BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD

RECORD 1981/34

GEOLOGICAL INVESTIGATIONS IN ANTARCTICA 1968-1969 :

THE PRYDZ BAY - AMERY ICE SHELF - PRINCE CHARLES MOUNTAINS AREA

COMPILED BY

R.J. TINGEY

FROM DRAFTS BY

J.H.C. BAIN, D.J. GRAINGER, & I.R. McLEOD

Bureau of Mineral Resources, Geology and Geophysics

RECORD 1981/34

GEOLOGICAL INVESTIGATIONS IN ANTARCTICA 1968-1969 :
THE PRYDZ BAY - AMERY ICE SHELF - PRINCE CHARLES MOUNTAINS AREA

COMPILED BY

R.J. TINGEY

FROM DRAFTS BY

J.H.C. BAIN, D.J. GRAINGER, & I.R. McLEOD

Bureau of Mineral Resources, Geology and Geophysics

CONTENTS

CONTENTS (cont.)

FIGURES

PLATES

ABSTRACT

Four Bureau of Mineral Resources' (BMR) geologists joined a helicopter and aircraft-supported field operation of the Australian National Antarctic Research Expeditions (ANARE) in the 1968-69 austral summer. Field operations were centred on the base camp at Landing Bluff, in the extreme northeastern corner of the Amery Ice Shelf, and extended northeast to the Rauer Islands in Prydz Bay, south to Pickering Nunatak on the eastern side of the Amery Ice Shelf, and southwest to the Beaver Lake area and Mount McCarthy in the northern Prince Charles Mountains.

The rocks mapped in these areas are predominantly high-grade metamorphic types including syntectonic charnockite masses; migmatites are common. The high-grade rocks are considered to be the result of a high-grade metamorphic episode that affected wide areas of East Antarctica 1000 ± m.y. ago, and are intruded by early Palaeozoic granitoids in the base-camp area and nearby outcrops. The presence of metamorphosed basic dykes intersecting gneissic rock at Jetty Peninsula in the Prince Charles Mountains is interpreted as evidence that the gneissic rocks there may be considerably older than 1000 m.y., whereas alkaline mafic dykes in the Prince Charles Mountains and possibly also at New Year Nunatak are thought to be younger, Phanerozoic manifestations of activity along the major geological structure now occupied by the Lambert Glacier and Amery Ice Shelf. A small enclave of coal-bearing Permian sedimentary strata near Beaver Lake is thought to have been deposited in a fault-bounded trough somewhat akin to coalfields within the basement of peninsular India. Alkaline intrusives in both places give K-Ar ages of 110 m.y.

The field operations were governed by the needs of the concurrent topographic survey program. The study was the first of six such ANARE ventures in the Prince Charles Mountains. The interpretation and description presented in this Record incorporates geochronological data and regional relationships deduced in these subsequent investigations.

INTRODUCTION

The fieldwork for this Record was carried out in the Prydz Bay-Amery Ice Shelf-Prince Charles Mountains area in January and February of 1969. This field season was the forerunner of five more field seasons during which geological investigations were made throughout the Prince Charles Mountains.

Writing up of the 1969 work was delayed for various reasons but was completed in preparation for further fieldwork in the Vestfold Hills/Prydz Bay area in the 1980/81 summer field season. Since the original drafts were prepared, knowledge of the regional geology of the Prince Charles Mountains and other parts of East Antarctica has made considerable progress, and concepts in metamorphic geology have changed. Also, Rubidium-Strontium geochronological data for the whole area has become available and revealed that, in the Vestfold Hills, the basement gneisses which are intersected by a network of dolerite dykes are of Archaean age whereas the basement gneisses further south, where there are no such dykes, are about 1000 m.y. old. The intrusive granites at Landing Bluff were emplaced about 500 m.y. ago, and the Polarforschung Granite and other unfoliated granitoids in the area are inferred to be about the same age. In addition, various basic igneous rocks with alkaline affinities have been described from the Prince Charles Mountains, and range in age from 420 m.y. to 53 m.y.; they are thought to document activity along the major geological structure now occupied by the Lambert Glacier system.

The 1969 work area is described in a sequence which progresses southwest from the Rauer Islands around Prydz Bay to Landing Bluff, south along the eastern side of the Amery Ice Shelf to the New Year Nunatak area, and thence to Jetty Peninsula, Fox Ridge, and Mount McCarthy in the Prince Charles Mountains west of the Amery Ice Shelf. Work in the Beaver Lake-Radok Lake area is summarised in a published account (Mond, 1972). In the original drafts, the rocks of particular areas were grouped together into formally named units. These groupings are retained although emphasis is placed upon descriptions of the rocks encountered at each locality. Thin-section descriptions are alluded to in the text as necessary, and are derived from detailed descriptions given in the Australian Mineral Development Laboratories (AMDEL) report MP 4460/69 held in the Technical files of the Bureau of Mineral Resources, although most have been rechecked in the 1980 compilation of this Record. Sample numbers refer to the BMR rock collection. This Record is intended as a description of the geological work that was done in the 1968-69 field season as part of the overall scientific program of the Australian National Antarctic Research Expeditions (ANARE), and as a basis for future fieldwork and regional geological interpretations.

METHOD OF WORKING

A base camp was set up near Landing Bluff, which is at the eastern junction of the Amery Ice Shelf front with the edge of the continental ice sheet. Establishment of the camp began on 4th January, and the camp was closed on 21st February, although bad weather delayed the loading of all equipment onto the relief ship until 25th February.

Two of the geologists (Bain and Grainger) each worked with a surveyor as two-man field parties, camping at localities selected for survey stations. They assisted the surveyors with their work, and examined the geology around the camp after the survey work at that station was finished, and, when possible, during pauses in the survey work. The parties were moved from place to place by helicopters; using a helicopter for transport, the geologist examined the area around the survey station by landing at several places before flying to the next survey station locality. Another geologist (McLeod) remained at the base camp and made helicopter traverses from there to map the areas not covered by Bain and Grainger; on occasions, McLeod also worked with Bain and Grainger. The fourth geologist (*Medveckey) worked independently; Medveckey, together with a radio operator and a weather observer, camped at the southeastern corner of Beaver Lake for a few days, then moved from there by helicopter and camped near the head of 'Pagodroma Gorge' for 4 weeks. Medveckey made foot traverses from these camps, and a brief helicopter traverse to the southern part of Jetty Peninsula. Plains for more extensive helicopter traversing had to be abandoned because of weather conditions. Although helicopter traversing around some of the survey stations was also curtailed and, in two cases, prevented by bad weather or lack of time, the technique of combining camps and helicopter traverses for geological mapping was found to work well, especially in regions of scattered outcrop. On some

* now known as Mond

occasions, however, the geologists' flexibility of movement was limited by the surveying requirements; furthermore, the location of survey stations was not always convenient to the best rock exposures.

During the mapping, samples were collected from several places for isotopic age measurement, and most of the coal seams in the sediments were sampled.

PREVIOUS INVESTIGATIONS

Several ANARE geologists have visited localities in the region dealt with in this report. Their reconnaissance work showed the rocks of the region to be predominantly high-grade metamorphic rocks (mostly quartzo-feldspathic gneisses) with flat-lying unmetamorphosed Permian sediments extending for a few kilometres to the west and south of Beaver Lake.

The first to work in the region was Crohn (1959), who sledged through the northern Prince Charles Mountains during the 1956-57 summer. He visited Mount McCarthy, and also the northern end of Beaver Lake where he discovered Permian coal-bearing sediments which he called the Amery Formation. Stinear examined the sediments at the southwestern corner of Beaver Lake in November 1957, and McLeod examined those at the south-eastern end of the lake in 1958 (McLeod, 1959). Stinear also briefly visited the south end of Fisher Massif in 1957, and McLeod visited Jennings Promontory and the north end of Jetty Peninsula during his stay at Beaver Lake. Palynological work on the coal-bearing sediments by the Commonwealth Scientific & Industrial Research Organisation (CSIRO, 1957) and by Balme & Playford (1967) showed them to be Permian in age, and analysis of coal samples (CSIRO, 1957) showed the coal to be near the dividing line between brown and black coal.

Geologists of the Soviet Antarctic Expedition (SAE) landed at several places, mostly in the south of the region, during the 1965-66 summer (Soloviev & others, 1969). ANARE geophysicist J. Haigh, who spent a week with the SAE party, collected specimens from Manning Nunataks, Haigh Nunatak, and Pickering Nunatak.

The islands north of Mount Caroline Mikkelsen were visited by Stinear in August 1957 and, in the same period, he examined localities in the northeast of the Larsemann Hills. McLeod (1959) landed at three places in the north and west of the Larsemann Hills and outlying islands early in 1958. Crohn (1959) had landed at Lichen Island, 20 km northwest of the Larsemann Hills, early in 1955, and Stinear at Cleft Island, 15 km west-northwest of the hills, in August 1957. Stinear visited Torckler Island, in the southern Rauer Islands, in August 1959, and early in 1960 McLeod examined the western end of Filla Island, Hop Island, and the southernmost of the coastal rock exposures east of the Rauer Islands.

The Vestfold Hills, 15 km north of the Rauer Islands, were first visited by Crohn in 1955 and by several ANARE geologists since then, notably McLeod & others (1966). SAE visited places in the Rauer Islands, Larsemann Hills, and Vestfold Hills in 1957 (Ravich & Voronov, 1958; Ravich & others, 1965).

At the request of BMR, ANARE surveyor J. Quinert collected rock specimens from Moore Pyramid in 1966, and geophysicists V. Dent and R. Smith collected specimens from the Landing Bluff area early in 1968. Specimens were collected from the Rauer Group by the late Sir Hubert Wilkins in 1939, but specific localities were not recorded.

PHYSIOGRAPHY

The region (Plate 1) is dominated by the vast indentation in the continental ice sheet occupied by the Amery Ice Shelf and its main feeder glacier, the Lambert Glacier. Outcrops in the eastern part of the region are confined to the coast and the margins of the Amery Ice Shelf. Except for the more extensive rock exposures of the Larsemann Hills and Rauer Islands, these outcrops are either isolated nunataks or small groups of nunataks and islands. On the western side of the Amery Ice Shelf and Lambert Glacier, numerous large rock exposures constitute the northern Prince Charles Mountains.

Most of the larger rock exposures around the Amery Ice Shelf are more or less flat-topped having level or gently sloping upper surfaces; Flagstone Bench, Rubeli Bluff, and the north end of Jetty Peninsula (Else Platform) are notable examples. Further, numbers of groups of nunataks tend to have a common summit altitude. Individual exposures tend to have gently-rounded upper surfaces which either disappear under snow which is at much the same level as the rock surface, as in the Statler Hills, or drop steeply, even vertically, to a snow surface 50 metres or more below, as in the Mistichelli Hills. Some outcrops - for example, those on Gillock Island - project as terraces or crags from steep snow-slopes.

Little is known of the altitudes of exposures on the eastern side of the Amery Ice Shelf and around Beaver Lake but they are relatively low, probably in the range 200 to 300 metres, and appear to increase southwards.

The groups of islands and coastal exposure along the eastern side of Prydz Bay also have common summit altitudes; this is particularly noticeable in the Larsemann Hills and Rauer Islands, where many high points are 130 to 160 metres above sea level.

These various congruent summit levels rise gently southwards from an altitude of rather more than 100 metres in Prydz Bay, and are interpreted as relics of an erosion surface of low relief and probable pre-glacial origin. Ice radar data is not available for the ice sheet to the east of the Amery Ice Shelf and so the subglacial topography in this area is unknown.

West of Beaver Lake, concordant summit altitudes in the Prince Charles Mountains rise westwards, and are somewhat higher than those of outcrops east of the Amery Ice Shelf. The upper surfaces of flat topped massifs on either side of the Lambert Glacier to the south (outside the region described in this report) may be remnants of the same surface, now much dissected. It is not known whether this surface and the surface to the east are part of the same original surface disrupted by a fault west of Beaver Lake such as the Mount Loewe Fault proposed by Crohn (1959). The work around Radok Lake indicated that the Permian Amery Group Sediments are unconformable on the metamorphic rocks, rather than faulted down into them (Mond, 1972). This does not preclude faulting during or before deposition of the sediments, and similar enclaves of Permian strata in India - such as the Mahanadi and Godavari coalfields - are thought to have been deposited in fault-bounded troughs in the basement rocks.

Evidence that ice levels were once higher is abundant in the ice-sculptured form of rock features, such as Samson Island and some of the Manning Nunataks, which have striated and polished rock surfaces, and till deposits well above present ice level or at a considerable distance from the present ice edge. These tills range in size from small accumulations of sand, gravel, and boulders to deposits apparently many metres thick, e.g. the valley on Holder Peak. Cirques, now partly abandoned, were seen in several places, notably the Mistichelli Hills and McKaskle Hills; the mouths of some are marked with arcuate ridges of moraine. Weathering since the ice receded has resulted in the partial disintegration of outcrop surfaces, and was probably enhanced by solar heating in cirques with a northerly aspect.

Weathering processes combined with frost heaving or nivation have created the mantle of loose angular rock debris (or felsenmeer) which covers many rock surfaces around the Amery Ice Shelf. When viewed from the air, these exposures display a marked banding of light and dark coloured rocks that reflects underlying bedrock trends although it is outlined in loose but essentially in situ debris. The fragments range in size from granules to blocks 2-3 m across; 0.5-1.0 m is a common size range. Felsenmeeren of almost in-situ debris are particularly well developed on Fox Ridge, Rubeli Bluff, and at Jetty Peninsula where the trace of basic dykes probably less than a metre wide can easily be seen on the ground and traced for several kilometres using aerial photographs.

The same process has broken down granite and charnockite to its constituent mineral grains, which are small enough to be blown by strong winds into depressions in the surface, leaving the bare rock projecting above expanses of gravel predominantly composed of fragments of the feldspar crystals. Some of these gravel patches extend for many tens of metres.

Stone polygons have formed on many of the surfaces covered by rock fragments. The regularity of the pattern, size of the polygons, and degree of sorting (with coarsest fragments at the margin) differ from place to place.

Indirect evidence of a former higher sea level can be seen in the Rauer Islands where flat, low-lying valley floors consist of sandy mud containing only scattered larger fragments. In contrast, substantial erratics were found on most exposures visited nearby although there were only a few scattered boulders on some features. Direct evidence of a higher sea level has been reported from the Vestfold Hills 15 km to the north where raised beaches about 10 m above sea level are common and saline lakes have formed by evaporation of salt-water bodies isolated by the retreat of the sea (McLeod, 1964).

GEOLOGY

PRYDZ BAY AREA (Central)

The migmatitic rocks exposed along the east-central coast of Prydz Bay between the Sorsdal and Polar Record Glaciers are grouped together as the Prydz Bay Migmatite. Outcrops in the Rauer Islands, the Larsemann Hills, Bolingen Islands, and the Sørstrene Islands, and coastal outcrops to their south were examined; other outcrops were reconnoitred. The large, westernmost peninsular in the Larsemann Hills is provisionally defined as the type area of the Prydz Bay Migmatite (reference Fig. 3).

The main rock type in this part of Prydz Bay is medium-grained garnet-biotite-quartz-feldspar gneiss with gradations through granoblastic gneiss to gneissic granite. The rocks are banded, and boundaries between different varieties are diffuse and irregular. In the type area in the Larsemann Hills, the granitic component of the migmatite consists mainly of diffuse nebulous gneissic granite, but elsewhere more discrete granitic veins, lenses, and bands are common. Small scale ptygmatic granitic and pegmatitic veins are widespread.

Mafic-rich lenses and streaks in the migmatite appear to outline major folds; they may be the metamorphosed relics of dykes that were sheared out during the 1000 ± m.y. metamorphism that affected the area but whose possible correlatives are still preserved in the Vestfold Hills. In addition, a few metamorphosed dykes were recognised in the Rauer Islands. Major, darker-coloured bands in the migmatite are tens of metres wide and hundreds of metres long. They consist of biotite-pyroxene gneiss and minor garnet and sillimanite, assemblages which could be interpreted as a reflection of a possible sedimentary origin for the rocks.

Metamorphism in the Prydz Bay area was clearly high grade, and the contrast between original mafic and felsic rocks was probably emphasised by the segregation of granitic fractions from originally intermediate rocks by partial melting. Some of the more mafic rocks may be melanosomes left behind after such segregation rather than true relics of the original rocks. The specific grade of metamorphism is difficult to identify because the production of different mineral assemblages in different rock types was influenced by rock composition, and especially by water content. In migmatitic rocks, the assumption that metamorphism was isochemical is clearly only partly true, and assignation of one rock type to a particular metamorphic facies and another, nearby, to a different facies, is pointless.

Rauer Islands

A survey station was established on Filla Island in the Rauer Group, and nearby rocks were examined in detail. Other Rauer Islands outcrops were also examined. The predominant rock types are banded migmatitic quartzo-feldspathic gneisses with mineral assemblages that signify high-grade metamorphism. Subordinate, small mafic bands and lenses are common but, although a few metamorphosed basic dykes were mapped, the numerous dolerite dykes, which are such a conspicuous feature of the Vestfold Hills 15 km to the north, are absent. Geochronological studies of rocks from Filla Island have yielded a Rubidium Strontium (Rb/Sr) total rock age of 1073 ± 111 m.y. for the gneissic rocks with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7086. The low initial ratio could be interpreted as evidence that the rocks had not had a long crustal history prior to the high-grade metamorphism.

The quartzo-feldspathic gneisses consist predominantly of plagioclase (oligoclase to andesine), potash feldspar, and quartz, with more or less biotite and garnet, minor clinopyroxene and orthopyroxene, and traces of apatite, zircon, and opaque minerals. The less-felsic varieties contain a greater proportion of pyroxene, as well as some hornblende, and little or no potash feldspar. Mafic rocks typically consist of either plagioclase (andesine), biotite, and garnet, with traces of opaque minerals and apatite, or of biotite, garnet, and orthopyroxene. Some of the mineral assemblages are characteristic of the amphibolite metamorphic facies; others are more typical of the transitional hornblende granulite facies.

The amphibolite-facies rocks are mostly banded, garnetiferous quartz-feldspar gneisses of diverse appearance; they range from foliated garnet-biotite-quartz-feldspar gneiss to massive coarse-grained leucocratic granite. Thin, dark-coloured bands, rich in biotite and garnet, form only a very small part of the sequence. The garnet-biotite-quartz-feldspar gneiss is a fine-grained to medium-grained equigranular rock composed of plagioclase, potash feldspar, quartz, biotite flakes, and clear brownish-red garnet. A small outcrop on Filla Island contains one or two percent of molybdenite flakes up to one centimetre long, disseminated throughout the rock, but no other mineralisation was seen.

Near the Filla Island survey station, various types of felsic gneiss are exposed; contacts between them are mostly gradational. Most contain garnet and biotite but orthopyroxene is rare; potash feldspars are perthitic in most cases, and antiperthites are present in some rocks. Minor retrograde metamorphism is indicated by slight sericitisation of feldspars, and alteration of biotite to chlorite. Two felsic gneisses from this area were sampled. Sample 69280091, a strongly-banded rock, is composed of about 55 percent andesine (An_{35}), 30 percent quartz, 10 percent orthoclase, 5 percent biotite and minor apatite, zircon, opaques, and muscovite. The potash feldspar contains a few quartz inclusions but is described as homogeneous. Sample 69280092, by contrast, is a massive poorly-foliated, pink and grey rock with scattered deep-red garnets and black streaks, as opposed to distinct bands, rich in biotite. It has a granoblastic texture, and is composed of about 35 percent microperthitic orthoclase, 30 percent quartz, 25 percent antiperthitic Oligoclase (An_{25}), 7 percent biotite, 3 percent garnet and minor pyroxene, muscovite, apatite, zircon, and opaques. The few pyroxene grains in the thin section were tentatively identified as clinopyroxene in the AMDEL reports although the straight extinction and slight pleochroism from pink to green suggests orthopyroxene. In contrast to the biotites, which are commonly altered to opaques and chlorite, and the feldspars, which are commonly altered to sericites, the pyroxenes are unaltered; they are commonly close to apatite crystals. The presence of pyroxene and perthitic feldspars in the rock is possibly evidence of near-granulite-facies metamorphism although the differences between samples 69280091 and 69280092 are probably more governed by rock composition than by local variations in metamorphic conditions.

Interbanded with the biotite/garnet-bearing felsic gneisses are light coloured fine to medium-grained moderately foliated hornblende-pyroxene-feldspar gneisses in indistinct bands up to several tens of metres wide. These rocks and especially a few garnet bearing variants closely resemble the main felsic gneisses in outcrop, and both are accompanied by less abundant, but nonetheless conspicuous, irregular bodies of dark biotite-garnet-pyroxene gneiss and hornblende-pyroxene granulites. The hornblende/pyroxene-bearing felsic gneisses have a moderate foliation and light and dark minerals are locally segregated into compositional layering. Some contain diopsidic augite in addition to greenish-brown hornblende; others contain hypersthene. Sample 69280094, a brown, slightly foliated, equigranular, coarse-grained rock is a somewhat felsic example that consists of a granoblastic aggregate of about 50 percent orthoclase perthite, 30 percent andesine antiperthite, and 10 percent quartz with about 10 percent of pyroxene of which the bulk is clinopyroxene. Minor red-brown to green-brown hornblende and opaques are intergrown with some pyroxene crystals, but most pyroxenes are fresh. The rock also contains minor zircon and apatite and there is minor alteration of feldspars to clay minerals. Although contained in a migmatite suite, sample 69280094 could be classified as a product of granulite-facies metamorphism; other samples, however, contain more hornblende and biotite and are best regarded as transitional amphibolite to granulite-facies rocks. Obviously rock composition exerted a strong control over the nature of the eventual metamorphic rock.

No samples of the concordant mafic rocks on Filla Island were sectioned but samples were collected from discordant dyke-like bodies of basic rock near Broan's Glacier. These bodies are from 5 to 30 cm wide, have sharp margins, and most are straight. Sample 5561 is composed of about 50 percent andesine, 45 percent brown hornblende, 5 percent biotite, and traces of apatite; obviously a metamorphic assemblage. The dykes appear to postdate the main banded gneiss sequence, but have been metamorphosed possibly in the same metamorphism that produced minor retrograde effects in many of the felsic gneisses. Field relationships between the basic dykes and granitic intrusives in the migmatite complex are not known and require further investigation.

Within the banded felsic gneisses there are numerous, generally concordant bands and irregular masses up to 1 metre thick, of coarser-grained poorly-foliated to massive quartz-feldspar granitoid. These rocks contain prominent, pink potash feldspars plus minor garnet and biotite, although some examples contain almost no ferromagnesian minerals, and are typically heterogeneous and uneven grained. They consist of irregular patches of pink potash feldspar, intermingled with white plagioclase, and quartz. Such pegmatitic masses are characteristic of migmatite terrains, and sample 15424 is composed of about 40 percent quartz, 35 percent microperthite, 25 percent andesine (An_{30}), and minor zircon, chlorite, and opaques. Some retrograde alteration and cataclasis of the pegmatite is indicated by strain extinction of quartz, local alteration of feldspars to calcite and sericite, and by scattered, small aggregates of chlorite and opaques, possibly the alteration products of biotite.

The granitoid masses in the migmatites commonly have sharp contacts with the surrounding gneisses but, in several places, an along-strike gradation was observed from pink uneven-grained granite to biotite quartz-feldspar gneiss with thin, ill-defined fingers of granite extending along foliation planes of the gneiss. This is interpreted as direct evidence for derivation of the granitoids by partial mobilisation of felsic gneisses, probably during the main metamorphism. Locally, however, some granitoid veins intersect and are clearly younger than others. In general the younger veins have more pink feldspar and less garnet than the older ones, and some have aplitic selvages about 2 cm thick, possible evidence of multiple intrusion. A feature associated with the younger, generally discordant granitic intrusives is that the brown iron-staining that is common in the country rocks is frequently absent in zones up to 1 metre wide along the margins of the veins. This could well be due to contact metamorphic effects of the veins rendering the local country rocks more resistant to weathering, and may be evidence that the discordant granitoid veins, unlike the concordant granitoid masses, were intruded well after the main metamorphism, perhaps at about 500 m.y. when granitic intrusive activity was widespread in East Antarctica (see Tingey, in press).

Other islands in the Rauer Group

An unnamed island west of Hop Island is composed of fine-grained biotite-quartz-feldspar gneiss in which a vague foliation is due to the alignment of numerous small (1-15 cm by 1-4 m) streaks of mafic gneiss containing biotite and pyroxene. The foliation strikes 130^{o}, and dips steeply to the southwest. Elsewhere in the Rauer Islands, extremely complex folding is developed in migmatitic gneisses, especially on Torkler Island where richly garnetiferous biotite-quartz-feldspar gneisses are particularly common. Large similar and convolute folds are outlined by concentrations of garnet and alignment of sparse biotite flakes. Leucocratic rock types predominate in the southern and eastern Rauer Islands, where there are gradational boundaries between strongly-banded varieties of garnetiferous biotite-quartz-feldspar gneiss. However, the southeastern-most island consists of massive hornblende-pyroxene-quartz-feldspar gneiss which contains numerous concordant lenses or veins of mafic granulite.

Outcrops between the Rauer Islands and Larsemann Hills

Several outcrops between the Rauer Group and the Larsemann Hills were briefly visited. These were 1) the headland on the western side of the Ranvik Glacier; 2) the headland at the northeastern corner of Amanda Bay; and 3) the Steinnes headland about 8 km southwest of the Amanda Glacier. All other outcrops were inspected from the air.

The rocks exposed are predominantly felsic biotite-quartz-feldspar gneisses containing various amounts of garnet. Banding is defined by biotite-rich and biotite-poor layers, and ranges in type from a vague whispy microbanding to well-defined bands a few centimetres thick. Garnet is not abundant and rarely accounts for more than 10 percent of the rock; it is either distributed evenly through the rock or concentrated in, and in some cases constituting up to 30 percent of, rare biotite-rich layers up to tens of centimetres thick. Within the gneisses there are irregular, poorly defined, generally subconcordant granitic lenses and layers, most of them less than two centimetres thick. Discordant, locally garnetiferous, quartz-feldspar veins, most of them less than 10 cm thick, are irregularly distributed; some on the headland at the northeastern corner of Amanda Bay are ptygmatically folded.

Mafic bands like those described from the eastern Rauer Islands, are uncommon although more occur around Amanda Bay and in the islets 10 km to the west, where they are several metres wide.

The banded gneiss exposed on the headland west of the Ranvik Glacier (sample 69280190) resembles the garnet-biotite-quartz-feldspar gneiss of the central Rauer Islands but lacks interbanded granitic rocks. The gneissic foliation strikes 120^{o}, and dips about 20^{o} to the south. A 1.25-m wide dyke-like body, with well-defined margins and prominent banding parallel to these margins, strikes 080^{o} obliquely to the country rock, and dips about 30^{o} north. In general, this body is similar in composition to the country rock, and consists of alternating reddish-grey and pinkish-white bands about 1 cm thick. The reddish-grey bands contain much more garnet than the lighter-coloured bands, which are plagioclase rich. Thin section 69280189 included both types; their estimated mineral assemblages are -

	Reddish grey band	Pinkish white band
Quartz	25	25
Andesine	10	25
Potash feldspar	10	30
Garnet	35	5
Biotite	7	10
Opaques	5	3
Apatite	Trace	Trace
Sericite	Trace	Trace
Carbonate	Trace	Trace

In this specimen, quartz generally has a ribbon texture and the potash feldspar is cryptoperthitic; both features suggest high-grade metamorphism. Biotite and garnet are poikiloblastic and highly irregular in outline. Post-crystallisation deformation is indicated by widespread mineral-cracking perpendicular to the foliation, and undulose extinction especially in quartz; nearby country rocks (sample 69280190) display similar features.

The origin of the dyke-like body is not known although recrystallisation of a shear zone appears a plausible explanation. The mineral assemblages are more consistent with derivation from sedimentary than from igneous rocks.

Compared with the rocks described from the Ranvik Glacier area, the gneiss exposed at the northeastern corner of Amanda Bay is less prominently banded since the biotite is more evenly distributed, mostly in thin sub-parallel whispy streaks; biotite segregations likewise are less common here. Thin bands and lenses of granitic rock are relatively more common, and on a macro scale give the gneiss an uneven, irregular texture. Some rocks contain abundant garnet (up to 50 percent), and most of them are also biotite-rich. However, specimen 69280192, a pelitic schist, consisting of quartz, plagioclase, sector twinned cordierite, spinel, sillimanite, and 15 percent garnet, contains no biotite, a feature that could be interpreted as evidence of local granulite-facies metamorphism. This rock also displays abundant evidence of cataclasis, granulation, and recrystallisation in the form of crystal fracture, trains of small mineral grains among larger ones, symplectic intergrowths, reaction rims, and signs of garnet rotation. By contrast, a nearby mafic rock (sample 69280191), which contains 20 percent orthopyroxene, 30 percent biotite, and 40 percent calcic plagioclase, shows few signs of post-crystallisation stress, presumably because it was able to accommodate stress by virtue of the high biotite content.

Mafic bands were also found southeast of Amanda Bay but are much less common than in the locality just described. Specimen 69280193, a representative sample, consists of about 50 percent labradorite, 40 percent hornblende, a total of about 10 percent ortho- and clinopyroxene, and minor biotite and quartz. The formation of pyroxenes by reaction of hornblende and quartz in this rock appears to have been restricted by the small quantity of available quartz. The mafic bands emphasise the gneissic foliation at this locality, and outline a pattern of contorted curves and swirls rather than regular folds. At one place at least, the pattern suggests the possible superimposition of two generations of fold. Metamorphism in the Amanda Bay area was clearly high-grade, but mineral assemblages in individual rocks are strongly governed by rock composition, and there is little point in assigning particular metamorphic facies.

Larsemann Hills

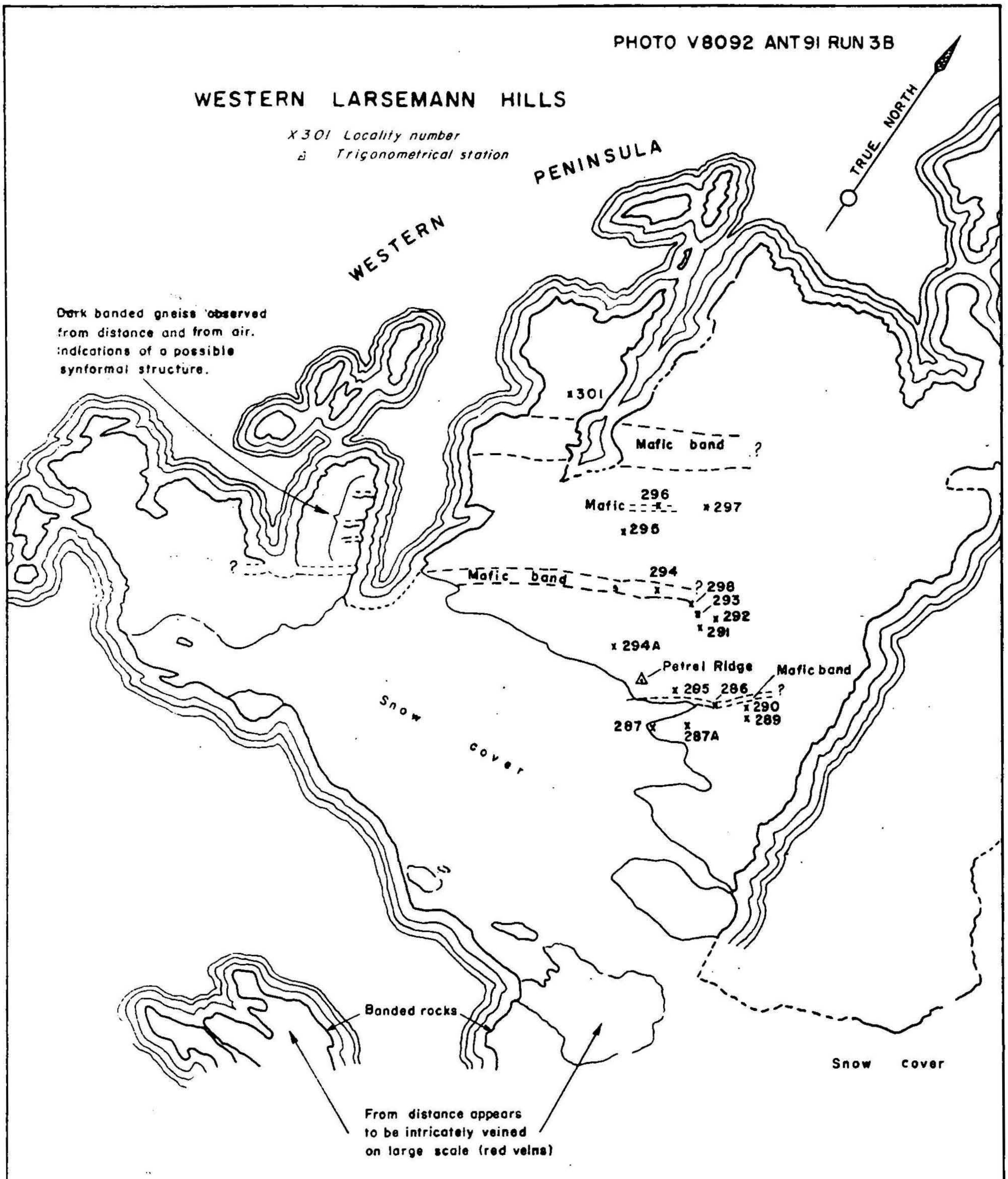
Banded migmatitic gneisses, which range from well-foliated garnet-biotite-quartz-feldspar leucogneiss through granoblastic gneiss to granite gneiss, are exposed in the Larsemann Hills. large-scale colour banding of the rocks is evident from the air but less obvious on the ground although garnet-rich, biotite-poor rocks generally weather to a yellow-brown colour whereas biotite-rich rocks are more commonly grey. There are also a few concordant bands of melanocratic rock, some of basic igneous and others of metasedimentary origin. By far the most common mineral assemblage is potash feldspar, andesine, and quartz, with lesser garnet and biotite, and minor apatite, opaques, zircon, and sphene. Some pelitic gneisses contain up to 15 percent sillimanite, minor plagioclase and opaques, a few grains of spinel, and abundant garnet, biotite, quartz, and potash feldspar. Mafic rocks are typically composed of andesine, quartz, orthopyroxene, biotite, and hornblende. The mineral assemblages of the migmatitic suite as a whole are characteristic of upper amphibolite facies metamorphism, although the absence of cordierite from the pelitic assemblage could be interpreted as evidence of slightly higher than normal metamorphic pressure.

The main rock type (sample 69280230) is a medium-grained granoblastic textured, banded or microbanded garnet-biotite-quartz-feldspar gneiss in which compositional layering is defined by the relative concentration of garnet and biotite into mafic-rich bands and emphasised by the preferred orientation of biotite crystals. There are also some felsic layers composed almost wholly of potash feldspar, but most consist of quartz and plagioclase. Sample 69280230 is composed of about 50 percent andesine plagioclase, 20 percent cloudy cryptoperthitic potash feldspar, 20 percent quartz, and about 5 percent of both garnet and biotite; apatite is a common accessory mineral. Minor alteration of potash feldspar to sericite and clay minerals, and of garnet to chlorite and muscovite, may signify minor retrograde metamorphism.

Variants of this rock type contain lenticular quartz-feldspar augen, and streaks up to 6 cm long and 2 to 3 cm wide. Garnet and biotite are common in selvages adjacent to both the felsic augen and the more felsic layers of the gneiss. Increasing abundance of the felsic aggregates governs a gradation from a basically banded gneiss to more granoblastic textured, medium to coarse-grained rocks consisting of a quartz-feldspar mosaic, with minor biotite and garnet. In these rocks, biotite streaks reveal relict gneissic fabrics and outline minor folds. A typical example (sample 69280233) consists of about 50 percent cryptoperthitic potash feldspar, 25 percent andesine, 20 percent quartz, and about 3 percent each of biotite and garnet and opaques. Biotite-bearing quartz-plagioclase rich bands alternate with garnet-bearing potash-feldspar rich bands to define the compositional layering. Thus in these rocks biotite, which is the only mineral to display any preferred orientation, is mutually exclusive of garnet whereas the two minerals tend to be associated in banded gneisses such as specimen 69280230.

The granoblastic textured rocks grade into nebulous granite gneiss (sample 69280231) with diffuse, irregular compositional variations. Small 'books' of biotite are common, and there are garnet aggregates up to 15 mm size; the coarser rock types also contain feldspar porphyroblasts. Sample 69280231 consists of about 40 percent cryptoperthitic orthoclase, 25 percent andesine, 15 percent quartz, 15 percent garnet, and 5 percent biotite. The orthoclase and plagioclase crystals are xenoblastic, rather larger than those of the other minerals, and somewhat cracked and sericitised. Subidioblastic biotite flakes generally occur either singly or in clusters together with garnet and accessory minerals; they are slightly altered to chlorite and opaques. The garnets are subrounded or irregular and also slightly altered to chlorite clay cracks. Specimen 69280235 is generally similar to 69280231 except that it contains only 1 percent biotite and rather more andesine. The alteration of orthoclase, biotite, and garnet in this rock again is evidence of slight retrograde metamorphism.

Figure I.



To accompany Record 1981/34

AN2/82

Each of the varieties of migmatitic gneiss discussed above, grades into diffuse veins, lenses, and small irregular pods of gneissic granite, although such rocks make up only a small proportion of the migmatitic suite at the Larsemann Hills. Veins of unfoliated, post-tectonic granite are uncommon in the Larsemann Hills, but small-scale ptygmatic veins are ubiquitous and consist of coarse-grained cream or pink quartz-feldspar rock with minor biotite. The presence of the ptygmatic veins and of the gneissic granite bodies is evidence of upper-amphibolite-facies metamorphism with partial melting; the widespread alteration of certain minerals could well have occurred during cooling after the peak of metamorphism.

Concordant dark-coloured bands tens of metres wide and hundreds of metres long are conspicuous among, but constitute only a minor part of, the Larsemann Hills migmatite complex (Fig. 1). The rocks are medium grained biotite-garnet pelitic gneisses, some of which contain sillimanite; cordierite has not been observed. Narrow biotite and garnet-rich bands occur locally within the pelitic rocks, the dark colour of which is due to the abundance (locally, up to 75 percent) of an intergrowth of dark-green spinel and magnetite. This order of abundance of magnetite suggests that these rocks grade towards banded ironstones in composition. The pelitic rocks are characteristically heavily iron-stained because of their high magnetite content, and locally, there are also minor secondary copper stains. Typical of the metapelites is sample 69280238, a coarse-grained, well-foliated, garnetiferous gneiss containing thin bands and streaks of opaque minerals which give the rock a generally dark appearance and emphasise its gneissic foliation. Sample 69280238 is granoblastic-textured and consists of about 40 percent quartz, 40 percent of a magnetite-spinel symplectite, 10 percent potash feldspar, 10 percent garnet, and minor biotite and sillimanite. The quartz grains have lobate outlines, but many are elongated in the foliation plane. Feldspars are crypto-perthitic and limonite stained along cracks; the feldspar crystals are more equidimensional than the quartz crystals. The magnetite-spinel symplectite forms streaks which consist of sieve-like clots and poikiloblasts which enclose fragments of quartz, sillimanite, feldspar, zircon, and rutile. The garnets are irregular-shaped and slightly poikiloblastic.

Sample 69280236 is a banded sillimanite-biotite-garnet gneiss that lacks prominent accumulations of spinel and magnetite. It consists of about 30 percent orthoclase cryptoperthite, 30 percent quartz, 30 percent garnet, 5 percent biotite, 5 percent sillimanite, and minor streaks of spinel-magnetite symplectite; some rare small isolated crystals were tentatively identified as cordierite. The feldspar and quartz crystals have irregular, lobate forms, and together form a granoblastic aggregate. Parallel biotite and sillimanite flakes, elongate feldspar crystals, and streaked-out spinel-magnetite symplectites combine with the uneven distribution of garnet to define the compositional banding and gneissic foliation of the rock. The garnet crystals have irregular shapes, ranging from rounded to elongate, and show conspicuous transverse cracking perpendicular to the foliation; some poikiloblastically enclose small fragments of quartz, biotite, and sillimanite. Biotite is present as generally idioblastic, undeformed, and unaltered flakes; the sillimanite crystals are also idioblastic, and generally rod-shaped.

The mineral assemblages in the metapelites are typical of upper-amphibolite-facies metamorphism although the presence of cryptoperthites and the absence of cordierite suggests granulite facies conditions. Mafic rocks from the Larsemann Hills contain orthopyroxene, but hornblende and biotite are also present. Metamorphic conditions thus were obviously high-grade more or less on the granulite/amphibolite-facies interface.

Intrusive rocks

McLeod (1959) described veins of coarse, massive, red or cream-coloured granite up to 3 m thick from the Larsemann Hills and noted their sharp and straight contacts. The only granitic intrusives seen in the Larsemann Hills locality visited in 1969 are narrow discordant veins, the largest being 1 metre wide and at least 100 metres long and having fine or medium-grained margins, with typically sharp but locally diffuse contacts marked in places by biotite-garnet selvages. Sample 69280237 from this vein consists of a coarse-grained mosaic of pink feldspar, quartz, and biotite with local garnet aggregates; the estimated mineral composition of the sample is 65 percent orthoclase cryptoperthite, 25 percent quartz, 5 percent andesine plagioclase, 5 percent garnet, and minor biotite. The minerals show neither preferred orientation nor significant segregation. The potash feldspar is slightly cracked and displays incipient alteration to clay, quartz crystals are irregular, lobate-shaped and slightly cracked, and the garnets are large and poikiloblastic and contain small quartz and biotite fragments; they are slightly altered to sericite and chlorite along cracks. The few biotite flakes are xenomorphic and occur in patchy concentrations near garnets. Slight cracking in quartz, feldspar, and garnet, undulose extinction in quartz, and minor alteration of garnet could be interpreted as evidence for post-crystallisation low-grade metamorphism.

There are a few garnet-biotite-quartz-feldspar pegmatite lenses, pods, and irregular veins, but in general pegmatites are not common; most are concordant. The largest pegmatite observed extends for 50 metres and is up to 3 metres wide; it contains brown euhedral feldspars up to 10 cm long, and dark-red garnet aggregates 2 cm in diameter.

Bolingen Islands

The Bolingen Islands, 10 km southwest of the Larsemann Hills, are composed of rocks generally similar to those in the Larsemann Hills, although the presence of orthopyroxene in felsic rocks is interpreted as slight evidence of higher metamorphic grade.

In the northern and central islands, medium-grained garnet-orthopyroxene-biotite granulite and gneiss (samples 69280239, 69280195) are intersected by ptygmatic veins, and invaded by irregular bands, lenses, and pods of medium to coarse-grained quartz-feldspar rock (sample 69280240) containing scattered biotite and garnet. These felsic bands and veins range in width from a few centimetres to several metres and are up to hundreds of metres long; some concordant ones display incipient boudin structures.

Sample 69280239, a typical granulite, is a medium grained, granuloblastic-textured, weakly-foliated but strongly-lineated garnet-orthopyroxene-biotite-felsic granulite. It consists of about 60 percent andesine, 20 percent quartz, 10 percent biotite, 5 percent each of garnet and pyroxene, and accessory minerals; the uneven concentration of the mafic minerals defines a crude compositional layering. Andesine crystals are xenoblastic, and some are aligned parallel to the weak foliation;

quartz shows minor cracking and undulose extinction, and biotite is subidioblastic. The orthopyroxene lies within the bronzite-hypersthene compositional range and comprises irregular, somewhat poikiloblastic crystals which are slightly altered along cracks to possible montmorillonite. This mineral assemblage might have resulted from high-grade metamorphism of an intermediate igneous rock or greywacke, but the co-existence of biotite and orthopyroxene suggests that granulite-facies conditions were only just attained.

Interleaved with the orthopyroxene-bearing felsic granulites are rocks which lack orthopyroxene. Specimen 69280195 is a garnet-biotite-quartz-feldspar gneiss composed of about 35 percent cryptoperthitic potash feldspar, 35 percent quartz, 10 percent andesine, 15 percent biotite, and 5 percent garnet. Texturally, it consists of a granoblastic polygonal quartz-feldspar mosaic with scattered subparallel biotite flakes and garnet porphyroblasts. High-grade, possibly granulite-facies metamorphism is indicated by the granoblastic texture and cryptoperthitic feldspar but the abundance of biotite points to conditions intermediate between the amphibolite and granulite facies, with significant P_{H_2O}.

The leucocratic veins and bands which intersect the gneissic complex are further evidence of significant P_{H_2O} and partial melting during metamorphism. A typical sample, 69280240, is a medium-grained, unfoliated, granoblastic textured, biotite-garnet-quartz-feldspar rock which consists of 45 percent orthoclase cryptoperthite and microcline cryptoperthite, 25 percent quartz, 25 percent andesine, and a total of about 5 percent of garnet and biotite. There are no obvious planar structures, and the distribution of mafic minerals is patchy. Many crystals are fractured. In the potash feldspar, orthoclase cryptoperthite shows inversion to microcline and andesine. Garnets are present in clusters of irregular or sub-rounded grains surrounded by biotite and myrnekite or quartz, although small flakes of biotite also occur throughout the rock.

South Bolingen Islands

The metamorphic rocks exposed in the South Bolingen Islands are generally similar in metamorphic grade and mineral content to those described from the Larsemann Hills and northern and central Bolingen Islands, but they lack garnet. Concordant granitic bands 50 cm to 2 m wide with sharp contacts invade the enclosing gneiss.

Sample 69280186 is typical of the metamorphic rocks of the South Bolingen Islands. It is a banded, fine to medium-grained, biotite-orthopyroxene-quartz-feldspar gneiss in which mafic minerals are concentrated in thin discontinuous bands. Aligned biotite flakes and orthopyroxene crystals, together with felsic lenticles in other parts of the rock, define a moderate foliation. The sample consists of about 55 percent andesine, 25 percent quartz, 15 percent orthoclase, 5 percent orthopyroxene, and minor biotite, and has a granoblastic to elongate polygonal texture. The potash feldspar contrasts with that described from other rocks in the northern and central Bolingen Islands because it is not perthitic. Quartz crystals have broadly sutured contacts with surrounding feldspars and show minor undulose extinction and cross fracturing, while the orthopyroxenes are irregular-shaped, commonly elongated, and fractured, and partly altered along the fractures and cleavages to possible montmorillonite. Biotite occurs as tiny isolated flakes.

A range of granitoids occur as concordant veins and lenses within the banded gneiss complex. Some are composed predominantly of grey-white quartz with scattered red orthoclase crystals up to 10 cm long; others, such as sample 69280187, consist mostly of red orthoclase and minor white-plagioclase, but have irregular masses of quartz up to 10 cm long aligned parallel to the axis of the vein outcrop. Both types contain only very minor amounts of biotite. Sample 69280187 is a massive, medium to coarse-grained, granoblastic textured, quartz-feldspar rock with macroscale lineation defined by aligned quartz lenticles. It is composed of 70 percent orthoclase cryptoperthite and microcline, 20 percent quartz, 10 percent albite-oligoclase, and traces of biotite, muscovite, montmorillonite, and carbonate. The quartz lenticles consist of large, elongate, ribbon-like crystals, some more than 1 cm long. These have broadly sutured margins, and most have transverse fractures. The potash feldspar is mostly cryptoperthitic, but some is wholly or partly inverted to microcline, and the plagioclase generally forms discrete layers up to 2 mm thick.

The granite rocks clearly intruded the gneissic country rocks, and their perthitic feldspars indicates high temperature crystallisation. This may be a relict igneous feature but it could signify syntectonic emplacement and crystallisation after partial melting during high grade metamorphism. Inversion to microcline would have taken place at lower temperatures, either during slow cooling or subsequent retrograde metamorphism. As the potash feldspar in the nearby country rocks are apparently not perthitic it would however seem likely that the perthitic feldspars in sample 69280187 are of igneous origin.

Sørstrene Islands

The Sørstrene Islands, 10 km southwest of the Bolingen Islands, consist of similar rocks, but there are no granitic bands and veins. The main rock type is fine to medium-grained, poorly-foliated granular quartz-feldspar gneiss with minor garnet and biotite (sample 69280184). The biotite defines a whispy banding and in places is concentrated into bands a few centimetres wide. A few thin bands of microbanded hornblende-biotite-pyroxene-feldspar gneiss (sample 69280185) occur within the quartzo-feldspathic rocks.

Sample 69280184 is a fine-grained laminated felsic rock which contains dark-red garnet porphyroblasts, and has a strong lineation but a weak foliation; it is composed of about 50 percent andesine, 30 percent orthoclase-microperthite, 15 percent quartz, 5 percent garnet, and minor biotite. The texture is predominantly granoblastic to elongate polygonal with some preferred orientation of elongate mineral grains. Plagioclase tends to form narrow monomineralic layers. Potash feldspar is untwinned; some grains show traces of myrmekite, and finely granular quartz and feldspar are locally concentrated in felsic layers. Quartz forms equant or elongated crystals, some of which show undulose extinction and minor fracturing; garnets are sub-rounded or ovoid porphyroblasts. Biotite flakes are small and irregular, and mainly concentrated in poorly defined pressure shadows around garnet. The mineral assemblage is not diagnostic.

Sample 69280185, a medium-grained, dark-coloured hornblende-biotite-pyroxene-plagioclase gneiss, is typical of the mafic rocks of the area. It is strongly foliated, and streaks and large irregular open aggregates of dark minerals make up about 25 percent of the rock. In thin section the sample is seen to be granoblastic textured and to consist of about 75 percent andesine, 15 percent clinopyroxene, 10 percent biotite, and minor hornblende. Biotite flakes and some flat plagioclase grains define the foliation microstructure. The bulk of the rock (approximately 75 percent) has an equigranular, slightly-sutured polygonal texture; the rest (25 percent) consists of a fine-grained aggregate of a part-mosaic and part-symplectic intergrowth of plagioclase and pyroxene. The clinopyroxene crystals are generally equant, but some are elongated and aligned in the foliation. They generally occur as clusters, commonly in close association with other dark minerals. Biotite forms subidioblastic and xenoblastic flakes, while irregular hornblende grains are patchily distributed, in places being intergrown with biotite, elsewhere with plagioclase and pyroxene, perhaps as a consequence of reaction between hornblende and quartz to form pyroxene and plagioclase being limited by lack of quartz.

The bands of dark minerals outline tight folds and a lineation which pitches 70^{o} east-southeast probably represents an axial plane cleavage/compositional banding intersection. The gradation along strike of some biotite-rich layers into thin, anastamosing seams of probable mylonite suggests that the gneiss has been sheared parallel to its foliation. This impression is strengthened by the outcrop pattern; the rock has been broken by frost action into flaggy slabs, many of which are a metre across but only a few centimetres thick. Nowhere else was this type of weathering seen developed to such a degree, even in well-foliated rocks.

The Sørstrene Islands rocks are somewhat transitional between the Prydz Bay Migmatite and the gneissic rocks to the southwest and show, in comparison to the Bolingen Islands rocks, conspicuously fewer migmatitic features, the lack of granitic rocks being especially noticeable.

Polar Record Glacier area

The rocks exposed in this area also appear to be transitional between the Prydz Bay Migmatite to the northeast, and the Munro Kerr gneiss to the southwest. The presence of orthopyroxene in both felsic and mafic rock types, and of sillimanite and possible cordierite in a metapelite, is consistent with granulite-facies metamorphism. The granitic veining so typical of the Prydz Bay Migmatite is not prominent in the Polar Record Glacier area.

The nunatak 9 km northeast of the Polar Record Glacier is composed of quartzo-feldspathic gneiss with up to 20 percent pearly-grey or pink augen-like potash feldspar porphyroblasts up to 4 cm long together with minor garnet porphyroblasts up to 5 mm across, and biotite. This augen gneiss is medium-grained and well-foliated with a commonly lenticular compositional and grain size microbanding: similar rocks were examined at nunataks on the eastern side of the Polar Record Glacier. Parts of the augen gneiss contain schlieren and veinlets of fine to medium-grained pink feldspar and quartz; these occur with, and are generally similar in size to, or a little larger than, the feldspar augen. In addition there are scattered lenses composed of minor biotite, quartz, and feldspar, as well as parts of the gneiss which lack augen and therefore resemble the biotite-garnet-quartz-feldspar gneiss mapped as 'Munro Kerr Gneiss' further west.

Sample 69280182, typical of the augen gneiss, consists of about 40 percent quartz, 30 percent orthoclase perthite, 10 percent oligoclase, 5 percent each of garnet, biotite, and sillimanite and minor amounts of clinopyroxene, cordierite, chlorite, white mica, spinel, and zircon. The rock matrix is essentially a granoblastic to irregular mosaic of quartz, feldspar, and biotite. Some feldspar porphyroblasts show signs of having been granulated and recrystallised, and trails of biotite flakes are draped around some as they are around some garnet porphyroblasts. The garnets contain generally-curved strings of sillimanite and flakes of deep-brown biotite, and are partly replaced along cracks by paler-brown biotite and white mica.

Sample 69280183 was collected from another part of the nunatak where the felsic gneiss includes thin mafic bands and thicker (up to 2 m thick) bands of biotite-pyroxene-feldspar granulite. The sample straddles the gradational contact between the felsic gneiss and a band of biotite-pyroxene-feldspar granulite. The granulite consists of about 65 percent andesine/labradorite, 25 percent orthopyroxene, and 5 percent each of opaques and biotite. It has a gradational contact over 0.5 mm with felsic gneiss which consists of about 35 percent andesine/labradorite, 35 percent quartz, 25 percent garnet, and 5 percent opaques and minor biotite, orthopyroxene, and clinopyroxene. This felsic gneiss thus bears little resemblance in composition to specimen 69280182. The garnets in the felsic gneiss contain inclusions of quartz, red-brown biotite, and yellowish biotite, and the hypersthene in both parts of 69280183 is partly altered to biotite.

Metamorphic conditions at this locality were clearly high-grade, and the occurrence of augen gneiss suggests strong concurrent deformation. There are some signs, such as minor alteration of hypersthene to biotite, of possible later retrograde metamorphism. The persistence of shearing stress after the peak of metamorphism is indicated by the curved strings of sillimanite inclusions in garnet crystals in sample 69280182; these are interpreted as evidence of post-crystallisation mechanical rotation of garnets. Partly-annealed granulation textures in some minerals further indicates some late stage crystallisation.

SOUTHWEST PRYDZ BAY AND OUTCROPS ALONG THE EASTERN EDGE OF THE AMERY ICE SHELF

The gneissic rocks found in these areas are grouped together into the Munro Kerr Gneiss, a name derived from the Munro Kerr Mountains ($74^{\circ}15'$E; $69^{\circ}50'$S) along the southern coast of Prydz Bay. Typical exposures were examined at Mount Caroline Mikkelsen ($74^{\circ}24'$E; $69^{\circ}45'$S) and the islands to the north of it. Rocks near the Polarforschung Glacier, and in the Statler, Mistichelli, McKaskle, and north Reinbolt Hills and at Rubeli Bluff are also assigned to the Munro Kerr Gneiss, which is intruded by early Palaeozoic granitoids at Landing Bluff and near the Polarforschung Glacier. A detailed description of fieldwork at Rubeli Bluff is given on page 29.

The Munro Kerr Gneiss comprises interbanded varieties of quartz-feldspar (felsic) gneiss and mafic pyroxene feldspar gneiss. Granitic veins are generally less abundant than in the New Year migmatite to the north. Banding is typically on a large scale; most bands are several tens of metres wide, but some are as narrow as a metre. Microbanding on scales between a couple of millimetres and a few centimetres is discernible within this large-scale banding, particularly in the mafic rock types. On the regional scale the proportion of mafic minerals in the Munro Kerr Gneiss differs considerably from place to place. Mafic-rich bands are relatively more common in outcrops on the south side of Prydz Bay where they constitute between 25 and 35 percent of total exposure. They are less common in the Statler Hills and exposures further south; the lighter-coloured rock bands in the Statler Hills contain up to 20 percent of mafic minerals, mostly biotite, but the average mafic content in light bands decreases southwards so that those exposed in the nunataks southeast of Jennings Promontory are quartz-feldspar gneiss with minor biotite and garnet. The proportion of mafic minerals in felsic gneisses at Rubeli Bluff is higher again.

The banding in the Munro Kerr Gneiss is emphasised by textural irregularities, especially in grain size (which ranges from medium to coarse-grained) and foliation development. Such irregularities are especially marked in rocks from the Mistichelli Hills and the nunataks southeast of Jennings Promontory where the irregularities may be due to incipient migmatisation. At these localities some of the coarser discordant felsic veins closely resemble nearby coarse-grained felsic gneisses in texture and mineral composition, and may be their mobilised equivalents.

Although some gneisses, notably coarse-grained felsic types, are massive and locally granitoid-textured, most have a distinct, and some a pronounced, foliation defined by the alignment of biotite flakes, elongate feldspar crystals, and small lenticular felsic aggregates. A combination of these features serves to give many rocks along the eastern flanks of the Amery Ice Shelf, a small scale, discontinuous, lenticular banding. Felsic aggregates in the Munro Kerr Gneiss outcrops along the southern side of Prydz Bay are spindle-shaped rather than lenticular, and impart a poor to moderate lineation to the rocks. They could be interpreted as evidence of more intense deformation in that area.

The most abundant rocks in the Munro Kerr Gneiss are biotite-quartz-feldspar rocks which commonly contain garnet. The proportions of the constituent minerals differ markedly from place to place: for example, quartz is either less abundant than or about equal to feldspar in most of the Munro Kerr Gneiss but constitutes up to 90 percent of a few quarzite bands in exposures on the south side of Prydz Bay and the biotite content ranges from a few rare grains in some rocks to 25 percent in others. Garnet makes up 20 percent of some rocks and exceptionally, in some metasediments, as much as 80 percent of total composition. Garnet is not common along the southern side of Prydz Bay, where it occurs only as small scattered grains, but, in rocks at Rubeli Bluff, the garnet forms abundant porphyroblasts up to 1 cm across. Pyroxene is locally a minor constituent, notably at Rubeli Bluff. In general there is a positive correlation between the garnet and biotite contents of the felsic rocks of the Munro Kerr Gneiss.

The pyroxene-feldspar gneiss or more-mafic component of the Munro Kerr Gneiss mostly consists of fine to medium-grained rocks banded on a generally smaller scale (less than 10 metres) than their more-felsic counterparts. Many of the finer-grained types have a uniform granular texture and are massive, apart from a limited microbanding. By contrast, most of the coarser rocks, especially those that contain biotite, are foliated.

The pyroxene-feldspar gneiss group includes a wide range of rock types, some of which contain only pyroxene and feldspar in various proportions, with perhaps minor opaques. Biotite is a common constituent and, in exceptional types, forms as much as 50 percent of the whole rock. Certain biotite-bearing mafic gneisses also contain minor amounts of quartz, and there is a range of rock types between this biotite-quartz-pyroxene-feldspar gneiss and the felsic, pyroxene-bearing, biotite-quartz-feldspar gneiss.

The Munro Kerr Gneiss contains several varieties of felsic vein rocks although these are much less abundant than in nearby migmatitic rocks (e.g. the Prydz Bay Migmatite). The felsic veins are thought to have resulted from the same metamorphic episode in which the gneisses themselves were formed, but may possibly be coeval with the discordant granitoids that intrude the Munro Kerr Gneiss at Landing Bluff and near the Polarforschung Glacier. These granitoids are of early Palaeozoic age while the gneisses are thought to be of roughly the same age as the Prydz Bay Migmatite, about 1100 m.y.

In exposures on the southern side of Prydz Bay, the Munro Kerr Gneiss is discordantly intersected by both coarse-grained quartz-feldspar veins, mostly 10 to 20 cm but exceptionally up to 1 m thick, and less commonly very coarse-grained biotite-bearing quartz-feldspar pegmatites generally less than 50 cm thick. Some of the latter are regular in width and trend, others are irregular.

Felsic veins are probably more abundant in exposures along the eastern side of the Amery Ice Shelf where several varieties were examined. Veins of medium-grained biotite granite and finer-grained quartzo-feldspathic rock in the southern and central Mistichelli Hills are also both regular in width and direction, and irregular. They are up to 50 cm thick, locally garnet-bearing, and in some places concordant to the gneisses and in other places, discordant. At one locality, thin (less than 5 cm) quartz-rich felsic veins grade into the enclosing gneiss. Some discordant veins in the central Mistichelli Hills have fingerlike apophyses which concordantly intrude the banded biotite-quartz-feldspar gneiss country rock. Coarse-grained biotite-bearing pegmatites were also seen in the Amery Ice Shelf exposures as patches or veins less than 25 cm thick, and subconcordant aplite veins up to 50 cm thick were mapped in the central Statler Hills. Some of the quartzo-feldspathic veins in the Munro Kerr Gneiss not unexpectedly resemble bands in the gneiss and are believed to be derived by partial melting of the gneiss.

The general trend of the Munro Kerr Gneiss is east-west and dips range from 20° to vertical. Very tight folding is best displayed in banded pyroxene-feldspar gneiss exposed along the southern side of Prydz Bay. There, fold axes are almost horizontal and fold amplitudes are probably of the order of a few metres; horizontal lineation in nearby biotite-garnet-quartz-feldspar gneiss probably reflects this fold geometry. In structures exposed on Strover Peak (69°43'S, 074°07'E) certain fold apices are emphasised by felsic veins 2 to 3 mm wide. Further east, in outcrops immediately east of the Polar Record Glacier, larger-scale, more open folds are exposed, dips again range from 20° to near vertical, and lineation pitches 20° east-northeast. Large scale tight folding is well displayed in cliff sections on the west side of Rubeli Bluff and to a lesser degree on Maris Nunatak.

Evidence of small-scale shearing of the Munro Kerr Gneiss is widespread. On Strover Peak for example, a mylonite zone composed of a network of pseudotachylite veins trends 060°; a similar zone on Holder Peak trends 110° and is probably associated with a local fault. At Holder Peak the lenticular foliation and general streaked-out appearance of much of the biotite-garnet-quartz-feldspar gneiss is interpreted as evidence of possible recrystallisation under stress. On the larger scale, there seems to be little manifestation in outcrops of the Munro Kerr Gneiss of the large scale faults which some authors believe must bound the structure now occupied by the Lambert Glacier and Amery Ice Shelf and postulated by Wellman & Tingey (1976).

The metamorphic conditions prevailing during the formation of the Munro Kerr Gneiss were clearly high-grade and locally caused partial melting. Some mafic mineral assemblages containing two pyroxenes could be interpreted as evidence of granulite-facies metamorphism, but the widespread presence of hydrous minerals such as biotite and hornblende indicates that the characteristically anhydrous conditions of granulite-facies metamorphism did not prevail.

Rubeli Bluff

Rubeli Bluff is a large flat-topped nunatak on the eastern side of the Amery Ice Shelf, 95 km south-southwest of Landing Bluff and 17 km east of Gillock Island. It measures 11 km from north to south, and is 6 km wide.

The central part of the bluff is a steep-sided plateau rising more than 100 metres above the nearby ice surface, but three large isolated hills occur in the northern part where relief is greater. The larger of two major east-west valleys forms a broad U-shaped depression south of a survey station, which was established towards the northern end of the plateau.

The central plateau has few outcrops: good exposures are restricted to the cliffs and are consequently difficult to examine. Such exposures as there are on the plateau consist mostly of frost-shattered boulders which form low rises above the general level of the felsenmeer. Frost-shattering has dismembered the original outcrop but there has been little movement of material and bedrock compositional layering is still visible. Exposures are better at the north and south ends of Rubeli Bluff.

Alternating light and dark-coloured gneisses are the most common rocks north of the major valley and around the survey station. On the cliffs near the survey station, the main rock type is medium-grained, brown, quartz-feldspar gneiss with irregular amounts of biotite and pyroxene. Banding a few metres wide results from different proportions of ferromagnesian minerals; overall, the gneiss contains a total of 20 to 30 percent mafic minerals, and has a granular texture. An ill-defined foliation is imparted by the alignment of biotite flakes and flattened quartz lenticles. Quartz and pegmatite veins are not common, but where present they are either concordant or subconcordant.

More coarsely-banded gneisses are exposed north of the survey station in cliffs on the west side of Rubeli Bluff. The large scale banding, which is on a scale of tens of metres, is due to the alternation of dark-coloured pyroxene gneiss (sample 69280213) with the more abundant coarser-grained light yellow-brown quartz-feldspar gneiss, which contains irregular but minor amounts of pyroxene, biotite, and garnet. The main rock type (specimen 69280214), a pyroxene-biotite-quartz-feldspar gneiss, is a medium-grained, even-textured rock with a granular fabric, and its outcrops have a characteristically flaggy appearance. Hand specimens are poorly foliated and have a speckled appearance because of the contrast between the granular lighter-brown-coloured feldspars and the dark pyroxenes; on fresh surfaces, quartz grains appear either blue or black. Flattened blue-grey quartz lenticles define what foliation there is. From aerial observations, similar light-brown felsic gneisses also make up between 30 and 40 percent of the central cliff faces of Rubeli Bluff.

This general pattern of large-scale alternation between light and dark-coloured gneisses continues to the northern end of Rubeli Bluff but there the felsic gneisses are commonly garnetiferous. There are also minor bands of garnet-biotite gneiss. Furthermore, compositional micro-banding on scales between a few millimetres and several centimetres is more pronounced in individual rock units in this area, especially in the garnet-rich horizons.

Large-scale banding was also seen in the three isolated hills at the northern end of Rubeli Bluff but only one locality was visited. There, irregularly-microbanded biotite-quartz-feldspar gneiss is invaded by irregular quartz and pegmatite veins up to 1 metre wide. Aerial inspection showed that such veins were quite abundant in the northern part of Rubeli Bluff; they may reflect either a more migmatitic character in the country rock - this was not particularly evident at the locality visited - or be due to post-metamorphic intrusives related, for example, to the Landing Bluff Adamellite (see p. 38).

Garnet-bearing gneisses are also exposed at a major outcrop in the north central part of Rubeli Bluff. They are medium to coarse-grained quartz-feldspar rocks with minor biotite and pyroxene and garnet porphyroblasts up to 1 cm diameter. Quartz grains are blue and commonly lenticular. Rare concordant dark-coloured biotite-pyroxene gneiss lenses up to 30 cm long have sharp contacts with the adjacent felsic gneiss. Brown feldspar and dark quartz grains emphasise the general dark appearance of the lenses, which may represent either minor variants of an original sedimentary pile or be boudinaged relics of mafic intrusives or melanosomes left by the local extraction of felsic minerals during partial melting.

More garnetiferous rocks are also exposed on the south flank of the east-west valley to the south of the survey station. They are irregularly microbanded at a scale of a few millimetres, well-jointed, and have a wavy foliation. They are medium-grained, and contain pink garnets, minor biotite, and pyroxene in addition to felsic minerals (samples 69280211 & 69280212). Further south, porphyroblastic coarser-grained granular biotite-garnet-pyroxene-quartz-feldspar augen gneiss grades into brown speckled pyroxene-biotite-quartz-feldspar rocks which resemble some of the coarser-grained pyroxene-bearing gneisses near the survey station, but contain green-brown feldspar porphyroblasts up to 2.5 cm long. Similar rocks, containing lenses of finer-grained pyroxene gneiss up to several metres long, are also exposed in cliffs near the southern end of Rubeli Bluff; aerial observations indicate that such rocks make up most of the southern part of Rubeli Bluff.

The generally strongly-jointed rocks at Rubeli Bluff appear to have a simple structure with a predominance of easterly structural trends, except in the north and south where northeasterly trends are more common. Dips are from 40^{o} to near vertical and towards the south. Measured lineations indicate folds plunging to the south-southwest at about 40^{o}. The two major east-west valleys on Rubeli Bluff appear to be controlled by the dominant structural trends although the garnet gneisses observed in their floors or on their flanks may have been rather more susceptible to erosion than the garnet-poor rocks in other parts of Rubeli Bluff. The classic U-shaped profile of the southern valley, which is continuous across the Bluff, is clear evidence that the present landscape of Rubeli Bluff has been modified by glacial erosion; whether or not this landscape is wholly attributable to glacial erosion is debatable.

Much of Rubeli Bluff is covered with loose rock debris or felsenmeer on which patterned ground is poorly developed in the guise of hummocks about 2 m across and 0-5 m high within polygons up to 25 m across, and bounded by cracks as deep as 0.5 m. The central hummocks are composed of larger (up to 15 cm) rocks than the marginal parts of the polygons. Patterned ground is best developed on low lying areas of Rubeli Bluff which receive appreciable quantities of melt-water during the summer; this appears to assist the formation of well-sorted stone polygons.

INTRUSIVE BODIES IN THE MUNRO KERR GNEISS

Jennings Promontory area

Charnockitic rocks at Jennings Promontory ($71^{o}31'$E; $70^{o}10'$S) and nearby Branstetter Rocks and Thil Island are designated the 'Jennings Charnockite'. According to Subramanian (1959), the term charnockite denotes a hypersthene-quartz-feldspar rock characterised by green-blue feldspars and grey-blue quartz and in which potash feldspars, commonly microperthitic, predominate over plagioclase. The equivalent rock in which plagioclase predominates over potash feldspar is 'enderbite' (Tilley, 1936).

The typical Jennings Charnockite is a dark-coloured massive rock containing anhedral potash-feldspar megacrysts up to 8 cm long in a matrix composed of quartz and feldspar with minor pyroxene amphibole, and biotite. Locally, there are large ophitic hornblende crystals up to 10 cm across; similar-sized plates of biotite are less common. Alignment of potash-feldspar megacrysts produces a foliation which trends 010° and dips 80°E near the north end of Jennings Promontory. Thin sections of coarse-grained inequigranular rocks such as the Jennings Charnockite may give rise to misleading estimates of the mineral composition because the thin sections do not adequately sample megacryst phases. Thus, thin sections of specimens 4566 and 69280162 reveal an estimated mineral assemblage of about 40 percent andesine, 25 percent quartz, 20 percent orthoclase perthite, 10 percent orthopyroxene, 5 percent hornblende and minor opaques, biotite, apatite, and zircon. In this assemblage, which, if representative, would indicate that the rocks should be classified as enderbites, the proportion of potash feldspar in the rock as seen in outcrop is seriously underestimated because the thin sections did not intersect sufficient potash-feldspar megacrysts.

The texture revealed in thin section is granular, and possible relics of an earlier hypidiomorphic granular igneous texture may be some broadly rectangular patches of feldspar and local concentrations of dark minerals, minor phases, and quartz into almost monomineralic patches. The plagioclase is rarely antiperthitic and displays albite, carlsbad, and possibly pericline twins; in specimen 4566 it is also zoned. Orthopyroxene commonly is intimately associated with, and appears to have been partly replaced by, brown-green hornblende, but some grains are contained within a poorly defined symplectite with plagioclase, whereas some of the larger ones contain short parallel opaque lamellae.

The Jennings Charnockite also contains scattered randomly-oriented lenses of fine to medium-grained brown pyroxene-quartz-feldspar granulite up to a metre wide; it is intersected by veins and small masses a metre or two across of pink coarse-grained pegmatite composed of perthite, greenish plagioclase, and quartz with smaller amounts of biotite, dark-red garnet, and hornblende. In addition, there is a fine to medium-grained pyroxene-bearing aplite dyke about 2 m wide at the south end of Jennings Promontory. It trends about 160 and contains mafic minerals in sparse irregular clots up to a centimetre across. Specimen 69280161 has a granuloblastic texture with slight preferred-orientation of mineral grains; its mineral assemblage is about 40 percent orthoclase perthite, 40 percent calcic andesine, 10 percent orthopyroxene, slightly less quartz, and minor brown-green hornblende, biotite, zircon, opaques, and apatite. The aplite thus contains much less quartz and much more plagioclase than the typical charnockite as defined by Subramanian (1959). The presence of orthopyroxene in the aplite may indicate that it crystallised during the late stages of the granulite-facies metamorphism which led to the termination of the whole Jennings Charnockite mass. All constituent minerals are cracked at right angles to the direction of their preferred orientation but this is virtually the only evidence for post-crystallisation deformation. The feldspars commonly contain round or long and curved inclusions of quartz, and biotite is locally symplectically intergrown with quartz.

Near the north end of Jennings Promontory where the charnockite has an indistinct foliation, shear zones are common and are filled either with thin veins of feldspar, quartz, red garnet, and biotite or with quartz veins. The shears are aligned in many directions but a northerly-trend is predominant with dips about 10^{o}E.

The origin of this charnockite, like that of others, is debatable but its orthopyroxene content and perthitic feldspars clearly signify crystallisation under conditions that would appropriately be described as high-grade metamorphic. Charnockites, and especially massive rocks like the Jennings Charnockite, typically display magmatic contact features yet have high-grade metamorphic mineral assemblages and metamorphic fabrics. Whether or not such rocks are igneous or metamorphic is really quite irrelevant; suffice to say that they crystallised under high-grade, probably granulite-facies, conditions. Spry considers (written communication, 1969) the Jennings Charnockite to be a granitoid intrusion emplaced before or during the granulite-facies metamorphism that gave rise to the Munro Kerr Gneiss; alternatively, it may have formed by palingenesis such as that postulated by Sheraton (in press) for the Mawson Charnockite.

The only available isotopic age date, 420 m.y. (Ravich & Krylov, 1964), is of little help; it was obtained by the potassium-argon total-rock method, and so could easily denote the imprint of the event recorded also in the Larsemann Hills - the ages 540 m.y. and 420 m.y. listed by Ravich & Krylov (1964) - which possibly was related to the emplacement of the Landing Bluff Adamellite. The date is probably quite meaningless since the K-Ar total-rock system in coarsely-crystalline rocks is especially susceptible to loss of radiogenic argon during metamorphism or weathering. It is thought likely that the Jennings Charnockite was produced by the 1000 m.y. $\pm$ metamorphism that formed high-grade metamorphic rocks over wide areas of East Antarctica including the Mawson Coast and Prince Charles Mountains.

Polarforschung Glacier area

Migmatic rocks in four outcrops near the Polarforschung Glacier are intruded by a range of granitoid types which are collectively assigned to the Polarforschung Granite. Only two outcrops, the Meknattane Nunatak and the Vestknatten Nunatak, were visited; the others were viewed from the air.

The lower hummocky southern part of the Meknattane Nunatak consists of thermally-metamorphosed banded migmatitic rocks whereas the high northern part is composed of granitoid. The mostly medium-grained migmatitic rocks appear to have a general 070^{o} trend and include bands of coarse-grained biotite-quartz-feldspar gneiss with subordinate mafic pyroxene-feldspar gneiss: quartz-feldspar veins are abundant, especially in the felsic gneiss. The distribution of biotite in these migmatites is far from uniform and governs the compositional layering on scales between a few millimetres and a metre; smaller-scale banding is discernible in the thicker macro-bands. The layers are commonly contorted and discontinuous and many are truncated by quartz-feldspar veins. Scattered bands of equigranular, medium-grained, massive or foliated mafic pyroxene-feldspar gneiss are mostly less than 1 metre thick and have sharp contacts with the surrounding felsic gneiss.

The grain size, direction, and thickness of the quartz-feldspar veins are all very irregular. Some veins are locally concordant and elsewhere discordant, others are discordant but have apophyses concordant with the host rock. The veins are up to 2 metres thick and consist essentially of massive white quartz-feldspar rock although there are some biotite-bearing varieties. Some of these veins also contain clusters of pink garnet up to 1 centimetre across in association with the biotite, the two minerals comprising up to 15 percent of the rock.

The contact between these migmatitic rocks (which are tentatively assigned to the Prydz Bay Migmatite) and the Polarforschung Granite is exposed near the base of the cliffs at the southeastern side of the high northern part of Meknattane Nunatak. It is knife-edged and, over a distance of at least 50 metres, appears to strike at about 110° and dip 20°N. The granite is thus regarded as intrusive and post metamorphic. At the contact, a 7-cm thick zone of medium-grained granite has well-defined contacts with both the country rock and the granitoid mass. Locally, what appears to be a fault gouge at the granodiorite country rock contact is a few millimetres thick and very fine-grained and constitutes the only known evidence for faulting at the intrusive margin.

Within a metre or so of the contact the Polarforschung Granite is a foliated medium-grained granite with scattered feldspar phenocrysts; specimen 69280178 consists of about 40 percent quartz, 40 percent perthite (orthoclase and microcline), 1-15 percent andesine, 1-2 percent biotite, 1-2 percent chlorite/iddingsite, and small amounts of allanite, opaques, amphibole, orthopyroxene, clinopyroxene, and zircon. Elongate mineral grains and quartz ribbons define the weak foliation, and the microcline crystals contain rounded quartz inclusions. The biotite also contains numerous inclusions and occurs with intergranular vermiform grains, some of them more than 1 mm long, of a yellow-brown mineral which is tentatively identified as allanite. The presence of minor but relatively unaltered grains of orthopyroxene and clinopyroxene is interpreted as marginal contamination of the granite.

Such contamination is also possibly indicated by the presence of ill-defined biotite streaks in the granite within a couple of metres of its contact. These make an angle of about 45° to the contact and are concave upwards, that is, away from the contact. Such an alignment might have resulted from the effects of boundary drag in a moving magma mass. If this was the case the direction of magma movement was from west to east.

Away from the contact, the proportion of feldspar phenocrysts in the Polarforschung Granite increases as does the total potash feldspar content. At the type locality, some two hundred metres from the contact in the northern part of Meknattane Nunatak, the feldspar phenocrysts have a preferred orientation perhaps because of the proximity of the contact. Specimen 69280179 from this locality is a porphyritic granitoid which consists of about 45 percent orthoclase and microcline perthite, 35 percent quartz, 10 percent oligoclase, 5 percent biotite, 5 percent actinolite, minor apatite and opaques, and traces of white mica, zircon, and allanite. The texture of this rock is not typically granitoid, and much of the quartz appears to have recrystallised. Some of the biotite is probably primary but other grains are intermixed with actinolite around a nucleus of opaque minerals. These may be the relics of former pyroxene crystals. Most of the actinolite crystals penetrate quartz crystals which are therefore presumed to have crystallised later.

Vestknatten Nunatak consists of two varieties of granitoid. One, a massive light-coloured adamellite, is very like the Landing Bluff Adamellite in outward appearances; specimen 69280107 consists of pink or creamy-coloured feldspar phenocrysts set in a medium-grained matrix of quartz, perthitic potash feldspar, saussuritised plagioclase, minor biotite and hornblende, and accessory opaques, apatite, zircon, and possible allanite. The other granitoid, which is the more abundant, has a similar texture to the light-coloured type but is dark brown in colour. Specimen 69280108 consists of about 35 percent of andesine (An_{38}), 30 percent perthitic potash feldspar including microcline, 20 percent quartz, 10 percent biotite, and about 5 percent amphibole and possible pyroxene and minor clay, opaques, muscovite, apatite, zircon, and carbonate (the minerals identified as possible pyroxene and clay could be metamict allanite). The dark colour of the rock is due to green/grey-coloured feldspars and is reminiscent of the Jennings Charnockite. The possible presence of orthopyroxene supports this comparison but the mineral is now much-altered, perhaps by later metamorphism. Alternatively, the so-called granitoid could be heavily contaminated with country rock gneisses, of which the altered pyroxenes are relict xenoliths or xenocrysts.

The two varieties of granitoid appear to have a one-metre wide, gradational contact in the one common exposure on the face of a near-horizontal rock slab. This contact supports the notion that the darker rock could be a contaminated equivalent of the lighter one. The darker rock appears to make up most of Vestknatten Nunatak and a typical gravel patch on the eastern side appears to consist almost entirely of brown feldspars derived by weathering of the granite.

The granitoids at Vestknatten Nunatak are intruded by apparently randomly-oriented aplite dykes up to 50 cm thick. There is also a 5-cm wide dyke of medium-grained biotite-granite and a rounded half-metre wide xenolith of medium to coarse-grained biotite granite. The 1 to 2-cm wide gradational contact between the xenolith and the host rock, pinkish grey granite, is marked by a biotite selvage.

The nunatak southwest of Vestknatten Nunatak and on the western edge of the Polarforschung Glacier was not visited but appears to consist of light-coloured granitic rocks cut by thin felsic dykes. Dark patches may be xenoliths of the darker granitoid from Vestknatten Nunatak.

The Polarforschung Granite resembles the Landing Bluff Adamellite exposed 50 to 60 km to the west but differs from it in having a significant component of country-rock contaminant. This is not altogether surprising since the specimens examined were from relatively close to the contact whereas no contact was seen at Landing Bluff. Both the Polarforschung Granite and the Landing Bluff Adamellite are clearly post-tectonic and both are thought to be about the same age. At Landing Bluff this age has been determined by Rb-Sr methods to be about 500 m.y.

Landing Bluff area and south to Gillock Island

In this area the Munro Kerr Gneiss is intruded by coarse-grained porphyritic biotite adamellite termed the Landing Bluff Adamellite. Landing Bluff (73°43'E; 69°45'S), the type locality, and nearby islands and coastal outcrops are composed entirely of the adamellite, which is almost certainly continuous in this area. The intrusive may extend to Collins Nunatak although the granitoid specimen from there is a granite. Continuity 90 km south to Corry Rocks, where the exposed granitoid is also a granite, is perhaps less likely. Contacts with the intruded country rocks were not found at any of the exposures visited but the granitoids are all considered to be post tectonic, and are grouped together on this basis. Rb-Sr geochronological studies of whole-rock specimens show the age of the Landing Bluff Adamellite to be 504 ± 17 m.y. with an initial $^{87}Sr/^{86}Sr$ ratio of 0.7184. The Landing Bluff Adamellite is thus a manifestation of the widespread early Palaeozoic thermal-metamorphic episode that produced anorogenic granitoids in the southern Prince Charles Mountains, reset Rb-Sr isotopic systems in biotites in many rocks in the Prince Charles Mountains-Mawson area (Tingey, in press), and had various effects over wider parts of East Antarctica. This episode is apparently equivalent to the Ross Orogeny in the Transantarctic Mountains, and the Pan African event over wide areas of Gondwanaland.

The typical Landing Bluff Adamellite is a massive pinkish-grey rock consisting of pale pink or fawn-coloured blocky perthite phenocrysts in a coarse-grained matrix of quartz, plagioclase, and biotite. The phenocrysts, most of which are about 5 cm long, form about 50 to 60 percent of the rock. Some contain concentric zones of small biotite flakes about half way between their centres and their edges; these zones may mark the boundary between an original feldspar core and a later-growth outer-shell although there is no striking optical discontinuity or zoning between the two parts.

Samples 69280140 and 69280145 are representative of the Landing Bluff Adamellite, and consist of about 40 percent perthitic microcline, 30 percent oligoclase, 25 percent quartz, 5 percent biotite, and minor hornblende, sphene, opaques, zircon, apatite, and allanite. The thin sections did not adequately sample the phenocryst phase.

The microcline grains observed in thin section commonly contain inclusions of quartz, biotite, and plagioclase, and some have fringes or inclusions of myrmekite; the perthitic texture is of the ribbon type (Spry, 1969, p. 182). Plagioclase crystals have combined carlsbad and albite twinning, and a few grains are zoned; quartz crystals commonly form aggregates several millimetres across and the red-brown biotite contains inclusions of apatite, metamict zircon, opaques, and allanite. In sample 69280145, sphene fringes opaque grains that are presumed to be ilmenite, whereas in sample 69280140, quartz rims some of the biotite and occurs along the cleavage traces of the biotite. Hornblende is described as being associated with, and partly replaced by, biotite in both samples; in sample 69280140, it is a blue-green type, and in sample 69280145, a brown-green type. Minor hornblende may be a xenocryst phase derived from the country rock that the adamellite intruded or from which it derived. The marked difference in observed types and the alteration, could be interpreted as evidence in support of this idea, which suggests that the Landing Bluff adamellite should be classed as an 'I'-type granitoid, derived by melting of igneous rocks deep in the crust.

Locally, the rocks classed as the Landing Bluff Adamellite contain patches which are less porphyritic than the typical rock; phenocrysts comprise less than 50 percent of these patches, and biotite is relatively more abundant, in some places accounting for up to 15 percent of the rock. Such patches are irregularly distributed, although at one place on Nickols Island a vertical band of the more equigranular rock is 1 metre wide at its base and widens to 2 metres at a height of 5 metres. Near its margins, this band contains abundant biotite and few feldspar phenocrysts, but the biotite content decreases and phenocrysts become more common towards the centre so that the central part of the band is of adamellite composition, contains little biotite, and has numerous perthite phenocrysts, most of them rather larger than those seen in the main Landing Bluff Adamellite.

The vertical rock feature just described from Nickols Island has sharp contacts with the surrounding adamellite, a feature which, in concert with the textural variations described above, indicates a possible intrusive origin. Similar rocks on one of the southern outcrops of Landing Bluff grade laterally into the typical porphyritic adamellite over about 1 or 2 cm with the rocks on either side of the junction displaying no apparent changes away from the junction. Such a contact, which is quite sharp and therefore possibly of intrusive origin, could develop when a residual phase of the adamellite melt intrudes the still hot but partly crystalline main mass of porphyritic adamellite; it could also be due to folding of the still-plastic adamellite mass.

The more equigranular patches within the adamellite are composed (samples 69280135 & 69280139) of about 40 percent oligoclase, 30 percent quartz, 25 percent potent feldspar, 5 percent biotite, and minor opaques, zircon, allanite, and apatite. The lesser abundance of potash-feldspar phenocrysts as compared to the typical adamellite is thus reflected in the mineral assemblage, which is strictly of granodiorite type. In the example described from Nickols Island, the more porphyritic rock in the centre of the non-porphyritic rock body could represent a portion of the main rock mass caught up in the late-stage magma.

The granitoids exposed at Collins Nunatak and Corry Rocks are granites rather than adamellites. The granitoid at Collins Nunatak has about 65 percent microcline and about 10 percent oligoclase, whereas the granitoid at Corry Rocks has 50 percent microcline and 15 percent oligoclase. The remaining 30 percent or so of these rocks comprises about 20 percent quartz, 5 percent biotite, and 1 percent hornblende. In sample 69280154 from Corry Rocks, the biotite and hornblende are clustered together within a mosaic of quartz crystals. The biotite is partly replaced by white mica and clinozoisite, and some of the hornblende is partly replaced by biotite and a paler variety of hornblende. Aggregation of the mafic minerals is less obvious in the Collins Nunatak sample (69280171) but the same minor alteration features are evident; the Collins Nunatak contains plagioclase of composition An_{15}, somewhat more sodic than that in other samples of the Landing Bluff Adamellite.

The aggregations of mafic minerals in the Collins Nunatak and Corry Rocks granitoids resemble those described from the type Landing Bluff Adamellite and are considered to be altered xenocrysts incorporated into the rock either from the intruded country rocks or from the igneous substatum from which the granitoids were derived. Thus the Collins Nunataks and Corry Rocks granitoids can, like the Landing Bluff Adamellite in the type area, be classed as 'I'-type granitoids.

This classification is supported by the occurrence in the adamellite, particularly at Landing Bluff, Nickols Island, and Sansom Island, of scattered basic segregations and xenoliths of massive, medium to coarse-grained hornblende-biotite granodiorite. The granodiorite xenoliths are mostly lenticular, aligned NNE on Nickols Island and about NW or WNW elsewhere; the largest one observed was 5 m wide and 20 m long, the smallest less than a metre long. Contacts with the surrounding adamellite are generally sharp. Some xenoliths are equigranular, others contain scattered feldspar phenocrysts up to 2 cm long; most contain up to 20 percent of dark minerals in aggregates about 2 or 3 cm wide. A few grains of purple fluorite were seen in one xenolith on Nickols Island. The xenoliths are composed (samples 69280131 & 69280132) of about 45 percent andesine (An_{40}), 20 percent quartz, 15 percent perthitic microcline, 15 percent biotite, 5 percent hornblende, and minor sphene, apatite, zircon, and opaques, a composition similar to that of the equigranular patches in the adamellite from Nickols Island (see p. 40). They may have a similar late-stage origin but appear to be more like xenoliths derived from an igneous substatum; a further (faint) possibility is that liquid immiscibility in the magma chamber has controlled their production. This possibility has not been investigated.

The basic segregations within the adamellite are much less common than the xenoliths but a similar origin is thought likely. They are black, medium-grained, and generally less than 50 cm wide but up to 20 m long; they consist essentially of biotite and hornblende. There are also a few xenoliths more than 50 cm long of very fine-grained granitoid and biotite gneiss.

The Landing Bluff Adamellite is intersected by narrow dykes, most of them only a few centimetres wide, some of alaskite, and others of aplite; there are also pegmatites on Landing Bluff, Nickols Island, and near Palmer Point, pods of massive grey quartz near the summit of Landing Bluff, and smaller masses of white quartz on Sansom Island and near Palmer Point. Sample 69280130 from a 1-m wide aplite dyke on Sansom Island consists of about 55 percent microcline perthite, 25 percent quartz, 20 percent andesine (An_{35}), 1 or 2 percent biotite, and minor fluorite, zircon, and opaques. Many of the plagioclases have a saussuritised andesine core surrounded by a wide rim of more-sodic antiperthite. The pegmatites consist essentially of graphically-intergrown perthite and quartz and a few percent biotite; locally there are a few white plagioclase crystals. Zoned pegmatites typically consist of quartz-rich cores and medium to coarse-grained alaskitic margins.

In addition to these very acidic dyke rocks, there are a few dykes with a higher content of mafic minerals that approximate to biotite-diorite or granodiorite composition. Some have coarser felsic central zones, others contain felsic schlieren; contacts between the felsic zones and the surrounding dyke rocks are gradational. The biotite-diorite and granodiorite dykes are irregular in width and direction, and locally form anastomosing networks; a general trend of about 110° is discernible.

The Landing Bluff Adamellite is typically a massive porphyritic rock with no discernible foliation but on one part of Landing Bluff, oriented feldspar phenocrysts define a vague foliation that strikes 110° and dips 80°N. All outcrops of the adamellite granitoids are broadly jointed; closer joints in the highest outcrop adjacent to Palmer Point dip vertically and trend 030°, that is, more or less parallel to the Amery Ice-Shelf-Lambert Glacier depression and to major lineaments visible on Landsat imagery. Several straight gravel-filled depressions in the exposed granitoid are interpreted as shear zones, and there are vertical shears in the southern part of Landing Bluff which trend 130°. Possible shears on Nickols Island trend between 080° and 110°, and dip 85° to the north.

EXPOSURES ON THE EASTERN SIDE OF THE AMERY ICE SHELF BETWEEN GILLOCK ISLAND AND PICKERING NUNATAK

These exposures are generally composed of migmatitic rocks of high metamorphic grade that are grouped together as the 'New Year Migmatite'. The type area is New Year Nunatak in the Manning Nunataks where a survey station was established. There are other small exposures around the margins of Gillock Island, at Spayd and Mousinho Islands in the Manning Nunataks, and at Haigh and Pickering Nunataks. The migmatite grouping consists of gneisses and granulites containing bands, lenses, and veins of granitic rocks; the grouping is intruded by the Gillock Charnockite in the central part of Gillock Island and by rocks assigned to the Landing Bluff Adamellite at Corry Rocks, at the northern tip of Gillock Island.

The New Year Migmatite appears to become increasingly migmatitic to the south where the differentiation of mafic and basic rock types is more pronounced and granitic and pegmatitic veins and lenses are more common. Whole-rock Rb-Sr geochronological studies of samples from Pickering Nunatak have given an age of 1042 ± 547 m.y., with an initial ratio of 0.7082. Despite the uncertainty, which may be due to the field sampling procedures, this age is considered to be that of the metamorphism which produced the New Year Migmatite. It is comparable to the age of the

Prydz Bay migmatite on Filla Island in the Rauer Group, and to ages in the northern Prince Charles Mountains-Mawson area (see Tingey, in press).

The New Year Migmatite is intersected at New Year Nunatak by a mafic dyke rock described as a pyroxene porphyrite. The presence or absence of networks of mafic dykes that intersect metamorphic rocks has been recognised by Tingey (in press) as a critical field relationship in the Prince Charles Mountains-Mawson-Vestfold Hills area and by Sheraton & others (1980) in Enderby Land to distinguish older and younger rocks. However, the basic dykes used in this sense are mostly of doleritic or tholeiitic composition and at least Proterozoic age whereas the dyke at New Year Nunatak is of unknown age and appears to have alkaline affinities. Alkaline igneous rocks that range in age from Silurian to Eocene have been found in the Prince Charles Mountains and their genesis has been speculatively related to activity along the major structure now occupied by the Lambert Glacier System. The New Year Nunatak dyke may belong to the Phanerozoic alkaline intrusive grouping and is being chemically analysed to see if this is the case. If the dyke is not alkaline but tholeiitic, its presence at New Year Nunatak may indicate that the migmatites there may be older than the others grouped in the New Year Migmatite. This is thought to be improbable in the light of Rb-Sr ages cited above for the Pickering Nunatak rocks.

The New Year Migmatite consists of gneisses and felsic granulites which contain bands, lenses, and veins of granitic rock. In essence the migmatites are banded biotite-quartz feldspar gneisses in which banding on both macro (up to tens of metres) and micro (one to ten millimetres) scales is governed by the distribution of the mafic minerals biotite, pyroxene, and hornblende. Garnet is a widespread but generally minor component of the rocks.

Interbanded with the migmatites are narrow bands and lenses up to a few metres wide of biotite-bearing two-pyroxene mafic granulites. These may be streaked-out relics of original discordant basic intrusives. The granitic rocks that give the suite its migmatitic character occur both as sub-concordant bands up to 3 metres wide and as cross-cutting dykes and veins. The concordant bands are seen to advantage at Pickering Nunatak where they comprise up to 30 percent of the exposed section; the discordant veins are most numerous at Haigh Nunatak, where they are randomly oriented and about 30 cm wide. The concordant bands are slightly foliated and probably synmetamorphic in origin; the discordant veins are unfoliated and probably post-metamorphic. Both consist of quartz, potash-feldspar, and plagioclase with minor biotite and garnet.

New Year Nunatak

Some parts of New Year Nunatak (Fig. 2) consist of typical migmatitic rocks with abundant granitic veins and interbands, and others consist of more strongly banded rocks not accompanied by the granitic phase. The migmatitic rocks are well exposed at the southern end and along the western side of New Year Nunatak, the weathered outcrop being a reddish-brown colour, and the fresh rock being bluish-grey. The gneissic component consists of finely-banded medium-grained felsic rocks with biotite-rich streaks and lenses mostly less than 1 cm wide. Locally, the felsic gneisses contain garnet which is generally found close to the biotite streaks, and there are scattered feldspar porphyroblasts. Despite local disruptions by granitic interbands, the gneissic banding is generally regular and more or less constant in direction over several exposures.

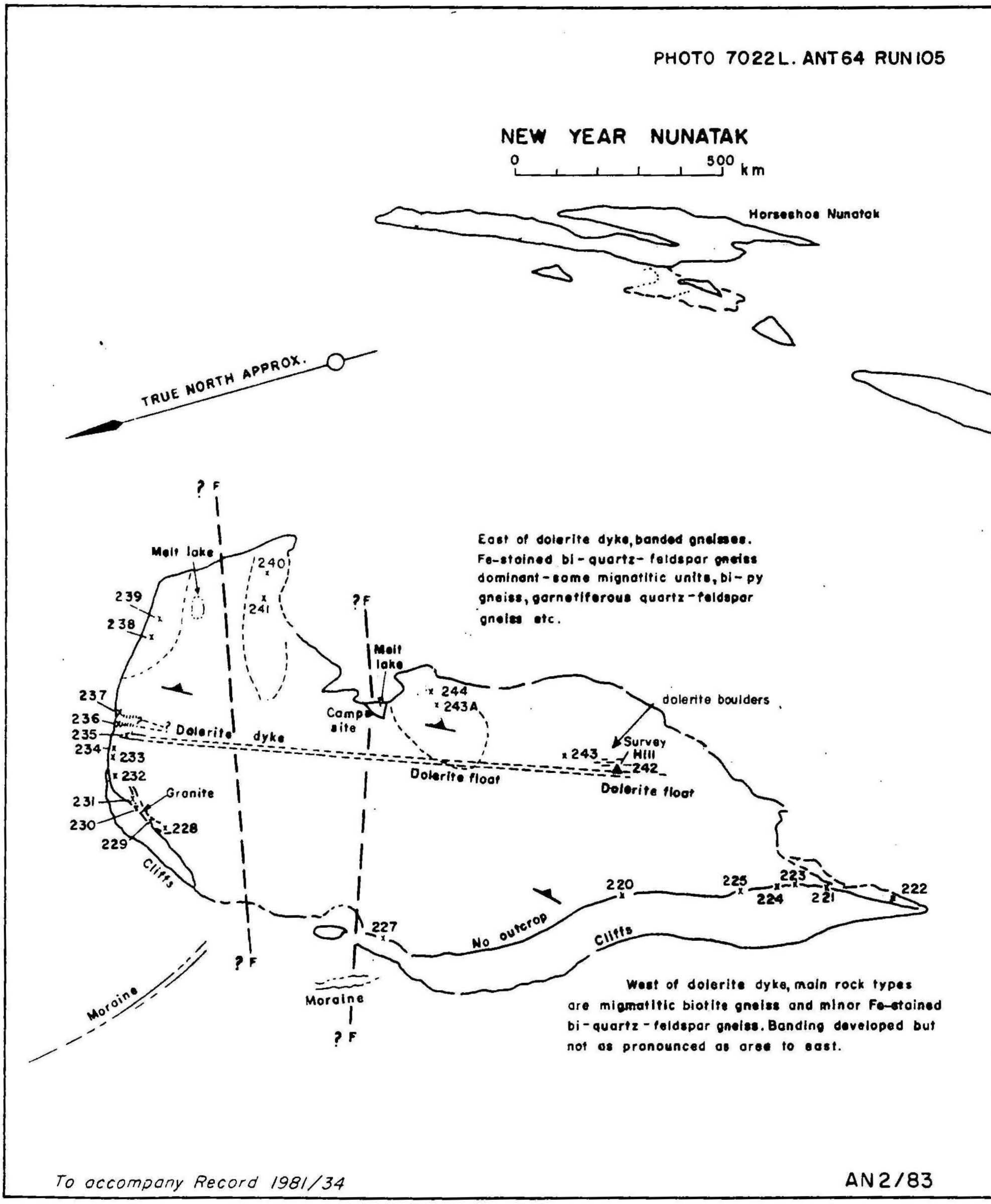
A typical sample from the felsic gneiss (sample 69280215) is strongly-banded with thin garnet and biotite-rich bands set in an equigranular aggregate of xenoblastic quartz and feldspar. It consists of about 60 percent perthitic potash feldspar, 20 percent andesine, 15 percent quartz, and a total of about 5 percent of biotite and garnet. Slight alteration of garnet to biotite and biotite to chlorite provides some evidence for retrograde metamorphism and the presence of perthitic feldspars is consistent with high-grade, probably upper amphibolite facies, metamorphism. The strongly developed microbanding probably resulted from mineral segregation during this metamorphism which was clearly accompanied by partial melting and mobilisation of granitic fractions within the rocks.

The migmatites contain lenses and bands up to 2 metres wide of mafic granulites. Such rocks comprise up to 10 percent of the outcrop at the southwestern end of New Year Nunatak but are generally less abundant than this. They are medium to coarse-grained, and have a moderate foliation that is subparallel to that of the enclosing migmatites, and defined by the alignment of pyroxene, hornblende, and biotite crystals. The foliation is emphasised by an incipient microbanding that is caused by partial segregation of mafic and felsic minerals. Sample 69280216 has granoblastic texture and consists of about 50 percent of equant grains of andesine, 20 percent orthopyroxene, 15 percent hornblende, 10 percent clinopyroxene, 5 percent biotite, and minor amounts of quartz. The brown-green hornblende commonly rims, and therefore appears to have formed after, the orthopyroxene, presumably because of retrograde metamorphism either during a subsequent metamorphic episode or during cooling after the peak of prograde metamorphism. The basic granulites within the migmatite complex may be either melanosomes left behind after the migration during metamorphism of felsic components of the original rocks or sheared out relics of either once discordant basic dykes or basic strata within the pre-metamorphic sequence.

The granitic fraction of the migmatitic suite consists of concordant and discordant quartz veins and mica pegmatites up to 50 cm thick; concordant pegmatitic pods and lenses up to several metres long are also common. Some pegmatites have a quartz core, others have a core of coarse feldspar and a quartz-feldspar mosaic along the margins. In some places, contacts between the gneissic and granitic fractions of the migmatite are gradational, in others it is quite sharp and marked by a biotite selvage.

The west part of the north face of New Year Nunatak is composed of migmatites like those described from the southern and western parts of New Year Nunatak, but the northeastern part of the nunatak is made up of strongly banded gneissic rocks. Intrusive granitic rocks are scarce in this area. The predominant rock-type in the banded gneiss sequence is pyroxene-plagioclase granulite which locally contains a few feldspar porphyroblasts; there are, in addition, minor biotite-pyroxene mafic granulites, leucocratic quartz-feldspar rocks, and migmatised biotite gneiss that resembles the gneissic fraction of the migmatite suite elsewhere on New Year Nunatak. Individual rock bands are tens of metres wide but several are also microbanded; most of the gneisses are garnet bearing.

Figure 2



To accompany Record 1981/34

AN2/83

The typical brown weathered pyroxene-plagioclase gneiss consists of thin biotite/pyroxene-rich lenses and streaks within a medium to coarse-grained quartz-feldspar aggregate. Sample 69280219 consists of a granoblastic polygonal aggregate of about 45 percent andesine, 25 percent orthoclase perthite, 15 percent quartz, and a total of about 15 percent of orthopyroxene and clinopyroxene concentrated into narrow stringers and bands, with minor biotite, zircon, and apatite. Some of the biotite rims pyroxene grains, but most has developed around opaque nucleii. Variations in the pyroxene-plagioclase gneisses appear to be governed by the relative abundance of quartz and pyroxene; sample 69280102 for example contains about 25 percent quartz, 5 percent orthopyroxene and no clinopyroxene. Other minerals are present in the same proportions as in sample 69280219, and biotite again rims some orthopyroxene grains.

Intrusive rocks

The metamorphic rocks at New Year Nunatak are locally intruded by abundant granitic rocks and younger dyke intrusives. Granitic components of the migmatite complex that was examined in the southern part of New Year Nunatak have been described (p. 45) but there are also a few granitic intrusions in the banded gneiss sequence near the north end of the nunatak.

One such intrusion is a 25 metre wide dyke that crops out for about 200 metres on the top of the northern cliffs of New Year Nunatak. The dyke is a complex of medium to coarse-grained biotite granite, graphic granite, and very coarse-grained pegmatitic granite. The southern contact is obscured by loose rock debris but the northern contact, where the dyke is a medium-grained biotite granite, is sharp and steeply southward dipping with small granite apophyses penetrating along foliation planes within the gneiss. Graphic granite predominates in the southern part of the dyke and is found as isolated boulders along strike from the eastern end of the biotite granite outcrop.

The basic dyke intrusives on New Year Nunatak are marked by northeasterly-trending gullies on the upper surface of the mountain. One such gully ends in a major indentation in the northern cliffs of the nunatak which contains rubble of porphyritic 'dolerite'. Poor exposures obscure the relationship between the basic dykes and the granitic intrusions in this area but slight displacement of at least one granite dyke is inferred. This implies that the basic dykes are younger than the granite dykes.

The porphyritic dolerite exposed near the northern cliffs is dark greenish-grey and has dark clinopyroxene phenocrysts set in a very fine-grained matrix of plagioclase and clinopyroxene (sample 69280217). The clinopyroxenes are zoned and the rock is somewhat altered, probably deuterically, to chlorite; no evidence for post-intrusion metamorphism of the dyke has been discerned.

Several such basic dykes may intersect the metamorphic rocks on New Year Nunatak and the known extent of the main one is shown on Figure 2. The dyke rocks are of considerable significance; either they are equivalent to the basic dyke rocks exposed in the Vestfold Hills and are of Proterozoic age, intruding early Proterozoic or Archaean metamorphic rocks, or they belong to the suite of generally alkaline dykes of Phanerozoic age that intrude the high-grade Late Proterozoic metamorphic rocks of the northern Prince Charles Mountains. The second explanation is favoured because Rb-Sr whole-rock data from the migmatitic rocks at Pickering Nunatak appear to indicate a Late Proterozoic age for the New Year Migmatite and because the dyke rocks show alteration that closely resembles that seen in the alkaline dyke rocks. The first explanation cannot be entirely discounted and the dyke rock is currently being analysed to determine whether or not it has alkaline affinities.

Structure

The main foliation in the metamorphic rocks of New Year Nunatak trends about northeast, and commonly dips to the southeast at angles less than 50°. Minor folds exposed in the northern cliffs have axial planes aligned parallel to the main foliation, which probably reflects isoclinal folding of the whole sequence. The minor folds plunge 20° to the southwest. East-west trending valleys on the nunatak's upper surfaces and the main northern cliffs themselves may be the result of faulting which however does not appear to affect, and therefore possibly predates, the dolerite-dyke intrusives.

Other Manning Nunataks

New Year Nunatak is the major exposure in the Manning Nunataks group but Luff Nunatak[1], 5 km to the south, and Foster Nunatak[2], 5 km to the southeast, were also briefly visited. They consist of metamorphic rocks which are banded on a large scale and resemble those described from New Year Nunatak although they are generally more mafic in composition.

At Luff Nunatak, the main rock types are coarse-grained banded pyroxene-hornblende gneiss and medium-grained felsic biotite-gneiss, which contain thin concordant and discordant granite veins and streaks. The north face of the nunatak consists of a network of granitic veins that contains rafts of gneissic country rock. The pyroxene-hornblende gneiss (sample 69280220) consists of about 50 percent perthitic microcline, 20 percent hornblende, 15 percent clinopyroxene, 10 percent oligoclase and minor quartz, opaques, and biotite. Mafic minerals are generally segregated into, and orientated within, distinct bands, and the hornblende commonly rims the pyroxenes, a relationship that suggests re-equilibration after the peak of prograde metamorphism. Upper amphibolite facies metamorphism is indicated by the perthitic feldspars and the abundance of granitic rocks, presumably of anatectic origin, within the gneisses.

Foster Nunatak, to the east of Luff Nunatak, consists of interbanded garnet-bearing felsic-gneiss and biotite-gneiss, again accompanied by granitic veins and mafic streaks.

Pickering Nunatak

Pickering Nunatak is a heterogeneous rock-mass made up of a wide range of strongly banded and foliated, mafic and felsic gneisses and granulites, together with numerous small, semi-concordant leucogranite lenses up to 3 metres thick and 50 metres long. In general these rocks appear far more migmatitic than those assigned to the New Year Migmatite at other exposures. The following mineral assemblages, which are listed in order of decreasing abundance, were described from rocks sampled in a 1-km traverse across strike at Pickering Nunatak:-

---

Note. [1,2]. These localities are informally referred to as Razorback Nunatak and Pyramid Nunatak respectively in field notebooks and AMDEL Report MP 4460/69.

(a) Felsic rocks (>10 percent quartz)
Quartz, potash feldspar, plagioclase, orthopyroxene, biotite, hornblende*, plus minor opaques, apatite, and zircon.

Quartz, plagioclase, orthopyroxene, biotite, opaques, apatite, potash feldspar, plagioclase, quartz, biotite*, opaques, minor garnet*.

(b) Intermediate rocks (<10 percent quartz)
Plagioclase, orthopyroxene, quartz, biotite, hornblende, opaques, apatite, and minor garnet*.

Plagioclase, orthopyroxene, clinopyroxene, quartz, biotite, hornblende, opaques, apatite, zircon.

(c) Mafic rocks (<1 percent quartz)
Plagioclase, clinopyroxene, biotite, opaques.

Plagioclase, orthopyroxene, hornblende, biotite, clinopyroxene, opaques, apatite.

The potash feldspar is confined to felsic rocks whereas clinopyroxene is absent from them. Several of the assemblages are characteristic products of granulite-facies metamorphism although the migmatitic nature of the rock indicates that isochemical metamorphism was unlikely to have occurred. Thus the rocks are generally not considered to represent chemically-unmodified pre-metamorphic rock types, and the metamorphism is best categorised as high-grade.

Detailed descriptions

Specimen 69280015, a strongly-banded pyroxene-hornblende-biotite-quartz-feldspar granulite, is typical of the felsic granulites and gneisses that, excluding the leucogranite bodies, comprise the bulk of Pickering Nunatak. It contains about 35 percent quartz, 10 percent potash feldspar, 40 percent andesine (An_{40}), 5 percent orthopyroxene, 1 percent hornblende, 5-10 percent biotite, 1 percent apatite plus small amounts of opaques. Foliation is governed by segregation and orientation

* Signifies that these minerals are not present in all samples.

of mafic components and the elongation of feldspar and quartz grains. The presence of green hornblende and possibly biotite suggest that the rocks may have crystallised under 'low' granulite-facies conditions with relatively high P_{H_2O}. Alternatively the partial replacement of some pyroxene grains by green hornblende suggests partial re-equilibration under amphibolite-facies conditions perhaps during slow cooling after the peak of metamorphism. The strongly banded granulites and gneisses differ greatly in composition from band to band, and there is a wide range of mafic and felsic types; however, the composition of specimen 69280015 is thought to be about average.

At the southern end of Pickering Nunatak the outcropping felsic and intermediate granulites and gneisses are more gneissic; specimen 69280034, for example, is a fairly coarse-grained porphyroblastic pyroxene-feldspar gneiss or augen-gneiss but with a composition very close to that of specimen 69280015. It too shows signs of an amphibolite facies overprint. Interbanded with the felsic and intermediate granulites and gneisses are small (less than 50 cm thick) and large (2-10 metres thick) bands of dark-coloured weakly-foliated one and two-pyroxene basic granulites typified by specimen 69280022 which contains about 25 percent bytownite (An_{70}), 70 percent diopsidic augite, 5 percent yellow to reddish-brown biotite, 2 percent opaques, and minor interstitial quartz; specimen 69280034, another basic granulite, consists of about 55 percent andesine (An_{30}), 20 percent hypersthene, 2-5 percent diopsidic clinopyroxene, 10 percent hornblende, 10 percent biotite, and minor opaques, apatite, and interstitial quartz. Both rocks have granulite-facies mineral assemblages but show incipient replacement of pyroxenes by green hornblende and pale-coloured biotite, and traces of interstitial quartz. These features are collectively interpreted as possible evidence of the slight retrograde reversal of the reaction between hornblende and quartz which gives a two-pyroxene granulite-facies assemblage*. The two-pyroxene granulites may also be melanosomes left after the extraction of felsic minerals during metamorphism rather than true representatives of pre-metamorphic rock types.

---

* Binns (1964) has shown experimentally that at 850°C and with water pressure of 1000 bars, amphibole and quartz will react to give pyroxene and plagioclase according to the reaction Hbl+Qtz $\rightleftarrows$ O'px (C'px)+Plag+Water.

Greyish leucocratic banded biotite-garnet-quartz-feldspar gneiss at the northern end of Pickering Nunatak is in part granitic-tectured with only a slight foliation. Differences in mineral proportions from band to band, swirls of biotite flakes which form up to 5 to 6 percent of the rock, and randomly spaced garnets of all sizes up to 1 cm diameter make this a heterogeneous rock. In places quartz forms 70 to 100 percent of the rock, which must therefore be partly of metasedimentary origin.

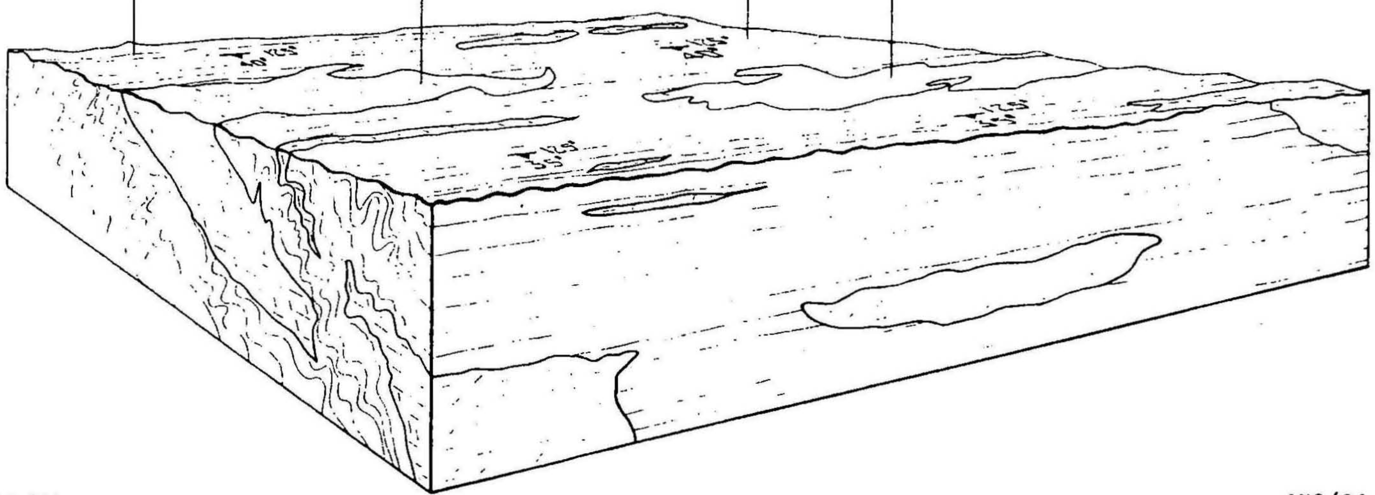
Granites

Leucocratic medium-grained to pegmatitic granite and adamellite intrusions at Pickering Nunatak are interbanded with the granulites and gneisses, and comprise about 30 percent of the total outcrop. All variants consist essentially of quartz (15-20 percent), potash-feldspar (40-50 percent), and andesine (35-40 percent), and may contain up to 2 or 3 percent of red-brown biotite and/or garnet. Specimen 69280014 is a typical medium to coarse-grained biotite-bearing granitoid; it has a granoblastic-polygonal texture, with rounded mutual grain boundaries between quartz and potash-feldspar crystals. Some of the large potash-feldspar grains have rounded inclusions of quartz and plagioclase. Many boundaries between potash feldspar and plagioclase feature a vermiform intergrowth in which some of the potash feldspar is ribbon-type perthite, and some appear to be an orthoclase cryptoperthite with incipient microclinisation. The potash-feldspar is slightly kaolinised and the biotite is partly chloritised.

In some places along the margins of these granitoid bodies a faint foliation parallel to the margin is due to subparallelism of the mafic minerals, which are generally concentrated near those margins. Most granitoid variants are white to grey, but some pinkish-coloured types contain large (up to 10 cm long) crystals of pink potash-feldspar. Small streaks and clusters of garnet occur in some of the finer-grained adamellites and there are large books of biotite in the pegmatites. Like the enclosing gneisses and granulites, the granitoids show signs of incipient alteration to lower-grade mineral assemblages.

In plan, the granitoids occur as small lenticular bodies (30 cm to 3 metres by 20 to 60 metres) concordant with the regional macro-banding of the gneisses and granulites which trends 125^{o} to 130^{o} and dips south at 40^{o} to 60^{o}. In cross-section, the margins of these bodies are

Figure 3



Record 1981/34

AN2/94

Relationship of granitic bodies to enclosing gneiss in the New Year Migmatite at Pickering Nunatak sharp and irregular and they intersect and interfinger with the banding of the enclosing gneiss (Fig. 3).

In addition to the generally concordant intrusives small (10-40 cm) irregularly shaped dykes and veins of dark grey pegmatitic biotite-granite intersect the gneisses and granulites at high angles. The veins are generally only found where the concordant bodies are absent, and were not seen to cut the semi-concordant granite bodies.

Within the strongly-banded acid granulites and gneisses, small isoclinal, concentric and similar intrafolial folds are common; they plunge about 40^{o} towards 160^{o} and have near-vertical, axial planes.

Haigh Nunatak

Strongly-banded leucocratic, granoblastic gneiss is the main rock type on Haigh Nunatak, which consists of small, low, rounded outcrops and a large area of moraine. The gneiss is composed of biotite, quartz, and feldspar with minor garnet; locally, there are more mafic bands. Specimen 65280249, from one of the more-mafic bands, is a garnet-biotite-quartz-feldspar gneiss collected by J. Haigh in 1966 and consists of about 30 percent quartz, 30 percent plagioclase, 16 percent orthoclase (1 percent myrmekite), 15 percent biotite, 8 percent garnet, and small amounts of zircon, apatite, and opaques. This assemblage indicates amphibolite-facies metamorphism.

No concordant granitic bodies occur within these gneisses although numerous small dykes and veins of light-coloured biotite-granite cut the banding at all angles. The dykes range from about 5 mm to 30 cm in width. Some are relatively fine-grained; others are strongly pegmatitic. Tight and, in places, complex folds in the gneiss pre-date the intrusion of the granitic dykes and veins, which are undeformed.

INTRUSIVE BODIES IN THE NEW YEAR MIGMATITE

Gillock Island

Rocks assigned to the Gillock Charnockite crop out on the eastern and southwestern sides of Gillock Island. Although they are broadly similar to the Jennings Charnockite 40 km to the northeast (see p. 32) there are significant mineralogical and textural differences. No contacts between the Gillock Charnockite and other rock units are exposed, but it is presumed to be intrusive into the New Year Migmatite although of roughly the same age. The northern outcrops of the Gillock Charnockite on the eastern side of Gillock Island (at about 70°34'S and 072°00'E) are considered typical, and consist of dark-coloured, massive, medium to coarse-grained rocks composed of perthite megacrysts up to 4-cm long, set in a plagioclase and quartz-rich matrix. Specimen 69280109 consists of about 35 percent andesine (An_{35}), 30 percent orthoclase perthite, 25 percent quartz, 5 percent hypersthene, 5 percent biotite, and minor opaques, apatite, garnet, blue-green amphibole, and zircon. The garnets poikiloblastically enclose grains of quartz, biotite, zircon, and apatite, and the hypersthene displays marginal alteration to blue-green amphibole and biotite. The thin-section estimates of the mineral assemblage seriously underestimate the potash-feldspar content as estimated from outcrop since the section does not cut across a representative number of potash-feldspar megacrysts.

The Gillock Charnockite differs from the Jennings Charnockite in containing garnet but lacking significant hornblende. It has also been deformed to a much greater degree as is evident from bent twin lamellae in plagioclases, the shredding of biotite crystals and their partial interbanding with quartz, the finely granulated boundaries of quartz, feldspar, and mafic minerals, and the partial optical anisotropy of garnet which displays a distinctly-anomalous, mottled extinction. Deformation effects are more marked on the western side of Gillock Island where the Gillock Charnockite has a texture that approaches that of an augen-gneiss. Some quartz grains in charnockite specimens from both sides of Gillock Charnockite could be the result of large-scale shearing activity along the structure now occupied by the Lambert Glacier and Amery Ice Shelf (Wellman & Tingey, 1976). The Gillock Charnockite, like the Jennings Charnockite, is thought likely to be the product of 1000 ± m.y. metamorphism which produced high-grade metamorphic rocks, including the Prydz Bay Migmatite, Munro Kerr Gneiss, and New Year Migmatite, over wide areas of East Antarctica.

Corry Rocks

The New Year Migmatites at the northern end of Gillock Island are presumed to be intruded by the granitoid rocks exposed at Corry Rocks although no contacts are known. The Corry Rocks granitoids are described with the Landing Bluff Adamellite intrusives on p. 41.

AREAS WEST OF THE AMERY ICE SHELF

Jetty Peninsula

Three places in the central part of Jetty Peninsula were briefly visited but no bedrock outcrops were found at any of them, the surface being covered by rock fragments. These fragments are believed to be virtually in situ because a well-defined large-scale banding is visible from the air, and dykes can be traced on the ground by following lines of rock fragments.

Jetty Peninsula consists largely of gneissic metamorphic rocks of which cream-coloured, medium-grained felsic gneiss is the most abundant. Specimens from the northern and southern localities visited have a pronounced lineation due to the alignment of spindle-shaped and lenticular quartz aggregates. Pale-pink garnet grains, or aggregates of them, are scattered through the gneiss but rarely form more than 5 percent of it, and biotite only occurs as small local concentrations. Both biotite and garnet are partly altered to chlorite.

Darker-coloured layers of fine to medium-grained equigranular garnet-pyroxene-quartz-feldspar gneiss and garnet-biotite-quartz-feldspar gneiss between 10 and 50 cm thick are interbanded with the creamy-coloured felsic gneiss. Some of these rocks contain up to 40 percent ferromagnesian minerals and a few contain hornblende which is believed to be, at least in part, of secondary origin. The thicker layers of darker-coloured rocks are themselves microbanded with light and dark minerals alternately concentrated into distinct layers. There are also zones of darker rocks up to 10 m wide which constitute the darker component of the large scale banding that is easily seen from the air but less easily discerned on the ground. The dark layers at southern Else Platform (the northern part of Jetty Peninsula) generally contain more mafic minerals than their counterparts elsewhere and some contain less than 15 percent felsic minerals.

The gneisses are intruded by dykes of porphyritic basalt up to 2 or 3 m thick most of which strike northwards although some trend north-northwest. The basalt (specimen 69280151) consists of scattered medium-grained feldspar and clinopyroxene phenocrysts set in a fine-grained matrix of feldspar, clinopyroxene, and opaques. At one place, feldspar phenocrysts predominate over pyroxene, but pyroxene is generally the dominant phenocryst phase. The dyke rocks have been altered with recrystallisation of feldspars, and alteration of pyroxene to aggregates of possible actinolite or chlorite.

Partial recrystallisation, discernible even in hand specimen, of most of the rocks on Jetty Peninsula is notable. Its ubiquity suggests that a second metamorphism affected the rocks formed by the original high-grade metamorphism; because the basic intrusives which postdate the initial metamorphism are also affected, the second metamorphism must postdate their emplacement. The dykes may be equivalent to metamorphosed dykes mapped in the southern Prince Charles Mountains (see Tingey, in press) and the unmetamorphosed dykes of the Vestfold Hills. If these correlations are valid, the gneisses exposed at Else Platform may be considerably older than the rocks exposed elsewhere in the northern Prince Charles Mountains.

Fox Ridge area

A trigonometrical station was established on the summit of Fox Ridge on the southern edge of McLeod Massif 4.8 km northwest of the northern end of Radok Lake and 9 km west of Beaver Lake. The area has strong relief; the Fox Ridge trig station is at an elevation of about 1150 m and Beaver Lake is at sea level. The contact between the Beaver Lake-Radok Lake sedimentary basin (Mond, 1972) and the metamorphic terrain to the west is marked by a 500-m scarp along the western shore of Radok Lake, and a lesser escarpment along strike to the north. Crohn (1959) regarded this scarp as a fault along which the Permian sediments near Beaver Lake had been downfaulted. This interpretation is not favoured by Mond (1972). However, it appears likely that the scarp marks the site of a fault which controlled sedimentation in the Beaver Lake area in Permian times (see p. 63).

McLeod Massif, and Manning Massif to the north, are parts of a dissected plateau of about 1000 m elevation which has higher features like Fox Ridge and is intersected by Grainger Valley, a deep, northeast-trending snow-filled depression. Further south, near McLaren Ridge, the metamorphic terrain is at a similar elevation but is intersected by a deep valley now occupied by the Battye Glacier. In this area, there are also several well-developed cirques and cirque glaciers. The extensive snow field to the south of Fox Ridge has a discontinuous terminal moraine at the foot of its steep, eastern slope, and to the north, Loewe Massif (formerly known as Mount Loewe) supports a local ice cap that feeds a number of hanging glaciers.

The few good bedrock outcrops in the Fox Ridge area are tor-like heaps which protrude through the boulder and rock-fragment fields that mantle most of the landscape. The boulder fields are crudely patterned, but patterned ground is better developed on finer-grained rock debris. In the 1968-69 season, traverses were made around the Fox Ridge trigonometrical station, wider afield on McLeod Massif, and northwest across the Grainger Valley to Manning Massif. Photogeological and long-distance field observations indicate that the rest of Manning Massif, as well as Martin Ridge and the southern part of Loewe Massif, are composed of banded metamorphic rocks like those that underlie McLeod Massif.

The predominant rock type on McLeod Massif is poorly-foliated medium to coarse-grained quartzo-feldspathic gneiss which is banded on a large scale. The banding is governed by the distribution of ferromagnesian minerals; some bands approach quartzite in composition, others are quite dark-coloured. Enclosed within the gneiss are small bodies of coarse-grained porphyroblastic granitic gneiss, pelitic gneiss, and mafic granulite; the presence of pelitic gneisses suggests that the banded gneiss sequence is at least, in part, of metasedimentary origin.

The felsic gneisses can be divided into those that contain hypersthene and those that contain garnet and biotite. Potash feldspars in the felsic gneisses are invariably perthitic and testify to high-grade metamorphism, but there is also abundant evidence of late-stage grade metamorphism, but there is also abundant evidence of late-stage retrograde alteration of the gneisses in the form of alteration of feldspars to sericite, hypersthene to biotite, and garnet to biotite. A typical orthopyroxene-bearing felsic gneiss (specimen 69280228) is composed of about 35 percent plagioclase (An_{40}), 30 percent quartz, 20 percent perthitic potash-feldspar, 10 percent orthopyroxene and 5 percent biotite, whereas a typical garnet-bearing felsic gneiss (specimen 69280224) is composed of 45 percent plagioclase (An_{30}), 30 percent quartz, 20 percent perthitic orthoclase, 5 percent biotite, and minor garnet.

The pelitic gneiss that was sampled (specimen 69280226) is strongly zoned with some parts rich in spinel and sillimanite, others rich in quartz and others rich in garnet. The rock has a strongly-linear fabric and a finely-granular texture in the groundmass which indicates crystallisation under considerable stress. The general composition of this rock is about 40 percent quartz, 15 percent sillimanite, 10 percent potash feldspar, 10 percent cordierite, 10 percent garnet (some in largish subhedral crystals set in a quartz groundmass and some strung out parallel to the linear fabric), 10 percent spinel, 5 percent magnetite, and minor plagioclase, biotite, rutile, and zircon. A few grains of kyanite and corundum are also reported. This assemblage is clearly high-grade and consistent with the high stress conditions indicated by the fabric; metamorphism was apparently not accompanied by significant partial melting. This is consistent with the low P_{H_2O} conditions, signified by the presence of orthopyroxene in some of the surrounding felsic gneisses, and typical of granulite-facies metamorphism.

The porphyroblastic granitic gneiss bodies are commonly exposed in the tor-like outcrops and a number were mapped on the northern flank of Fox Ridge. The granitic gneiss is massive and reddish-brown coloured and consists essentially of elongate blue quartz grains and large red-brown potash feldspars up to 4 cm long. It is well-foliated because of the parallel orientation of the quartz and smaller feldspar crystals, and outcrops are controlled by strong rectilinear jointing. Similar outcrops continue to the east of Fox Ridge for at least 3 km, and one outcrop was examined at the head of Grainger Valley where the fresh granitic gneiss is grey, and contains more mafic minerals and is less porphyroblastic than the Fox Ridge examples.

Large-scale folding of the banded gneisses is well displayed on aerial photographs of Manning Massif but is less easily identified on the ground which is covered by loose rock debris, to the virtual exclusion of bedrock outcrop. The large-scale banding of the bedrock gneiss is reflected in the distribution of various rock types in the loose debris but structural observations, apart from gross trends, are essentially precluded. The main fold structures have east-west trends and the main rock type in the northern limb is light-coloured, coarse-grained, poorly-foliated garnet-quartz-feldspar gneiss in bands commonly more than 25 metres wide. Darker-coloured, medium to coarse-grained, massive pyroxene granulites, with up to 70 percent ferromagnesian minerals, are interlayered with the felsic gneisses in bands up to 10 metres wide. Individual bands in the southern limb of the structure appear to be much thinner than those in the northern limb and form a complex of narrow, discontinuous units that cannot, with any certainty, be matched with those displayed in the northern limb. The predominant rock types in the southern limb are felsic gneiss and pyroxene-rich gneiss, and garnet is much less common than in the northern limb. The contrast between the thickness of layers in the two limbs provides evidence that the structure has a northward-dipping axial plane, and field observations indicate that it is a synform.

Near the Grainger Valley, the fold structure plunges west-southwest and its southern limb is truncated by an east-northeast trending fault. Southeast of the fault, a smaller east-northeast plunging synform is exposed although most of its northern limb has been obscured by the fault. Other fold structures were seen at a distance in outcrops south of Fox Ridge near the Battye Glacier. The east-northeast fault-trend on Manning Massif appears to be repeated on a larger scale in the Grainger Valley and in subsidiary shear zones along its flanks.

Several north-northeast striking silicified shear zones up to 5 metres wide were mapped at the eastern end of Fox Ridge and between tors further east on McLeod Massif. This is approximately the same trend as that of the western side of Radok Lake and the topographic break between the Permian sediments to the east and the metamorphic rocks, and the shear zones may be subsidiary structures of faults that bounded the Permian sedimentary basin.

Within the same general area as the silicified shear zones, there are also a number of northeast-trending basic dykes about 3 metres thick. All have alkaline affinities and most have prominent deuteric alteration. One has given a K-Ar pyroxene age of 504 $\pm$ 20 m.y. (Tingey, 1976), and the proximity within a fairly small area of alkaline intrusives ranging in age from 504 m.y. at Fox Ridge to 246 $\pm$ m.y. at Taylor Platform (32 km southwest of Fox Ridge) to 110 m.y. at Radok Lake is considered to be evidence for continued activity along the major geological structure tentatively identified by Wellman and Tingey (1976). The proximity and similar trend of the alkaline intrusives on Fox Ridge to the Amery Fault postulated by Crohn (1959) suggests that this may be a peripheral feature of the major structure and possibly the site of long, continued, if intermittent, faulting. The possibility that the Permian sediments in the Beaver Lake Radok area were deposited in a fault bounded trough is mooted on page 63.

[Note. An olivine leucitite flow of Eocene age was later mapped on Manning Massif - see Tingey (1976)].

Mount McCarthy

Gneissic rocks banded on scales between 5 and 20 metres are exposed on Mount McCarthy (066°30'E, 70°24'S - Plate 1) and trend fairly regularly between 080° and 090°. Steep dips to the north and south indicate tight or isoclinal folding. In most outcrops, foliation and compositional layering are parallel, but locally, near fold hinges, they intersect at various angles. Patterns in gneisses and granulites on the eastern face of Wignall Peak to the west of Mount McCarthy are also consistent with tight, possibly isoclinal, folding about axial surfaces to which the regional foliation is generally parallel. The banded gneisses at Mount McCarthy are also microbanded on a scale of between 1 and 20 mm, and all banding reflects different local proportions of ferromagnesian minerals.

Granulite-facies mineral assemblages predominate in the gneisses at Mount McCarthy, but there is local overprinting of cataclastic and retrograde metamorphic effects, presumably the result of deformation and retrograde metamorphism after the peak of prograde metamorphism. The dominant rock type is felsic gneiss but pelitic and calc-silicate gneisses are quite common and mafic granulites are widespread.

The felsic gneisses display a wide range of composition from quartz-rich types to quartz-poor types with predominant feldspar. Sample 69280054 is a typical quartz-rich felsic granulite composed of about 50 percent quartz, a total of about 45 percent of perthitic orthoclase and slightly antiperthitic plagioclase (An_{30}), and 5 percent hypersthene with minor opaques, rutile, white mica, biotite, and zircon. White mica, produced by minor alteration of feldspars, and biotite, produced by alteration of hypersthene, are attributed to retrograde metamorphism. Sample 69280044, another quartz-rich felsic gneiss, is composed of about 40 percent quartz, 35 percent orthoclase some of it perthitic, 15 percent andesine (An_{35}), 10 percent garnet and minor clinopyroxene, biotite, zircon, and possibly also sillimanite. There are few signs of retrograde alteration in this rock but cataclasis has produced an incipient mortar texture and lenticular crush zones which define a weak foliation.

The quartz-rich felsic gneisses have compositions that are clearly consistent with metasedimentary protoliths but the less quartzose rocks are of equivocal origin. Sample 69280045, for example, is composed of about 40 percent plagioclase (An_{44}), 25 percent quartz, 20 percent perthitic orthoclase, 10 percent hypersthene, 5 percent garnet, and minor hornblende and opaques. It has prominent deformation textures, such as bent plagioclase crystals, fine granoblastic quartz mosaics and pyroxene twins, as well as retrograde metamorphic features, such as thin hornblende and garnet rims around orthopyroxene. A rock such as specimen 69280045 could be derived from either igneous or sedimentary protoliths.

Felsic gneisses that predominate at the western end of Mount McCarthy are examplified by sample 69280043, a coarse-grained, massive, pink granulite composed of about 80 percent antiperthitic andesine (An_{35}), 10 percent perthitic orthoclase, 5 percent hypersthene, 5 percent quartz, and minor apatite, opaques, and possibly monazite; the granulite is of metasedimentary origin. The rock displays abundant evidence of cataclasis (irregular and sutured margins to felsic minerals, bent and distorted twin planes, undulose extinction of felsic minerals, and cross fracturing of crystals) and some evidence of retrograde alteration (alteration of hypersthene to biotite along irregular crystal margins).

Mafic granulites are concordantly interlayered with the felsic gneisses at Mount McCarthy and are much more abundant than at other localities described in this Record. Sample 69280062, a medium-grained, granoblastic-textured granulite, is very dark-coloured and composed of about 40 percent hornblende, a total of 35 percent orthopyroxene and clinopyroxene, and 25 percent labradorite (An_{65}). The presence of two pyroxenes and hornblende but no quartz in this rock may indicate that the reaction

$$\text{hornblende} + \text{quartz} \rightarrow \text{hypersthene} + \text{clinopyroxene} + \text{plagioclase} + H_2O$$

has proceeded until all quartz has been consumed. This rock shows few signs of cataclasis and retrograde alteration, but the lack of cataclastic effects can probably be attributed to the ductility of amphibolites. Sample 69280062 was probably derived from an ultramafic source rock; the apparent abundance of concordant mafic granulites in the sequence suggests that they might be the metamorphosed representatives of either ultramafic flows or intrusives.

Rocks of undoubted metasedimentary origin are interlayered with the felsic and mafic gneisses at Mount McCarthy, and include aluminous pelitic rocks and calc-silicate gneisses. Sample 69280050 is a pelitic gneiss composed of about 35 percent cordierite, 30 percent garnet, 15 percent sillimanite, 10 percent potash feldspar, 5 percent quartz, a total of about 5 percent of biotite and opaques, and minor spinel, zircon, and rutile. Calc-silicate gneisses at Mount McCarthy are exemplified by sample 69280053, a light-grey faintly-banded rock composed of about 35 percent calcite, 25 percent diopside, 20 percent scapolite, 10 percent wollastonite (?tremolite), 5 percent quartz, 5 percent calcic plagioclase (An_{55}), and minor sphene, zircon, and opaques. The calc-silicate gneisses at Mount McCarthy are typically complexly folded because they are less competent than contiguous layers. However, specimen 69280053, like the felsic gneisses, shows some signs of post-metamorphic cataclasis.

Metamorphism at Mount McCarthy was clearly high-grade as signified by the widespread occurrence of orthopyroxene and perthitic feldspars, but there is little evidence of partial melting. Metamorphism was therefore probably under low P_{H_2O} conditions typical of the granulite facies. The banded-gneiss sequence has yielded abundant evidence of a sedimentary origin for most of the rocks.

Numerous small shears intersect the banded gneisses at Mount McCarthy, and a few are occupied by small pegmatite masses. There are also minor pegmatite veins between 30 and 60 cm thick which are composed of coarse leucogranite with scattered biotite flakes. A few small pegmatite veins between 1 and 5 cm thick contain tourmaline, garnet, and magnetite. Although pegmatites locally form vein networks they are generally uncommon at Mount McCarthy, a fact that reflects a low degree of partial melting during metamorphism.

Beaver Lake-Radok Lake area

Traverses were made in this area by a geological field party led by A. Medvecky. The results are summarised in the publication by Mond (1972), and Bennett & Taylor (1972) gives details of chemical analyses of coal samples. No further account is necessary here, although it might be noted that the coal-bearing Permian sequence in the Beaver Lake area is the lowest exposed rock in the Prince Charles Mountains. Although the so-called Amery Fault, postulated by Crohn (1959) as separating the Permian rocks from nearby basement gneisses, may not down fault the sediments to the east and separate them from the metamorphic rocks further west, it appears likely that the sediments accumulated in a fault-bounded enclave in the basement rocks. Similar circumstances applied in the case of Permian sedimentary strata in graben-like enclaves in the Precambrian rocks of peninsular India, such as the Godavari and Mahanadi Basins. A further parallel between the Prince Charles Mountains and Indian Permian rocks lies in the fact that both are intruded by alkaline igneous rocks of Cretaceous age. Alnoites from the Radok Lake area are described by Walker & Mond (1971) who quote K-Ar ages of 110 m.y.; lamprophyres from the Indian coal basins yield K-Ar ages between 105 and 121 m.y. according to Sarkar & others (1980).

REGIONAL GEOLOGY

The regional relationships between the various mapped rock units can only be defined in largely speculative terms because of the sparse outcrop, and time and logistic restraints in the field. The rocks on the eastern side of the Amery Ice Shelf are not easily related to those on the west although all the metamorphic rocks, with the possible exception of those at Jetty Peninsula, appear to be the result of high-grade metamorphism about 1000 m.y. ago.

The relationships between the Munro Kerr Gneiss and the migmatite units to the north and south are not well known, and the possibility has been mooted (in earlier drafts of this Record) that the Gneiss represents an older unit from which the migmatites have been derived. Since these drafts, the presence or absence of tholeiitic dykes has been recognised as a critical relationship in the Prince Charles Mountains-Mawson-Vestfold Hills region and elsewhere for distinguishing older and younger rock units (Tingey, in press; Sheraton & others, 1980). In brief, the presence of multiple tholeiitic dykes signifies that the rocks they intrude are older than the 1000 $\pm$ m.y. metamorphism and are possibly of early Proterozoic or Archaean age; the absence of such dykes signifies rocks produced by the 1000 $\pm$ m.y. metamorphism. The relationship is well displayed at the northern end of the area described in this Record; gneisses at the Vestfold Hills which are intruded by a swarm of dolerite dykes of Middle Proterozoic age are 2500 m.y. old (Tingey, in press) whereas there are no such dykes intersecting the migmatites in the Rauer Islands 15 km to the south. These migmatites give a Rb-Sr whole-rock age of 1142 m.y. Because the Prydz Bay Migmatite, the Munro Kerr Gneiss, and probably the New Year Migmatite are not intersected by tholeiitic dykes, they are all considered to be products of the 1000 $\pm$ m.y. metamorphism which also affected the northern Prince Charles Mountains (see Tingey, in press, for geochronological data). Of the metamorphic rocks examined in 1969 in the Prince Charles Mountains, those at Jetty Peninsula, which are intruded by metamorphosed possibly tholeiitic dykes, perhaps constitute an enclave of older rocks; the Fox Ridge and Mount McCarthy rocks are considered to be attributable to the 1000 $\pm$ m.y. metamorphism.

Given this information, it is thought likely that differences between the Munro Kerr Gneiss and the other metamorphic rock units are best explained as functions of the exposure of different structural levels in different areas. The apparently transitional increase in migmatisation between the Munro Kerr Gneiss and the New Year Migmatite is compatible with this hypothesis; evidence of the transition includes increased abundance of felsic intrusive rocks in the Munro Kerr Gneiss at nunataks southeast of Jennings Promontory. Conversely, an apparent decrease in the degree of migmatisation in the New Year Migmatite is reported from south to north in outcrops on the western side of Gillock Island. Clearly in this area very similar rocks are assigned somewhat arbitrarily to the Munro Kerr Gneiss and New Year Migmatite; the boundary between the two units is postulated, again arbitrarily, to be east of Gillock Island between it and Rubeli Bluff (see Plate 1).

The eastern boundary of the Munro Kerr Gneiss with the Prydz Bay Migmatite is somewhat less arbitrary. No signs of migmatisation were seen in gneiss outcrops on the east side of the Polar Record Glacier, whereas similar gneiss on the nunatak 10 km to the northeast contains numerous feldspar porphyroblasts and augen. There is also an apparent northeastwards increase in the degree of migmatisation in the Bolingen Islands area, where gneiss on the southern large island is identical to that of the Sørstrene Islands 8 km to the southwest, except that there are also pink pegmatite veins. Migmatisation is more abundant in the central Bolingen Islands. However, the outcrops near the Polarforschung Glacier where the Polarforschung Granite intrudes migmatite rocks appear to be slightly anomalous unless the migmatisation can be attributed entirely to contact effects of the granite. In this area also, a transition between the Munro Kerr Gneiss and the nearby Prydz Bay Migmatite cannot be discounted. By contrast, there appears to be a major structural boundary between the New Year Migmatite in the Rauer Islands and the Archaean gneisses 10 km to the northeast in the Vestfold Hills.

The two migmatite units mapped respectively on the southern and northern margins of the Munro Kerr Gneiss have contrasting field characteristics. The New Year Migmatite, for example, consists of well-defined and regularly-banded gneissic rocks with discrete, elongate, concordant or subconcordant lenticular granite and pegmatite masses up to 20 metres wide: by contrast, gneissic compositional layers in the Prydz Bay Migmatite generally have diffuse or gradational boundaries particularly in the Larsemann Hills. Furthermore, the gneissic and granitic fractions generally grade diffusely into one another in a manner which renders the gneissic foliation highly contorted and gives no regular shape to the granitic rocks. A few thin, well-defined discordant granitic veins are present in the Prydz Bay Migmatite, which is essentially a heterogeneous mass of biotite-quartz-feldspar gneiss, with irregular granitic masses. In general the Prydz Bay Migmatite contains less pyroxene and more garnet than the New Year Migmatite. This slight difference probably reflects different original rocks rather than markedly different metamorphic conditions.

The Jennings and Gillock Charnockites, which are respectively thought to intrude - although no contacts are exposed - the Munro Kerr Gneiss and New Year Migmatite, are slightly different in character but are probably the products of the same high-grade metamorphism that produced the nearby country rocks. In the northern Prince Charles Mountains small enclaves of charnockite in the granulite-facies gneisses appear to be of much the same age as those rocks, that is, about 1000 ± m.t. (Tingey, in press). The two charnockites on the east side of the Amery Ice Shelf are thought to be of about the same age because of the Rb-Sr age (1042 m.y.) of the New Year Migmatite as determined at Pickering Nunatak. A K-Ar whole-rock age of 420 m.y. reported by Ravich & Krylov (1964) for rocks from the Jennings Promontory is, if meaningful, a minimum estimate only; however, K-Ar whole-rock isotope systems in coarsely crystalline rocks are notoriously susceptible to disturbance and argon loss, and the age is quite likely to be meaningless.

The intrusives at Landing Bluff and near the Polarforschung Glacier are, by contrast, considered to postdate the main metamorphism. The differences between those two intrusives can probably be attributed to the amount of country rock contamination, which is especially marked in the Polarforschung Granite, near its exposed contact with migmatitic rocks. Samples of the Landing Bluff Adamellite have given a Rb-Sr whole-rock age of 504 m.y., and the Polarforschung Granite is thought to be of similar vintage. Production of granitic intrusions at about this time appears to be a manifestation of a widespread thermal-metamorphic episode which could perhaps be related to the Ross Orogeny in Antarctica and the Pan African event over Gondwanaland; and Tingey (in press) describes intrusive activity and isotope system resetting at about 500 $\pm$ m.y. from the Prince Charles Mountains/Mawson Coast area.

The Pan African event and the thermal metamorphic episode recorded in the Prince Charles Mountains-Mawson Coast-Amery Ice Shelf area took place in what was then the interior of the Gondwanaland supercontinent; Sutton (1977) has suggested that 'early Palaeozoic changes' were presumably related either to contemporary movements of the Pacific floor relative to the continental block of Antarctica or connected with a widespread fracturing of the interior of the (Gondwanaland) supercontinent. He further postulates that both mantle and crust may have been permanently altered by an event such as the Pan African or Ross episodes, and notes that Kennedy (1965) was the first to observe that many coastlines formed by the Mesozoic and Cainozoic break-up of Gondwanaland lie within Pan African belts. Sutton also suggests that structures related to 'early Palaeozoic changes' provide an opportunity to link the pre-break up deformation of Gondwanaland with movement of the surrounding ocean floor now recorded in the Ross Orogen of the Transantarctic Mountains, which was the Gondwanaland Pacific Margin in early Palaeozoic times. Sutton concludes that although there is evidence for extensive intra-plate deformation during the Pan African event, there is none in the Antarctic and African cratons for the opening and closing of newly-formed oceans. Clearly, then, Sutton believes that early Palaeozoic events had profound significance for the ultimate break up of Gondwanaland. Since the early Palaeozoic intrusives in the area at present under consideration lie along a major intra-Gondwanaland rift structure it seems reasonable to link them with the intra-plate Pan African structures discussed by Sutton (1977).

The regional significance of the Permian strata at Beaver Lake has been discussed and needs no further elaboration. The younger rocks found during the 1969 season are the alkaline intrusives near Fox Ridge and at Radok Lake. These may reflect the evolution of the major crustal structure now occupied by the Lambert Glacier and Amery Ice Shelf. The dyke described from New Year Nunatak may also be attributable to this. Wellman & Tingey (1976) describe gravity evidence for the crustal structure but there are few signs in outcrop. Soviet scientists carried out a seismic traverse across the Amery Ice Shelf and deduced a graben structure

(Fedorov & others, in press). Some lateral displacement along the east side of the Amery Ice Shelf might be inferred if the Jennings and Gillock Charnockites were assumed to be displaced relics of the same original rock mass. In this case, a speculative estimate of displacement might be 25 km.

The history of Antarctic glaciation is as yet poorly documented from this part of East Antarctica although appropriate Cenozoic sediments may exist beneath Beaver Lake, and in the Vestfold Hills lakes. Kemp (1975) described Eocene palynomorphs from marine sediments dredged to the north of the Amery Ice Shelf, and deduced that the area was forested at that time. The possibility of accumulations of Mesozoic and Cenozoic sediments beneath the Amery Ice Shelf is an interesting speculation, particularly from the point of view of Antarctic mineral (specifically petroleum) resources, but appropriate investigations have yet to be made. The possibility of surging of the Lambert Glacier system has attracted considerable interest since it was postulated on glaciological grounds (Budd & McInnes, 1979). Wellman (in press) has deduced from geomorphological data that at least the upper part of the Lambert Glacier system has surged; this is supported by the glaciological research reported by Allison (1979). In a related analysis, Wellman & Tingey (1981) postulate that the removal of up to 1½ km of rock by glacier erosion in narrow channels has caused about 1 km of local isostatic uplift.

The region described in this Record will be revisited in subsequent field seasons. It is a poorly-exposed and poorly-known part of the overall Lambert Glacier basin which provides the best geological cross-section of the interior of East Antarctica. In 1969, field techniques, and especially the use of helicopters, were at an early stage of the development which has seen the progressive evolution of highly efficient multidisciplinary ANARE field operations in the Prince Charles Mountains and in Enderby Land. Future field seasons on the east flanks of the Amery Ice Shelf and Prydz Bay should help clarify several problems that remain.

ACKNOWLEDGEMENTS

We gratefully acknowledge the assistance given to us often under arduous conditions by our ANARE field party companions, ably led by G. McKinnon then Geographical Officer of the Antarctic Division. All field support, transport to and from Antarctica, and field clothing was supplied by the Antarctic Division.

ALLISON, I.R., 1979 - The mass budget of the Lambert Glacier drainage basin, Antarctica. Journal of Glaciology, 87, 223-35.

BALME, B.E., & PLAYFORD, G., 1967 - Late Permian plant microfossils from the Prince Charles Mountains, Antarctica. Revue Micropaleontologie, 10(3), 179-192.

BENNETT, A.J.R., & TAYLOR, G.H., 1972 - Coals from the vicinity of the Prince Charles Mountains. In ADIE, R.J., (Editor) - ANTARCTIC GEOLOGY AND GEOPHYSICS. Universitetsforlaget, Oslo, 591-98.

BINNS, R.A., 1964 - Zones of progressive regional metamorphism in the Willyama Complex, Broken Hill district, New South Wales. Journal of the Geological Society of Australia, 11, 283-330.

BUDD, W.F., & McINNES, B.J., 1979 - Periodic surging of the Antarctic Ice Sheet - an assessment by modelling. Hydrological Sciences, 24(1), 95-104.

CSIRO (1957) - Examination of samples from Prince Charles Mountains, Antarctica. CSIRO unpublished report.

CROHN, P.W., 1959 - A contribution to the Geology and Glaciology of the western part of Australian Antarctic Territory. Bureau of Mineral Resources, Australia, Bulletin 52.

FEDOROV, L.V., GRIKUROV, G.E., KURININ, R.G. & MASOLOV, V.N., in press - Crustal structure of the Lambert Glacier area from geophysical data. In CRADDOCK, C.C. (Editor) - ANTARCTIC GEOSCIENCE. University of Wisconsin Press, Madison.

KEMP, E.M., 1975 - Reworked palynormorphs from the West Ice Shelf area, East Antarctica, and their possible geological and palaeoclimatological significance. Marine Geology 13, 145-57.

KENNEDY, W.Q., 1965 - The influence of basement structure on the evolution of the coastal (Mesozoic and Tertiary) basins of Africa. In SALT BASINS AROUND AFRICA. London Institute of Petroleum, London, 7-16.

McLEOD, I.R., 1959 - Report on Geological and Glaciological work by the 1959 ANARE, Bureau of Mineral Resources, Australia, Record 1959/131, (unpublished).

McLEOD, I.R., 1964 - The saline lakes of the Vestfold Hills, Princess Elizabeth Land. In ADIE, R.J. (Editor) - ANTARCTIC GEOLOGY. North Holland, Amsterdam, 65-72.

McLEOD, I.R., TRAIL, D.S., COOK, P.J., & WALLIS, G.R., 1966 - Geological work in Antarctica, January-March 1965. Bureau of Mineral Resources, Australia, Record 1966/9 (unpublished).

MOND, A., 1972 - Permian sediments of the Beaver Lake area, Prince Charles Mountains. In ADIE, R.J. (Editor) - ANTARCTIC GEOLOGY AND GEOPHYSICS. Universitets-Universitetsforlaget, Oslo, 585-90.

RAVICH, M.G., & VORONOV, P.S., 1958 - Geological structure of the coast of the East Antarctic continent (between 55° and 110° east longitude). Soviet Geology, 2, 3-26.

RAVICH, M.G., & KRYLOV, A.J., 1964 - Absolute ages of rocks from East Antarctica. In ADIE, R.J., (Editor) - ANTARCTIC GEOLOGY. North Holland, Amsterdam, 579-589.

RAVICH, M.G., KLIMOV, L.V., & SOLOVIEV, D.S., 1965 - THE PRECAMBRIAN OF EAST ANTARCTICA. English translation published 1968 for the United States National Science Foundation, Washington, D.C., by the Israel Program for Scientific Translations.

SARKAR, A., PAUL, D.K., BALASUBRAMMANYAN, M.N., & SENGUPTA, N.R., 1980 - Lamprophyres from Indian Gondwanas - K-Ar ages and Chemistry. Journal of the Geological Society of India, 21, 188-193.

SHERATON, J.W., in press - Origin of charnockitic rocks of MacRobertson Land. In CRADDOCK, C.C. (Editor) - ANTARCTIC GEOSCIENCE. University of Wisconsin Press, Madison.

SHERATON, J.W., OFFE, L.A., TINGEY, R.J. & ELLIS, D.J., 1980 - Enderby Land, Antarctica - an unusual Precambrian high grade metamorphic terrain. Journal of the Geological Society of Australia, 27, 1-18.

SOLOVIEV, D.S., KAMENEV, E.N., & RAVICH, M.G., 1967 - Geological activities in 1965/66. Soviet Antarctic Expedition Information Bulletin No. 62, 10-18.

SPRY, A., 1969 - METAMORPHIC TEXTURES. Pergamon Press, Oxford, 350 pages.

SUBRAMANIAM, A.P., 1959 - Charnockites of the type area near Madras - a reinterpretation. American Journal of Science, 257, 321-53.

SUTTON, J., 1977 - Antarctica, a key to the understanding of the evolution of Gondwanaland. Philosophical Transactions of the Royal Society of London, Series B, 279, (No. 963), 197-206.

TILLEY, C.E., 1936 - Enderbite - a new member of the Charnockite Series. Geological Magazine, 273(865), 312-316.

TINGEY, R.J., 1976 - Basic and alkaline intrusive rocks in the Prince Charles Mountains. In GEOLOGY BRANCH SUMMARY OF ACTIVITIES. Bureau of Mineral Resources, Australia, Report 194, p.73.

TINGEY, R.J., in press - The Geologic evolution of the Prince Charles Mountains - an Antarctic Archaean cratonic block. In CRADDOCK, C.C., (Editor) - ANTARCTIC GEOSCIENCE. University of Wisconsin Press, Madison.

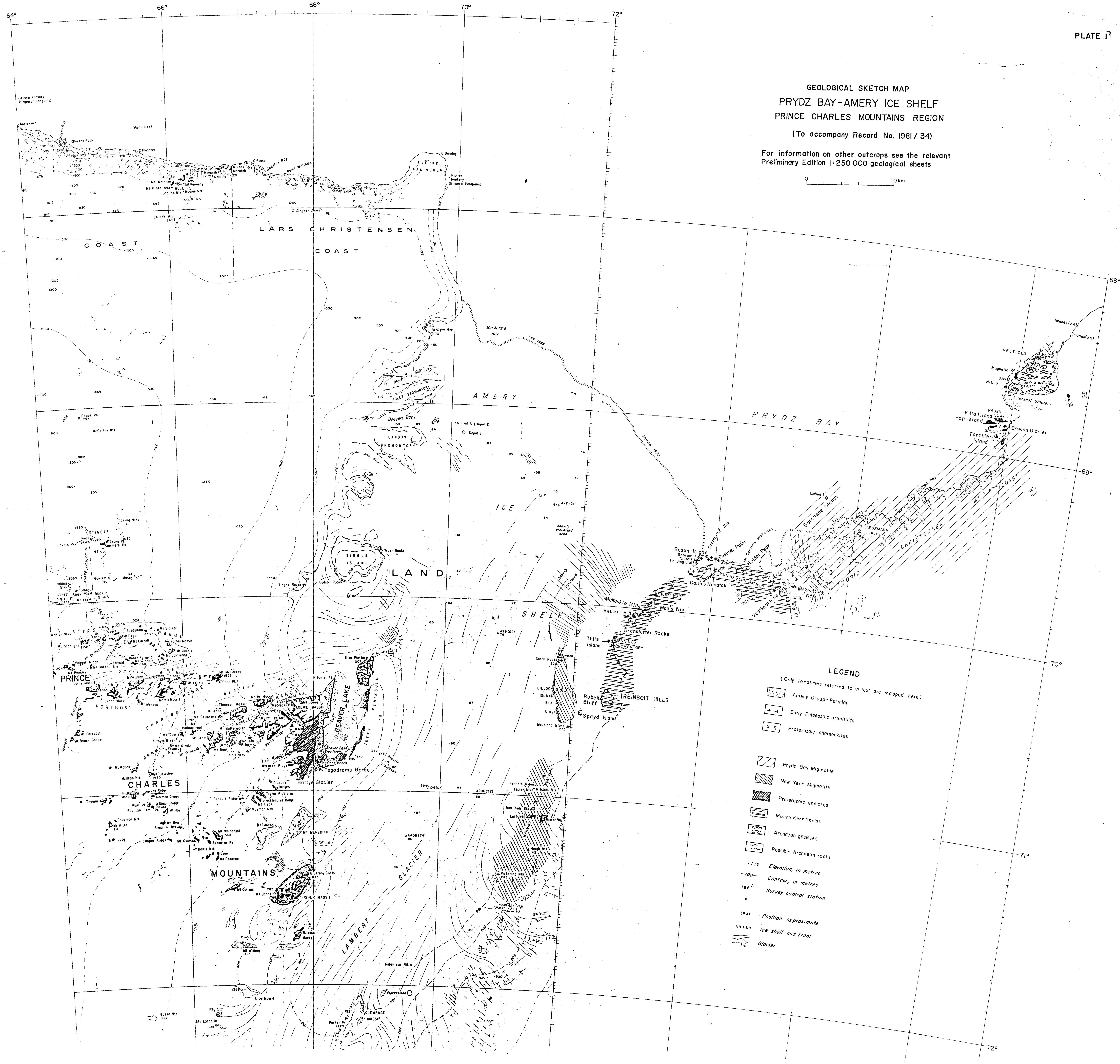
WALKER, K.R., & MOND, A., 1971 - Mica lamprophyre (alnoite) from Radok Lake, Prince Charles Mountains, Antarctica. Bureau of Mineral Resources, Australia, Record 1971/108.

WELLMAN, P., in press - Surging of the Fisher Glacier, Eastern Antarctica; evidence from geomorphology. Journal of Glaciology.

WELLMAN, P., & TINGEY, R.J., 1976 - Gravity evidence for a major crustal fracture in eastern Antarctica. BMR Journal of Australian Geology and Geophysics, 1, 105-108.

WELLMAN, P., & TINGEY, R.J., 1981 - Glaciation, erosian and uplift over part of East Antarctica. Nature, 291, 142-144.

PLATE II


GEOLOGICAL SKETCH MAP
PRYDZ BAY-AMERY ICE SHELF
PRINCE CHARLES MOUNTAINS REGION
(To accompany Record No. 1981/34)
For information on other outcrops see the relevant Preliminary Edition 1:250 000 geological sheets
50 km
LEGEND
(Only localities referred to in text are mapped here)
Amery Group - Permian
Early Palaeozoic granitoids
Proterozoic charnockites
Prydz Bay Migmatite
New Year Migmatite
Proterozoic gneisses
Munro Kerr Gneiss
Archaean gneisses
Possible Archaean rocks
Elevation, in metres
Contour, in metres
Survey control station
(PA) Position approximate
Ice shelf and front
Glacier
LARS CHRISTENSEN COAST
AMERY ICE SHELF
LAND
PRYDZ BAY
INGRID CHRISTENSEN COAST
PRINCE CHARLES MOUNTAINS
BEAVER LAKE
LAMBERT GLACIER
VESTFOLD HILLS
LARSEMANN HILLS
REINBOLT HILLS
FISHER MASSIF
CLEMENCE MASSIF
Mackenzie Bay
Pagodroma Gorge
Battye Glacier
Bosun Island
Collins Nunatak
Mt Meredith
Mt Collins
Mt Willing
64°
66°
68°
70°
72°
68°
69°
70°
71°
72°