 1 centimetre to 50 centimetres across; a few range up to 4 metres; fragments less than 1 millimetre are rare. Most fragments are sub-angular; a few are sub-round; the largest are angular.

On the surface of the moraine the fragments are grouped into low cones typically between 2 metres and 7 metres in diameter and between 0.5 metres and 2 metres in hieght. The largest cones seen are about 10 metres in diameter and about 3 metres in height.

The hollows between the cones are commonly obscured by uncompacted snow, but the fragments in the hollows appear to be much the same size as the fragments forming the cones. Crohn (1959) describes low cones, in the northern Prince Charles Mountains, separated by strips of fine-grained material, and others separated by re-frozen melt water.

In places cones are arranged in linear groups; some groups trend across the overall slope of the moraine surface, some trend down the slope. Crohn (1959) records stone strips running downhill, in fine moraine.

The patterned moraine forms a blanket-like deposit partly covering almost all gently sloping rock surfaces. It lies on most summit plateaux, and on Mount Menzies it extends up to heights between 1000 and 1500 metres above the present ice surface, and about 500 metres short of the summit. In places patterned moraine extends beneath the present ice surface.

On Mount Menzies patterned moraine cut by a small mountain-glacier valley is at least 50 metres thick.

Accumulations of hillocky moraine and unpatterned moraine in many places lie on patterned moraine or on ice overlying patterned moraine. The hillocky moraine and much of the unpatterned moraine appear to be the products of mountain glaciation and of fluctuations in the ice cap, all of which post-date the formation of the pattern on the patterned moraine.

The blanket-like appearance and the distribution, from summits to ice level, of the patterned moraine suggest that it was laid down during the recession of the ice cap from its highest level to a position below the present level.

DISCUSSION

On nunataks where a gentle slope links the floor of a cirque to a bench or to a summit plateau, a continuous blanket of patterned moraine commonly extends from the bench or plateau over the slope to the cirque floor. Some small cirques are almost buried under a moraine blanket, which is evidently not a product of mountain glaciation.

Cirques, benches, and summit plateaux, all appear to have been formed before the deposition of the patterned moraine.

Cirques on the south side of Mount Bayliss are smooth-sided and are separated by rounded ridges (Fig. 8). Cirques on the north side have craggy sides and are separated by rough broken ridges. Striations on the summit plateau suggest that the high level ice cap flowed from south-west to north-east across Mount Bayliss, broadly parallel to the present direction of ice flow. The flow of the ice cap appears to have smoothed the outlines of the cirques on the south, stoss face. These cirques were certainly cut before the vertical maximum of the ice cap, and do not appear to have been active since they were rounded.

With the exception of Mount Menzies, nunataks with small summit areas in the southern Prince Charles Mountains are considerably lower than nunataks with broad summit plateaux. In the northern Prince Charles Mountains the highest nunataks have broad summit plateaux.

Nunataks with broad summit plateaux generally have small cirques and nunataks with small summit areas almost all have large cirques. The differences in heights and in their cirques between the two types of nunatak, suggest that nunataks with small summit areas were formed by the erosion of converging cirques gnawing into higher and larger mountains with broad summit plateaux.

A prominent bench in the northern ridge of Mount Menzies, about 300 metres above the surface of the Fisher Glacier, is interrupted by large and small cirques which have cut into and through the bench (Fig. 5). Some of these cirques are floored with patterned moraine. This bench appears to have been formed before the cirques.

The summit plateaux and one bench at least appear to pre-date the cirques. Many of the cirques were probably formed before the vertical maximum of the ice cap. If these cirques began to form at the onset of glaciation, then the summit plateaux, and possibly the benches, are relics of a pre-glacial landscape.

The pre-glacial landscape was certainly not a simple peneplain, for plateaux and adjoining benches, and neighbouring plateaux, commonly have height differences of several hundred metres (Fig. 3). It was probably composed of rolling high hills, whose summits are preserved in the broad summit plateaux, separated by broad valleys whose floors are partly preserved in the benches. This landscape may have been produced from a peneplain by faulting some time before the onset of glaciation, but the faulted features have probably been greatly modified by pre-glacial and glacial erosion since the faulting, to which Crohn (1959) attributes the present configuration of the mountains.

GLACIAL HISTORY

Tentatively, the glacial history of the Prince Charles Mountains may be summarised as follows :

1. At the onset of glaciation the mountains were high rolling ranges, separated by broad valleys mostly trending east-west parallel to the dominant strike of the metamorphic rocks.

2. With increasing cold, ice accumulated in favourable sites and scooped cirques in the rolling hills. Mountain glaciers coalesced in the valleys and built up to form an ice cap. The predominance of broad summit plateaux in the southern Prince Charles Mountains suggests that they were covered by a protective ice cap fairly early in the glacial period, while cirque erosion and frost weathering steadily reduced many of the northern mountains.

3. In the Prince Charles Mountains the ice level probably reached its greatest height before the ice cap glaciers had cut far enough into the original valley bottoms to produce the efficient drainage system which keeps the mountains free of ice at present, and to leave the margins of the valley bottoms as benches.

4. The ice cap receded either because precipitation was drastically reduced in the interior of the continent or because the erosion of the valley bottoms permitted larger volumes of ice to drain to the sea. (The very small number of mountain glaciers in existence now reveals that precipitation was very much greater at the time of formation of the cirques.) As the ice cap receded it left behind a blanket-like deposit of moraine on level ground and on gentle slopes. The ice reached some level below its present surface, and a pattern of unsorted nets was developed on the moraine.

5. Since its first recession, the surface of the ice in the Prince Charles Mountains has no doubt risen and fallen several times in response to variations in precipitation. Mountain-glacier valleys cut in the patterned moraine, the unpatterned terminal moraines of these mountain glaciers, and the unpatterned lateral moraines up to 50 metres above the present ice surface, mark at least one phase of increased precipitation.

Throughout the glacial period the great glaciers of the Prince Charles Mountains have continued to lower the bottoms of their valleys, and this has probably contributed very largely to the downward recession of ice from the mountains. The long gently sloping stretch of the Lambert Glacier extending 150 kilometres south of the Amery Ice Shelf may have reached a base level of erosion and may now be a mature glacier.

This glacial maturity will spread sourcewards along the glaciers of the Prince Charles Mountains, though fluctuations in climate or in sealevel may either accelerate or retard the downward recession of ice from the mountains.

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REFERENCES

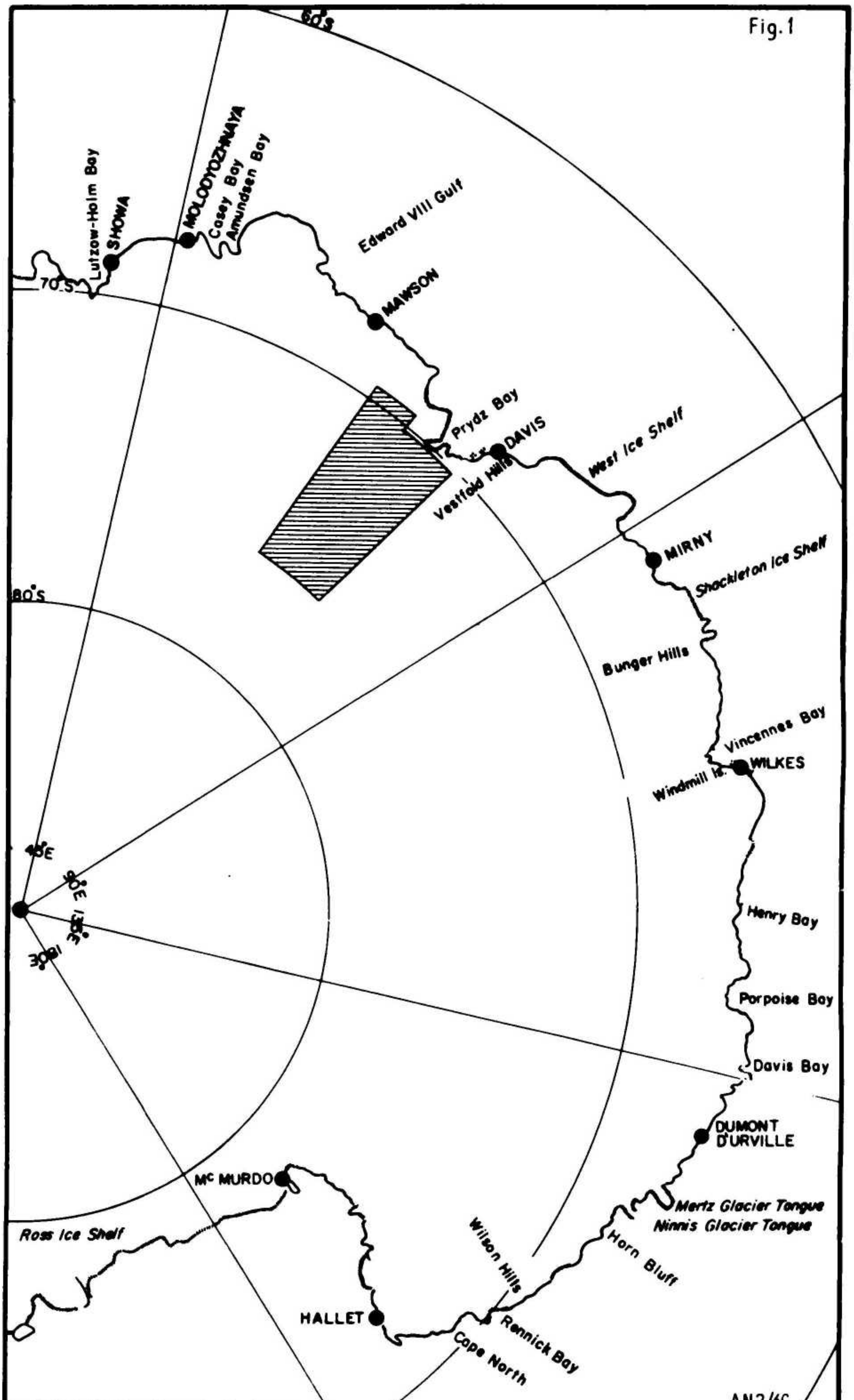
CROHN, P.W., 1959 - A Contribution to the Geology and Glaciology of the Western part of Australian Antarctic Territory. Bur.Min.Resour.Aust.Bull. 52.

McLEOD, I.R., 1959 - Report on Geological and Glaciological Work by the 1958 Australian National Antarctic Research Expedition. Bur.Min.Resour.Aust.Rec. 1959/131 (unpubl.).

RUKER, R.A., in prep.- Geological Reconnaissance in Enderby Land and Southern Prince Charles Mountains, Antarctica. Bur.Min.Resour.Aust.Rec. in preparation

STINEAR, B.H., 1956 - Preliminary Report on Operations from Mawson Base, Australian National Antarctic Research Expedition 1954-55. Bur.Min.Resour.Aust.Rec. 1956/44 (unpubl.).

WASHBURN, A.L., 1956 - Classification and Origin of Patterned Ground. Bull.geol.Soc.Amer., 67,7.



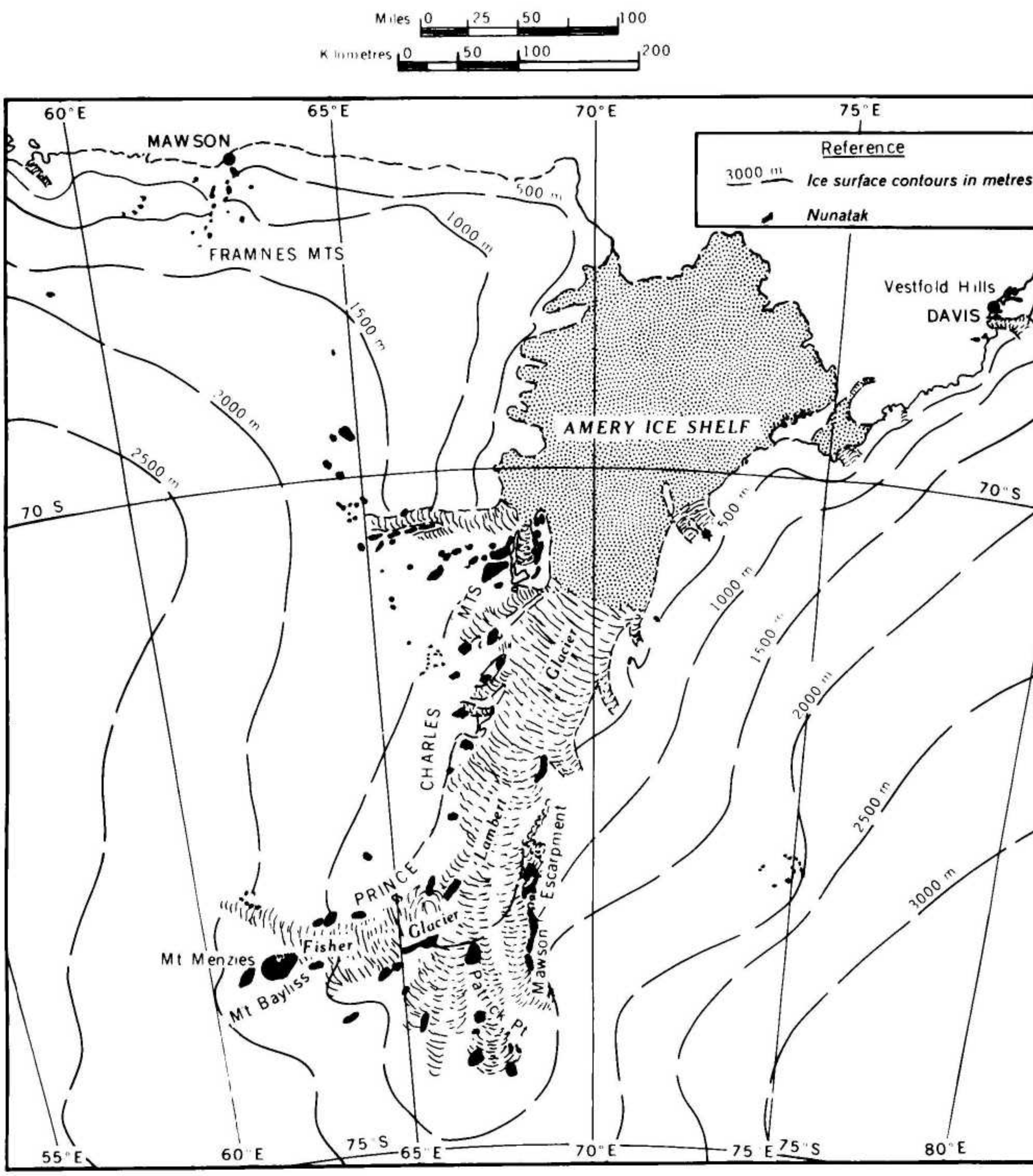
LOCATION OF

PRINCE CHARLES MOUNTAINS

ANTARCTICA

Fig. 2.

PRINCE CHARLES MOUNTAINS
ANTARCTICA



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(Photo by Royal Australian Air Force Antarctic Flight)

Fig. 3: View south across Mount Stinear, southern Prince Charles Mountains. Broad summit plateau is covered by patterned moraine, cirques at south end, moraine-covered bench on left. Other nunataks with broad summit plateaux in background. Centre background is confluence of Fisher and Lambert Glaciers. Reproduced with the authority of the Royal Australian Air Force.

(Photo by P.W. Crohn)

Fig.4: Part of the northern Prince Charles Mountains. Many nunataks have small summit areas, and summit plateaux are relatively small.

(Photo by Royal Australian Air Force Antarctic Flight)

Fig.5: Mount Menzies from north. Bench at right and centre interrupted by cirques. Floor of large cirque and north side of left peak are covered by patterned moraine. Reproduced with the authority of the Royal Australian Air Force.

(Photo by Royal Australian Air Force
Antarctic Flight).

Fig. 6: View south-west across Mount Bayliss. Smooth cirques on south, stoss side; rough cirques on north, lee side; striations at left. Broad summit plateau covered by patterned moraine. Reproduced with the authority of the Royal Australian Air Force.

(Photo by Royal Australian Air Force
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Fig. 7 : North-west part of Mount Menzies, looking west. Mainly patterned moraine. Hillocky moraine on floor of valley adjacent to stagnant ice. Sinuous ridges of unpatterned moraine lie on patterned moraine in foreground. Reproduced with the authority of the Royal Australian Air Force.