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GEOLOGICAL WORK IN ANTARCTICA, JANUARY TO MARCH, 1965

by

I.R.McLeod, D.S.Trail, P.J.Cook and G.R.Wallis

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CONTENTS

		Page
SUMMARY		
PART I :	GENERAL INTRODUCTION	
	INTRODUCTION	1
	BACKGROUND	1
	ACKNOWLEDGMENTS	2
	OBJECTIVES	3
	LOGISTICS	3
	RESULTS	4
	NARRATIVE	5
PART II :	MAC.ROBERTSON, KEMP, AND ENDERBY LANDS	10
	INTRODUCTION	10
	PREVIOUS WORK	10
	GEOMORPHOLOGY	10
	ICE	10
	LANDFORMS	12
	Nunataks	12
	Cirques	12
	Coastal erosion surface	12
	Weathering	14
	QUATERNARY DEPOSITS	15
	Lake sediment	15
	Stream sediment	15
	Raised beaches	16
	Rock detritus	18
	Moraine	18
	PATTERNED GROUND	20
	GEOLOGY	23
	REGIONAL GEOLOGY	23
	CHARNOCKITE	24
	Framnes Mountains	25
	Baillieu Peak and neighbouring nunataks	26
	Outlying islands	27
	Ufs Island and Stump Mountain	28
	William Scoresby Bay	31
	Western Kemp Land	31

Page

BANDED GNEISS 32

Outlying islands off William Scoresby Bay 33
Bertha Island 34
Stillwell Hills 34
Cosgrove Glacier to Gwynn Bay 37
Cape Boothby to Turbulence Bluffs 40

QUARTZ-FELDSPAR GNEISS 44

GNEISSES OF TAYLOR GLACIER 45

GARNETIFEROUS GNEISSES OF MOUNT KERNOT, ETC. 47

GNEISS, MARBLE AND MIGMATITE OF HANSEN MOUNTAINS 51

PYROXENE-QUARTZ-FELDSPAR GNEISSES OF CASEY RANGE 54

BASIC AND ULTRABASIC DYKES 56

STRUCTURE 58

Foliation 58
Lineation 59
Folds 59
Mylonitic rocks 60
Faults 60

ECONOMIC GEOLOGY 60

Sulphides 60
Iron oxide and related minerals 61
Graphite 62
Sillimanite 62
Silica 62
Guano 62

GEOLOGICAL HISTORY 62

Original rocks 62
Metamorphic history 63
Late geological history 64

SAMPLES FOR AGE DETERMINATION 65

PART III: THE VESTFOLD HILLS 71

INTRODUCTION 71

PREVIOUS WORK 71

PHYSIOGRAPHY 71

GEOLOGY 72

UNIT 1 72

UNIT 2 74

UNIT 3 75

DOLERITE DYKES 76

NORITE 77

STRUCTURE 77

PART IV : RECENT MARINE SEDIMENTS, CONTINENTAL SHELF 79

INTRODUCTION 79

PREVIOUS WORK 80

SAMPLING PROCEDURE 80

RECOMMENDATIONS 81

	Page
LABORATORY TECHNIQUE	81
RESULTS OF SEDIMENTOLOGICAL WORK	82
PALAEONTOLOGICAL RESULTS	83
REFERENCES	85

TABLES

Table I	Locality references for specimens collected for radiometric age determination	70
Table II	Sea floor sample localities	79
Table III	General textural proportions of Recent marine sediments from the continental shelf, Antarctica.	84

ILLUSTRATIONS

FIGURE

1 Plateau summits in the Jagar Islands

2 Raised beach and strandline, Chapman Ridge

3 Fan of rock debris, with typical Stillwell Hills topography

4 Channel cut in fan of rock debris, Stillwell Hills

5 Typical mound in ice-cored moraine, Stump Mountain

6 Polygonal pattern of cracks in rock detritus, Ives Tongue

7 Stone circles on Kemp Peak

8 Charnockite containing bodies of quartz-feldspar rock, with both rocks cut by seams of mylonite

9 Typical banded gneiss, Stillwell Hills

10 Ptygmatic-like fold in banded gneiss

11 Fold in banded gneiss, cut off by recrystallization

12 Pegmatite in banded gneiss, Cape Dalton

13 Glacial markings on pyroxene-garnet-biotite-quartz-feldspar gneiss, Striated Nunatak

14 Recumbent fold in garnet and pyroxene-bearing quartz-feldspar gneiss.

15 A. Near-isoclinal folds, Fram Peak
B. Open folds, Hansen Mountains

16 Folding and thrusting in finely-banded gneiss, Casey Range

17 Metamorphosed basic dyke in banded gneiss, Jagar Islands

18 Sketch section showing possible zone of secondary enrichment, Stillwell Hills

19 Possible relict cross-bedding, Vestfold Hills

20 Oceanographic bottom sampler

21 Oceanographic bottom sampler being lowered through sea-ice

PLATE

1 Geological camps and helicopter traverses, Mac.Robertson, Kemp, and Enderby Lands

2 Geological sketch map, Mac.Robertson, Kemp, and Enderby Lands

3 (a) Interpretative sketch map of geological structure between Ufs Island and Norris Island

PLATE

(b) Diagrammatic sketch map of contact between charnockite and gneiss near Ufs Island

(c) Sketch map of biotite-rich band transgressing foliation, Tschuffert Peak.

4 Geological sketch map, Bertha Island

5 Geological sketch map, northern Stillwell Hills and adjacent islands

6 Geological flight lines and ground traverses, Vestfold Hills

7 Geological sketch map, Vestfold Hills

8 Location of sea floor sampling sites.

GEOLOGICAL WORK IN ANTARCTICA, JANUARY TO MARCH, 1965.

SUMMARY

Early in 1965, Bureau of Mineral Resources geologists, seconded to the Australian National Antarctic Research Expeditions, used ship-based helicopters to survey the coastal region in Mac.Robertson Land and Kemp Land, Antarctica. Mapping was completed on six 1:250,000 sheets and brief traverses were made on three others. The Vestfold Hills (long. 78°E.) were also traversed, and sea-floor sediment samples were taken on the continental shelf between long. 57°E. and long. 78°E.

In Mac.Robertson Land and Kemp Land, charnockite forms the bulk of exposures between long. 61°E. and long. 64°30'E., and crops out within the banded gneiss, and at Magnet Bay and Wheeler Rocks. It is principally feldspar and quartz with minor pyroxene, generally uniform, poorly foliated, and even-grained, but porphyroblastic in places. Banded gneiss is predominant between long. 56°30'E. and long. 60°E., north of lat. 67°30'S. Bands, up to 10 metres wide, of light-coloured, foliated quartz-feldspar gneiss alternate regularly with dark, rather massive pyroxene-feldspar gneiss. Quartz-feldspar gneiss forms most exposures examined west of long. 56°30'E. and north of lat. 67°10'S. It is medium-grained and moderately foliated to massive, with thin discontinuous banding in parts. Its boundary with the banded gneiss is possibly transitional. Biotite-garnet-quartz-feldspar gneiss, commonly with sillimanite and with migmatitic granite, occupies the coast around Taylor Glacier, between the main area of charnockite and the area of banded gneiss. It is typically medium-grained, well foliated and thinly banded. It appears to be interbanded locally with both charnockite and banded gneiss. Garnetiferous gneisses are a heterogeneous unit forming nunataks at about long. 56°E. lat. 67½°S. The rocks are principally variants of pyroxene-feldspar gneiss, quartz-feldspar gneiss, biotite-bearing gneiss, and quartzite, with more or less garnet, and range from well banded and well foliated to massive. A transition may exist between this unit and the quartz-feldspar gneiss. The isolated Hansen Mountains are made up of foliated migmatitic granite and biotite-quartz-feldspar gneiss, garnet quartzite, and thick bands of impure marble. Casey Range is predominantly finely banded, fine-grained to medium-grained biotite-garnet-pyroxene-quartz-feldspar gneiss and quartzite, commonly with sillimanite; its relation to the other units is not known.

Basic and ultrabasic dykes cut charnockite, banded gneiss, garnetiferous gneiss, and quartz-feldspar gneiss. Some are foliated and poorly banded; many are metamorphosed. The basic dykes are pyroxene-feldspar rocks, the ultrabasic are predominantly pyroxene. Some are cut by massive pegmatite.

East of long. 60°E. foliation trends approximately north; west of this meridian the predominant trend is about east-south-east. Large and small near-isoclinal folds are common in the

banded rocks. Mylonitic rocks are common throughout the charnockite. Only minor occurrences of metallic minerals were found.

The prominently banded rocks are probably metasediments or metavolcanics. The massive and uniform charnockite and quartz-feldspar gneiss may be metamorphosed igneous rocks or thoroughly recrystallised metasediments. The first discernible metamorphism took place under granulite facies conditions. Later, the rocks were folded, basic dykes were intruded, and some recrystallization occurred under almandine-amphibolite facies conditions.

In the Vestfold Hills three rock units were distinguished. Boundaries between them appear to be transitional over a fairly narrow interval. Unit 1 is quartz-feldspar gneiss with thin bands resulting from variations in the content of mica, garnet, and pyroxene. Unit 2 is a uniform quartz-feldspar gneiss with minor thin dark bands rich in pyroxene, garnet, diopside, or biotite. Unit 3 is a quartz-feldspar gneiss with variable amounts of pyroxene and biotite; amphibolite and mica schist are minor variants. Dolerite dykes, up to 25 metres thick, form a prominent swarm. Most trend about north-north-east or north-west, and dip steeply. A norite intrusion about 300 by 100 metres may be a feeder.

Sea-floor sediment samples were obtained at localities unevenly distributed on the continental shelf between long. 57°E. and long. 78°E. Much of the ruditic fraction in the one terrestrial glacial deposit examined is absent in the marine sediments. The arenite:lutite ratio averages about 1:1 in marine and possibly lacustrine samples.

PART I GENERAL INTRODUCTION

INTRODUCTION

This Record describes the geological work done in 1965 in conjunction with the relief of the Australian National Antarctic Research Expeditions (ANARE) stations Mawson and Davis. The main aspects of the investigation were: examination of the Vestfold Hills, continuation of mapping of the coastal area from Mawson to west of Edward VIII Gulf and up to 50 miles inland, and collection of sea-bottom sediment samples. Each of these three aspects is described in a separate part of this Record.

The report is a preliminary one only. With a few exceptions, thin-section descriptions of rock specimens collected are not available, and petrographic names are based on hand-specimen identifications. A final report, which will also take into account the results of earlier work, will be prepared when laboratory work is completed.

BACKGROUND

The ANARE scientific station Mawson was established early in 1954. In this and succeeding years, a geologist of the Bureau of Mineral Resources was seconded to ANARE each year to make a geological survey of the region accessible from Mawson and, later, from Davis, another station 400 miles east of Mawson. By early 1961, the geologists had made a reconnaissance geological survey of most of the sector between longitudes 45°E and 80°E, inland to latitude 75°S. They used several means of transport, ranging from aircraft to dog sledge, for this work. However, aircraft were not available to the 1961 and later expeditions, so that the much slower surface transport had to be used for all journeys from Mawson.

In 1961, the wintering geologist (D.S. Trail) commenced systematic mapping at a scale of 1:250,000. He covered part of the Framnes Mountains, and much of the coast between the Robinson Group (30 miles east-north-east of Mawson) and the Oygarden Group and Kloa Point (160 miles west of Mawson). He also spent three months on a long sledging journey to Mount Menzies, 400 miles south of Mawson, to investigate a small part of an important area outstanding from the earlier reconnaissance work.

It was apparent, however, that if only the surface transport then available was used, travelling would take a large part of the geologist's time, and extension of the 1:250,000 scale mapping would be slow. Consequently, the 1962 and later expeditions did not include a geologist. Another difficulty was that Mawson is usually relieved in late January, so that at least a month of the best part of the year for field work could not be used.

Those connected with the geological and cartographic survey work were agreed that the most efficient use of men and facilities could be made by mounting a largely self-contained, expedition during the summer, using several geologists and surveyors, and transporting them from place to place by helicopter. By such intensive work, a large area of country could be covered in a short time, during the season best suited for field work. In 1962, officers of the Bureau and of the Antarctic Mapping Branch of the Division of National Mapping in consultation prepared an outline proposal for work along these lines.

Because only one ship was then available each summer, the time remaining after ANARE relief operations was not sufficient to enable the proposals to be put into effect.

In mid-1964 the Antarctic Division of the Department of External Affairs learnt that it could charter a second ship for three months. An intensive field operation was planned, using several geologists and surveyors, with helicopter transport. The ship's prime function was to relieve Mawson and Davis, but 5 weeks were to be available for the field work. The region selected for the operation was eastern Enderby Land, Kemp Land, and MacRobertson Land, i.e. the sector between longitude 54°E and about the longitude of Mawson (63°E). Four geologists were seconded from the Bureau of Mineral Resources for the expedition: I.R. McLeod, D.S. Trail (each of whom had wintered at Mawson), P.J. Cook, and G.R. Wallis (on loan from the New South Wales Geological Survey).

ACKNOWLEDGEMENTS

The authors have pleasure in acknowledging the assistance given by many expedition members; these members are too many to name individually, but we would like to single out: R. Lachal, of the 1965 party, for his assistance in the field in the early stages of the work, P. Martin, leader of the 1964 Mawson party, who helped collect samples for age measurement, and N. Trott, leader of the 1964 Davis party, for his interest and enthusiasm in collecting water samples from the lakes of the Vestfold Hills; the helicopter pilots, Captains J. Arthurson, G. Treatt, and B. Saw, and Beaver pilot Captain J. Whiting; the members of the survey team, S. Kirby, R. Maruff, M. Corrie, and J. Farley; the leader of the expedition, Dr. P.G. Law, who had responsibility for the overall programme of the expedition and the safety of the men; his lieutenant, E. Macklin, for his assistance in many ways; and finally Captain H. Chr. Petersen and the officers and crew of the "Nella Dan", especially the Chief Officer, B. Heckmann, for their never-failing courtesy and co-operation, and particularly for their help in the oceanographic work.

The Officer-in-Charge of the Antarctic Mapping Branch of the Department of National Development, Dr. A. T. Gale, and his staff readily supplied maps and other cartographic information. Dr. K.A.W. Crook, of the Australian National University, kindly made sedimentological equipment available and offered valuable advice related to study of the sea-bottom sediment samples.

OBJECTIVES

The aim of the geological programme was to map at a scale of 1:250,000 the rock exposures within about 60 miles of the coast, from longitude 54°E eastwards to Mawson and the Framnes Mountains. The work was to be directed to completing successively the areas covered by the standard 1:250,000 sheets in the sector, viz. SQ40-41/9 (Magnet Bay), SQ40-41/10 (Oygarden), SQ40-41/13 (Leckie Range), SQ40-41/14 (Law Promontory), SQ40-41/15 (Mawson), SQ40-41/16 (Mount Henderson), SR40-41/1 (Dismal Mountains), SR40-41/2 (Hansen Mountains), SR40-41/3 (Mt. Twintop), and SR40-41/4 (Anniversary Nunataks). Less than 5 percent of the area represented by these sheets is rock; the remainder is either ice sheet or sea. Parts of the Oygarden, Law Promontory, Mawson and Mount Henderson sheets had already been mapped at 1:250,000 scale by Trail; mapping of these sheet areas was to be completed, but the main effort was to be concentrated on the numerous outcrops in and south of the eastern half of the Enderby Land Peninsula. Specimens were to be collected for age determination and palaeomagnetic work where appropriate, and samples of sea-bottom sediments were to be collected as the opportunity offered. While the ship was at Davis, the Vestfold Hills were to be investigated to the fullest possible extent, and water samples collected from Deep Lake.

The surveyors planned a tellurometer traverse between Mawson and the Napier Mountains, via the Framnes Mountains, Baillieu Peak, Fram Peak, Leckie Range, Rayner Peak, and Aker Peaks. Several runs of trimetrogon aerial photography were to be flown.

LOGISTICS

The field parties were transported by three Bell H47-G2 helicopters, on charter from Helicopter Utilities Pty.Ltd. The DHC-2 Beaver owned by ANARE, and operated by Helicopter Utilities, was used for trimetrogon photography, and to build up fuel dumps and move the field parties. Weather forecasts were provided by an officer of the Meteorological Bureau (Mr. N. Lied) using data radioed from Mawson (which is a "mother" station in the Antarctic weather network) and synoptic charts received by "Seafax" equipment on the ship.

The ship was the base for all operations, except those in the vicinity of Mawson and Davis. It was moored to the edge of fast-ice or large floes near the Jagar Islands, north-east of Edward VIII Gulf, and the Beaver (until the mishap which rendered it unserviceable) and helicopters operated from this ice.

The original intention was for the geologists to work as separate parties. The parties were to stay in the field for the whole operation if necessary, moving from place to place by helicopter. The larger rock exposures were to be traversed on foot, and the smaller and outlying nunataks visited by helicopter. For several reasons, this plan was not adhered to: the time available for work in the Edward VIII Gulf area was less than planned, the performance of the helicopters was less than was anticipated, and the Beaver was unserviceable after it had broken through the sea-ice (see "Narrative"). Consequently, only six geological camps were established during the whole operation, and most of the work was done during helicopter traverses which allowed only a short time on each outcrop. The location of the camps, and traverse routes, are shown on Plate 1.

In the Vestfold Hills, the geologists were positioned for, and picked up from, foot traverses by helicopter; they also landed briefly at several places (Plate 6). The helicopter also transported equipment to and from Deep Lake for the water sampling there.

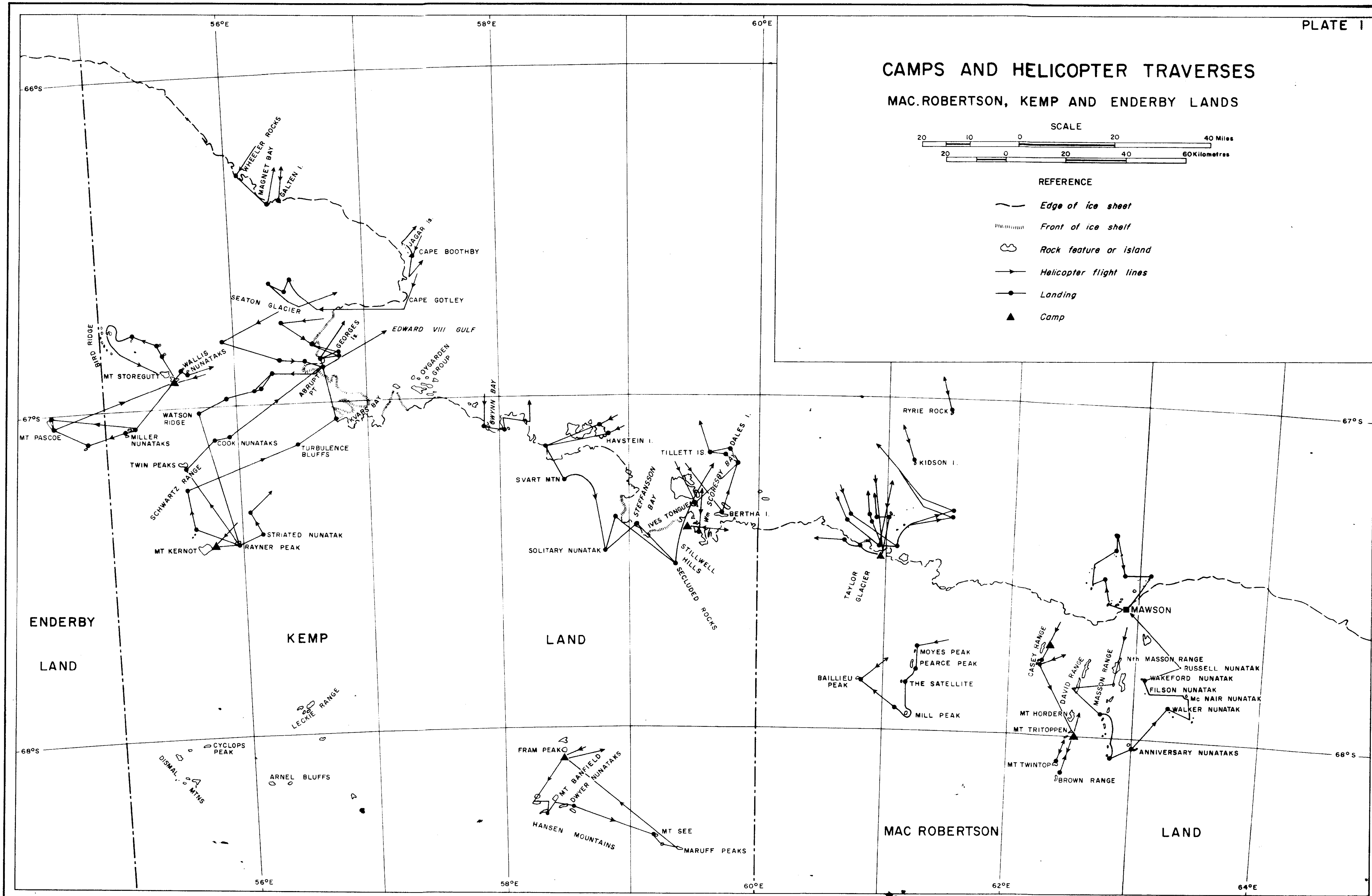
RESULTS

For various reasons, which will be apparent from a reading of the "Narrative", the objectives were only partly achieved.

Almost all the previously unvisited exposures on the Øygarden, Law Promontory, Mawson and Mount Henderson sheets were examined, and mapping of these sheets and the Mt. Twintop and Anniversary Nunataks sheets was completed to a satisfactory standard. Most of the exposures on the northern half of the Leckie Range sheet were visited briefly, but the only ground traverse occupied half a day, on Mount Kernot. On the Magnet Bay sheet the exposures visited are all on the eastern half of the sheet; the only ground traversing was a day and a half spent on Mount Storegutt and Mount Mueller. The exposures examined on these two sheet areas are mostly small nunataks. Examination of the few nunataks on the Hansen Mountains sheet was, except for Fram Peak, brief and only at reconnaissance standard. No outcrops on the Dismal Mountains sheet were visited.

Samples for age measurement were obtained from most of the mappable units encountered, and samples for palaeomagnetic work were collected. The Vestfold Hills were traversed on foot from north to south, and some helicopter traverses made. Water samples were collected at various depths from one of the saline lakes. Sea bottom sediment samples were collected from 16 localities.

PLATE I



Bureau of Mineral Resources, Geology and Geophysics, Jan. 1966

To Accompany Record 1966/9

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NARRATIVE

The M.S. "Nella Dan" (Captain H. Chr. Petersen) sailed from Melbourne about 5.15p.m.on22nd December, 1964. The voyage to Mawson was remarkably smooth, and only a few miles of pack ice, about 30 miles from Mawson, had to be traversed. The ship anchored outside the harbour on the evening of 3rd January. Mail, some fresh food, and equipment were flown ashore by helicopter; some of the new party went ashore and some of the old party came on board, and the "Nella Dan" sailed for Edward VIII Gulf shortly before midnight.

About 9.30 a.m. next day, heavy pack ice was encountered about lat. 66°50'S, long. 60°E, and the ship turned north, skirting the edge of the pack. The weather was too bad for flying - overcast, with snow showers and poor visibility.

The ship steamed northwards to lat. 64°55'S, long. 61°40'E without finding any break in the pack, and after remaining hove to for some time turned south again. On the afternoon of 7th January, with the ship at about lat. 66¾°S, long. 60°E, the weather cleared sufficiently for an ice reconnaissance flight to be made. This showed that the edge of the pack extended to the north and east of the ship's position as far as the eye could see; pack ice, with fast ice beyond it, stretched westwards and southwards to the coast. Edward VIII Gulf was obviously quite inaccessible. The leader of the expedition, Dr. Law, decided to return to Mawson and relieve the station, while the geologists and surveyors did the work planned for that part of the sector. The ship would then go to Davis and close that station. By the time this was finished, the ice would probably have broken out, so that Edward VIII Gulf could be reached.

On the 8th January, the four geologists were landed by helicopter about 5 miles south-east of Taylor. Trail and R. Lachal, a member of the 1965 party, remained camped there, while the others returned to the ship, traversing some of the offshore islands on the way. Next day McLeod and Cook were flown into the Stillwell Hills, south-west of William Scoresby Bay, for several hours geological work. On their return, they flew to Ryrie Rock and Kidson Island, two previously unvisited islands well out from the coast, and meanwhile, the "Nella Dan" got under way for Mawson. The same morning the Beaver aircraft was flown from sea-ice alongside the ship to a temporary base on the ice airfield 10 miles inland from Mawson. On the several occasions from 6th to the 9th when the ship was hove to, samples of sea bottom sediments were collected.

The ship reached Mawson early on the morning of 10th January, but was unable to tie up in the harbour because the katabatic wind was blowing strongly. It was not until that afternoon, when the wind died down, that the ship was tied up and relief operations began.

Cook and Wallis were flown to a camp at the Casey Range that afternoon. The next afternoon, McLeod was flown to Mount Twintop in conjunction with a survey party, and returned to the ship late that night. On the 12th January, Trail was moved from his camp near Taylor to the north end of the Stillwell Hills, near

Stefansson Bay. The next day, Cook and Wallis were moved to Mount Tritoppen; they also visited Woodberry Nunataks and Lucas Nunatak, south of the Casey Range, and Brown Range, south of Mount Twintop. Meanwhile, the surveyors had extended their traverse to Baillieu Peak. On the 14th January, wind speeds at Mawson were up to 50 knots, and flying was not possible. The wind did not moderate until the 19th, and the two geological parties were brought back to the ship later that day. The next day, McLeod spent several hours at Baillieu Peak while survey parties were moved.

The 21st January was overcast and snowing. The "Nella Dan" sailed for Davis that afternoon, taking one helicopter, and leaving the other two (one of which was temporarily unserviceable), and the Beaver. Trail also remained at Mawson to try to complete that part of the geological programme.

The "Nella Dan" arrived at Davis on the afternoon of 23rd January. The "Thala Dan" had arrived that morning, and much of the work of closing the station had been done. The "Thala Dan" sailed shortly after midnight to relieve Wilkes. In the next two days, the three geologists between them completed a traverse across the strike, from the north to the south of the Vestfold Hills, made short traverses across other parts of the hills, and collected water samples to obtain a vertical composition profile of Deep Lake, one of the highly saline lakes which have been sampled at intervals since the establishment of the station.

The 26th January was overcast, with snow showers. Cook, using the launch "MacPherson Robertson", collected several samples of sediment from the sea bottom off Davis. A helicopter flight was attempted, but conditions were too turbulent for landing, and snow showers forced a return to the ship after 20 minutes.

The "Nella Dan" sailed for Mawson at 1 p.m. It was suspected that part of the Amery Ice Shelf might have broken away, and the ship detoured into Prydz Bay to map the front of the shelf by radar. The amount of shelf which had broken away was far greater than had been expected. The ship was able to sail to within 10 miles of Mount Caroline Mikkelsen, at the head of Prydz Bay, and was prevented from going closer only by fast ice.

Although the visibility was good, conditions were rather turbulent, and it was decided that to attempt landings on the mountains with the single helicopter would be unwise, so the ship turned north and steamed along the edge of the ice shelf, mapping it by radar. This mapping revealed that the ice shelf north-east of a line from the head of Prydz Bay to the head of MacKenzie Bay (which no longer existed), an area of 3000 square miles, had broken away and disappeared. Large icebergs, more than 70 miles long, sighted later off the Enderby Land Peninsula, may represent this vanished part of the ice shelf.

The ship reached the islands off Mawson shortly before midnight on the 28th January, but because navigation marks could not be seen in the poor light, and because of the inevitable katabatic wind, the ship did not enter the harbour until the early afternoon. While the ship was away from Mawson, Trail had flown by Beaver to Fram Peak and visited by helicopter several peaks in the Hansen Mountains. Helicopter unserviceability and poor weather, and the high proportion of helicopter time which had been taken up in depoting fuel, had prevented him from completing the work which was to have been done from Mawson. However, on the afternoon of the ship's return to Mawson, he was able to fly to several small nunataks in the south-eastern Framnes Mountains, and next day he visited Moyes Peak, Pearce Peak, The Satellite and several nearby small nunataks, west of the Framnes Mountains.

While the ship was at Mawson, the geologists collected specimens for age measurement and palaeomagnetic work, and Trail and Wallis visited several offshore islands by helicopter. Several planned flights had to be abandoned because of known or forecast turbulence and strong winds at places to be visited. On this, as on the previous occasion of work at Mawson, the katabatic wind commonly did not abate until early or even mid-afternoon; as it commonly began to blow again about 11 p.m., only a few hours were available for helicopter operations. Even when wind speeds were down at Mawson, turbulence around nunataks and peaks of the Framnes Mountains was commonly too strong for safe helicopter operations.

The ship sailed from Mawson shortly before midnight on the 1st February, and tied up at the edge of fast ice at 66°27'S, 57°39'E on the morning of the 3rd. All geologists flew to the Jagar Islands, a group of small islands 15 miles to the south-west near Cape Boothby, and spent a short time on the islands. That afternoon the weather deteriorated, and flying was not possible the next day.

The weather was marginal for flying on the 5th February. Trail and Wallis were flown to Gwynn Bay, and put in several hours work there while the helicopters depoted two 44-gallon drums of fuel at Abrupt Point, on the southern side of Edward VIII Gulf. That afternoon the Beaver, which hiterto had operated from Rumdoodle, the airfield 10 miles south of Mawson, flew via Leckie Range to the ship, landing on the fast ice near the ship.

Bad weather again prevented flying the next day, but on the afternoon of 7th February, McLeod and Wallis were flown to a camp at Mount Kernot. The same afternoon, a large area of the fast ice to which the ship was moored broke away and drifted towards several icebergs. The ship was obliged to move, and tied up again to the fast ice, about a mile away.

The Beaver, which had taken off about midday, returned that evening. It landed safely on the new floe, but later, while taking off, broke through the ice, and in about 30 seconds, sank until its wings were resting on the ice. Fortunately the passengers scrambled out in time. The aircraft was quickly supported by rubber pontoons used for taking bulky cargo ashore at the stations. The captain skilfully broke the ship through the ice until it was alongside the Beaver, and the aircraft was hoisted aboard. Although it was structurally undamaged, the whole cabin and engine had been submerged in salt water. The aircraft was now quite unusable.

The loss of the Beaver was a serious blow. It was to have been used for depoting fuel, and to move the surveyors (whose field gear was much heavier than that of the geologists) as much as possible. Because of the limited range of the helicopters it was now clearly out of the question for the geologists to get to Leckie Range, Doggers Nunataks, and the mountains south of these places. Extensive fuel depoting would be needed even to get the survey parties back to the ship from Fram Peak and the Leckie Range. As a first step, McLeod and Wallis were returned to the ship on the 8th February, visiting several small nunataks on the way.

The next day was fine, but all aircraft were due for a periodic overhaul, and did not fly. The ship moved south, close to the southernmost of the two large islands in the Jagar Islands. The day after was overcast, with whiteout over the continent, but the helicopters depoted another four drums of fuel at Abrupt Point. The geologists collected specimens for age measurement and palaeomagnetic work from the island near the ship, and Trail examined some islands which had been only briefly visited when the ship had first arrived.

On the 11th, the survey party at Fram Peak was moved to Rayner Peak, and the Rayner Peak party returned to the ship. The weather next morning was poor, but an improvement during the afternoon enabled Trail and Cook to visit several outcrops on the north side of the Seaton Glacier.

The morning of the 13th February was overcast, with semi-whiteout conditions in the morning. Snow began falling and the wind increased in the afternoon, and snowfalls, high winds and poor visibility prevented flying until the afternoon of the 17th, when a survey party was flown to Mount Mueller. The survey party at Leckie Range was flown back to the ship the next day.

A local coastal squall on the morning of the 19th delayed the start of flying, but that afternoon the survey party at Rayner Peak was returned to the ship. Trail and Wallis were then flown to Mount Mueller, and the surveyors there returned to the ship.

The following day McLeod and Cook set off on a helicopter traverse of outcrops around and west of the King Edward Ice Shelf, and around Twin Peaks. When less than a third of the traverse had been completed, a fuel blockage forced one helicopter to land on the sea ice near Abrupt Point. By the time the trouble had been rectified and the other machines checked for the same fault, most of the day had gone, and the traverse was not completed till the next day.

On the 22nd February, the helicopters flew to Mount Mueller. Trail and Wallis made a helicopter traverse of outcrops between Mount Mueller and Mount Pasco. The take-off from Mount Pasco was difficult because of the altitude (6,000 feet), and on the second traverse, around Bird Ridge, few landings were possible for the same reason. The geologists then returned to the ship. During this flight, one aircraft was forced to land because of loss of oil, but was able to reach the ship after oil was flown out to it. Another machine suffered the same trouble (it was caused in both cases by blockage of a breather pipe by frozen water vapour). The third machine, which had consistently given magneto trouble, was declared unserviceable pending a complete engine overhaul, so only two helicopters were now available for the rest of the operation.

That evening, the ship sailed towards Magnet Bay, and spent the next day cruising offshore; the weather was overcast, with occasional snow showers. The day after, the 24th, Trail was flown to Galten Island for a couple of hours of geology, while McLeod made a helicopter traverse of the Wheeler Rocks and small islands at the head of Magnet Bay.

A characteristic of the weather in north-eastern Enderby Land is the prevalence of overcast and semi-whiteout over the sea and near-coastal part of the continent. Thus although the sky further inland may be clear, flying is not possible. The weather pattern suggested that these conditions would continue for several days. Meanwhile, the weather was clear at Stefansson Bay and Taylor, where some geological work remained to be done. It was, therefore, decided to abandon the work remaining in Kemp and Enderby Lands, and take advantage of the good weather further east. That evening the "Nella Dan" sailed for Stefansson Bay.

Next morning, with the ship about 30 miles north of the head of Stefansson Bay, Trail was flown to Ives Tongue and Wallis to Bertha Island, north-east of the Bay. A drum of fuel was flown to Ives Tongue, and McLeod and Cook then made a helicopter traverse to Bell Bay, and outcrops along and inland of the southern side of Cirque Fjord and southern Stefansson Bay. By the time Trail and Wallis returned, the ship had tied up to a floe for the night, at about 67°04'S, 59°24'E.

Early the next morning, the ship moved towards Taylor. Soon after midday, McLeod and P. Martin of the 1964 party were flown to Norris Island (3 miles east of Taylor) to collect samples for age measurement, then Trail and Wallis traversed the numerous offshore islands. That night, the ship steamed slowly towards Mawson, and tied up in the harbour about 10 a.m. next morning.

Little useful geological work remained to be done around Mawson, except to visit two nunataks in the Framnes Mountains. Trail had attempted to reach these by helicopter on previous visits to Mawson but had been unsuccessful because of turbulence around them. Conditions on this day indicated the same turbulence at these nunataks, so no attempt was made to visit them.

That afternoon, Cook flew to Lucas Nunatak with a survey party and spent several hours on geological work. Meanwhile Trail went by surface transport to Painted Peak, at the north end of the Masson Range, and collected a sample for age measurement.

All necessary movement of cargo between ship and shore was completed that evening, and the sailing time was announced as about midday on Sunday the 28th February. On Saturday night, it was found that a refrigerator keeping pathological samples deep-frozen was not operating properly on the ship's electrical system. Attempts to improve matters next morning were not successful, and the refrigerator was taken ashore about midday. While this was being done the wind increased, and by the time the last DUKW had been hoisted aboard, the wind was too strong for the ship to be safely unmoored and turned in the confines of the harbour. For two days the wind blew strongly. On the morning of Tuesday 2nd March it was blowing at 50 knots with gusts up to 70 knots, but that afternoon dropped to 20 knots with occasional gusts to 30 knots. Renewed deterioration in the weather was forecast, so although the wind was till rather strong, the ship was unmoored and sailed without mishap at 4.30 p.m.

The voyage to Australia was uneventful, and the "Nella Dan" berthed at Hobart at 8 a.m. on the morning of the 15th March. Equipment and specimens needed immediately were unloaded and the ship sailed for Macquarie Island that evening, while most of the expedition members flew to Melbourne that afternoon.

PART II MACROBERTSON, KEMP AND ENDERBY LANDS

INTRODUCTION

The work in this sector was a continuation of the 1:250,000 scale geological mapping commenced by Trail in 1961 (Trail, in prep.), when he traversed the coastline from Mawson to Edward VIII Gulf. In 1965, the mapping was extended inland; places along the coast which were inaccessible to Trail were also visited, and some places which he had visited were re-examined in an attempt to solve problems arising from his work. The places visited, and helicopter flight lines, are shown in Plate 1.

PREVIOUS WORK

The first geological work in the region was by the British, Australian and New Zealand Antarctic Research Expedition (BANZARE) which in 1930 briefly examined Proclamation Island and Cape Bruce (Tilley, 1937). Bertha Island, in William Scoresby Bay, was visited by the Discovery Expedition in 1936 (Rayner and Tilley, 1940).

Various places in the region were visited by ANARE geologists in the years 1954 to 1961 (Stinear, 1956; Crohn, 1959; McLeod, 1959; Ruker, 1963; McCarthy & Trail, 1964). Their work showed that the rocks of the region are predominantly charnockites and pyroxene-bearing gneisses of several varieties. The petrography of the gneisses, and the occurrence of metamorphosed basic dykes in the metamorphic rocks, suggested at least two episodes of metamorphism (McLeod,,1964[b]).

The Soviet Antarctic Expedition briefly visited the Oygarden Group in 1957 (Ravich and Voronov, 1958), and Mawson in 1959.

GEOMORPHOLOGY

The geomorphology of parts of the area covered in 1965 has been described by McLeod (1959) and Crohn (1959).

The coastal slope of the continental ice sheet covers most of the area. Most of the Enderby Land peninsula appears to maintain an independent ice sheet, and small independent ice caps have been identified by Crohn covering the King Edward Plateau and Law Promontory. Several large islands carry ice caps or small glaciers.

ICE

In 1965 it was observed that the Hansen Mountains appear to present a formidable barrier to the northward flow of the continental ice sheet. The ice is banked up behind the eastern Hansen Mountains in particular to a height of 50 to 100 metres, and where it flows through these mountains it commonly forms steeply sloping ice falls.

A thick blanket of poorly compacted snow lies on large parts of Mount Storegutt, Mount Mueller, Twin Peaks, and other nunataks in their vicinity, on slopes up to 30^{o} from the horizontal. In places it is discharged from the slopes by small hanging glaciers. Broad patches of poorly compacted snow, up to a few km. in diameter, also occur on the ice sheet in this vicinity; on harder snow, sastrugi are small or absent and no blue ice was observed though blue ice is exposed at Mount Kernot and Rayner Peak. The snow accumulation probably results from the diversion and slowing up of the north-flowing katabatic wind by the northward-rising slope of the ice sheet covering the Enderby Land peninsula.

A similar blanket of snow covers the north-western part of Mount Banfield in the Hansen Mountains. This may have been deposited in a wind shadow produced by the abrupt rise of the south-east side of the mountain.

No large mountain glaciers exist in the coastal exposures or in the inland nunataks examined in 1965, though restricted snow basins feed small glaciers on many higher peaks, and a very small "misfit" glacier occupies part of a large cirque, about 500 metres in diameter and almost 500 metres high, on the west side of Mount Elliott in the Framnes Mountains.

The many ice streams prominent on the coast examined in 1965 are of two types: those which terminate in promontories and those which terminate in embayments in the ice coast.

The ice streams which terminate in promontories, such as the Jelbart, Taylor, and Hoseason Glaciers, have surfaces which rise above the general level of the ice sheet near the coast and which merge with the ice sheet only a few kilometres from the coast; farther inland the ice stream cannot be delineated. These ice streams appear to be constricted in narrow rock valleys, whose walls are exposed at the Hoseason and Taylor Glaciers. They are over-supplied with ice and the addition of relatively little more would cause them to overlow and possibly expand at the coast in a large bulge similar to that formed by the ill-defined Scoble Glacier, perhaps producing a spectacular local advance of the ice sheet.

The ice streams which terminate in embayments, such as the Dovers, Robert, and Wilma Glaciers, have surfaces depressed below the general level of the ice sheet and they can be traced many kilometres inland. They occupy wide and probably deep rock valleys which could carry very much larger quantities of ice than they carry at present.

The constrictions in the valleys of the ice streams terminating in promontories may only be local. However, the absence of well-defined drainage channels and drainage basins inland from these glaciers suggests that their valleys are narrow and short, and that they are less mature and relatively minor features compared to the major drainage channels occupied by the ice streams terminating in embayments.

In Greenland, Petersen (1964) reports that "taqsaq", sea waves generated by ice calving from a glacier, may reach a few metres in height where the glacier is contained in a constricted inlet of the sea, typically in a fjord. Evidence of these waves was sought in 1965 in a small inlet almost closed by a small part of the terminal face of the Dovers Glacier, in the northern Stillwell Hills. Patchy thin moraine, recently deposited by the glacier, appears to have been washed away up to about 1½ metres above sea level. This suggests that only fairly small waves up to 1½ metres high are generated here, though they must be common. The observed collapse of only 30 cubic metres of ice into the sea produced a succession of waves up to 30 centimetres in height, and much larger masses must frequently break off the Dovers Glacier.

Since no large glacier in this part of Antarctica terminates in a fjord-like inlet, the effects of these waves will not be widespread, but will be confined to localities similar to that described.

LANDFORMS

Nunataks

Most large nunataks more than a few kilometres from the coastline are peaks or sharp ridges. Small, gently-rounded summit plateaux occur on the southernmost members of the Framnes Mountains (Mount Twintop, Brown Range, Anniversary Nunataks and possibly Bypass Nunatak), on Baillieu Peak, and on Mount Pasco. These rounded plateaux summits may be vestiges of an elevated surface from which the nunataks were carved by ice movement and nivation.

Cirques

Large cirques, either dry or partly buried by the continental ice sheet, are common in the Framnes Mountains, and buried cirques appear to be outlined by ridge systems in the Hansen Mountains and at Mount Kernot. Bird Ridge has the form of a huge cirque, 7 kilometres across, but it may be a step in the rock surface which has been preferentially eroded by the ice sheet, a pseudo-cirque as described by Gunn and Warren (1962).

The rarity of well-developed cirques in the higher coastal exposures is striking. Only small cirques are evident on Ufs Island and Kemp Peak. The steep head of the valley east of Stump Mountain may be a cirque or a pseudo-cirque. Its floor is mantled by an apparently thin cover of moraine, some of which is ice-cored. Small amphitheatre valleys on some of the larger islands probably also represent cirques, but generally conditions appear to have been unfavourable for the development of sizable cirques near the present-day coast-line.

Coastal erosion surface

An old erosion surface is described by Crohn (1959) as rising from a level of about 35 metres above sea level at Mawson to about 60 metres at Taylor Glacier and about 110 metres at Stefansson Bay (Fig. 3). The many concordant summits on Broka and Havstein Islands, shown as 120 to 140 metres above sea level by Hansen (1946) may represent the westward extension of this surface. Summit plateaux on many islands in the Oygarden Group, and on coastal exposures round the head of Edward VIII Gulf, are shown by Hansen as generally about 110 metres above sea level; these summits may represent a level or gently falling extension of the surface west of Broka Island. Kidson Island has a broad plateau summit estimated by Hansen as 90 metres above sea level, and may be an outlying representative of the erosion surface. The Jagar

Islands (Fig.1) whose plateau summits lie about 45 metres above sea level, may also be outlying representatives of the surface.

The southern edge of the erosion surface probably lies some way south of the ice coast, for the high rock masses forming Ufs Island, Kemp Peak, Mount Whiteside, and the higher hills of Alphard and Shaula Islands are surrounded by the erosion surface and appear to be monadnocks. They are strike ridges probably formed by particularly resistant rocks. Stump Mountain, Hayes Peak, Tschuffert Peak, and Solitary Nunatak appear to be similar features.

Fig. 1 Plateau summits in the Jagar Islands. The summits, here about 45 metres above sea-level, are typical of many of the headlands and islands around Edward VIII Gulf. The rocks are banded gneiss intruded by a dyke (right hand side) which is shown in Fig. 17.

Weathering

On most exposures examined in 1965 the effects of weathering are generally slight. Most rocks are somewhat discoloured on exposed surfaces by patchy iron staining and in a few samples biotite appears to be altered by weathering, but many rocks, particularly those from which ice has recently receded, are quite fresh. Even fragments in moraine are rarely much weathered, and compared to material described from McMurdo Sound by Péwé (1960), none of this moraine appears to be very old.

"Honeycomb weathering", which is probably a product of wind erosion, occurs in places (Fig. 8), but the cavities rarely exceed a few centimetres in diameter; large cavities like those recorded in the Sor Rondane (van Autenboer, 1964), and in the region of McMurdo Sound (Caillieux, 1962) were not found. The "honeycomb weathering" tends to be best developed in large areas of exposed rock, such as the Stillwell Hills, whose weathering provides sand for wind erosion. It also tends to be better developed in the coarser-grained rocks.

Large exposures of weathered rocks permeated and heavily stained by limonite occur within a sub-circular area about 3 kilometres in diameter extending from the north end of the Stillwell Hills to Ives Tongue. Most of the weathered rocks are garnet quartzites and biotite-garnet-quartz-feldspar gneisses, though graphite and sillimanite are prominent in gneiss on Ives Tongue.

The exposures are commonly coloured red and yellow, evidently as a result of limonite staining. The degree of weathering varies considerably. In some heavily stained rocks garnet is comparatively fresh; in other rocks with little staining garnet has weathered out. Generally biotite is much weathered or has been removed by weathering. Feldspar is commonly dull but is nowhere evidently kaolinized. Large lenses of fresh pyroxene-feldspar gneiss are common in the weathered rocks.

The depth of weathering has not been measured, but among hills 60 metres high exposures of little-weathered rock, particularly of those with fresh biotite, appear to be confined to deep depressions whose floors lie near sea level. Depressions which lie some way above sea level have floors, of bedrock or detritus, which are stained deep red and appear to be intensely oxidized. The presence of a zone of dark yellow-brown stained rock at the base of both walls of a deep valley in the northern Stillwell Hills suggests that a weathering profile may be exposed here, and it appears that the weathering may generally approach a level approximating to present-day sea-level.

The heavy staining in this area has probably not been produced by weathering and oxidation of the iron in garnet and biotite, since bands rich in these minerals in the adjacent banded gneiss are little weathered and only lightly stained. The heavy staining and perhaps the weathered appearance of the rocks may result mainly from the decomposition of some mineral particularly susceptible to oxidation, most probably disseminated iron sulphide.

The weathering and oxidation probably did not occur under the prevailing climate. Bateman (1951) emphasises that oxidation is generally negligible in polar regions, and that in glaciated regions now enjoying a favourable climate, the interval since glaciation is too short for much oxidation to have occurred. The oxidation of sulphide minerals appears to be inhibited in the present climate, even in the coastal exposures in this part of Antarctica, for sulphide minerals in several specimens collected in 1961 only became visible on acquiring a tarnish after exposure for two years in Canberra.

Since the ground is presumably perenially frozen a short distance below the surface, permafrost would also inhibit deep weathering and oxidation. The weathering and oxidation most probably occurred over a considerable interval of time when the climate of this part of Antarctica was warmer than it is at present and when the ground was not perennially frozen.

The possible weathering profile in a valley in the northern Stillwell Hills suggests that the weathered rocks may have been dissected, and the presence of young moraine on the valley floor strengthens this possibility. However, had the valley been occupied by a lake or by an arm of the sea at the time of weathering, the water level may have determined the base of weathering here, and have controlled the weathering profile.

The weathered surface generally appears to have been preserved from glaciation since its formation, perhaps because it is close to the fast-flowing Dovers Glacier which would have channelled away from it any small advances of the continental ice sheet.

Bands, up to several metres thick, in quartz-feldspar gneiss at Wallis Nunataks, Cook Nunataks, and Mount Mueller, and in biotite-bearing gneiss at Painted Hill in the Framnes Mountains, have weathered and stained surfaces similar to the rocks described above. This staining is again possibly a result of the oxidation of disseminated iron sulphide minerals, carried out when the climate was more favourable than at present. Desert varnish was found on the rocks of the outcrop at lat. 66°57'S, long. 56° 14'E, south of the Downer Glacier.

QUATERNARY DEPOSITS

On coastal exposures and on inland nunataks examined in 1965, moraine is relatively scarce. A few raised beaches were noted, none more than 10 metres above sea level. Patches of rock detritus occur in places, accumulated by surface creep locally assisted by intermittent stream action, and fine-grained sediment is accumulating in lakes in the coastal exposures.

Lake sediment

The beds of small dried-up ponds in the northern Stillwell Hills are composed of poorly-sorted, green, silty and pebbly sand ranging from fine to very coarse. Similar sediment is probably accumulating in the lakes among these hills and in other large coastal exposures and islands; in the lakes the degree of sorting is no doubt higher than in the ponds.

Stream sediment

Streams were observed only in the Stillwell Hills, in January, 1965. They range up to 20 metres in width, but are rarely more than a few centimetres deep. Their sources are generally lakes and they follow more or less braided courses among moraine flooring broad valleys.

The streams remove the relatively fine fraction - silt, sand, and small pebbles - from the moraine and re-deposit some of this among moraine where the stream velocity drops. However, much of the load is deposited as small fans where the streams enter lake or sea.

On the floors of gently sloping gullies in the Stillwell Hills elongated bodies of coarse sand and small pebbles, more than 10 metres long and between 15 and 50 centimetres in width, wind downhill around and between boulders. The tops of these bodies are raised up to 15 centimetres above the general level of the rock detritus on the gully floor. They appear to be miniature eskers and no doubt were deposited by meltstreams running in the gullies when they were choked by snow.

These miniature eskers are not regularly repeated, and do not therefore constitute a pattern, but two or three may occur together in a broad gully.

Raised Beaches

A well-formed raised beach was observed from a distance in an inlet a few hundred metres west of the crest of Chapman Ridge (Fig. 2). The beach at the head of the inlet corresponds with a distinct notch cut in slabby rock forming a promontory at the entrance to the inlet. This appears to be about 10 metres above present sea-level. The beach is probably composed of coarse sand and pebbles and is about 15 metres wide. Probable raised beaches were seen from the air at several other places in the hills and islands in the vicinity of Taylor.

Fig. 2. Raised beach (left) and strandline (right). West side of Chapman Ridge, south of Taylor, January 1965.

At the mouth of a small valley fronting the sea, in the northern Stillwell Hills, a fan-shaped deposit appears to have been formed by the sea re-working moraine on the valley floor (Fig. 3). The flat top of the fan lies about 6 metres above sea level, and a narrow bench is cut in the fan about 5 metres above sea-level. A stream which cuts through the fan reveals that it is composed of coarse sand and small pebbles with scattered boulders up to 2 metres in length. (Fig. 4).

Since the fan lies at the head of a well-sheltered inlet, wave action probably took a considerable time to form the platform, about 20 metres wide, forming the top of the fan. The formation of the narrow bench, 1 metre below the top of the fan, probably occupied a short pause during the fall of sea-level.

Fig. 3 Fan of rock debris (centre, in front of hills in distance) with flat, wave-worked upper surface (see also Fig. 4). Stillwell Hills, January, 1965. Typical Stillwell Hills topography in background, with many summits at about the same height of 110 metres above sea level.

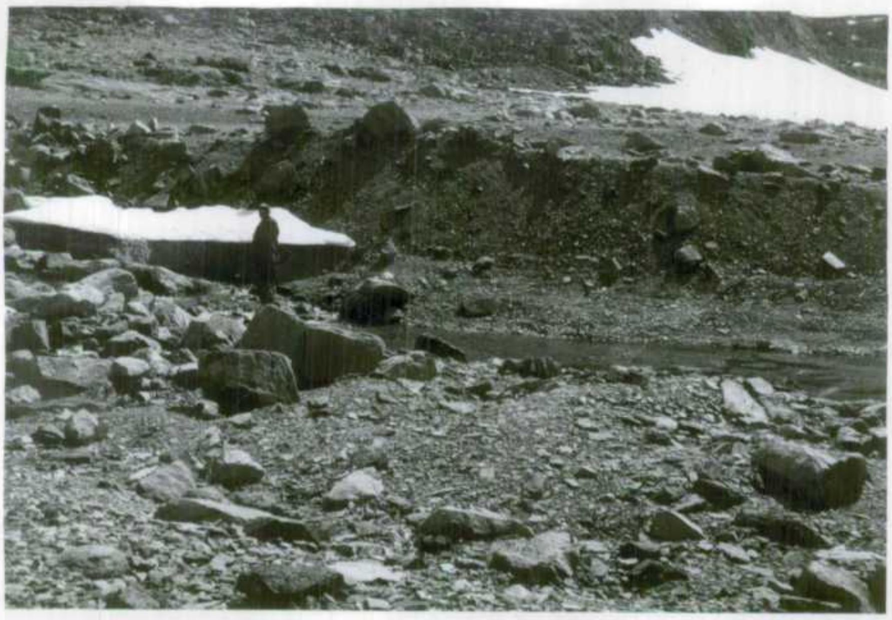


Fig. 4. Channel cut in fan (illustrated in Fig. 3) with level upper surface, 6 metres above sea-level, by stream rejuvinated by relative fall in sea level, Stillwell Hills, January 1965.

Rock detritus

Large accumulations of rock detritus occur as scree at the bases of most steep slopes. Only the absence of erratics distinguishes this material from moraine. Relatively fine rock detritus, mostly of pebble size, apparently formed by in situ weathering, covers most gentle slopes on Ives Tongue, and in depressions there the finer fraction has been concentrated by intermittent stream action.

A plateau summit examined in Anniversary Nunataks is covered by small boulders to a depth of about 1 metre. A few erratics occur among these, but weathering bedrock nearby appears to be forming the same type of detritus, and the deposit is probably a boulder field, developed in situ. Boulders covering the saddle on Mount Twintop appear to reflect the distribution of particular underlying rock types; this debris, also, is probably a boulder field.

Moraine

Crohn (1959) subdivides moraine deposits into an older high-level group deposited when the ice sheet surface stood at a much higher level than it now does, and a younger group lying close to the present margins of the ice sheet and evidently recently deposited by it.

Younger moraine noted in 1965 included patches up to several metres thick along the west side of the Stillwell Hills immediately adjacent to the Dovers Glacier. This moraine is light grey and has a fresh appearance resulting from the presence of a matrix of fine sand, silt, and clay. A large body of light grey, younger moraine, about 500 metres long, occurs on ice adjacent to the southern margin of the area of rock exposures at Campbell Head. It is probably a shear moraine deposited from the base of the ablating ice sheet as the sheet rides up a ramp of stagnant ice on the upstream side of the bedrock exposure, as described by Hollin (1962) from Wilkes.

Fig. 5. Typical mound in ice-cored moraine, with loose rock debris scraped away to expose ice. Sample T10 (used for textural analysis) was obtained from this locality. Stump Mountain, south of Taylor; January 1965.

Ice-cored moraine was found in 1965 only in a valley at the east side of Stump Mountain (Fig. 5). The moraine is mainly formed by sub-conical ice-cored mounds about 50 centimetres in height and about 2 metres in diameter. On steep-sided mounds some ice is exposed, but generally the ice cores are mantled by material ranging from sand to small boulders, forming a deposit on the ice between 5 centimetres and 30 centimetres thick. One large mound 20 metres in diameter and 3 metres high has a central depression 5 metres in diameter and 1½ metres deep drained through a breach on the north side of the mound. The central depression contains some silt-size material among the moraine on its floor.

Older moraine, in the area examined in 1965, generally occurs as scattered boulders on the slopes and on the summits of exposures both along the coast and in the inland nunataks. Large accumulations of moraine were observed only on the floors of abandoned cirques in the Framnes Mountains. McLeod (1959) records extensive terraces of high-level moraine in the Leckie Range. No deposits here approach in extent or thickness the great accumulations of moraine present at high and low levels in the Prince Charles Mountains (Crohn, 1959; Trail, 1964).

Rock detritus flooring valleys in the Stillwell Hills and near Stump Mountain appears to be old moraine to which scree shed from the valley walls has been added. It has also been reworked in places by streams originating in small lakes dammed back by the detritus. Bedrock is commonly exposed on the valley floors and generally the moraine cover is probably little more than a few metres thick.

This moraine is generally unpatterned. In one valley in the northern Stillwell Hills hummocks, forming a small group on otherwise unpatterned material, range up to 3 metres high and 10 metres in diameter. They have no ice cores. The large hummocks are composed predominantly of angular boulders up to 1 metre long, and the small hummocks, less than 50 centimetres high, are composed of clay and have cracked apices. These hummocks may be relics of larger ice-cored structures.

PATTERNED GROUND

Since patterned ground develops only on unconsolidated deposits and these are few and small in the area examined, few observations of patterned ground were made in 1965.

The most common type found is a polygonal pattern of cracks or narrow depressions typically several centimetres wide by a few centimetres deep, outlining polygons ranging from 2 metres to 10 metres and more across (Fig. 6).

The deposits on which these cracks develop are generally poorly-sorted mixtures of coarse sand, pebbles, and small boulders which have accumulated as moraine, as scree, or as products of *in-situ* weathering. The cracks forming the pattern generally contain only pebbles and small boulders; the finer fraction is missing. Where large boulders lie on the surface of a deposit the cracks pass round them rather than under them.

In places, particularly on the floors of narrow sloping depressions in the rock surface in which detritus has accumulated, sub-parallel cracks are present but do not outline polygons. These cracks resemble stream channels and the fine fraction has probably been washed out of them.

Fig. 6. Polygonal pattern of cracks in rock detritus, forming polygons about 5 metres across. Ives Tongue, off the Stillwell Hills; February 1965.

Polygonal patterns of cracks were recorded in moraine in the North Masson Range, in rock detritus on Mount Hordern and Mount Twintop, in scree on the west side of the Casey Range, and on rock detritus in the Stillwell Hills and on Ives Tongue.

A second type of pattern observed is the smaller stone circle, observed in the Stillwell Hills and on Stump Mountain (Fig. 7). On Kemp Peak, stone circles occur mainly in the beds of dry ponds. Rings, about 15 centimetres thick, of pebbles and cobbles enclose circular patches, about 50 centimetres in diameter, of silt, coarse sand, and small pebbles. The marginal rings are depressed a few centimetres and the higher fine-grained centres have empty radial cracks. Excavation of a circle revealed that coarse marginal material grades downwards into sand and small pebbles (similar to the material in the centre at the surface) at a depth of 30 centimetres. The fine central material passes abruptly at a depth of one centimetre into finer material - coarse sand and silt with few pebbles - which continues to a depth of 15 centimetres. All the material immediately below the surface is saturated with water, and in January at 30 centimetres depth this was not frozen.

Fig. 7. Stone circles on Kemp Peak, Stillwell Hills. The finer-grained centres to the circles are about 1 metre across. January 1965.

The stone circles found on Stump Mountain are of similar size to these but are composed of coarser material. They have centres of small pebbles surrounded by rings of small cobbles. Stone circles of this type were found also on gently sloping ground in the Stillwell Hills, where their raised centres produce a succession of small terraces, running across the slope.

A few ill-defined, large, fine-centred circles which occur among the thin mantle of debris covering a plateau summit in the Anniversary Nunataks in the Framnes Mountains range up to 1½ metres in diameter and contain small pebbles in the centre and boulders in the marginal ring. These circles may be related to low terraces on this material, running along the contours of the gentle slope.

Circular patches of pebbles, between 20 centimetres and 50 centimetres in diameter and raised a few centimetres above the general level of unsorted rock detritus, were found on some islands, up to 40 metres above sea-level. They are the nesting sites of skuas or of Adelie penguins and where abundant may be confused with patterned ground.

The large polygons are ice-wedge or sand-wedge polygons, described in Victoria Land by Péwé (1959) and Black and Berg (1964). Since they mostly occur in saturated ground the small stone circles are presumably formed by an ice-wedge mechanism.


PLATE 2
GEOLOGICAL SKETCH MAP
MAC. ROBERTSON, KEMP AND ENDERBY LANDS
SCALE 1:500,000
10 0 10 20 30 MILES
10 0 10 20 30 40 KILOMETRES
Porphyroblastic charnockite
Even-grained charnockite
Banded gneiss
Quartz-feldspar gneiss
Gneisses of Taylor Glacier
Garnetiferous gneisses of Mount Kernot, etc.
Gneiss, marble and migmatite of Hansen Mountains
Pyroxene-quartz-feldspar gneisses of Casey Range
Garnet-quartz-feldspar gneiss
Basic and ultrabasic dykes
Strike and dip of foliation
Vertical foliation
Horizontal foliation
Rake of lineation measured in plane of foliation
Direction and plunge of lineation
Anticline, showing plunge
Syncline, showing plunge
Plunge of minor anticline
Plunge of minor syncline
Plunge of minor folds
Doubly plunging minor folds
Minor folds, plunge zero
Rock feature
Ice coast
Front of ice shelf or glacier
Glacier
Station
Radiometric age determination sample site
KING EDWARD PLATEAU
EDWARD VIII GULF
ENDERBY LAND
KEMP LAND
MAC. ROBERTSON LAND
MAWSON COAST
MAWSON
CONRADI PEAK
WHEELER ROCKS
MAGNET BAY
GALTEN IS.
CAPE DAVIS
CAPE BOOTHBY
JAGAR IS.
KLOA POINT
STYLES BLUFF
CAPE GOTLEY
MARTIN I.
MT BRIDE
MT GRIFFITHS
WILKINSON PEAKS
NAPIER MOUNTAINS
YOUNG NUNATAKS
AKER PEAKS
JENNINGS BLUFF
SEATON GLACIER
WILSON GLACIER
DOWNER GLACIER
WILMA GLACIER
ROBERT GLACIER
GEORGES IS.
CAPE DALTON
ABRUPT PT.
OYGARDEN GROUP
MT STORER
MT PASCO
WATSON RIDGE
MILLER NTKS.
COOK NTKS.
TWIN PEAKS
SCHWARTZ
Edward Ridge
MT KERNOT
ELSE NTKS.
PAYNE PEAK
HAVSTEIN I.
LAW PROMONTORY
CIRQUE FJORD
STEFANSSON BAY
TILLETT IS.
GALES I.
WARNOCK IS.
SOLITARY I.
SOLITARY NTK
STILLWELL HILLS
SVANT MT
BELL BAY
THORFINN ISLANDS
KIDSON I.
STEVENSON
ENSTOOING IS.
Nelson Rock
Williams Rocks
HOLME BAY
MAWSON
HENDERSON
RUSSELL NTK.
MASSON
DAVID
MOUNTAINS
FRAMNES
CASEY RANGE
LUCAS NTK.
GOODBERRY NTKS.
MT HORDERN
MT TRITOPPEN
VAN HULSSEN NTK.
BYPASS NTK.
ANNIVERSARY NUNATAKS
MT TWINTOP
BROWN RANGE
MOYES PEAK
PEARCE PEAK
THE SATELLITE
BAILLIEU PEAK
MILL PEAK
FRAM PEAK
FOLEY NTK.
MT BANFIELD
MT CORRIE
HANSEN MOUNTAINS
SEE NTK
MARUFF PEAKS
WHITING NTK
MT COOK
LECKIE
DOGGERS NUNATAKS
KNUCKEY PEAKS
MT CHANNON
CYCLOPS PEAK
DISMAL MOUNTAINS
ARNEL BLUFFS
Bureau of Mineral Resources, Geology and Geophysics, Jan. 1966
To Accompany Record 1966/
AN 2/59

GEOLOGY

REGIONAL GEOLOGY

On a broad lithological basis, the rocks of the sector can be divided into eight units, according to the predominance of a particular rock type, or the widespread association of particular rock types (Plate 2). Each unit contains numerous textural, mineralogical and petrological variants, and a particular specimen could possibly belong to several of the units: the classification depends on overall field characteristics rather than detailed petrology.

The units, and their characteristics, are:

Charnockite: Massive to poorly foliated, medium-grained to coarse-grained, granulitic textured; principally feldspar and quartz and minor pyroxene.

Banded gneiss: Regularly alternating bands, up to 10 metres wide, of light-coloured, foliated quartz-feldspar gneiss and dark-coloured, rather massive pyroxene-feldspar gneiss; overall, the pyroxene-feldspar gneiss forms about 20 to 30 percent of the unit.

Quartz-feldspar gneiss: Medium-grained, moderately foliated to massive, with thin, discontinuous banding in parts; predominantly quartz and feldspar; in hand specimen does not have the granulitic texture and dark colour of the charnockite.

Gneiss of Taylor Glacier: Predominantly medium-grained, well-foliated, thinly banded biotite-garnet-quartz-feldspar gneiss, with migmatitic granite bodies; sillimanite commonly present.

Garnetiferous gneisses: Heterogeneous unit, the components ranging from well-banded and well-foliated to massive; principally variants of pyroxene-feldspar gneiss, quartz-feldspar gneiss, biotite-bearing gneiss, and quartzite: garnet common in many varieties.

Gneiss, marble and migmatite of Hansen Mountains: Foliated, migmatitic granite and biotite-quartz-feldspar gneiss, garnet quartzite, and thick bands of impure marble.

Pyroxene-quartz-feldspar gneiss of Casey Range: Finely-banded, fine-grained to medium-grained, biotite-garnet-pyroxene-quartz-feldspar gneiss with sillimanite in places, and quartzite.

Basic and ultrabasic dykes: Fine-grained to medium-grained, with dyke form; some foliated and poorly banded; composed of pyroxene or feldspar and pyroxene; many metamorphosed.

CHARNOCKITE

The charnockites of MacRobertson Land have been described and discussed by Stinear (1956), Crohn (1959), McLeod (1959, 1964b), and McCarthy and Trail (1964); Stinear and Ruker found charnockite in western Kemp Land (Ruker, 1963).

Geologists of the Soviet Antarctic Expedition have sampled the charnockite at Mawson for radioactive age determination (Ravich & Krylov, 1964). The ages of four samples were measured as 490, 535, 555 and 650 m.y.

In this Record the term charnockite is applied, following Holland (1900), to "great masses of rock whose two leading characteristics are a granulitic structure and the invariable presence of a rhombic pyroxene amongst the constituents". However, charnockite is here restricted to those rocks which show little small-scale or large-scale textural or compositional variation. They are separated from the banded gneiss, described below, which is composed of alternating bands of radically different compositions, although many individual bands are granulitic rocks with rhombic pyroxene.

The charnockite is subdivided to even-grained charnockite, a type which fits closely the description by Holland (1900), and porphyroblastic charnockite.

The earlier work has shown that the charnockite is essentially composed of hypersthene, quartz, and feldspar; it may also contain garnet or biotite; hornblende is uncommon. Its feldspar content is at least 30 percent plagioclase, which ranges from oligoclase-andesine in rocks containing much potash feldspar to labradorite-bytownite in rocks without potash feldspar. The potash feldspar is almost invariably perthitic orthoclase.

The grainsize of the charnockite ranges from medium to very coarse. Quartz and feldspar are equigranular in the even-grained charnockite, and hypersthene and other dark minerals are generally smaller. In the porphyroblastic charnockite, rectangular feldspar crystals, generally between 10 and 50 millimetres in length, lie in a groundmass resembling the even-grained charnockite. Both types commonly have a marked foliation conferred by stringers of dark minerals and small lenses of felsic minerals; the feldspar porphyroblasts commonly are oriented parallel to be foliation.

The even-grained charnockite was called charnockitic granular gneiss by Crohn (1959). It has been renamed to separate it more emphatically from the other gneisses.

In MacRobertson Land, charnockite forms 90 percent of the bedrock exposures in an area of 10,000 square kilometres around Mawson. Most of this area is covered by ice or sea, but the charnockite appears to extend 130 kilometres from Howard Bay in the west to Austskjera in the east, and 80 kilometres from Williams Rocks in the north to Mount Twintop in the south. The only large exposure of significantly different rocks within the area is formed by the sillimanite and garnet bearing gneisses of the Casey Range. Ten other small exposures of biotite-bearing and garnet-bearing gneisses are known within the charnockite outcrop.

Where it is exposed in association with large bodies of significantly different rocks, as at Ufs Island and Chapman Ridge, the charnockite forms high peaks and ridges and the other rocks floor the valleys. Therefore, in the Framnes Mountains in particular, a large proportion of the low-lying bedrock covered by ice within the charnockite outcrop may be composed of other rocks.

In 1965, charnockite exposures were examined in the outlying islands off Mawson, at Stibbs Bay and Howard Bay, in the southern and eastern parts of the Framnes Mountains, and in the large nunataks exposed near Baillieu Peak. The interrelation of charnockite and other rocks was investigated between Ufs Island and Chapman Ridge. Charnockite was also found at the Wheeler Rocks and Magnet Bay, in western Kemp Land, and small bodies of charnockite were examined at Bertha Island, Dales Island, and Warnock Islands, in eastern Kemp Land.

Framnes Mountains

All previously unvisited nunataks in the Framnes Mountains were inspected from the air in 1965, and wherever possible representative exposures were examined on the ground. Gneiss outcrops were examined from the air at Phillips Ridge and the nunatak west of Mount Coates, but they could not be visited.

The nunataks forming the south-eastern part of the Framnes Mountains are all composed of charnockite.

The exposures examined in detail, at Walker Nunatak, Wakeford Nunatak, and Anniversary Nunataks, are porphyroblastic charnockite which is massive or poorly foliated, with a coarse-grained matrix. At Anniversary Nunataks only, the rocks have a clear foliation conferred by prominent lenses, typically 2 metres long by 1 metre thick, of fine-grained rock with biotite-rich margins. At Wakeford Nunatak a few thin lenses of fine-grained garnet-feldspar rock, typically 3 metres long by 30 centimetres thick, and parallel bands of mylonitic crush-rock, about 2 millimetres thick, produce a poor foliation. This nunatak has small light green patches of copper stains.

The nunataks forming the south-western part of the Framnes Mountains are also composed entirely of charnockite, but all those examined in detail are the even-grained variety.

Price Nunatak and a small exposure 1½ kilometres south of the unnamed nunatak 1260 metres high, are massive, medium-grained to coarse-grained, even-grained charnockite.

Mount Tritoppen, Bypass Nunatak, and Mount Twintop are composed of fine-grained and medium-grained, even-grained charnockite, and Brown Range is formed by a coarse-grained variety. At Mount Tritoppen the charnockite contains bands rich in quartz and feldspar, in which the quartz has a distinctive blue colour. Most bands range from 2 centimetres to 50 centimetres in thickness; one is 1 1/3 metres thick and at least 70 metres long; in some the quartz has a marked preferred orientation parallel to the foliation of the enclosing charnockite.

The eastern part of Mount Tritoppen is composed of dark charnockite, containing about 10 percent pyroxene. The western part is light-coloured rock made up of about 40 to 50 percent quartz, 40 to 50 percent feldspar, 1 to 5 percent black pyroxene, 1 to 2 percent diopside, and 2 to 3 percent garnet. Some bands rich in quartz and feldspar contain up to 15 percent diopside but no black pyroxene.

At Mount Twintop, the even-grained charnockite is rich in quartz and poor in pyroxene. Quartz forms up to 50 percent of the rock, and small lenses, lenticles, and schlieren of quartz, up to several centimetres thick, are common. In one exposure, bands of pyroxene-rich charnockite, up to 7 metres thick, alternate with bands of quartz-rich rock tens of metres thick. At the contacts of these bands, thin bands (a few centimetres in thickness) of the two rock types alternate. The central part of one distinct band of feldspar-pyroxene rock, at least 60 metres thick, contains up to 50 percent feldspar; in the band are thin, irregular veins and patches of quartz and feldspar, and a discordant vein of white quartz 15 centimetres thick. Green copper stains are common along the contact of this band with the charnockite. Zones of mylonitic crush-rock up to 20 centimetres thick parallel the strike of the rocks. Garnets are scattered in the charnockite at one exposure on Mount Twintop.

Brown Range is composed of massive even-grained charnockite with accessory garnet in places. This rock contains fine-grained stringers, attenuated lenses, and bands of pyroxene-rich material. Boudinage is common in the bands; the boudins are about 50 centimetres long.

Baillieu Peak and neighbouring nunataks

Baillieu Peak and the six nunataks within 25 kilometres of it on its eastern side were examined in 1965; they are all composed predominantly of even-grained charnockite.

At Moyes Peak and Pearce Peak the foliation is marked by streaks of rock rich in feldspar or rich in pyroxene, ranging up to 30 centimetres long by 10 centimetres thick. Many of these streaks appear to be the cores of disrupted small-scale isoclinal folds, whose axes plunge in the dip of foliation. Larger lenses, a metre or so long, are composed of biotite charnockite and parallel the foliation. Biotite-quartz-feldspar rock also forms irregular patches. The small nunatak 1½ kilometres south-east of The Satellite is similar to these peaks.

The Satellite is formed by feldspar-rich garnet charnockite containing many lenses of pink garnet-feldspar pegmatite, typically 1 metre by 30 centimetres with a marked preferred orientation. In places the pegmatite has a migmatitic relationship with the charnockite; irregular patches of one rock type are surrounded by the other, and a complete gradation exists between the two types. Similar pink lenses were observed from the air on the small nunatak 2½ kilometres north of Pearce Peak.

The even-grained charnockite forming Mill Peak has been described by McLeod (1959). It is relatively poor in pyroxene, and consists of quartz and andesine with small amounts of hypersthene, magnetite, and diopside.

A small nunatak 5½ kilometres north-west of Mill Peak is composed of biotite charnockite, which weathers red in contrast to the normal yellow-brown charnockite, and which contains, in an inaccessible part, prominent white bands up to 3 metres thick. Lenses of mylonitic crush-rock, up to 1 metre long by 30 centimetres thick, are common here.

The even-grained charnockite forming Baillieu Peak contains a few bands of pyroxene-rich rock, up to several metres in thickness. The only contact seen with the normal charnockite is sharp. The charnockite also contains patches of coarse-grained garnet-biotite-quartz-feldspar rock a few metres across, zones of mylonitic crush-rock between 15 and 30 centimetres thick, and one thick vein of coarse-grained quartz-feldspar rock with feldspar crystals up to 25 millimetres long. Small discontinuous quartz-feldspar veins, up to 5 centimetres thick, are commonly sigmoidal or hook-shaped, and in one place outline tight irregular folds, a few centimetres in amplitude, whose axial planes coincide with the foliation of the charnockite. The fold axes pitch 40° southwards and the foliation dips 80° eastwards.

Outlying islands

The outlying islands off Holme Bay are predominantly composed of charnockite, with the exception of Nelson Rock. Of those examined in detail in 1965, Victor Smith Rocks and a small island about 1¼ miles west-north-west of Azimuth Island are composed of even-grained garnet charnockite; Williams Rocks and Sawert Rocks are made of porphyroblastic garnet charnockite, with rare biotite at Williams Rocks; Nelson Rock is composed of garnet-quartz-feldspar rock with the texture of coarse-grained, even-grained charnockite.

Lenses, up to 1 metre long by several centimetres thick, of garnet-quartz-feldspar rock, typically coarse-grained and commonly with blue quartz, define a poor foliation at Williams Rocks. At Nelson Rock the garnet-quartz-feldspar rock contains many lenses with a marked preferred orientation, ranging up to 2 metres long by 30 centimetres thick; the dark lenses are pyroxene-bearing and appear to be composed of even-grained charnockite; the light lenses are broadly similar to the host rock.

At Sawert Rocks, feldspar perphyroblasts are so numerous that they are intergrown and form the bulk of the rock; the matrix in their interstices is dominantly garnet and quartz, with small grains of pyroxene associated with the garnet. One band, 20 metres long by 15 centimetres thick, of coarse-grained quartz-feldspar rock with blue quartz cuts the massive charnockite.

Aerial inspection of the islands between 1 kilometre and 8 kilometres north-east of Mawson shows that the numerous lenses of dark granulitic rock occurring within the charnockite have marked preferred orientations, but the orientations differ sharply from place to place.

Most outlying islands, including Ryrie Rock, between the group 18 kilometres north-north-west of Einstoding Island and the string extending 15 kilometres north-north-west from Stevenson Island, are composed of even-grained charnockite with a clear foliation produced by stringers and lenses of pyroxene-rich rock and by quartz-feldspar lenses. The lenses are generally a few centimetres long, but some reach 2 metres. Garnet or biotite occurs in the charnockite on a few islands, and the westernmost charnockite island, about 18 kilometres north of Taylor Glacier, contains coarser patches with garnet, biotite, and possible hornblende. Thin veins of mylonitic crush-rock are common throughout these islands.

On many islands the charnockite contains bands and discordant veins, up to 1 metre thick of, yellow-brown, coarse-grained quartz-feldspar rock, which form a network in places.

Locally these veins carry garnet or pyroxene. In one exposure on Stevenson Island the veins outline isoclinal folds, one of which has its axial plane parallel to the foliation in the charnockite; the axial planes of the others were not determined. Within this fold biotite and diopside occur.

Also on Stevenson Island, the charnockite and veins are cut by veins and sheets of red quartz-feldspar granite, which ranges from fine-grained to very coarse-grained. Islands examined from the air north and north-north-west of Stevenson Island appear to be formed by similar, interrelated rocks.

Though Kidson Island is surrounded by charnockite exposures, it differs significantly from them in colour and mineralogy. It is composed of grey quartz-pyroxene-feldspar gneiss, with some clusters of garnet, which contains bands of massive biotite-garnet-quartz-feldspar rock with possible cordierite in places.

One of a group of small islands about 10 kilometres north of Taylor Rookery is composed of pyroxene-biotite-quartz-feldspar gneiss in which the biotite is much more abundant than the pyroxene; another island consists of garnet-quartz-feldspar gneiss.

A group of small islands about 10 kilometres north of Campbell Head is composed of dark grey, fine-grained garnet-pyroxene-quartz-feldspar gneiss, with a few bands of light grey quartz-feldspar rock. The foliation in these rocks, defined by textural bands between 1 centimetre and 10 centimetres in thickness and by stringers of dark minerals, is tightly folded in places.

The pyroxene-bearing gneisses described from Kidson Island and the two island groups above differ from the charnockites in their grey colour and their finer grainsize. They resemble more closely rocks forming a large outcrop of hypersthene bearing gneiss at Cape Bruce, sampled by Trail in 1961 and mapped in 1965, which is almost completely surrounded by the sillimanite-bearing gneiss predominant there.

Ufs Island and Stump Mountain

In 1965 a traverse was made on foot across the transition between the pyroxene-bearing (charnockitic) rocks which predominate along the coast east of Ufs Island, and the biotite-bearing rocks which are abundant on the coast west of Stump Mountain. Since Crohn (1959) has described the coastal exposures in this transition, the traverse was made along the inland margin of the rock area.

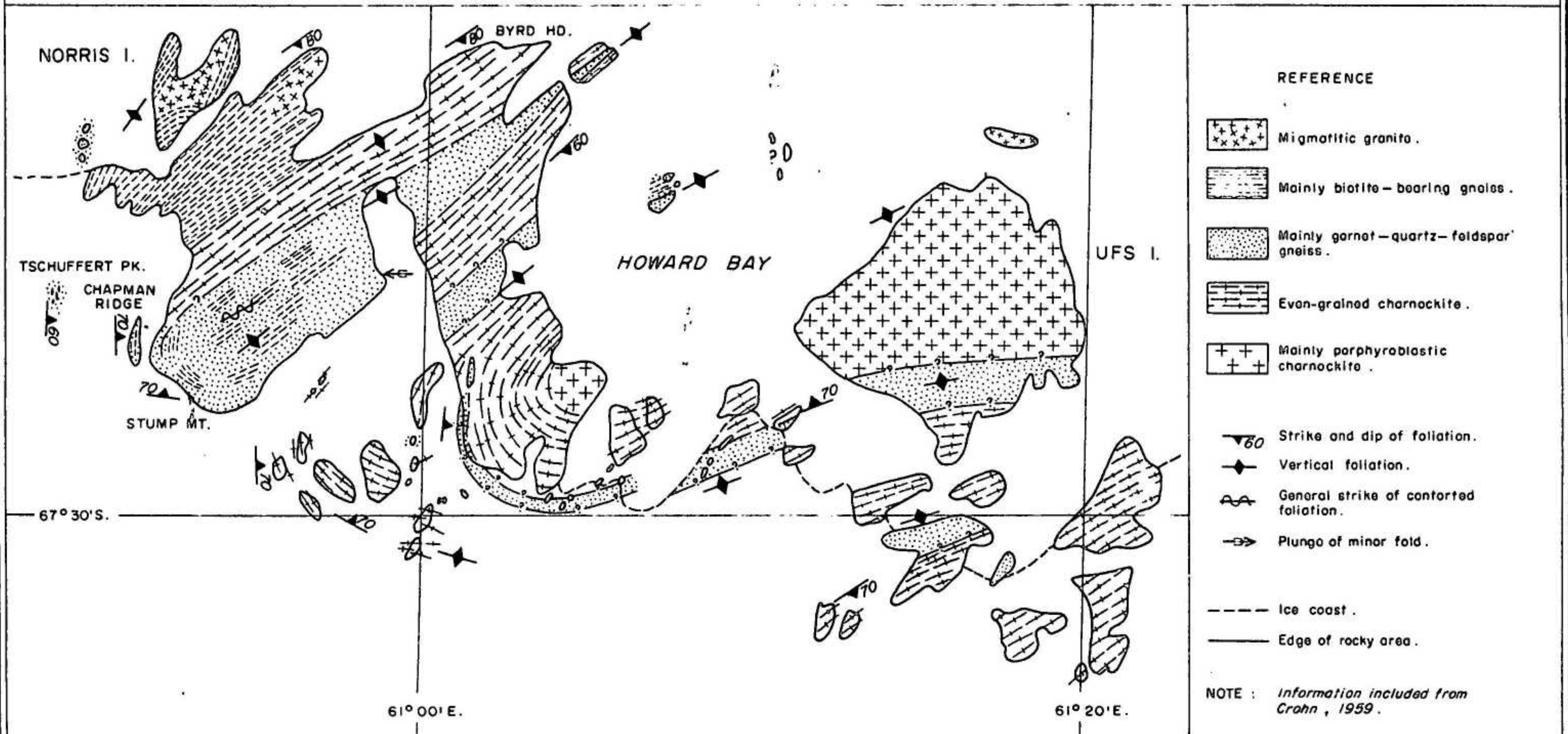
Even-grained charnockite (Crohn's charnockitic granular gneiss) predominates south and east of Stump Mountain, but it contains several exposures of garnet-quartz-feldspar gneiss which form distinct bands over 100 metres and a few kilometres long (Plate 3).

Across the hummocky plateau which forms the summit of Stump Mountain, ill-defined bands of even-grained charnockite are interspersed with gneisses made up of various proportions of quartz, feldspar, garnet, and biotite; a single thick band of even-grained charnockite forms Chapman Ridge, a prominent escarpment extending 5 kilometres along the north-west side of the mountain from the summit to the sea at Byrd Head.

PLATE 3.

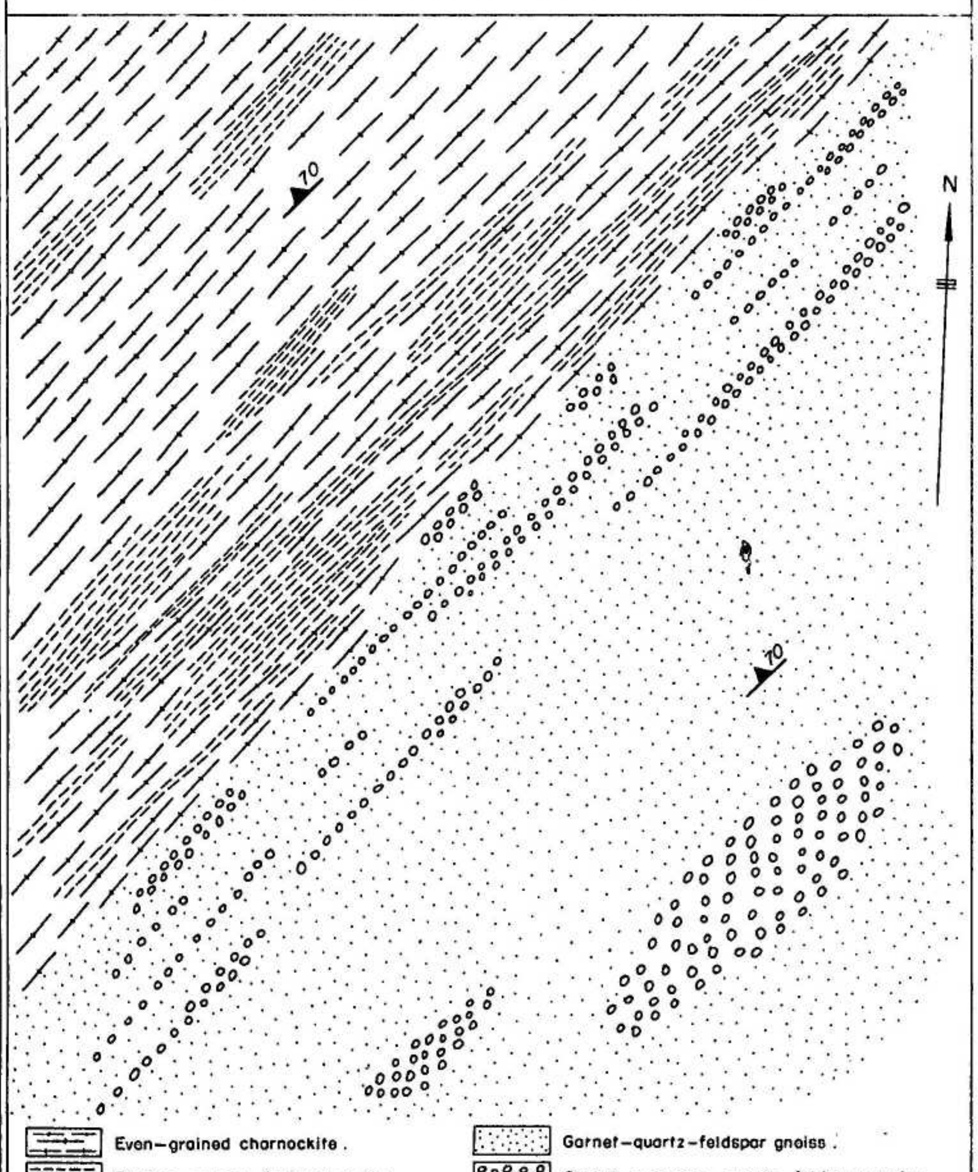
(A) INTERPRETATIVE SKETCH-MAP OF GEOLOGICAL STRUCTURE BETWEEN NORRIS ISLAND & UFS ISLAND, MAC. ROBERTSON LAND, ANTARCTICA.

MILE 1 0 2 MILES
KILOMETRE 1 0 1 2 3 4 KILOMETRES



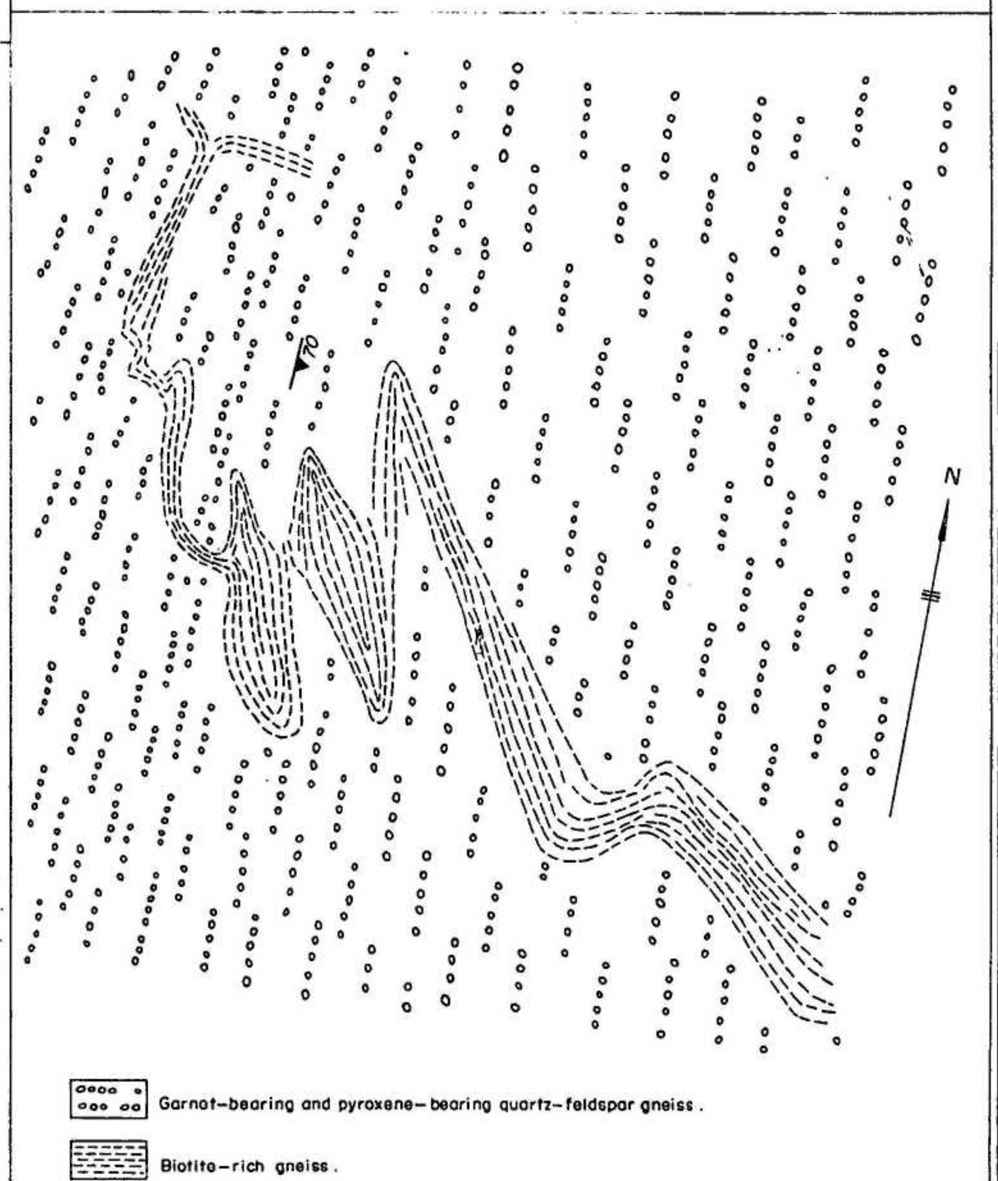
(B) DIAGRAMMATIC SKETCH-MAP OF CONTACT BETWEEN EVEN-GRAINED CHARNOCKITE & GARNET-QUARTZ-FELDSPAR GNEISS, 1 KILOMETRE SOUTH-WEST OF UFS ISLAND, MAC. ROBERTSON LAND, ANTARCTICA.

METRE 1 0 1 2 METRES



(C) SKETCH-MAP OF BIOTITE-RICH BAND TRANSGRESSING FOLIATION ON TSCHUFFERT PEAK, MAC. ROBERTSON LAND, ANTARCTICA.

METRES 5 0 5 10 15 20 METRES



Bureau of Mineral Resources, Geology and Geophysics, Jan. 1966 *To Accompany Record 1966/9* AN 2/60

North-west of Chapman Ridge, the coastal exposures for 15 kilometres to the Scoble Glacier are composed predominantly of biotite-bearing, garnet-bearing, and sillimanite-bearing gneisses, among which pyroxene-bearing rocks are rare.

The even-grained charnockite where weathered is red or brown; where fresh, the rock is dark grey or black. It is generally a medium-grained pyroxene-quartz-feldspar rock, with garnet in a few exposures.

The charnockite is generally massive, but it commonly contains lenses and bands of yellow-brown quartz-feldspar rock (Fig. 8), which are a few centimetres thick in some exposures and up to a few metres thick in others; these thicker bands may be 20 metres long. The bands and lenses generally have a marked preferred orientation; some small lens-like bodies outline isoclinal folds; in some exposures thick bands branch, producing a network.

Fig. 8. Even-grained, foliated charnockite (dark) with abundant large and small bodies of quartz-feldspar rock (light); both rock types are cut by seams of mylonitic rock. Honeycomb weathering is prominent in the quartz-feldspar rock. West side of Stump Mountain, south of Taylor.

These quartz-feldspar rocks generally form less than 20 percent of any exposure. Their margins are well defined but contain some pyroxene, and they grade into the finer charnockite.

Thin branching zones of mylonitic crush-rock, generally a few millimetres thick, are common throughout the charnockite. In places, zones of brecciated charnockite up to 50 centimetres thick have a matrix of mylonitic rock. These zones generally have a preferred orientation and commonly cut across the quartz-feldspar bands, though in a few exposures they are parallel.

On the mainland south of Ufs Island, concordant bands of pegmatitic pyroxene-quartz-feldspar rock are common in the even-grained charnockite. Some of these bands contain feldspar porphyroblasts and resemble very coarse-grained porphyroblastic charnockite.

Garnet-quartz-feldspar gneiss is prominent in bands within the charnockite. It includes much of the quartz-rich and feldspar-rich gneisses recorded by Crohn (1959). It contrasts markedly with the charnockite because of its light brownish-grey colour and its coarse grain-size. It commonly has a faint foliation or banding resulting from concentrations of the constituent minerals.

Mylonitic rocks are conspicuously absent from the garnet-quartz-feldspar gneiss, though they may be abundant in adjoining charnockite.

Observed from a distance, most contacts of the garnet-quartz-feldspar gneiss with the charnockite appear to be sharp. The only contact exposure examined in detail in 1965 is located on a bluff on the mainland 1 kilometre south-west of Ufs Island. It is shown diagrammatically in Plate 3. Within 2 metres of the well-defined contact the charnockite contains many lenses and bands, between 10 centimetres and 1 metre thick, of coarse-grained biotite-quartz-feldspar rock. Within 1 metre of the contact, the garnet-quartz-feldspar gneiss contains many ill-defined lenses and bands, between 2 and 15 centimetres thick, of garnet-pyroxene-quartz-feldspar rock, which grade into the host rock. The rocks forming these lenses and bands each occur in the respective host rock in other places, but they are unusually abundant close to the contact.

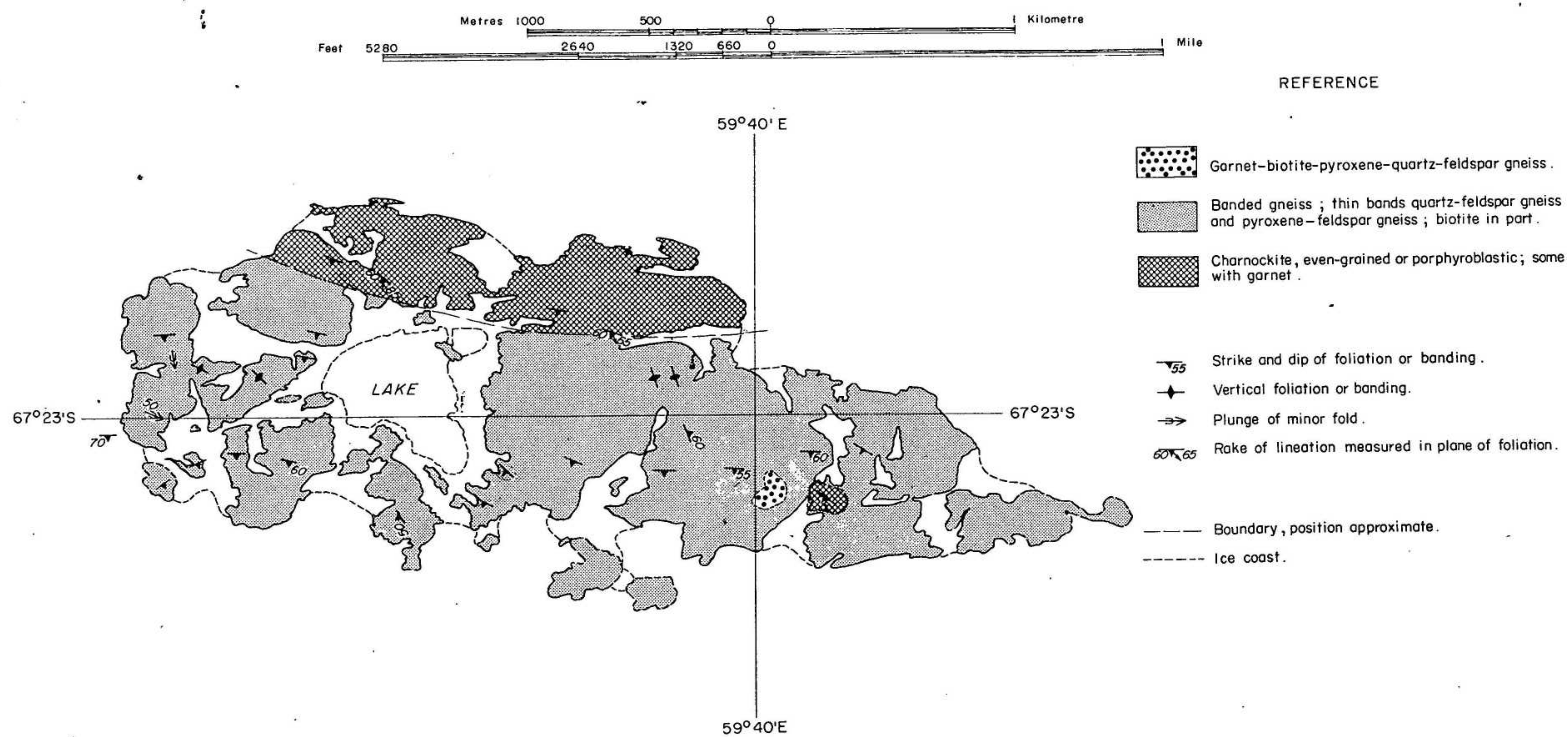
Garnet-quartz-feldspar gneiss is also abundant on Stump Mountain. It forms light purple-grey bands, up to 20 metres thick, which outline structures in charnockitic rocks on the south-east side of the mountain. Towards Chapman Ridge, bands of light grey, coarse-grained, garnet-quartz-feldspar rock, several metres thick, contain bands and lenses of fine-grained garnet-biotite-quartz-feldspar gneiss up to a metre thick, which commonly outline open or tight folds.

Biotite-quartz-feldspar gneiss is interspersed with pyroxene-bearing and garnet-bearing rocks on the plateau summit of Stump Mountain. Diopside is prominent in a few rocks and some irregular bodies of muscovite-quartz-feldspar pegmatite are also exposed here. The charnockite band forming Chapman Ridge is cut by irregular dykes of red biotite-feldspar pegmatite and by bodies of blue quartz.

The well-developed foliation in the biotite gneisses is commonly tightly folded, but significantly these rocks do not appear to contain mylonitic material. Patches of coarse-grained, massive biotite-quartz-feldspar rock commonly interrupt the foliation of the gneiss.

PLATE 4.

GEOLOGICAL SKETCH MAP OF BERTHA ISLAND, KEMP LAND



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Tschuffert Peak, 1½ kilometres west of Stump Mountain, is composed of rather massive quartz-feldspar rocks containing small quantities of garnet, biotite, and pyroxene. An ill-defined foliation in these rocks is revealed by lenses rich in dark minerals, from a few centimetres to a few metres long. A few metres north-west of the summit of the peak a tightly folded band of biotite-rich rock, between 1 metre and 5 metres thick, trends across the ill-defined foliation, which appears to be developed parallel to the axial planes of the folds in the band (Plate 3).

Biotite appears to increase in prominence across Stump Mountain, though nowhere on the mountain is it the predominant dark mineral. The abundant evidence of deformation suggests that the original metamorphic relationship of biotite-bearing and pyroxene-bearing rocks has been greatly complicated and obscured by an episode of intense deformation which followed the metamorphism.

William Scoresby Bay

Warnock Islands, adjacent to a long string of islands off William Scoresby Bay, composed of banded gneiss, are formed by medium-grained, even-grained charnockite with a foliation conferred by stringers and small lenses rich in dark or light minerals. This rock resembles many of the light bands in the banded gneiss, but the only concentrations of mafic material on the islands, which are up to 100 metres across, are a few lenses of relatively fine-grained granular rock, up to 1 metre long by 20 centimetres thick.

Dales Island is predominantly composed of similar rock, with a better foliation formed by long stringers of pyroxene-rich material. Some of the charnockitic rocks here are very coarse-grained, with large pyroxene crystals. A few dark bands, less than 1 metre in thickness, are exposed low on the south face of Dales Island.

Well within the area of the banded gneiss, the northern part of Bertha Island (Plate 4) is formed by fine-grained to medium-grained, even-grained charnockite, with patches and blebs of coarse feldspar crystals which give the rock in places the appearance of the porphyroblastic charnockite; some exposures of porphyroblastic rock are between 50 and 70 metres wide. Stringers and small lenses of pyroxene-rich material produce clear foliation, though this is locally absent. Rare bands of pyroxene-rich rock range up to 30 centimetres in thickness. In some exposures garnet is scattered through the rock, or is grouped in lenses a few millimetres thick and up to 3 metres long.

A sub-circular mass of charnockite, over 100 metres in diameter, appears to cut the banded gneiss forming the remainder of Bertha Island. A large massive exposure on the coast about 4 kilometres east of Bertha Island carries the prominent rounded boulders and tors that distinguish the charnockite from the banded gneiss on Bertha Island. It also lies on strike with the northern part of Bertha Island, and is probably composed of charnockite.

Western Kemp Land

Two isolated groups of small exposures on the coast of western Kemp Land, Wheeler Rocks and the islands in Magnet Bay, are composed of even-grained charnockite. At Wheeler Rocks, coarse-grained lenses of brown feldspar, ranging from 1 centimetre to 8 centimetres in thickness and up to a few metres in length, make up about 30 percent of the rock. They alternate with bands of medium-grained charnockite, into which they grade. Vertical veins of similar feldspar, 1 centimetre thick and spaced about 70 centimetres apart, strike normal to the banding, and another feldspar vein 10 centimetres thick cuts the banding acutely and fingers along it. The charnockite also contains short streaks of pyroxene grains.

The islands ajoining the mainland ice at the south end of Magnet Bay are composed of similar charnockite. A large island, which was not visited, displays numerous dark bands up to 2 metres thick. The same island also contains two dykes of grey rock, each about three-quarters of a metre thick.

At Galten Island, in Magnet Bay, the medium-grained charnockite has a foliation defined by stringers of coarse blue quartz ranging up to 6 metres long and 5 centimetres thick, and spaced a metre or so apart. The foliation direction ranges widely over the island. Well-defined lenses, ranging up to 1 metre long by 30 centimetres thick, rich in pyroxene, biotite, or both, are scattered though the charnockite, but are generally parallel to neighbouring quartz stringers. The lenses are themselves foliated as a result of the preferred orientation of biotite or of small elongated aggregates of quartz and feldspar. W. Fander, of Australian Mineral Development Laboratories, describes a sample of charnockite from Galten Island as composed mainly of quartz and orthoclase-perthite, with antiperthitic oligoclase and andesine. Granular, poikiloblastic gains of hypersthene and some diopside commonly occur in groups with ore minerals, apatite, rare patches of brown hornblende, and a few rough grains of zircon.

BANDED GNEISS

Exposures within the banded gneiss outcrop were first sampled in 1936 at Bertha Island (Rayner and Tilley, 1940), and in 1954 at several points by ANARE surveyor R. Dovers (Stinear, 1956). Crohn (1959) described the geology of several localities within the banded gneiss; and Ruker (1963) described a few exposures on the north side of Edward VIII Gulf. The unit was proposed by McCarthy and Trail (1964) for the gneisses composed of alternating felsic-rich and mafic-rich bands, which form a long stretch of coastal exposures in Kemp Land.

According to McCarthy and Trail the banded gneiss is essentially composed of dark bands of pyroxene-plagioclase rock alternating with light bands of quartz-feldspar gneiss (Fig. 9).

The plagioclass of the dark bands is commonly labradorite. The pyroxene is predominantly hypersthene, commonly accompanied by clinopyroxene; hornblende also occurs in some samples. Garnet, biotite, and quartz are common in some dark bands.

In the light bands, the feldspar is both orthoclase and more abundant plagioclase - commonly oligoclase or andesine. Dark minerals are minor constituents; biotite and garnet appear to be more common than pyroxene, which is accompanied by hornblende in some samples.

Fig. 9. Typical banded gneiss, north face of Kemp Peak, Stillwell Hills.

Banded gneiss forms over 90 percent of the rock exposed on the coast between Tilley Nunatak and King Edward Ice Shelf, from where it extends north to Cape Boothby and south to Turbulence Bluffs. It is bounded on the west by the quartz-feldspar gneiss, on the south-west by the garnetiferous gneiss, and on the east by the sillimanite-bearing gneisses of Campbell Head. Within the outcrop of the banded gneiss a few bodies of other rocks occur; they are generally biotite-bearing gneisses resembling the rocks exposed at Taylor Glacier, or charnockites. Metamorphosed basic dykes are common in the western part of the banded gneiss outcrop.

In 1965 the examination of previously unvisited exposures defined more accurately the limits of outcrop of banded gneiss. The exposures examined are described in order, from east to west.

<u>Outlying islands off William Scoresby Bay</u>

Islands adjacent to Endresen Island appear from the air to be composed of banded gneiss.

Farrington Island and nearby islands are banded gneiss in which dark bands form from 40 percent to 70 percent of the rock. The light bands are quartz-feldspar rocks, some with very little dark mineral, and range from 1 metre to 3 metres in thickness. Many dark bands are elongated lenses, typically 20 metres long by 1 metre thick.

At Tillett Islands light bands form about 60 percent of the banded gneiss; light and dark bands are thin, ranging from 1 centimetre to 1 metre in thickness. Tight folds outlined by dark bands appear to plunge approximately in the direction of dip of the banding. Some dark bands have prominent blebs composed of large crystals of pyroxene and feldspar.

Bertha Island

This island was mapped in some detail in 1965 (Plate 4) because on air photographs it appears to lack the banded rocks prominent in nearby exposures. The northern part of the island is composed of charnockite, described above (p. 31). The remainder of the island is composed of banded gneiss in which the bands are too thin to show on air photographs; most range from 1 centimetre to 50 centimetres in thickness.

The banded gneiss is separated from the charnockite by a depression running the length of the island. The more rugged topography on the gneiss, with rounded hills and steep-sided valleys, is not distinctive enough to permit separation on the air photographs from the tors and rounded boulders which characterise the charnockite.

The light bands are pyroxene-quartz-feldspar gneiss, of which pyroxene forms less than 15 percent. These alternate with dark bands composed predominantly of pyroxene and feldspar, of which pyroxene forms between 50 and 95 percent. The contacts of the contrasting bands are distinct; any gradation occupies a very small part of each band. Some bands extend for more than 100 metres; others are elongate lenses less than 20 metres long.

Stillwell Hills

The southern Stillwell Hills are composed of banded gneiss in which some thick, light bands strongly resemble charnockite; some contain large feldspar crystals and are essentially porphyroblastic charnockite. Some steeply dipping bands seen from the air range up to 200 metres in thickness. On a small scale, as seen on the ground, bands are poorly defined in places, but are generally present, ranging from 2 centimetres to 1 metre in thickness.

The light bands are pyroxene-quartz-feldspar gneiss, commonly coarse-grained, ranging to fine-grained in places. Some light bands are massive but many have a foliation conferred by stringers of pyroxene, by small lenses and streaks of feldspar, or by schlieren of relatively coarse-grained quartz-rich rock. Some light bands are made up of thin quartz-poor bands alternating with quartz-rich bands, and others of alternating coarse-grained and medium-grained bands.

Dark bands are commonly massive, but many are themselves made up of bands and lenticles, from a few millimetres to a few centimetres thick, distinguished by their dark mineral content which ranges from 10 percent to 90 percent.

Some bands outline open folds and a few outline fairly tight folds. Attitudes of banding in the south-east of the hills suggest the presence of a large-scale fold measuring many hundred metres from limb to limb, and plunging north-east at 10° to 20°. A discordant band of feldspar-quartz-pyroxene rock, 30 centimetres thick, has sharp boundaries against the light quartz-feldspar gneiss.

In the central Stillwell Hills (Plate 5), the predominant type of banded gneiss is the widespread type in which light bands of quartz-feldspar gneiss alternate with dark bands of pyroxene-feldspar rock. A second, distinctive type, occupying 1½ square kilometres in the core of a large antiform north of Kemp Peak, is formed by bands of white quartzite alternating with thick black bands of pyroxene-feldspar rock which commonly contains bands rich in iron ore minerals and garnet.

In the predominant type of banded gneiss light bands form between 60 and 90 percent of the rock. They are generally thicker than the dark bands and range from a few centimetres to 30 metres in thickness; many can be traced along strike for more than 500 metres. Most weather light reddish-brown, and are medium-grained to coarse-grained pyroxene-quartz-feldspar gneiss, with a foliation conferred by stringers of pyroxene and small lenses, a few centimetres thick, of quartz or quartz-feldspar rock. Garnet and biotite are locally common and in a few bands they are the predominant dark minerals. A lens of light grey pyroxene-bearing rock, 30 metres long by 5 metres thick, which cuts the foliation of the banded gneiss about 4 kilometres north of Kemp Peak, resembles scapolite-pyroxene rocks seen in the Framnes Mountains and at Tilley Nunatak.

Most dark bands are elongated lenses; the largest are only about 10 metres thick by 100 metres long. They are generally medium-grained pyroxene-feldspar rocks, though in a few pyroxene predominates. Biotite, garnet, and diopside are locally common in the dark bands; a few thin dark red bands are composed of biotite and garnet and carry a network of green copper stains. Thin concordant lenses of very coarse biotite rock also occur. Some dark bands contain a considerable proportion of quartz, commonly as lenses or vein-like bodies, and in one band bodies of quartz contain aggregates of iron-ore minerals up to 8 centimetres by 12 centimetres in size. Many dark bands have a good foliation produced by stringers of feldspar or stringers of dark minerals.

About 3½ kilometres north-north-east of Kemp Peak a greenish grey band, 20 metres thick and over 100 metres long, appears to be made up of 40 percent diopside, 10 percent garnet, and 50 percent feldspar possibly including some quartz. It is a medium-grained gneiss with a foliation produced by stringers and thin bands rich in garnet, diopside, or feldspar. It contains irregular thin veins of coarse-grained feldspar and pyroxene-feldspar rock, and is separated from a thick band of dark feldspar-pyroxene rock by a zone of coarse-grained garnet rock about 1 metre thick. The feldspar-pyroxene band contains lenses of the diopside-rich gneiss and concordant bands and lenses of biotite-quartz-feldspar pegmatite, all up to 3 metres thick.

Several lenses and dykes, up to 5 metres thick, of pink, massive biotite-quartz-feldspar pegmatite cut the banded gneiss; they generally extend for at least several metres. Irregular and smaller bodies of coarse-grained rock composed of iron-ore mineral and quartz also cut the banding of the gneiss in places.

A distinctly different type of banded gneiss crops out over about 1½ square kilometres in the core of a large antiform whose axis lies about 1 kilometre north-west of Kemp Peak. The type is made up of white quartzite, forming about 10 percent of the outcrop, alternating with thick dark bands forming about 90 percent of the outcrop. Most quartzite bands are a few metres thick; a few range up to 25 metres in thickness. The quartzite is almost pure quartz with some layers, a few centimetres thick, of a white fibrous mineral resembling sillimanite.

Most of the dark bands are over 100 metres long and range from several metres to 70 metres in thickness. They are mainly composed of pyroxene-feldspar rock, though pyroxene predominates in places. Several contain thin bands of iron-ore minerals, garnetiferous in part, up to 50 centimetres in thickness and more than 50 metres long. The bands containing thin iron-ore mineral and the feldspar-pyroxene rock within 1 metre of them commonly have a network of green copper stains following surface cracks.

At the contacts of quartzite and pyroxene-feldspar bands the two types generally interfinger, and the pyroxene-feldspar band contains abundant garnet within 50 centimetres of the contact. At one place, a band of garnet and iron-ore mineral rock, several centimetres thick, occupies the contact, and most bands containing iron-ore mineral appear to be located relatively close to these contacts. Within a few metres of one contact the quartzite contains several lenses, typically 1 metre thick by 2 metres long, of dark pyroxene-feldspar rock.

In the <u>northern Stillwell Hills</u> (Plate 5), about 4 kilometres north-north-east of Kemp Peak, thick reddish-grey garnet quartzite bands are prominent in the banded gneiss. A rock face 50 metres high is composed of 25 percent garnet quartzite, 50 percent light brown pyroxene-quartz-feldspar gneiss, and 25 percent dark grey and black pyroxene-feldspar rock. Garnet quartzite bands increase in thickness and in abundance towards the northern margin of the hills. Another distinctive type of light band in the northern part of the hills is a quartz-feldspar gneiss with brick-red feldspar and with garnet and biotite in places.

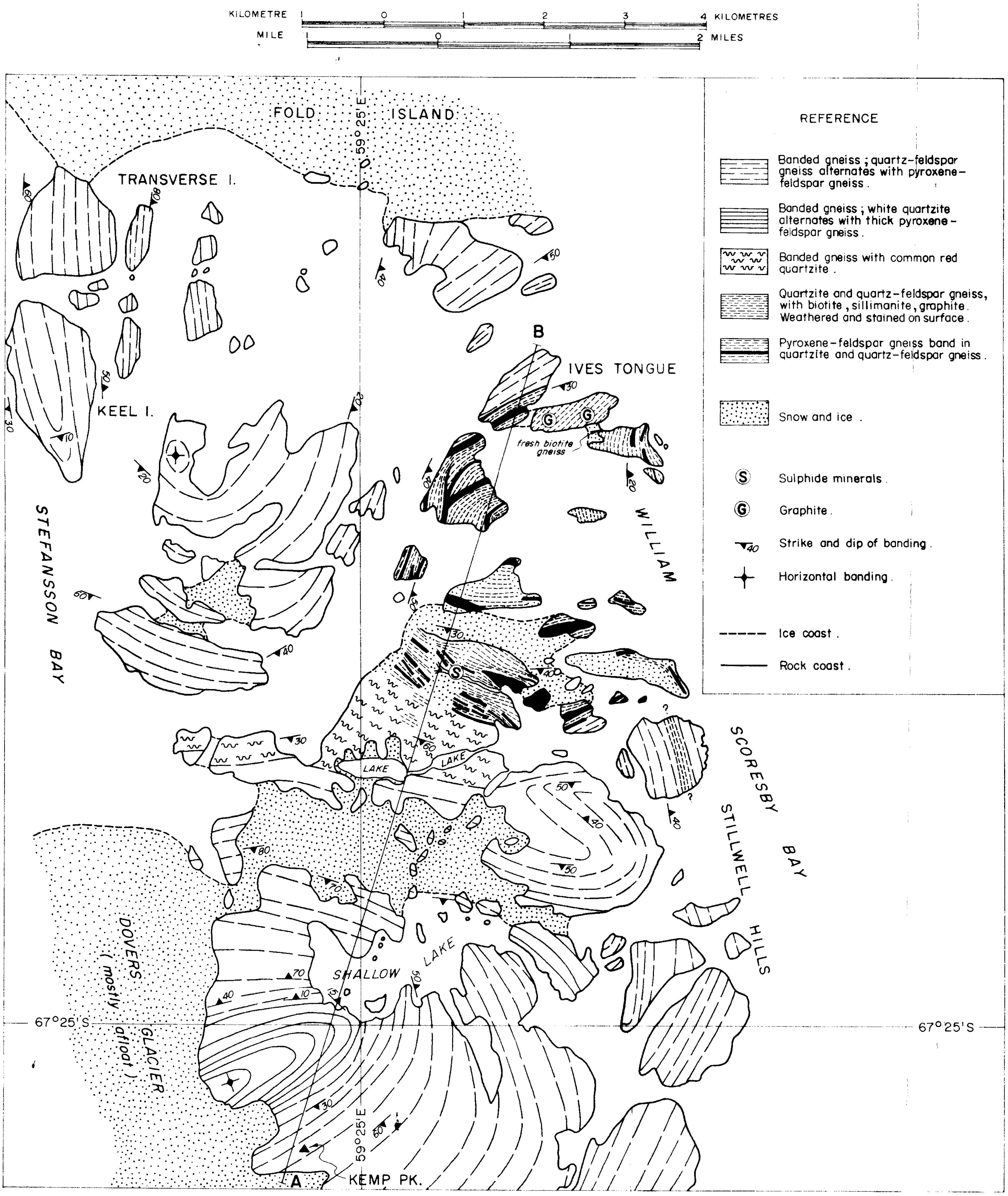
Along the northern margin of the Stillwell Hills and on several small islands, all within a sub-circular area about 4 kilometres in diameter, massive light grey, red, and yellow weathered quartzite and quartz-feldspar gneiss predominate. Banding is poorly developed in most exposures. Dark minerals are weathered in many of the rocks; garnet is predominant and biotite is common.

At the north end of the Stillwell Hills thin bands of biotite-garnet rock and of very coarse-grained biotite-iron-ore-mineral-quartz-feldspar rock reveal the structure of the massive rocks. In Ives Tongue, the northernmost island in the sub-circular area, the quartzite and quartz-feldspar gneiss contain combinations of garnet, graphite, sillimanite, and biotite. Graphite forms stringers and aggregates up to 2 centimetres across and makes up 2 percent of the rocks in places; sillimanite crystals form bands a few millimetres thick in the poorly foliated rocks.

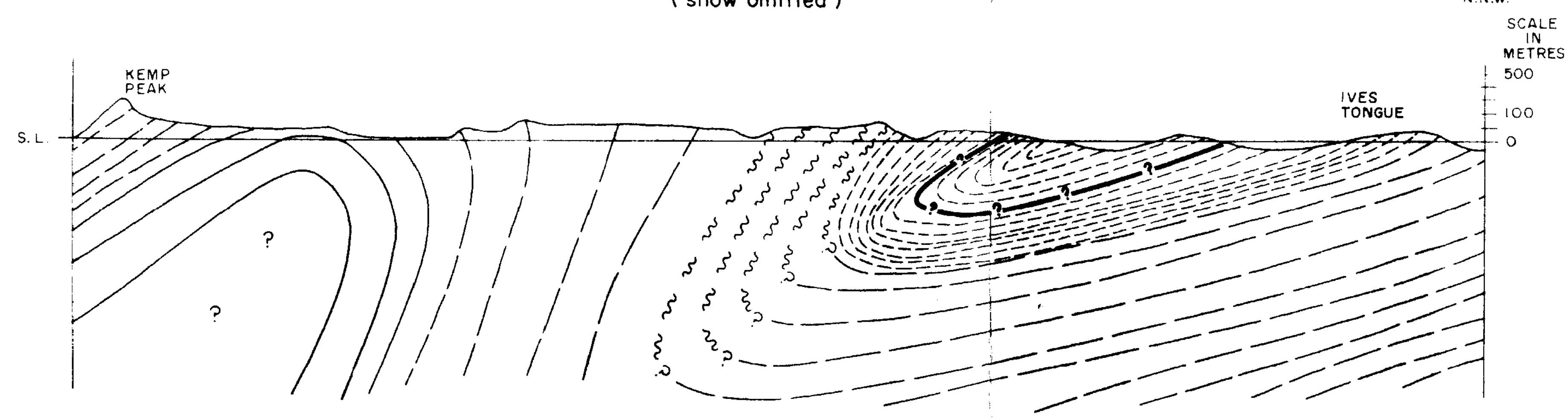
A few large lenses of little-weathered, dark grey pyroxene-feldspar rock occur within the outcrop of the weathered quartzite and quartz-feldspar gneiss. The contact of one lens, 30 metres long by 15 metres thick, with underlying biotite-garnet-quartz-feldspar gneiss is sharp but tightly folded, and the lens contains bodies of very coarse-grained biotite-garnet-quartz-feldspar rock, typically 3 metres long by 1 metre thick, within 5 metres of its bottom contact.

PLATE 5.

GEOLOGICAL SKETCH MAP OF NORTHERN STILLWELL HILLS & ADJACENT ISLANDS, KEMP LAND, ANTARCTICA



SECTION: KEMP PEAK TO IVES TONGUE
(snow omitted)



Large lenses and tongues, up to 50 metres thick, of similar dark grey pyroxene-feldspar rock, with biotite in places, are common in the weathered quartzite and quartz-feldspar gneiss near their contact with the normal banded gneiss. As described above, reddish quartzites in the banded gneiss in the northern Stillwell Hills increase in abundance towards this contact, which appears to be gradational on a large scale.

A few small yellow-brown exposures of fine-grained quartzite on the floor of a deep vally on the northern margin of the Stillwell Hills contain small crystals of metallic sulphides (see ECONOMIC GEOLOGY,60). Some of the lustrous mineral in this rock may be graphite, but fine detritus shed from it carries a yellow efflorescence smelling strongly of sulphur.

Green copper stains are common primarily on the garnet quartzites within the area of weathered rocks and in the banded gneiss for 2 kilometres south of it. Copper stains also occur in some quartz-feldspar rocks and two long dark lenses on the southern margin of the weathered rocks, each between 3 and 5 metres thick, carry patchy green stains up to 1 metre across.

Many of these quartzites and quartz-feldspar gneisses resemble stikingly the garnet-bearing and sillimanite-bearing gneisses of Cape Bruce and Campbell Head, and the relative scarcity of dark bands within their outcrop suggests that they should be classed with these gneisses rather than with the banded gneiss.

The graphite-garnet-sillimanite-quartz-feldspar gneisses have not been recognised elsewhere in Kemp Land or in Mac.Robertson Land, though they may be represented at Phillips Ridge in the Framnes Mountains, since graphite has been found in a sample of quartz-feldspar rock from that locality. These graphite-bearing rocks bear a marked mineralogical similarity to khondalites of Ceylon, described by Fernando (1950) as "garnet-sillimanite schists with disseminated flakes of graphite", which also contain feldspar and are commonly associated with quartzites.

Cosgrove Glacier to Gwynn Bay

Several exposures between Cosgrove Glacier and Gwynn Bay were visited for the first time in 1965, and others were inspected from the air to complete the geological examination of this stretch of coast.

The Secluded Rocks, several small exposures at the confluence of the Cosgrove Glacier and the Dovers Glacier, are formed by grey biotite-quartz-feldspar gneiss, medium-grained, with bands up to 50 centimetres thick relatively rich in dark minerals, which outline tight folds in places. The gneiss contains a few green lenses, typically 1 metre thick, rich in epidote and diopside, discordant veins and concordant bands, up to 10 centimetres thick, of red granitic quartz-feldspar rock, and some light-grey quartz-feldspar pegmatite. The rocks resemble strongly exposures in the vicinity of Taylor Glacier; the recurrence of the red granitic rock is striking.

In a group of small islands and coastal exposures near the south corner of Stefansson Bay (67°24'S., 59°02'E.), one island is composed of light grey, banded garnet-biotite-quartz-feldspar gneiss containing veins of red coarse-grained granitic rock. Most veins are less than 30 centimetres thick; some range up to 50 centimetres; they are generally concordant but in places form a network. This gneiss contains some dark bands of pyroxene-feldspar gneiss in which streaks of white feldspar produce a foliation. One lens-like body of dark fine-grained to medium-grained rock contains large plates of biotite. Folds are common here.

The coastal exposure south of the island appears to be formed by banded gneiss, and the coastal exposure south-east of the island appears to be made up of both banded gneiss and light grey rock similar to the garnet-biotite-quartz-feldspar gneiss described above.

The bands in a group of coastal exposures in the south-west corner of Stefansson Bay are generally thin, and dark and light bands are approximately equal in number. The dark bands are medium-grained pyroxene-quartz-feldspar rocks and the light bands differ from them mainly in containing less pyroxene, though biotite is common in some light bands. A few dark bands are composed almost entirely of pyroxene.

Solitary Nunatak, 10 kilometres south-west of Stefansson Bay, is composed of banded gneiss in which the light bands are quartz-feldspar gneiss; a few stringers of dark mineral, generally pyroxene but some of biotite, form the foliation. These bands contain irregular veins of quartz-feldspar rock, up to 10 centimetres thick, some of which are zoned with quartz in the centre of the vein. The dark bands generally range from 2 to 6 metres in thickness. Some of them are finely banded; others contain irregular but mainly concordant schlieren of pink feldspar up to 1 centimetre thick. Many of the dark bands carry green copper stains.

Scattered exposures on the north side of Cirque Fjord appear to be composed of banded gneiss.

Svart Mountain is formed of banded gneiss with rare concordant mica-quartz-feldspar pegmatite. Small exposures near the mountain are mainly composed of dark bands which are themselves banded and which contain irregular but mainly concordant veins and patches, up to 10 centimetres across, of pegmatitic pyroxene-quartz-feldspar rock, and veins of feldspar about 1 centimetre thick which form a network in places. The few light bands in these exposures contain little pyroxene. Dips are very irregular and folds are common. Green copper stains occur on both Svart Mountain and the small exposures.

On the west side of Bell Bay banded gneiss forming two large exposures is composed of light bands of pyroxene-quartz-feldspar gneiss with wispy aggregates of pyroxene, and numerous thin dark bands of pyroxene-feldspar rock ranging from 5 millimetres to 3 metres in thickness; the thicker dark bands are themselves banded. Some light bands contain garnet; some are quartz-rich and range up to 30 centimetres thick. Some dark bands contain black fine-grained stringers and bands of pyroxene and garnet between 1 and 5 centimetres thick. The light rocks and the dark rocks are approximately equal in volume in these exposures; contacts between the bands are sharp. Epidote coats a joint face in one light band.

In the northern part of Havstein Island, rather coarse-grained, massive, light bands alternate with dark bands between 2 and 10 metres thick. The light bands are quartz-feldspar rocks with little dark mineral; the dark bands are pyroxene-quartz-feldspar and biotite-pyroxene?-quartz-feldspar rocks. A lens about 1 metre thick is composed of diopside-biotite-quartz-feldspar gneiss, possibly with sillimanite.

The light bands in exposures along the west side of the Hoseason Glacier increase in number and thickness northwards. In the southernmost exposure they are rarely more than 2 metres thick and form less than 50 percent of the rock. Six kilometres to the north light bands range up to 20 metres thick and form up to 80 percent of the rock. The dark bands are less than 3 metres thick in the northern exposures; some are over 10 metres thick in the south.

In the large southern exposure the light bands are pyroxene-quartz-feldspar gneiss. The dark pyroxene-feldspar bands contain concordant small lenses of coarse garnet and stringers and discordant veins of pegmatitic pyroxene-feldspar rock. Zones of tight disrupted folds in the dark bands are veined by aplitic rock and are heavily stained by iron. Near-vertical dykes of almost pure pyroxene, about 3 metres thick, parallel the strike of the banded gneiss in this exposure, but cut across the relatively gentle dip.

On the west side of Gwynn Bay a large exposure of banded gneiss was examined in detail. The light bands are quartz-feldspar gneiss with biotite and garnet as their characteristic dark minerals, but pyroxene is also common and some light bands are pyroxene-feldspar quartzites. Garnet is common in the dark bands, and diopside is abundant in some. Both light and dark bands are themselves commonly composed of bands a few centimetres thick. Brick-red quartz-feldspar rock forms some light bands at the south end of the exposure. Bands of biotite-garnet rock up to 15 centimetres thick occur within some pyroxene-feldspar bands.

Dykes of biotite-quartz-feldspar pegmatite up to 2 metres thick cut or parallel the banding of the country rock. One dyke has biotite-rich margins; another contains accessory iron-ore mineral in crystals up to 5 centimetres long intergrown with garnet in places, including crystals up to 3 centimetres long of a black glassy mineral which may be goethite.

Many folds are outlined by the banded gneiss. The dominant type of large-scale fold appears to be a tight synform. The fold in one example is outlined by a massive dark band 5 metres thick and its core is occupied by massive quartz-feldspar rock. Outside the dark band the foliation of the quartz-feldspar gneiss follows the fold. In another tight fold of similar style both dark and light bands in the core contain discordant pods and irregular vein-like bodies of massive biotite-garnet-quartz-feldspar pegmatite. The existence of the massive rocks in the fold cores suggests that during the fold movements recrystallisation was restricted to the cores.

In another exposure in which the gneisses are intensely folded in an isoclinal pattern, they are cut by veins of brown quartz and of biotite-quartz-feldspar pegmatite which are straight in places and follow the fold pattern in others. These pegmatite veins range up to a few metres in thickness and contain feldspar crystals up to 15 centimetres long; in their centres they contain large lenses of blue quartz and of brown quartz, and crystals of biotite up to 5 centimetres long.

The eastern islands of the Oygarden Group were briefly re-examined from the air. Some thick dark bands on Borg and Lang Islands and on the Sirius Islands are in fact lenses about 100 metres long by 20 metres thick. Other concordant thin dark bands appear to unite with thick discordant dyke-like masses. Thick dark bands outline isoclinal folds at Lang Island, and isoclinal folds are evident in the Crooked Islands.

Cape Boothby to Turbulence Bluffs

Traverses made by helicopter in 1965 revealed that the boundary between banded gneiss and quartz-feldspar gneiss lies a relatively short distance west of a line from Cape Boothby through Cape Dalton to Turbulence Bluffs. The quartz-feldspar gneiss is strikingly similar to the rock which generally forms the light bands in the banded gneiss, and in some exposures between Cape Boothby and Turbulence Bluffs dark bands form only 5 percent of the banded gneiss. Even so, the two rock types may be separated with little difficulty because in the quartz-feldspar gneiss regularly repeated and well-defined dark bands do not occur.

Metamorphosed basic dykes up to 10 metres thick are common in banded gneiss exposures between Cape Boothby and Turbulence Bluffs. Some dykes are cut by massive mica-quartz-feldspar pegmatite.

The Jagar Islands, off Cape Boothby, are formed by banded gneiss in which dark bands, from a few centimetres to a metre in thickness, form about 5 percent of the total rock. The light bands are between 5 and 20 metres thick; they are dominantly pyroxene-quartz-feldspar gneiss of which pyroxene forms less than 10 percent, medium-grained to coarse-grained, and foliated by ill-defined, frayed bands of felsic or mafic material, with parallel scattered lenses of blue quartz up to 1 metre thick by 3 metres long. The light bands are light yellow-brown on weathered surfaces, but the fresh rock is considerably darker and resembles even-grained charnockite, principally because the fresh feldspar is dark brown.

The dark bands are mostly elongated lenses, several metres long, composed of feldspar with various amounts of garnet, biotite, and pyroxene; some have streaks of diopside. A few black bands have little or no feldspar, and some of these contain iron-ore mineral; one is made up of 60 percent pyroxene, 30 percent iron-ore mineral, and 10 percent garnet.

Some dark bands a few centimetres thick are intensely deformed into isoclinal folds. The thinnest resemble ptygmatic veins but they are broadly concordant with the poorly foliated coarse-grained light rocks which contain them (Fig. 10). A few of these thin dark bands are bordered by very coarse-grained massive felsic material which also appears to outline folds. Other small-scale folds are cut by similar massive felsic material (Fig. 11).

At least two dykes of grey metamorphosed dolerite cut the banded gneiss on Jagar Islands (Fig. 1), and both gneiss and dykes are cut by a sheet, 1 metre thick, of massive biotite-quartz-feldspar pegmatite on two adjacent small islands. In places the sheet pinches out and re-appears a few metres farther on, about 1 metre higher or lower in the sea-cliff exposure. The centre of the sheet is generally composed of milky quartz and the margins are composed of intergrown red feldspar and biotite. The pegmatite shows no sign of deformation; mica crystals and well-formed quartz crystals up to 15 centimetres long all lack a preferred orientation.

Fig. 10. Close, ptygmatic-like fold in banded gneiss. Southernmost of two large islands, Jagar Islands, Kemp Land.

Fig. 11. Fold in banded gneiss, cut off by recrystallization of the rock. Southern-most of two largest of Jagar Islands, Kemp Land.

Between Kloa Point and Martin Island scattered exposures observed from the air along the coast are all composed of banded gneiss, commonly cut by basic dykes up to 10 metres thick. Dark bands on Martin Island outline isoclinal folds tens of metres in amplitude, plunging approximately in the strike of the banding.

The rocks on Georges Islands resemble many exposures of banded gneiss, but they are predominantly composed of garnet-biotite-quartz-feldspar gneisses in which the banding results from variations in the dark mineral content; the bands are poorly defined. Some of the gneisses probably contain pyroxene. The gneisses are grey and pink, and typically medium-grained; schlieren and veins of coarse-grained material are common; the veins range up to 10 centimetres in thickness and some cut the foliation.

On the northern island many veins of quartz and of biotite-quartz-feldspar pegmatite, ranging up to 1 metre in thickness, cut an irregular metamorphosed dolerite dyke about 10 metres thick. The foliation of the gneiss adjacent to the pegmatite bodies is disturbed and the pegmatites contain blocks of gneiss up to 1 metre across.

The banding in similar gneiss on the southern island is more clearly defined and at least three dolerite dykes, up to 6 metres in thickness, sharply cut the banding; the dykes carry green copper stains.

Banded gneiss forming Cape Dalton is predominantly light quartz-feldspar bands, some containing garnet, with common dark pyroxene-feldspar bands. Massive bodies of biotite-quartz-feldspar pegmatite, up to 10 metres thick, cut and disturb the banding (Fig. 12), though ill-defined biotite-quartz-feldspar veins near the margin of one pegmatite appear to grade into the quartz-feldspar gneiss.

Fig. 12. Light-coloured biotite-quartz-feldspar pegmatite with very irregular margin cutting across dark-coloured foliated banded gneiss. Cape Dalton, Kemp Land.

Abrupt Point is composed of banded gneiss with relatively few and thin dark bands. The light bands are quartz-feldspar gneisses with various proportions of pyroxene; some massive bands have little dark mineral. Feldspar-pyroxene rocks form some dark bands, and a few bands up to 50 centimetres thick are pyroxene rocks. Garnets are scattered throughout. Light and dark bands are medium-grained; wispy banding occurs within some light bands, and some have schlieren of quartz and feldspar up to a few centimetres thick.

The banding outlines several isoclinal folds. In one folded dark band, about 2 metres thick, veins of pyroxene about 1 centimetre thick dip at right angles to the dip of the band.

A small part of the north-western side of Abrupt Point is composed of grey, well-banded biotite-quartz-feldspar gneiss and biotite-pyroxene-quartz-feldspar gneiss with some bands of feldspar-pyroxene gneiss. The rocks are medium-grained and scattered garnet occurs in all types. Pegmatite in these grey gneisses forms concordant and discordant veins in zones up to 20 metres thick; one irregular discordant body of white pegmatite is 6 metres thick.

A group of small exposures 10 kilometres west of Cape Dalton, at lat. 66°53'S, long. 56°33'E, is predominantly light pyroxene-quartz-feldspar gneiss and fine-grained garnet-quartz-feldspar gneiss, with very few dark bands, which are 30 centimetres or less thick. Lenses of garnet quartzite up to 20 metres long by 3 metres thick occur in minor amount. Small scale folds are common, especially in the garnet-quartz-feldspar gneiss.

One exposure contains a single dark band of pyroxene-quartz-feldspar rock 6 metres thick, which may be an intrusive rock. A few pegmatite dykes up to 1 metre thick also occur in these exposures.

Exposures at Kvars Bay are banded gneiss with numerous dark bands, mostly less than 10 centimetres thick; a few range up to 1 metre in thickness.

Pyroxene is relatively abundant in the light bands; garnet is rare, confined to a few pegmatitic schlieren 2 or 3 centimetres thick. In some dark bands pyroxene and abundant garnet are concentrated in irregular blebs up to 3 centimetres long and 2 centimetres thick. A pegmatite vein about 50 centimetres thick and a few pegmatite dykes cut the gneisses.

Turbulence Bluffs are composed of banded gneiss in which the dark bands range up to 3 metres in thickness and are themselves banded by quartz-rich schlieren up to 3 centimetres thick. The light pyroxene-feldspar gneiss bands contain thin scattered bands of pyroxene-rich rock a few centimetres thick. A basic dyke about 3 metres thick cuts the gneiss.

QUARTZ=FELDSPAR GNEISS

The area of outcrop of the unit called quartz-feldspar gneiss extends from the King Edward Ice Shelf at the western end of Edward VIII Gulf westwards to the limit of the survey, and southward to the garnetiferous gneisses cropping out around the upper parts of the Robert and Wilma Glaciers. The unit probably continues west through Enderby Land to the Tula Mountains and Amundsen Bay, where similar rocks were described by McLeod (1959). The rocks at Twin Peaks are considered to be intermediate between the quartz-feldspar gneiss and the garnetiferous gneisses; they are described under the latter rock unit.

As the name implies, the unit is dominantly quartz-feldspar gneiss. Pyroxene and garnet occur in small amounts and biotite is a minor constituent. Other lithologies present include feldspar-pyroxene gneiss, pyroxene rock, garnet-pyroxene rock, garnet quartzite, and biotite-rich rocks; stringers and veins of pegmatitic rock occur locally.

The typical quartz-feldspar gneiss is a predominantly medium-grained, light grey to white rock, mostly stained red, brown, or yellow by iron oxides. It is massive in some outcrops, but is more commonly foliated and/or banded to various degrees. Sub-spheroidal weathering is widespread.

The rock is composed mainly of quartz and feldspar; in places the composition approaches that of a quartzite. Minerals other than quartz and feldspar are rare or absent in much of the quartz-feldspar gneiss, but many outcrops contain a small amount (less than 5 percent) of dark minerals, principally pyroxene and garnet, and rarely, biotite. Pyroxene is finely disseminated in some occurrences, but is more common as thin stringers or trails of grains. The pyroxene content is minor, but exceeds the garnet in the unit as a whole. Where garnet occurs, it is locally more abundant than the pyroxene; it commonly is present as disseminated grains. Biotite mostly forms thin streaks of flakes in the gneiss.

The foliation and small-scale banding of the quartz-feldspar gneiss is the result of several features, which include: elongation of the quartz grains, small lenticular fine-grained quartz aggregates, variation in the proportions of quartz and feldspar, alternation of different grain sizes, and streaks of dark minerals. The small-scale banding tends to be thin and discontinuous. Where minerals other than quartz and feldspar are rare, the rock tends to be massive. In a few places, such as the nunataks south of the Downer Glacier (lat. 66°57'S, long. 56°14'E), otherwise massive quartz-feldspar gneiss contains irregular vein-like patches of coarser-textured rock. Except for the different grain size, the patches seem identical to the enclosing rock, and grade into it.

A large-scale banding results from alternations of other rock types with the quartz-feldspar gneiss. In most cases, the bands possess well-defined margins; many are themselves banded. Most common of these other types are feldspar-pyroxene gneiss and pyroxene rock, which form bands ranging in thickness from a few centimetres upwards. Some are garnetiferous, and some contain a few percent of opaque minerals. In some places, such as the nunatak near the junction of the Seaton and Wilson Glaciers, pods of pyroxene rock, a metre or so across, may have formed by disruption of bands by intense folding. Other minor banding in exposures near this nunatak is produced by bands of medium-grained to coarse-grained garnet-pyroxene rock alternating with bands of finer-gained biotite-rich rock. The bands range from 15 to 30 metres thick.

Bands of biotite-quartz-feldspar gneiss about a metre wide occur on several nunataks in the vicinity of Mount Storegutt. On Mount Mueller lenses of garnet quartzite occur, ranging from 15 centimetres thick and 30 centimetres long to over 15 metres thick and 150 metres long. These lenses are associated with bands of medium-grained pyroxene-garnet-quartz-feldspar rock.

In only a few places were the bands in the quartz-feldspar gneiss traced over any distance. Observations where this was done suggest that they are actually lenses rather than persistent bands. For example, on Mount Mueller bands of black, massive, medium-grained pyroxene-rich rock associated with thicker bands of quartz-feldspar gneiss are 2 to 7 metres thick and range from less than 15 metres to 60 metres long.

Pegmatitic rocks form pods, or veins up to 3 metres thick, in the gneisses, and in places form a network of veins about a centimetre thick. The veins may be concordant or discordant. Mineralogically they are generally composed of pink and white feldspar and quartz, with biotite flakes up to a centimetre across in some localities.

Bird Ridge, near the boundary between Kemp and Enderby Lands, was only inspected from the air since it was not possible to land on it. It is composed of red rocks in bands up to 150 metres thick and bands, approximately 15 metres thick, of white and light grey rock, probably quartzite, and a very few bands of black rock. The thick beds have the appearance of iron-stained quartz-feldspar gneiss.

The quartz-feldspar gneiss unit as a whole is weakly to moderately jointed; normally the joints dip steeply and strike in random directions.

The strike of these gneisses is generally east-west, with minor variations, especially around Mount Storegutt, and the nunataks east of Mount Pasco.

Most of the banded outcrops of the quartz-feldspar gneiss unit show tight isoclinal folding. The extent of this folding in the homogeneous outcrops was not ascertainable. A lineation is shown up in some places by elongated quartz grains or small aggregates of quartz.

GNEISSES OF TAYLOR GLACIER

These rocks are typically well-foliated biotite-garnet-quartz-feldspar gneisses, in which the foliation is tightly folded. Sillimanite-cordierite-bearing gneisses are prominent between Cape Bruce and Campbell Head.

Exposures of these gneisses, which extend from Norris Island to Campbell Head, were examined in 1965 near Hayes Peak and at the southern margin of the exposures extending south from Campbell Head. Hayes Peak is composed of reddish-grey biotite-bearing and garnet-bearing quartz-feldspar gneisses which contain large patches of coarse, massive, granitic rock of similar composition to the gneisses.

At the south-west corner of the area of exposed rock behind Campbell Head, bands of white quartzite alternate with dark bands of gneiss and massive rock composed of various proportions of garnet, biotite, pyroxene, quartz, and feldspar. Though large-scale banding in these exposures is evident from the air, the rocks, seen in detail on the ground, are tightly and irregularly folded and contorted.

Aerial observation revealed that light-grey hypersthene-bearing gneisses, sampled in 1961, crop out as a narrow north-trending band between Cape Bruce and the west side of the Taylor Glacier. These rocks appear to be underlain and overlain by the reddish sillimanite-bearing gneisses which predominate at Cape Bruce.

The boundary relationships of these gneisses with the charnockite are described in the section on charnockite. Their boundary with the banded gneiss may also be gradational. Sillimanite-bearing gneiss is interbanded with banded gneiss at Tilley Nunatak, and bodies of gneiss similar to the gneiss of Taylor Glacier occur in banded gneiss on the south-western side of Stefansson Bay, and at Striated Nunatak and Secluded Rocks.

GARNETIFEROUS GNEISSES OF MOUNT KERNOT, ETC.

The unit called here 'garnetiferous gneisses' crops out as nunataks near the head of the Robert and Wilma Glaciers at about latitude 67½°S, longitude 56°E. Mount Kernot and Rayner Peak are the largest of these nunataks, standing some 160 metres and 320 metres respectively above the ice surface. The rocks forming Twin Peaks (lat. 67°20'S, long. 55°30'E), described in this section, are intermediate in character between the garnetiferous gneisses and the quartz-feldspar gneiss.

The garnetiferous gneisses are a heterogeneous unit characterized by a variety of rock types and by the presence of garnet as a common mineral. The various rock types form bands which are generally from 1 to 5 metres thick; some range up to 15 metres. The most common types are variants of feldspar-pyroxene and pyroxene-feldspar gneiss, quartz-feldspar gneiss, biotite-bearing gneisses, and quartzite. Garnet is a constituent of most rock types, in amounts ranging from minor to predominant.

The pyroxene-feldspar gneiss is a moderately foliated, granulitic-textured, equigranular rock, commonly containing thin bands or lenses (mostly only one or two grains wide) of either feldspar or pyroxene, and massive in places, with no foliation. The feldspar content differs greatly from place to place; in parts it is only a few percent, and the rock is almost entirely pyroxene or garnet and pyroxene. On the whole the garnet content ranges from rare to common. In some of the garnet-pyroxene rocks it is concentrated in closely spaced ellipsoidal aggregates up to 7 centimetres in diameter, containing 75 percent or more garnet. Green diopside is common in many of the garnet-pyroxene rocks. On parts of Mount Kernot, the pyroxene-feldspar gneiss contains quartz-feldspar bands up to ½ centimetre thick. Near the north-east corner of Mount Kernot, and on the nunatak at lat. 67°22'S, long. 55°44'E, feldspar-pyroxene gneiss contains irregular, pink quartz-feldspar schlieren up to 10 centimetres wide and 2 metres long. The grain-size of these schlieren is variable; it tends to be coarser in the wider ones. Some of the coarser schlieren contain scattered crystals of black pyroxene.

The quartz-feldspar gneiss is a creamy-coloured rock with a rather uneven grainsize. Foliation is mostly poor, but parts display a good banding because of variation in the proportions of quartz and feldspar. The banding is commonly accentuated by dark minerals, mainly garnet or garnet and biotite. Garnet, when present in minor amount, is mostly disseminated through the rock; when more common, it occurs in bands up to a centimetre wide. Biotite, which is usually accompanied by garnet, tends to give a discontinuous streaky banding. Some bands in the rock, up to 2 or 3 centimetres wide, are rich in pyroxene.

The biotite-bearing gneisses are variants of the garnetiferous quartz-feldspar gneiss, and to a lesser degree, the garnetiferous pyroxene-feldspar gneiss. Normally the biotite and biotite-plus-pyroxene contents do not exceed 5 and 20 percent respectively. The biotite tends to be concentrated in bands through the rock, and most biotite-bearing types have a good foliation. The biotite-bearing rocks are best developed at Striated Nunatak (Fig. 13) and the one north-west of it on the other side of the Robert Glacier. At both places the rocks are fine-grained to medium-grained pyroxene-garnet-biotite-quartz-feldspar gneiss interbanded with minor garnet-pyroxene-biotite-feldspar gneiss. The predominant quartz-feldspar gneiss is itself prominently banded, the bands ranging up to half a metre in thickness. A few bands of garnet-pyroxene rock occur at both places. Biotite is also common at Else Nunatak, where the rock is predominantly fine-grained, foliated, garnet-biotite-quarz-feldspar gneiss with subordinate medium-grained feldspar-pyroxene gneiss. The garnet tends to be concentrated in bands or lenses up to 5 centimetres wide, but otherwise the rock is not markedly banded because of variation in the mineral content. A strongly banded appearance is produced, however, by veins of quartz up to 2 centimetres wide which are parallel to the foliation.

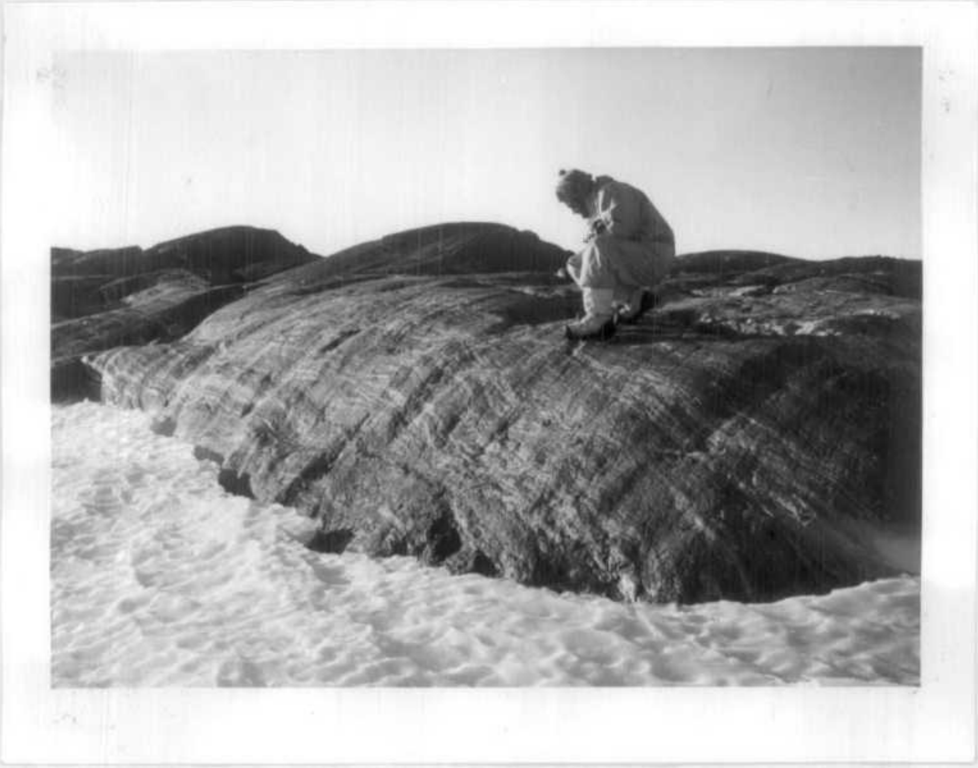


Fig. 13. Banded pyroxene-garnet-biotite-quartz-feldspar gneiss, showing grooves and striations caused by ice movement. Striated Nunatak, east side of Robert Glacier.

Bands of quartzite were found on Mount Kernot and Rayner Peak. The rock is massive and very well jointed, breaking into small rectangular blocks. The quartz is clear, giving the rock a greyish colour. Other minerals - mainly feldspar and garnet - are rare.

Coarse-grained pegmatitic quartz-feldspar veins, mostly less than a quarter of a metre wide, occur locally, especially in the pyroxene-feldspar gneiss.

The foliation of the rocks is parallel to the banding caused by alternation of the different rock types. Although the strike seems to be constant on each nunatak, large exposures reveal that the rocks are commonly folded into very tight isoclinal folds with an amplitude many times their wave length (Fig. 14). Near the western corner of Rayner Peak, a large open fold plunges east at about 30°.

Fig. 14. Recumbent fold in garnet and pyroxene bearing quartz-feldspar gneiss, with thin quartz-feldspar veins. The light-coloured central core is about 3 metres thick on the right-hand side. Rocks of "Garnetiferous gneiss" unit, north-east corner of Mount Kernot, Kemp Land.

Lineation was seen in several outcrops. It is caused either by elongation of the mineral grains or small lenticles of grains of the same mineral, or by small crenulations in the foliation. The latter type is particularly marked on Rayner Peak, in garnet-quartz-feldspar gneiss at its junction with garnet-pyroxene rock. Where lineation and isoclinal folding were seen together, the lineation is parallel to the fold axes.

Only one outcrop of Twin Peaks was accessible in the time available; this was at the base of the cliffs near the south-east corner of the mountain. This outcrop is garnetiferous-quartz-feldspar gneiss. A thick band of probable quartzite, near the north-west corner of the mountain, was inaccessible. The few observations which could be made suggested that the rocks on Twin Peaks represent an assemblage intermediate between the garnetiferous gneiss and quartz-feldspar gneiss units.

A dyke of metamorphosed basic rock, near the summit of Rayner Peak, is $1\frac{1}{2}$ to 3 metres wide. It strikes about N 50° and dips south-east at 80°. Two specimens were collected by surveyor M. Corrie; one is a coarse pegmatitic rock containing crystals of diopside up to 5 centimetres across, quartz and feldspar; the other is a medium-grained, equigranular, foliated garnet-diopside-feldspar gneiss. According to Mr. Corrie, there were two bands of each type over a width of $1\frac{1}{2}$ metres. The remaining width of the dyke was obscured by rubble.

GNEISS, MARBLE, AND MIGMATITE OF THE HANSEN MOUNTAINS

Fram Peak, the largest nunatak in a small isolated group north of the Hansen Mountains, has been described by McLeod (1959). In 1965 further investigation of Fram Peak and nearby nunataks and a rapid reconnaissance of the Hansen Mountains revealed that the geology of the entire range is substantially similar to that of Fram Peak.

McLeod (1959) records that Fram Peak is composed of migmatite formed by red granite and biotite-quartz-feldspar gneiss. In 1965 a detailed examination of Fram Peak added little to McLeod's observations. He describes the granite in thin section as a medium-grained mosaic of quartz and feldspar (potash feldspar and oligoclase-andesine) with clinochlore and rare biotite, magnetite, zircon, and apatite. It has a megascopic foliation produced by stringers of quartz and by large feldspar crystals, abundant in places, which have a marked preferred orientation. Where best developed the foliation produces a flaggy parting.

The granite contains bands, up to 5 metres thick, of coarse-grained, quartz-rich rock stained yellow and dark brown by iron. These bands carry a lustrous dark mineral, forming less than 2 percent of the rock, which may be graphite.

The dark brown biotite-quartz-feldspar gneiss is most abundant in an ill-defined zone about 50 metres thick, where it forms lenses up to several metres long and 2 metres thick. The gneiss has a migmatitic relationship with the surrounding red granite: the margins of the lenses are indefinite; many irregular patches of each rock type lie within the other; ill-defined tongues of each type penetrate the other; all gradations in composition exist between the two types.

Fram Peak is a bulky monolith connected by a narrow rock saddle on its north-eastern side to a high rock ridge which extends north-eastwards for about 500 metres. The high ridge is predominantly composed of biotite-quartz-feldspar gneiss, fine-grained to medium-grained, with abundant lenses and stringers of red fine-grained to very coarse-grained granite ranging from a few millimetres to a few metres thick. In the south-eastern face of this high ridge a concordant band of marble between 20 and 30 metres thick is exposed. This band strikes into the narrow rock saddle, where it inter fingers with the migmatitic rocks. On the south-west side of the saddle the marble is separated from the granite by a fine-grained to medium-grained quartzite, into which the granite grades. The quartzite has a fine flaggy parting and a strong lineation, possibly representing slickensides. McLeod (1959) describes it as a phyllonite occupying a shear zone.

The marble is predominantly a mid-grey, very coarse-grained, friable rock, which McLeod (1959) describes as being composed of calcite (more than 50 percent of the rock), olivine (almost completely altered to serpentine minerals and magnetite), magnetite, pyrrhotite, pleonaste, and minor apatite. Small spherical segregations a few centimetres in diameter, scattered in the rock, contain combinations of olivine, magnetite, pleonaste, enstatite, apatite, and rare calcite and zircon. Larger aggregates are composed of olivine and biotite with some magnetite.

In the saddle, a large sub-circular mass about 5 metres across in the marble is composed of dark green opaque and light green translucent minerals intergrown with biotite, calcite and magnetite. Small clots of red garnet are restricted to the west side of the saddle.

Near the end of the ridge, a small group of nunataks extends 3 kilometres north-eastwards. They are predominantly composed of red-weathering granite similar to the granite of Fram Peak, but lenses and bands of dark-brown biotite-bearing and pyroxene-bearing gneisses form about 20 percent of the exposures, and white quartzite bands form about 1 percent.

The granite is generally a medium-grained quartz-feldspar rock foliated by stringers of quartz a few millimetres thick; it contains some garnet or biotite, and iron-ore minerals may be associated with the quartz. The granite generally forms bands between 50 centimetres and 10 metres thick; a few bands are more than 50 metres thick.

The dark brown bands are quartz-feldspar gneisses rich in biotite with some iron-ore minerals and pyroxene. They are fine-grained to medium-grained rocks with a foliation conferred by stringers of dark minerals alternating with stringers of quartz and feldspar, each a few millimetres thick. Most dark brown bands are between 50 centimetres and 5 metres thick; a few range up to 30 metres in thickness.

The difference in colour between red and dark brown rocks is mainly produced in weathering. The fresh granite is almost as dark as the fresh pyroxene-biotite-quartz-feldspar gneiss, since feldspar and quartz are dark brown where unweathered.

The quartzite bands are medium-grained to coarse-grained garnet-feldspar quartzites. Quartz is blue-grey and its concentration in stringers gives the rock a foliation; some thicker stringers contain iron-ore mineral. Almost all the quartzite bands are less than 1 metre thick. They are generally concordant, but some of them cut across the banding of the granite and the gneiss in places.

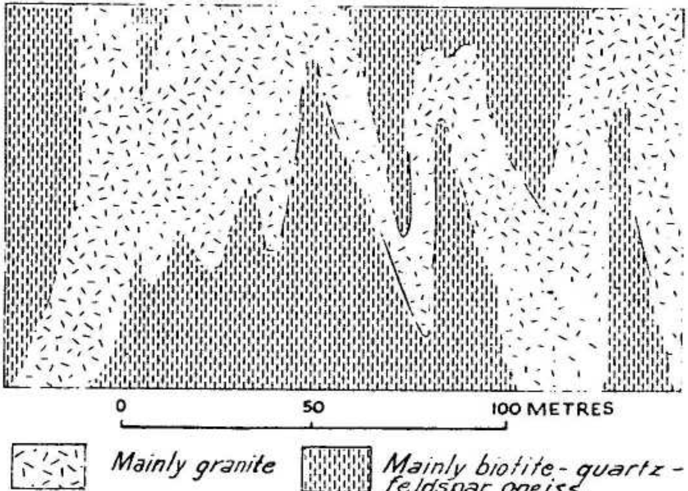
On the steep eastern side of the interrupted ridge, red and brown bands outline large-scale near-isoclinal folds (Fig. 15a). Erratic behaviour of the magnetic compass at one point on the ridge is probably caused by the iron-ore mineral common in all rock types.

The eastern Hansen Mountains are rock spires, hundreds of metres high, composed of red, white and brown banded rocks commonly deformed into large isoclinal folds. White bands form about 30 percent of the exposed rock and red bands most of the remainder; brown bands are only prominent in a few exposures.

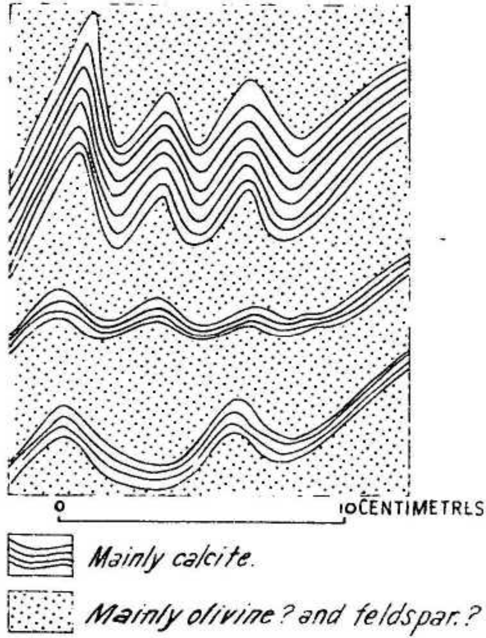
The rocks were examined at See Nunatak. The white bands here are garnet quartzites; the band sampled is medium-grained and poorly foliated. Red and reddish-brown bands are coarse-grained biotite-quartz-feldspar gneiss and contain a few dark brown lenses, up to 5 metres long by 2 metres thick, of medium-grained and fine-grained equigranular biotite-pyroxene?-quartz-feldspar rock. The stringers of dark minerals (garnet, biotite, or pyroxene), which define the foliation are intensely contorted, and large irregular patches of massive granitic coarse-grained biotite-quartz-feldspar rock produce a migmatitic appearance in places.

The white bands generally have sharp margins, but in places they appear to grade within a very small interval into the red bands.

Fig. 15



a. Near-isoclinal folds at Fram Peak, Kemp Land, Antarctica.



b. Small-scale folds in marble from Hansen Mountains, Kemp Land, Antarctica

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Maruff Peaks, observed from the air, are composed predominantly of thick red bands alternating with white bands up to 20 metres thick. The banding outlines large isoclinal folds, up to about 100 metres in amplitude and 20 metres from limb to limb, whose axial planes appear to trend parallel to the strike of the banding. However, the southernmost peak is composed of thick black and thinner white bands, and carries a prominent steeply plunging lineation apparently at right angles to the trend of the isoclinal folding in the other peaks. In places the white bands appear to cut across the banding of the red and brown rocks and on one peak the white bands form a network.

Whiting Nunatak, also observed from the air, is formed by white, red, and brown bands, broadly similar to See Nunatak and Maruff Peaks.

The western Hansen Mountains appear from the air to be formed by more massive rocks, but banding similar to that in the eastern Hansen Mountains is prominent in some nunataks, and thick, isolated bands of light grey marble occur in places.

Two nunataks were visited in the western mountains. One, the easternmost member of the Dwyer Nunataks, has a massive appearance when seen from the air but is composed of finely-banded grey gneiss and coarse-grained red-brown gneissic granite; irregular pods and lenses of massive granite contain blocks of grey gneiss.

The grey gneiss is a fine-grained, equigranular, finely-banded rock possibly composed of diopside and feldspar. It resembles in colour and texture fine-grained varieties of marble exposed at Fram Peak and the other nunatak visited in the western Hansen Mountains. The red-brown gneissic granite appears to be essentially a biotite-quartz-feldspar rock, but abundant small dark crystals may be iron-ore mineral.

Banding and foliation in these rocks are intensely deformed into isoclinal folds and the rocks are markedly lineated, but the pods and lenses of massive granite appear to lack a preferred orientation.

The long rock ridge about 5 kilometres south-south-west of Mount Banfield was also visited. It is composed of thick bands of dark brown rock and light grey rock outlining a pattern of open regular folds (Fig. 15b) markedly different in style from the tight folding observed in other exposures in these mountains. Within the light grey rocks fine banding also reveals an unusual pattern of crinkly tight folds, several centimetres in amplitude and wave-length.

The light grey rocks are fine-grained and appear to be composed predominantly of calcite and a green mineral, possibly olivine, with some iron-ore mineral. Calcite-rich bands up to 10 centimetres thick alternate with bands of similar thickness, poor in calcite. A few lenses and bands have a very coarse-grained texture and resemble the marble at Fram Peak.

The brown bands are composed of fine-grained, poorly foliated biotite-garnet-quartz-feldspar gneiss with a small proportion of a lustrous mineral which may be graphite or iron ore. Lenses of felsic material up to 1 centimetre thick give the rock its poor foliation, which in places appears to have been disrupted by shearing.

The marble bands range up to 20 metres in thickness; the bands of biotite-garnet-quartz-feldspar rock are generally between 20 metres and 50 or more metres thick.

All the other exposures in the western mountains were examined from the air. Mount Corry and most exposures in the Dwyer Nunataks all appear to be composed of massive dark red rocks, but may contain a considerable proportion of the grey gneiss which occurs in the visited member of Dwyer Nunataks. A light-coloured band traversing Mount Corry resembles from the air the marble band on Fram Peak.

The southernmost member of the Dwyer Nunataks, the northern part of Mount Banfield, and Foley Nunatak are composed of inter-banded white, grey, red, and dark brown rocks revealing a pattern of isoclinal folds which is most complex at Foley Nunatak. The bands range up to about 20 metres in thickness; at Mount Banfield the grey and the white bands appear to cut the red and the brown bands in places, but generally all bands are deformed concordantly.

In the southern part of Mount Banfield, massive grey bands, up to 30 metres and more in thickness, cut across red and brown bands and contain large lenses of brown rock, up to 10 metres long by 2 metres thick. These grey bands also resemble the marble of Fram Peak.

PYROXENE-QUARTZ-FELDSPAR GNEISSES OF CASEY RANGE.

Finely banded rock with an overall composition of sillimanite-garnet-pyroxene-quartz-feldspar gneiss crops out along the whole of the Casey Range, to the south-west of Mawson. Crohn (1959) had previously visited the Casey Range and referred to the rocks as "metasediment".

The main rock type is strongly resistant, forming prominent north-south trending strike ridges with a precipitous western face and a steep eastern dip-slope. The range reaches a maximum altitude of 950 metres.

The major gneissic rock is composed of thin alternating dark and light bands which have thicknesses of up to half a metre (Fig. 16). Many of the bands maintain a very uniform thickness for considerable distances. At the northern end of the Casey Range the dark and light bands form approximately equal amounts of the whole rock but to the south the darker bands become thicker and form a higher proportion than the light.

The dark bands are fine-grained to medium-grained and are composed of 40-50 percent pyroxene; 20-30 percent feldspar and quartz; 5-10 percent biotite; and 10-20 percent garnet. Garnet is not common at the northern end of the Casey Range but at places on Lucas Nunatak it is a major constituent of the dark bands, with crystals up to 1 centimetre in diameter. Sillimanite is very common in some of the dark bands of Lucas Nunatak.

The light bands are medium-grained to coarse-grained and are composed of an estimated 50 percent feldspar and 30 percent quartz with minor amounts of pyroxene, biotite and garnet.

Fig. 16. Tight folding with some thrusting in finely-banded gneiss at the north end of the Casey Range.

In addition to the pyroxene-quartz-feldspar gneiss which forms 80 to 90 percent of the Casey Range, there are bands of light-coloured garnetiferous quartzite. The quartzite is concordant, with bands ranging from ½ to 6 metres thick, and is fine-grained to medium-grained. The proportion of garnet in the quartzite also increases to the south.

Minor lenses of pyroxene are present in the Casey Range. Minor developments of discordant veins of quartz-feldspar pegmatite also occur in places. Green copper staining and brown or yellow iron-staining are common.

Relatively open folding (see Fig. 16) occurs at the northern end of the Casey Range. On Lucas Nunatak, tight isoclinal folds with amplitudes of 5 metres and more have limbs only ¼ to ½ metre apart. Little faulting was seen.

A well-developed lineation is apparent in many of the dark bands, due to either a preferential development of the lineation in the dark bands or because the presence of lath-like minerals such as sillimanite makes any lineation more obvious. The dip of the rocks is consistently 50° to 60° to the east throughout the range and the strike is approximately north. The lineation is in the plane of the banding and the plunge is sub-parallel to the dip.

The rock types of the Casey Range are not known from any other outcrops in the Mac.Robertson Land or Kemp Land area and their relationship to the other rocks of the Framnes Mountain is unknown.

BASIC AND ULTRABASIC DYKES

In 1965 dykes were examined in charnockite, banded gneiss, garnetiferous gneiss, and quartz-feldspar gneiss. Two types were found: an ultrabasic type composed almost entirely of pyroxene, and a doleritic type composed essentially of feldspar and pyroxene.

Dykes composed almost entirely of pyroxene occur in quartz-feldspar gneiss at Mount Storegutt and in banded gneiss at Gwynn Bay. In both places the dykes parallel the strike of the foliation of the gneiss, but cut across the dip of the foliation.

At Mount Storegutt the pyroxene dyke, a body more than 7 metres thick, is medium-grained with seams 2 millimetres thick of very fine-grained black material. It contains irregular veins up to 5 centimetres thick of red feldspar pegmatite, and has a prominent network of green copper stains following surface cracks.

Several pyroxene dykes at Gwynn Bay average about 3 metres in thickness. Dark red iron stains and green copper stains occur on the banded gneiss within 50 centimetres of the contacts of the dykes, and aplite veins cut the nearby gneiss. The pyroxene dykes contain many lenses, up to 2 metres long by 1 metre thick, of rock similar to the dark bands in the gneiss.

Doleritic dykes appear to be most abundant and are most easily recognized between Styles Bluff and the Jagar Islands; most of these dykes trend west-north-west. Doleritic dykes recognised east of these occurrences are commonly somewhat deformed and a strong preferred trend is not evident, though many of them trend approximately westwards.

A basic dyke in the charnockite forming Entrance Island at Mawson is about 2 metres thick; it branches and encloses lenses of country rock up to 1 metre thick and several metres long. Lenses in the adjacent country rock, up to 60 centimetres thick and 3 metres or so long, closely resemble the dyke.

The dyke appears to be a sheared, recrystallised dolerite. It is an even-grained granular aggregate of andesine-labradorite (forming about 60 percent of the rock) and clinopyroxene (30 percent) with small quantities of iron-ore mineral (about 1 percent) and possible quartz (1 percent). Biotite (5 percent) forms scattered large or small ragged plates. Elongated patches of very fine-grained granular material throughout the thin section examined are roughly parallel; they appear to be composed mainly of feldspar with a little quartz.

Basic dykes cutting banded gneiss at Jagar Islands range from 2 metres to 10 metres in thickness. One has a foliation conferred by wispy aggregates of feldspar and schlieren-like bands, defined by variations in dark mineral content, trending parallel to the margins of the dyke (Fig. 17). It also contains veins, between 2 and 5 centimetres thick, of quartz-feldspar rock, and it has a poorly-defined vertical lineation. The doleritic rock forming the dyke is an equigranular medium-grained aggregate of andesine-labradorite (about 50 percent), clinopyroxene (18 percent), orthopyroxene (12 percent), and hornblende (12 percent), with small crystals of possible pyrite (5 percent) and quartz (2-5 percent). Rather diffuse stringers of dark minerals give the rock a foliation in thin section.

Fig. 17. Metamorphosed basic dyke in quartz-feldspar gneiss (top right) of banded gneiss. The dyke shows a whispy banding parallel to its margin, which transects the foliation of the quartz-feldspar gneiss. A sample for age determination was blasted from the dyke. Southernmost of two large Jagar Islands, Kemp Land.

Another large dyke on the Jagar Islands is generally massive, medium-grained to fine-grained, and equigranular. In thin section it resembles the dyke rock described above, but it contains a little biotite, more pyroxene of both types, and less hornblende and quartz; stringers of dark minerals parallel the preferred orientation of markedly elongated plagioclase crystals. In places the centre of the dyke contains lenses of feldspar-rich material, typically 5 centimetres long by 1 centimetre thick, which trend parallel to the dyke margin.

The margins of the dykes have the same grainsize as the central parts. In one place a zone of small pyroxene crystals, 1 millimetre thick, lies in the banded gneiss against the dyke.

Where the banded gneiss dips steeply, the dolerite dykes tend to strike parallel to the banding in the gneiss; the trend of one dyke swings through 20 degrees to conform with the banding.

On two adjoining small islands in the Jagar Islands, a gently dipping sheet of pegmatite, about 1 metre in thickness, cuts two dykes. Within the dykes it commonly contains smoky quartz, white or red feldspar, greenish-white mica crystals up to 1 centimetre long, iron-ore mineral, and traces of pyrite. Iron-ore mineral crystals up to 1 centimetre across are abundant in the bottom 5 centimetres of the pegmatite sheet where it cuts one dyke, and iron-ore mineral crystals up to 5 centimetres long are scattered in the top 10 centimetres of the sheet. The centre of the sheet here is composed of milky quartz and red feldspar. The contact of the pegmatite with dyke rock is sharp, but the pegmatite is relatively fine-grained along the contact. In the dykes, zones about 1 centimetre thick enriched in dark minerals border the pegmatite contacts, and sheets of dark minerals a few millimetres thick and a few metres long parallel the pegmatite sheet a few metres from it.

Several basic dykes up to 7 metres thick cut the banded gneiss at Georges Islands, but foliation in the dykes runs parallel to the foliation in the banded gneiss. They are composed of rock similar to that forming the dykes at Jagar Islands.

At Turbulence Bluffs, a basic dyke about 3 metres thick in the banded gneiss is composed of fine-grained garnet-pyroxene-feldspar rock; it contains veins and schlieren of quartz-feldspar rock, some with garnet, and appears to have a faint foliation.

The basic dyke cutting the garnetiferous gneiss at Rayner Peak is 1½ to 3 metres thick and is composed of coarse-grained bands and fine-grained to medium-grained bands between 30 and 50 centimetres thick.

At the eastern end of Mount Mueller, a dyke about 5 metres thick cuts quartz-feldspar gneiss. It is composed of very dark, equigranular, medium-grained feldspar-pyroxene rock, with considerably more dark mineral than the metamorphosed doleritic rocks described above. The dyke is not evidently metamorphosed and has remarkably straight walls and sharp contacts outlined by a very fine-grained selvedge about 5 millimetres thick, which resembles a chilled margin. Within 1½ metres of the dyke the gneiss contains coarse-grained clots made up of various proportions of biotite, pyroxene, quartz, and feldspar, ranging up to 1 metre long by 15 centimetres thick.

STRUCTURE

Foliation

Foliation is present in all rock types described, though individual specimens or exposures of some types may be massive. The most common macroscopic elements of foliation are leaf-like aggregates of predominantly light or predominantly dark minerals, and since they characterise rocks as diverse as dolerite and marble they almost certainly have been formed as a result of deformation and metamorphism. The foliation parallels the banding everywhere except at Tschuffert Peak (Plate 3). However, foliation and banding are themselves deformed by almost all folds seen, and in places they are interrupted by recrystallisation (Fig.11).

Two markedly different trends of foliation are evident in the map area. Foliation almost everywhere within the charnockite between Mawson and Byrd Head and in the gneisses exposed between Byrd Head and Campbell Head, and at Tilley Nunatak and Solitary Island, trends approximately north. West of Tilley Nunatak the predominant trends of foliation and banding in the banded gneiss, the quartz-feldspar gneiss, the gneisses of the Hansen Mountains, and the garnetiferous gneiss lie between east and south-east, with the great majority trending about east-south-east. However, a northerly trend is again evident in the charnockite at Wheeler Rocks and Magnet Bay; foliation and banding on both sides of the boundary between quartz-feldspar gneiss and banded gneiss, from Cape Boothby to Schwarz Range, trend between north-east and east-north-east, that is, approximately parallel to the boundary. Trends of foliation and the distribution of outcrops suggest that other major lithological boundaries, between banded gneiss and the gneisses of Taylor Glacier, and between the latter gneisses and the charnockite at Stump Mountain, trend approximately north-eastwards, though marked northerly trends evident in the Thorfin Islands suggest that the direction of the boundary may swing from north-east to north-north-west here.

Lineation

A macroscopic lineation, caused by parallel arrangement of mineral grains or small elongated aggregates of grains, was seen at several places. In most cases, the lineation is not well defined, and in some outcrops is evident only in parts of the rock.

At Rayner Peak, a strong lineation is produced by fine crenulations in quartzite beds. The crenulations are quite prominent on the top and bottom of the beds, where the softer rocks have been eroded away and the quartzite stands out.

Folds

Folds were observed in all rock types except the basic and ultrabasic dykes; in the charnockite, folds are common only near Stump Mountain and at Baillieu Peak, near the western margin of the large area of outcrop.

The folds generally deform the foliation, but the development of a new foliation parallel to the axial planes of these folds is nowhere evident. The folds in the biotite-rich band at Tschuffert Peak (Plate 3) may be shear folds formed in the earlier deformation which produced the foliation.

Most of the folds observed are small-scale structures ranging from a few millimetres to 100 metres or so in wave-length. Outcrop patterns suggest that large-scale folds, about 1 kilometre or more from limb to limb, are present in the banded gneiss at the Stillwell Hills and in the charnockite between Stump Mountain and Ufs Island.

Where folds are best displayed, in banded gneiss and in the banded rocks of the Hansen Mountains and Mount Kernot, the predominant type appears to be a near-isoclinal overturned fold with a steeply dipping axial plane (Fig. 15a), but many variations in style are evident in small-scale folds in the banded gneiss (Figs 10, 11).

Both small-scale and large-scale folds observed in marble in the Hansen Mountains appear to differ in style from the majority of folds observed (Fig. 15). Presumably this difference reflects a fundamental difference in the competence of the marble.

The trends of most observed fold axes agree broadly with local trends of foliation.

Mylonitic rocks

The occurrence of thin seams of mylonitic rock in almost every charnockite exposure suggests that the charnockite has been sheared rather than folded during deformation of the area. Mylonitic rocks also occur at Fram Peak (as phyllonite) and the Casey Range.

Faults

No large faults were observed in 1965. Undoubtedly they exist, but the absence of marker bands, and the apparent relation of foliation and banding, and even of topography, to fold structures in coastal exposures, such as the Stillwell Hills and Stump Mountain, suggest that the certain identification of faults is a matter for detailed mapping.

ECONOMIC GEOLOGY

Metallic minerals, mostly iron oxides and sulphides, were found in 1965 in charnockite, banded gneiss, quartz-feldspar gneiss, gneiss and marble in the Hansen Mountains, and in pegmatite in the banded gneiss.

Graphite and sillimanite were found in gneiss at Ives Tongue and several exposures of sillimanite-bearing gneiss were recorded in the Casey Range. Some quartzite bands in banded gneiss in the central Stillwell Hills appear to contain very few impurities, other than thin layers of sillimanite.

Sulphides

At Entrance Island a small deposit of sulphide minerals was examined in detail in 1965. The minerals described were identified by G.J.G. Greaves, of the Bureau of Mineral Resources, from samples collected in 1961. The sulphide minerals form pods, ranging up to 1 metre long by 30 centimetres thick, within a vertical zone of sheared charnockite about 4 metres long by 1 metre thick. The zone strikes due north, parallel to the foliation of the surrounding porphyroblastic charnockite. The pods are composed of massive, flaky, black marcasite and pyrrhotite containing thin irregular veins of chalcopyrite, from 2 to 5 millimetres thick, and rare flakes of molybdenite a few millimetres long. Chalcopyrite forms about 10 percent of the sample described by Greaves. Some of the sheared charnockite between the nodules is impregnated with small sulphide crystals. In the exposure, the pods are completely coated by a dark yellow-brown encrustation, and in places they have weathered to a yellow-brown sandy clay which contrasts markedly in texture with the sand derived by weathering from the surrounding charnockite.

In the northern Stillwell Hills, metallic sulphide minerals occur in a small exposure of black, fine-grained quartzite, part of a band in the weathered quartzites and quartz-feldspar gneisses which form the north end of the hills and the adjacent islands. The

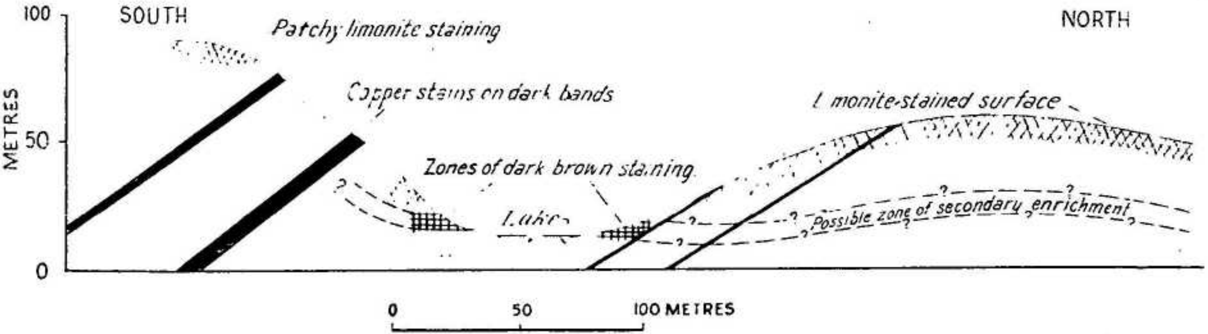


Fig. 18 Diagrammatic sketch section of valley in the northern Stillwell Hills showing possible zone of secondary enrichment.

AN2/67

sulphides appear to be mostly black pyrrhotite with some brassy marcasite; they form aggregates and stringers a few millimetres thick and make up possibly a few percent of the rock.

The sulphide-bearing exposure is on the valley floor at the base of a slope formed mainly by light reddish-brown, weathered, limonite-stained gneisses (Fig. 18). The exposure is coloured dark yellow-brown by a thin but dense encrustation of limonite, and this continues over detritus and outcrops at the base of the slopes on both sides of the valley, forming a distinctively coloured zone a few metres high. The coloured zone appears to result from enrichment in iron, and it may have been formed by one of several processes: It follows a strike valley, and it may be the surface expression of iron-rich bands in the gneisses.

The iron may have been deposited by run-off slowing at the base of the slope, or it may have been concentrated during the weathering of iron-bearing rock detritus shed from the valley walls. The valley may have been cut in weathered rock only, and the dark zone may represent the base of a fossil weathering profile. If this is so, metallic elements which migrated downwards during the weathering and oxidation of the overlying rocks may have accumulated near the base of the weathering profile. The dark zone and the sulphide minerals may be, to some extent, products of secondary enrichment by iron.

Iron oxide and related minerals

Boulders in the north-eastern part of the boulder field in the main saddle of Mount Twintop contain iron-ore mineral as thin bands and schlieren. The iron-ore mineral content is rarely more than 10 percent.

Small quantities of minerals resembling magnetite were found in pegmatitic rocks at the northern Stillwell Hills, Jagar Islands, and Gwynn Bay. G.J. Greaves, of the Bureau of Mineral Resources, has described samples collected from pegmatites in the banded gneiss in 1961, in which ilmenite and titanhematite accompany magnetite. A glassy mineral which may be goethite has a similar habit to possible magnetite in pegmatite at Gwynn Bay.

In the central Stillwell Hills possible magnetite, commonly accompanied by garnet, forms bands up to 50 centimetres thick and in places over 50 metres long. These occur within the thick, dark pyroxene-feldspar rocks which alternate with quartzite in the core of the large antiform 1½ kilometres north of Kemp Peak. These bands and the pyroxene-feldspar rock within 1 metre of them commonly carry a network of green copper stains following surface cracks. The bands make up less than a few percent of the thick dark bands which contain them, and they are generally separated by several metres of pyroxene-feldspar rock.

In the Hansen Mountains scattered aggregates of magnetite, up to 10 centimetres across, occur in marble at Fram Peak, and many samples of granite, gneiss, and marble from these mountains carry small crystals resembling magnetite, everywhere forming less than a few percent of the rock.

At Cook Nunataks, Wallis Nunataks, and Mount Mueller, dark yellow-brown weathered rocks, heavily stained by limonite, form bands up to several metres thick in the quartz-feldspar gneiss. Samples of the stained rocks appear to be somewhat shattered and the staining continues for at least several centimetres below the exposed surface. These rocks are generally quartz-rich and contain at least a few percent of iron-ore minerals weathered in varying degrees. A fresh, unshattered rock at Cook Nunataks, apparently associated with stained rocks, is composed of roughly 60 percent quartz and 40 percent possible magnetite. The magnetite(?) is disseminated among the quartz and in places forms stringers up to 1 centimetre thick. This rock forms numerous bands, a few centimetres thick, in the quartz-feldspar gneiss.

Graphite

In the central and western parts of Ives Tongue, graphite forms up to a few percent of some weathered, quartz-rich coarse-grained rocks. The graphite generally occurs as disseminated flakes a few millimetres in length, but the coarsest rocks contain aggregates of almost pure graphite up to 3 centimetres long.

Sillimanite

In the Casey Range, sillimanite is locally an abundant constituent of the predominant pyroxene-bearing gneisses. Sillimanite forms thin layers in the graphite-bearing rocks at Ives Tongue, but the rocks are much weathered and heavily stained by iron.

Silica

In the central Stillwell Hills, pure white quartzite forms bands, up to several metres thick, in the core of an antiform 1½ kilometres north of Kemp Peak. The quartzite contains a few layers of sillimanite generally less than a few millimetres thick.

Guano

Examination from the air in 1965 confirmed the occurrence of small patches of guano adjacent to Adelie penguin rookeries in the Rookery Islands and on Gibbney Island. Investigation in 1961 showed that few of these patches are deeper than 50 centimetres, and individual patches range up to about 10 square metres in area.

GEOLOGICAL HISTORY

Original rocks

The original natures of the various rock types are masked by deformation and metamorphism, but many of them appear to retain some characteristics of supracrustal - sedimentary or volcanic - formations. In the banded gneiss, the garnetiferous gneisses of Mount Kernot, etc., the pyroxene-quartz-feldspar gneisses of Casey Range, and the gneisses of Taylor Glacier, the great variations in composition from band to band and the similarities in composition of some bands to sedimentary or volcanic rocks, such as feldspathic sandstone or basalt, suggest that the gneisses with compositional banding are of supracrustal origin. Metamorphosed limestone is present in the Hansen Mountains, and diopside-rich rocks and skarns in the banded gneiss are possibly derived from impure limestone. Sillimanite and cordierite are locally abundant in gneisses of the Casey Range and at Taylor Glacier, and graphite occurs at Ives Tongue. These minerals are generally held to suggest a sedimentary origin for the host rock.

In the banded gneiss, thin dark bands with a considerable quartz content may represent basic pyroclastic rocks contaminated by quartz, while thick, sharply-defined dark bands composed essentially of calcic plagioclase and pyroxene may be lavas or minor intrusive rocks.

The charnockite and the quartz-feldspar gneiss have wide distributions and strikingly uniform compositions. Both rock types show some local variations: lenses of granulitic rock are abundant in the charnockite near Mawson; large bodies of gneiss similar to the gneisses of Taylor Glacier are common in charnockite in the Framnes Mountains; lenses of quartz-feldspar rock are abundant in the charnockite near Stump Mountain, and charnockite appears to be interlayered with garnet-bearing and biotite-bearing gneisses there. In the quartz-feldspar gneiss, lenses of pyroxene-feldspar gneiss, garnet quartzite, and biotite-bearing gneisses are locally abundant. Both rock types have structural resemblances to igneous rocks, and the charnockite has to some extent been mobilised (Crohn, 1959), but metamorphism and perhaps deformation have masked their original natures to such an extent that it is impossible to decide if they represent large masses of uniform sediments or of uniform igneous rocks, or if they have attained a uniform appearance by thorough recrystallisation.

Metamorphic history

The abundance of sillimanite or pyroxene, and calcic plagioclase, in most of the major rock types indicates that the first discernible metamorphism took place under granulite facies conditions. This metamorphism was presumably associated with the deformation which produced the widespread foliation.

The granulite facies metamorphism appears to have been succeeded by an episode of deformation which tightly folded the foliation and banding in many gneisses, and which perhaps simultaneously produced widespread cataclasis in the charnockite. Some folds in banded gneiss, at Gwynn Bay and the Jagar Islands, are cut by or contain recrystallised rocks, and discordant bands in folded gneisses in the Hansen Mountains also show that recrystallisation has occurred after the fold movements. Potash feldspar and biotite appear to be the diagnostic minerals of this recrystallisation, and suggest that it took place under the conditions of the almandine-amphibolite facies of metamorphism.

The recrystallisation appears to mark a second episode of metamorphism, the effects of which are particularly evident where biotite-bearing and granitic rocks are abundant. Otherwise the effects are relatively slight: many of the mylonitic rocks in the charnockite are recrystallised, minor biotite occurs in charnockite in places, and hornblende occurs in some pyroxene-bearing members of the banded gneiss (McCarthy and Trail, 1964).

The recrystallised dolerite dykes in the western part of the banded gneiss outcrop are not disrupted by the deformation which preceded the second metamorphism, and the few massive pegmatites which cut some dykes are also not evidently deformed. The marked tendency of basic and ultrabasic dykes to conform with the strike of the gneisses suggests that they were injected at a late stage in the deformation. They were then probably recrystallised in the subsequent episode of metamorphism, during which the massive pegmatites were formed. The pegmatite bodies have no preferred orientation and were probably emplaced when the stresses of deformation had been completely relieved.

Ravich and Krylov (1964) have obtained radiometric ages ranging from 620 to 535 m.y. for rocks from Edward VIII Gulf and from 650 to 490 m.y. for rocks from Mawson. These dates are probably related to the later episode of metamorphism, though the wide spread of the ages suggests that the earlier episode may also be reflected in the results.

Late geological history.

The formation of the coastal erosion surface is probably the first discernible event in the late geological history. Glacial erosion does not appear to form broad and level surfaces and, as Dietz (1963) has shown, marine erosion probably does not cut broad planes in hard rock. The very small tidal range on this coast would also limit the breadth of the platform which could be cut by wave erosion.

The coastal erosion surface is probably a peneplain formed by long-continued fluviatile erosion before glaciation. From this plain the pre-glacial land surface probably rose southwards and westwards and is perhaps represented by a few flat-topped remnants such as Mount Pasco and the southernmost nunataks of the Framnes Mountains. All other nunataks appear to have been sculptured by glacier ice and by frost action.

With the onset of glaciation, the next recorded event is probably the formation of some cirques. Large cirques, partly buried by the ice sheet, in the inland nunataks evidently formed when the ice sheet was much lower than at present, and moraine scattered over the walls of large cirques in the Framnes Mountains indicates that these formed before the ice sheet, which deposited the moraine, reached its maximum height. The lack of large cirques in the higher coastal exposures suggests that the cirques in the inland nunataks were cut by mountain glaciers at a time when the climate nearer the sea was too mild to permit glaciers to form.

Glacial erosion, in the beginning by mountain glaciers and later by the ice sheet, was probably directed at least in the high lands by the pre-glacial drainage pattern. The lowering of sea-level on the formation of the ice sheet may have initiated the dissection of the coastal erosion surface before the land sank under the weight of the ice.

The absence of islands seaward of the terminations of the large ice streams suggests that deep channels exist there: these ice streams appear to have cut their valleys to a base-level controlled by a sea surface considerably lower than the present surface. When the ice cap stood at its maximum height the ice streams terminating in embayments carried much greater quantities of ice than they do now.

The ice streams which terminate in promontories are overcharged with ice even at present, yet channels also appear to exist seaward of them. The valleys of these glaciers are relatively narrow, and perhaps at the onset of glaciation they were immature valleys, which were rapidly deepened but not widened by concentrated glacial erosion.

Only one great fluctuation of the level of the ice sheet is evident in the coastal region of Mac.Robertson Land and Kemp Land: it is recorded by the scattered moraine which occurs up to 300 metres above the present surface of the ice, according to Crohn (1959). The thick and extensive blankets of moraine evident in the Prince Charles Mountains (Trail, 1964) are absent here and this may indicate that glaciation has been less intense or even less prolonged.

The finer fractions which are evident in younger moraine have probably been removed from the scattered older moraine by wind.

The lack of fluvioglacial deposits suggests that rainfall was insignificant following the recession of the ice sheet, and even indicates that large quantities of meltwater were not channelled over the rock exposures. The absence of strandlines higher than 15 metres above present sea level suggests that wave action has reworked very little of the old moraine.

The rise in sea level following the melting of the ice cap appears to have been outstripped by the isostatic rise of the land relieved of its burden of ice, and the raised beaches of this coast probably reflect a complex interplay of rising land and rising sea, rather than a single period of higher sea-level.

Evidence for multiple glaciation in Antarctica has been found principally in the McMurdo Sound region (Black and Berg, 1964). In Mac.Robertson Land and Kemp Land the only major fluctuation of the ice sheet so far recognised is presumably the latest, which has obliterated any record of earlier fluctuations.

The weathering and oxidation of the rocks exposed between the north end of the Stillwell Hills and Ives Tongue probably occurred when the climate was considerably warmer than at present. Bateman (1951) believes that a long time is required for oxidation and weathering, certainly much longer than the 10,000 or so years since the last major glaciation in the northern hemisphere. This weathered surface may be a relic of an early interglacial period, and has perhaps been protected from intense glaciation by the proximity of the large Dovers Glacier. Since this large ice stream could carry much larger quantities of ice than at present flow down it, an advance of the ice sheet may have been effectively channelled into the ice stream and around rather than over the weathered surface.

SAMPLES FOR AGE DETERMINATION

Samples for age determination were collected from as many places as possible (Plate 2). Where circumstances allowed, a sample of fresh rock was obtained by blasting; the remaining samples consists of pieces of apparently fresh rock as large as the weight limitations of the helicopters allowed.

Details of the sampling sites are given in Table I. The geographic coordinates were obtained from the maps used in early 1965. Some of these may be changed slightly as a result of the accurate survey work done at that time.

The samples were submitted to Australian Mineral Development Laboratories (A.M.D.L.) for petrographic examination to assess their suitability for age determination work. The petrographic reports, by W.R. McCarthy, are quoted below. Grain size classification used in the descriptions are: coarse, greater than 1.0 mm, medium 1.0 mm to 0.05 mm., fine, less than 0.05 mm.

65 28 0112

This is a spinel-cordierite-plagioclase-sillimanite-biotite-quartz-alkali feldspar gneiss.

Major constituents are quartz, garnet and alkali feldspar. Biotite appears quite unweathered and forms perhaps 10 percent of the rock. It is intimately associated with sillimanite and garnet and also occurs as flakes in the alkali feldspar. The alkali feldspar is probably orthoclase-microperthite and is frequently poikiloblastic with inclusions of sillimanite, biotite and quartz. Both plagioclase and cordierite are present but their relative proportions are not known because of the difficulty of differentiating them in thin section.

Accessories observed were abundant opaques and several crystals of zircon.

65 28 0113

This is a medium-grained to coarse-grained, deformed and partially recrystallized, hypersthene-plagioclase-quartz-alkali feldspar rock. Before alteration, the rock had been crystallized under the conditions of the granulite facies. During deformation, a finer phase of quartz and possibly also feldspar crystallized. The biotite also formed during this period and is generally found with the hypersthene. Hypersthene is very altered in appearance. The minerals have been deformed to varying degrees during this period.

Estimated proportions of the mineral constituents are: biotite 1 percent, hypersthene 5 percent, plagioclase 25 percent, quartz 30 percent and alkali feldspar 40 percent. Accessories observed were zircon, and opaques.

The alkali feldspar is probably orthoclase-microperthite and it appears little weathered or unweathered. Some plagioclase grains are antiperthitic.

The biotite, in part, is weathered to ?antigorite.

65 28 0114

This is a medium-grained quartz-hornblende-pyroxene-plagioclase rock. It has a granulitic or hornfelsic texture.

Estimated proportions of the mineral constituents are biotite 1 percent, quartz 3 percent, hornblends 5 percent, clinopyroxene 15 percent, orthopyroxene 15 percent, and plagioclase 60 percent. Accessories observed were apatite, and opaques (forming perhaps 2 percent of the rock).

The anorthite content of the plagioclase is in the range 40-70 percent. No alkali feldspar, other than some patch-like bodies in several of the plagioclase grains, was observed. The minerals appear unweathered.

65 28 0115

This is a porphyroblastic charnockite of adamellitic composition. Coarse grains of alkali feldspar and antiperthite occur in a medium-grained matrix. Biotite, opaques, and hypersthene are found in close association. The rock compares to the charnockite of Mawson, Antarctica.

Estimated proportions of the mineral constituents are: quartz 10 percent, biotite 10 percent, hypersthene 13 percent, alkali feldspar 30 percent and plagioclase and antiperthite 35 percent. Accessories observed were zircon, apatite and opaques (about 2 percent of the rock).

Biotite laths or flakes are frequently inclosed in plagioclase. The alkali feldspar may be orthoclase-microperthite. The minerals appear unweathered.

65 28 0116

This is a very coarse-grained alkali feldspar-quartz-biotite-plagioclase rock. Plagioclase has a maximum diameter of 15 mm.

Biotite is found as "books" between the coarse plagioclase grains. It also occurs as intergranular aggregates with quartz and plagioclase. Lath-like bodies of quartz, and less frequently plagioclase occur along the (001) cleavage of biotite. The biotite appears unweathered. It also is found, infrequently, in bodies transgressing plagioclase.

Alkali feldspar, perhaps orthoclase-microperthite, is found as inclusions within the plagioclase.

Opaques and a single ?xenotime crystal were also observed.

65 28 0117

This is a biotite-quartz-alkali feldspar rock. Because it is so coarse-grained, it is not likely that the thin-section is a representative sample. Therefore, mineral proportions have not been estimated.

The alkali feldspar is probably orthoclase-microperthite. The perthitic inclusions are of the patch and hair types. The alkali feldspar appears unweathered, but has numerous, scattered and concentrated, dust-like, crystallite inclusions.

Two small, patch-like bodies of muscovite were observed as inclusions in feldspar.

One "book" of biotite has weathered? to chlorite, another appears altered, and the third and largest "book" appears unaltered.

65 28 0118

This is a massive charnockite of adamellite composition and is typical of charnockites found at Mawson, Antarctica. There are indications that the rock has been moderately deformed and partially recrystallized.

Estimated proportions of the mineral constituents are: traces of biotite, hypersthene 10 percent, quartz 20 percent, alkali feldspar (perhaps orthoclase-microperthite) 35 percent and plagioclase 35 percent. Accessories observed were opaques, apatite, and zircon.

The polycrystalline mineral assemblage appears unweathered. The feldspar is both coarse-grained and fine-grained.

65 28 0119

This is a deformed and partially recrystallized quartz-biotite-pyroxene-plagioclase granulite. The plagioclase and the pyroxene have recrystallized in parts, and the biotite formed during the deformation of an earlier rock, one which probably formed under granulite facies conditions.

Estimated proportions of the mineral constituents are: quartz 3 percent, biotite 5 percent, orthopyroxene 15 percent, clinopyroxene 20 percent, and plagioclase 57 percent. Accessories observed were apatite and opaques.

65 28 0120

This is a medium-grained, massive quartz-hornblende-pyroxene-plagioclase-amphibolite.

Estimated proportions of the mineral constituents are: quartz 5 percent, hornblende 15 percent, hypersthene 5 percent, clinopyroxene 18 percent, and plagioclase 55 percent. Accessories observed were zircon, abundant apatite, and opaques (2 percent).

Some plagioclase grains have inclusions of carbonate and others are antiperthitic.

65 28 0121

This is a hypersthene-plagioclase-quartz-alkali feldspar rock. It is medium-grained and appears to have crystallized under granulite facies conditions. There are indications that some slight adjustment of the rock to lower metamorphic conditions has occurred as some of the hypersthene appears to have been partially converted to hornblende.

Estimated mineral proportions are traces of blue-green coloured hornblende, clinopyroxene 1 percent, hypersthene 8 percent, andesine 15 percent, quartz 25 percent and alkali feldspar (probably orthoclase-microperthite) 40 percent. Accessories observed are zircon, apatite, and opaques. A single grain of possible allanite was observed.

Some of the plagioclase is antiperthitic. Occasionally it has inclusions of carbonate, and less frequently mica. Some wisp-like bodies of mica appear to have formed adjacent to or as a replacement of hypersthene.

65 28 0122

This is a medium-grained to coarse-grained, deformed and partially recrystallized quartz-biotite-pyroxene-plagioclase gneiss. The rock appears to have formed under granulite facies conditions initially and then deformed and partially recrystallized in a more hydrous situation. Biotite and part of the clinopyroxene appear to have formed during the latest crystallization.

Estimated proportions of the mineral constituents are: quartz 10 percent, biotite 15 percent, clinopyroxene 5 percent, hypersthene 15 percent, and plagioclase 55 percent. Accessory minerals observed were zircon, opaques and apatite.

Calcite and biotite crystallites are present as inclusions in many plagioclase grains, especially in "fractures". Biotite is frequently in close association with the pyroxene.

65 28 0123

This is a biotite-garnet-quartz-alkali feldspar-plagioclase rock. It is medium-grained to coarse-grained and the feldspar, particularly the plagioclase, is deformed. There are, in two instances, inclusions of hypersthene? within the biotite. Due to the deformed nature of the rock, the late crystallization appearance of biotite, and regular form of some of the garnet, the writer considers the hypersthene to be a relict mineral. Thus, these features imply that there has been at least two periods of crystallization.

Estimated proportions of the mineral constituents are: biotite 10 percent, garnet 19 percent, quartz 20 percent, alkali feldspar 20 percent, and plagioclase 30 percent. Accessories observed were xenotime, apatite, zircon, and opaques (1 percent).

The alkali feldspar appears to be microcline-microperthite and/or orthoclase-microperthite. Microcrystallites, transparent and opaque, are common in the plagioclase. The minerals appear unweathered.

TABLE I

LOCALITY REFERENCES FOR SPECIMENS COLLECTED FOR RADIOMETRIC AGE DETERMINATION.

Registered No.	Field No.	Rock (short name)	Locality	Grid Reference E	Grid Reference N	Air Photo Zone	Air Photo Run	Air Photo Photo	Air Photo Point	Remarks
65 28 0112	C58	Garnet - biotite gneiss	Lucas Nunatak, Casey Range	4658//	24785//	41	314	8206V	59	
0113	T113	Biotite-hypersthene gneiss	Painted Hill, Masson Range	4931//	24832//	41	306	9057R	27	Blasted
0114	T76	Hornblende granulite	Jagar Islands	5151//	26144//	40	1	9027R	470	Metamorphosed dyke same dyke as 0120.
0115	T13	Charnockite	Stump Mtn.	4133//	25116//	41	17	7201L	402	
0116	T34	Biotite gneiss	Kemp Peak	6048//	25213//	40	329	9120R	442	
0117	T77	Biotite gneiss	Gwynn Bay	5383//	25589//	40	310	8064V	475	
0118	M54	Charnockite	Mawson	4945//	25009//	41	302	8068V	245	Blasted.
0119	M50	Biotite granulite	Entrance Island	4947//	25018//	41	302	8068V	242	Metamorphosed dyke
0120	M77	Hornblende granulite	Jagar Islands	5152//	26143//	40	1	9025R	263	Metamorphosed dyke; blasted
0121	M79	Granulite	Jagar Islands	5152//	26143//	40	1	9025R	264	Blasted
0122	M148	Biotite-pyroxene gneiss	Norris Island	4120//	25165//	41	17	8201R	299	Blasted
0123	M150	Biotite-garnet gneiss	Norris Island	4121//	25166//	41	17	8201R	300	Blasted

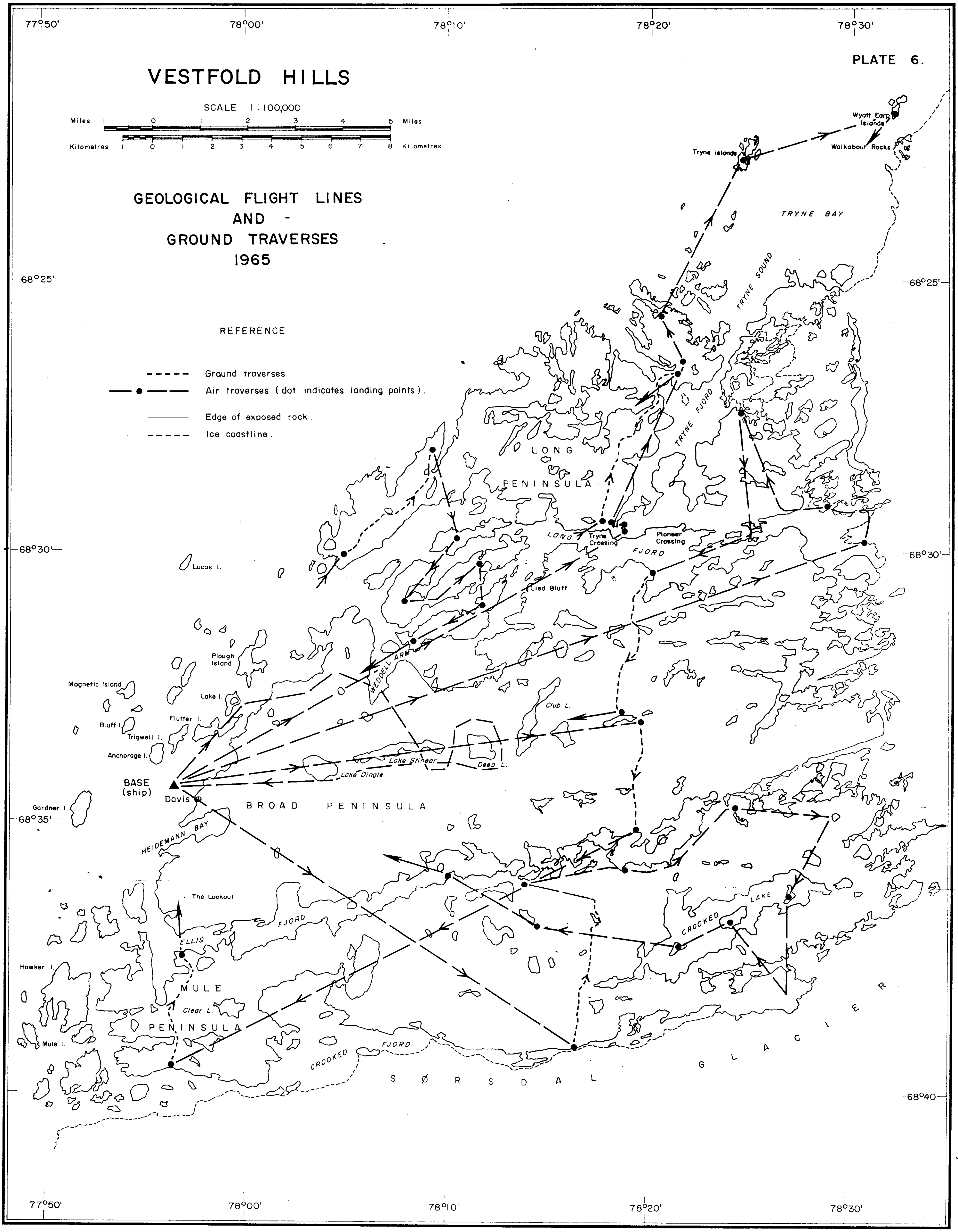


PLATE 6.
VESTFOLD HILLS
SCALE 1:100,000
Miles 1 0 1 2 3 4 5 Miles
Kilometres 1 0 1 2 3 4 5 6 7 8 Kilometres
GEOLOGICAL FLIGHT LINES
AND
GROUND TRAVERSES
1965
REFERENCE
Ground traverses.
Air traverses (dot indicates landing points).
Edge of exposed rock.
Ice coastline.
77°50'
78°00'
78°10'
78°20'
78°30'
68°25'
68°30'
68°35'
68°40'
Wyatt Earp Islands
Walkabout Rocks
Tryne Islands
TRYNE BAY
TRYNE SOUND
TRYNE FJORD
LONG PENINSULA
LONG FJORD
Tryne Crossing
Pioneer Crossing
Lucas I.
Lied Bluff
Plough Island
Magnetic Island
Lake I.
Flutter I.
Bluff I.
Trigwell I.
Anchorage I.
WEDDELL ARM
Club L.
Lake Stinear
Deep L.
Lake Dingle
BASE (ship)
Davis
BROAD PENINSULA
Gardner I.
HEIDEMANN BAY
The Lookout
ELLIS FJORD
Hawker I.
MULE PENINSULA
Clear L.
Mule I.
CROOKED LAKE
CROOKED FJORD
SØRSDAL GLACIER

PART III: THE VESTFOLD HILLS

INTRODUCTION

The Vestfold Hills are situated on the Ingrid Christensen Coast of Princess Elizabeth Land between latitudes 68°25'S and 68°40'S, and between longitudes 77°50'E and 78°31'E.

Three of the authors (I. McLeod, G. Wallis and P. Cook) were each able to spend two days in the field in the Vestfold Hills on 24th and 25th January, 1965. Using one helicopter for transport to starting points, a north-south ground traverse was made on about longitude 78°16'E right across the outcrop area. Additional north-south traverses were made between Crooked and Ellis Fjords at about longitude 77°57'E, and on the western extremity of Long Peninsula. A number of localities were also visited by helicopter (Plate 6).

In addition, brine samples were collected from Deep Lake for analysis; a sample of bottom sediment was also obtained from Deep Lake. Various types of littoral, lacustrine and glacial unconsolidated sediments were sampled.

PREVIOUS WORK

The first known visit to the Vestfold Hills was in 1935 by Mikkelsen but it was not until 1955 that the area was examined by a geologist (Crohn, 1959). In 1956 the area was visited by members of the first Soviet Antarctic Expedition (Ravich, 1960). The measured ages of five specimens collected by them range from 1185 to 1525 m.y. (Ravich and Krylov, 1964); these ages are the greatest yet found in Antarctica. Stinear worked in the area in 1957 and some of his findings are incorporated in this report. In 1957 ANARE opened Davis, on the west coast of the Vestfold Hills, and carried out programmes of lake sampling, the results of which were later discussed by McLeod (1959, 1964a). McLeod (1960) also visited the Vestfold Hills in 1960.

Davis was closed in January 1965.

PHYSIOGRAPHY

The Vestfold Hills, which cover an area of about 400 square km., are almost entirely ice-free, and apart from a few small snow drifts, are snow-free throughout much of the year. The area is one of low, rounded, bare hills with a maximum altitude of 160 metres above sea-level. Crohn (1959) considers that there are dissected peneplains at 30 and 120 metres. Some of the valleys are floored with moraine and moraine also covers some of the lower hills in places, especially south of Ellis Fjord. Many of the valleys are over-deepened and "U-shaped" and hanging-valleys are common. Despite the relatively low relief, parts of the hills, especially the eastern part of Broad Peninsula, are quite rugged. The rock is commonly striated and the whole area has obviously been glaciated fairly recently. McLeod (1959) suggests that the area has been ice free for at least 5000 years and may have been ice free for as much as 10,000 years.

Some of the ridges and most of the major valleys and fjords trend east-west, closely paralleling both the foliation and the banding of the country rock.

In many parts of the Vestfold Hills, raised beaches are a very common feature. They are exceptionally well-developed and generally undisturbed. Some of them are located up to 15 metres above the present sea level. Their significance and age has been discussed by McLeod (1964a).

The highly saline lakes of the Vestfold Hills are considered by McLeod (1964a) to have originated by the evaporation of a land-locked arm of the sea. The rise in land level relative to sea level in the Vestfold Hills may be attributed to the lowering of sea level with the waning of the climatic optimum, or to isostatic re-adjustment occurring once the overburden of ice had been removed.

GEOLOGY

Three distinctive rock units have been mapped in the Vestfold Hills. These units, which are informally referred to as Unit 1, Unit 2, and Unit 3, crop out in broad east-west trending belts (Plate 7). Although two belts of each unit are shown on the map, it is not known whether the two belts can be correlated, or whether the repetition is fortuitous, as a result of repetition of the original lithological types. The east to west extent of the units is uncertain as only limited north-south traverses were undertaken; time did not allow for the tracing of the units to the east or the west. The ground and helicopter traverses suggest that the three units are fairly uniform along their trend. Photo-patterns support this, but photo-interpretation is of only limited use because of the glaciated nature of the topography. All units are intruded by a prominent swarm of dolerite dykes. A small norite intrusion was found in the north-west of the hills.

UNIT 1.

This unit is the most varied of the three in the Vestfold Hills. The major rock type is a feldspar-quartz gneiss with several mineralogical variations which occur as thin, alternating bands. The unit crops out in two belts, one, 1½ kilometres wide, in the extreme south of the area and the other a broad belt on either side of Ellis Fjord, and about 6 kilometres in width.

The unit is moderately resistant to weathering, forming high, rounded hills and ridges.

The most common rock-type of Unit 1 is basically a quartz-feldspar gneiss or feldspar-quartz gneiss, with varying amounts of mica (mainly biotite with only very minor muscovite), garnet, and pyroxene. This rock type ranges in grain size from fine to very coarse, with the coarse bands having the appearance of concordant pegmatitic bands. In some cases the very coarse rock may be present as discordant veins. Biotite is in general fairly rare, pyroxene varies from rare to moderately common and garnet varies from

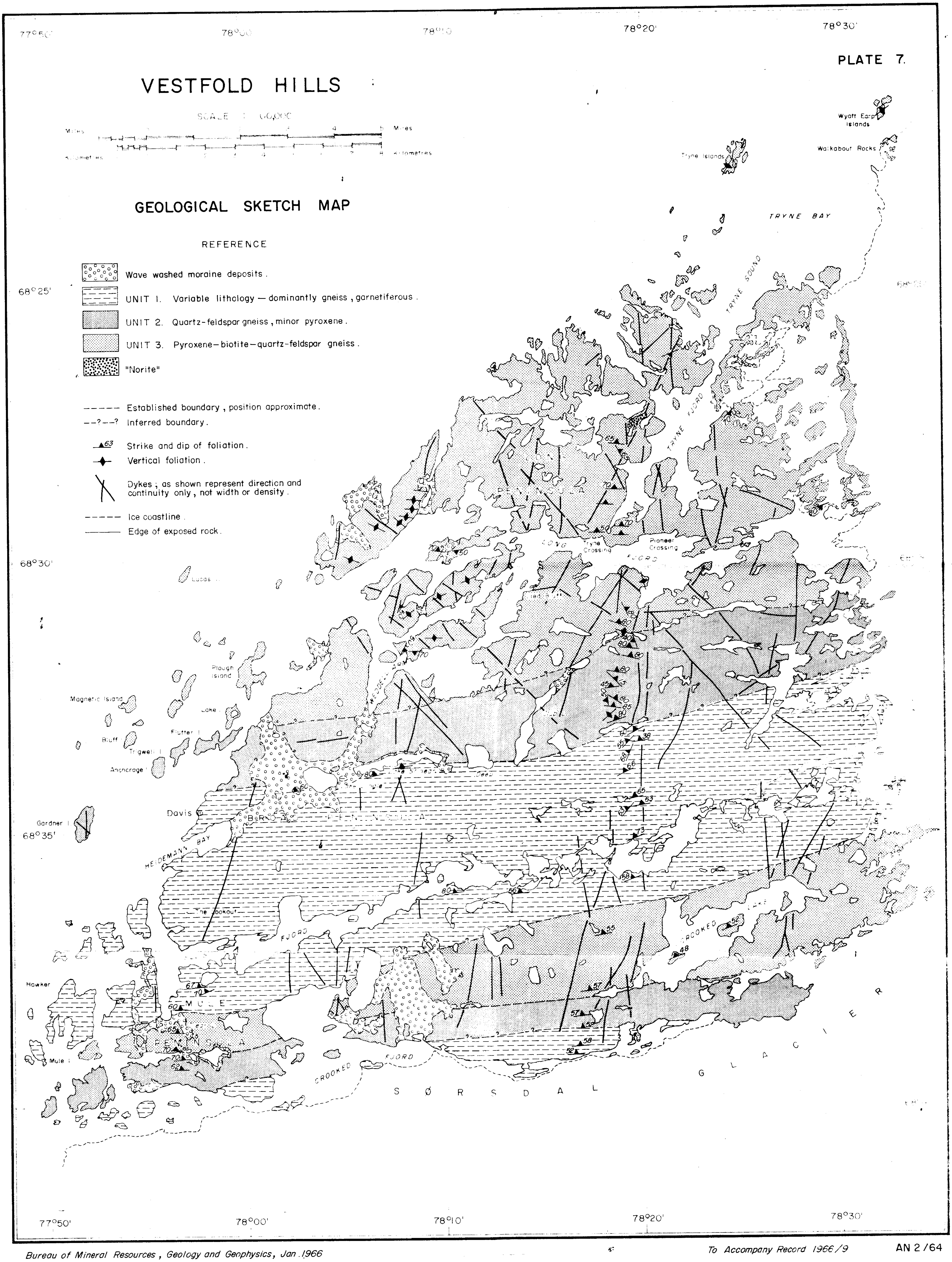


PLATE 7.
VESTFOLD HILLS
GEOLOGICAL SKETCH MAP
REFERENCE
Wave washed moraine deposits.
UNIT 1. Variable lithology — dominantly gneiss, garnetiferous.
UNIT 2. Quartz-feldspar gneiss, minor pyroxene.
UNIT 3. Pyroxene-biotite-quartz-feldspar gneiss.
"Norite"
Established boundary, position approximate.
Inferred boundary.
Strike and dip of foliation.
Vertical foliation.
Dykes; as shown represent direction and continuity only, not width or density.
Ice coastline.
Edge of exposed rock.
Miles
Kilometres
Wyatt Earp Islands
Walkabout Rocks
Tryne Islands
TRYNE BAY
TRYNE SOUND
TRYNE FJORD
Tryne Crossing
Pioneer Crossing
FJORD
Magnetic Island
Plough Island
Gardner I.
Davis
HEIDEMANN BAY
The Lookout
Hawker
Mule I.
CROOKED FJORD
CROOKED LAKE
SØRSDAL GLACIER
78°20'
78°30'
68°25'
68°30'
68°35'
77°50'
78°00'
78°10'

completely absent to extremely common. Some of the finer-grained bands of Unit 1 contain structures which might be interpreted as being of sedimentary origin e.g. cross-bedding and sedimentary slumping (Fig. 19).

Fig. 19. Possible cross-bedding in Unit 1, at a locality 6 kilometers east of Deep Lake, Vestfold Hills.

Bands and lenses of pyroxene rock are moderately common in Unit 1. They range in grain size from fine to medium and have a length ranging from one to many metres. In places the pyroxene rock is discordant.

A distinctive rock type occurring within Unit 1 is quartz-feldspar-diopside gneiss which has a highly characteristic green colour. This diopside-rich rock commonly occurs as concordant and discordant lenses within the quartz-feldspar gneiss. At one locality north of Ellis Fjord, the country rock surrounding a lens of diopside-rich rock is highly folded. This suggests that the diopside-rich rock has acted as a competent buttress.

Thin, strongly discordant veins of quartz are fairly common throughout Unit 1, apparently post-dating the main deformation of the unit. Copper and iron staining are common in this unit.

Unit 1 is apparently the most deformed rock-unit present in the Vestfold Hills. This may, in part, be attributable to the thinly-banded nature of the unit, which makes any deformation more easily visible than in the more uniform units. Unit 1 may, in addition, have acted as a more incompetent unit during deformation.

The southern outcrop of Unit 1 is succeeded by Unit 2 to the north, with a boundary which is transitional over a short distance. Similarly, a transitional boundary occurs between Unit 1 and the underlying Unit 3 in the area immediately to the south of Ellis Fjord. The nature of the contact between Unit 1 and Unit 2 to the north of Ellis Fjord is uncertain, but it is apparent that a rapid change from Unit 1 to Unit 2 occurs on the Lake Stinear lineament.

UNIT 2.

Unit 2 is a uniform feldspar-quartz gneiss, which crops out in two east-west trending belts. The more southerly of the two belts occurs at about latitude 68°38'S and is a kilometre wide. The northerly belt lies north of the Lake Stinear lineament and has a maximum width of about 4 kilometres.

The unit is strongly resistant to weathering and forms sharp strike ridges which give a fairly characteristic photo-pattern.

Unit 2 is composed almost entirely of a light grey or grey-yellow feldspar-quartz gneiss. It has a uniform fine-grained to medium-grained texture, though south of Long Fjord feldspar porphyroblasts up to 1 centimetre in length are fairly common in places. Quartz may occur rarely in coarse knots and schlieren up to several metres long and ½ metre wide. The overall appearance of the unit is uniformly massive, but thin banding is visible in places. Present within the main rock type are minor, thin, dark bands of feldspar-quartz gneiss rich in pyroxene, garnet, diopside, or biotite. Such bands form less than 5 percent of the rock types in Unit 2 but some have considerable lateral extent, with bands less than a centimetre wide commonly having a lateral extent of 10 metres and more.

A few rare, thin, discordant veins or lenses of pyroxene rock are present in places. Minor veins of coarse quartz-feldspar pegmatite up to ½ metre long occur in places.

There are no major structures visible within this unit. The strike of the rocks is generally east-west and dip 50° to 85° to the north. Foliation and lineation is only very poorly developed.

Unit 2 lies between Unit 1 and Unit 3. The nature of the boundary of the northern belt of Unit 2 with these two units is uncertain. The other boundaries are transitional over a short distance. At one locality (lat. 68°34'S., long. 78°19'E) north of Ellis Fjord there is a band of Unit 2 lithology about 30 metres thick and of unknown lateral extent, within the main development of Unit 1. The lithology of both units suggests that prior to metamorphism they were predominantly arenite sequences.

UNIT 3.

Rocks of this unit crop out generally in two east-west trending belts. The southern belt is between Ellis Fjord and Crooked Fjord; the northern one occupies approximately one quarter of the area of the Vestfold Hills and includes many of the near-coastal islands, Tryne and Wyatt Earp Islands, and the Walkabout Rocks.

The dominant rock type is quartz-feldspar gneiss containing variable amounts of pyroxene and biotite. Pyroxene rock, amphibolite, and mica schist are minor variants; diopside and garnet occur in places. Throughout the unit, coarse segregations containing quartz and feldspar with occasional biotite occur; these segregations are less common to the south. Pink coarse-grained quartz-feldspar veins, up to half a metre wide, are common on the south side of Long Fjord, opposite Pioneer Crossing.

The pyroxene content of the rock is as much as 40 percent, but is mostly in the vicinity of 10 to 15 percent. The pyroxene is generally fine-grained to medium-grained, though coarse-grained patches occur.

Pyroxene rock occurs sporadically throughout the unit but in small amounts only.

Biotite occurs in similar proportions to the pyroxene. Biotite-rich biotite-quartz-feldspar gneiss was found on the southern shore of Long Fjord opposite Pioneer Crossing. Since much of the biotite occurs in intimate association with pyroxene, it may have formed by retrogressive recrystallization of pyroxene.

The feldspars are commonly plagioclase, though potassium feldspar occurs as joint or fracture fillings. The plagioclase is normally yellow-brown or grey in colour.

Some outcrops exhibit zones of feldspar porphyroblasts, up to 4 centimetres long, in a medium-grained groundmass of pyroxene, quartz, and feldspar. The gneissic groundmass in these does not possess a well developed foliation. Garnet occurs only very sporadically in Unit 3, in beds of garnet-rich pyroxene-or-biotite-quartz-feldspar gneiss. Diopside was also noted in very limited amounts.

Rare occurrences of amphibolite and mica-schist were noted along the north-west shore of Tryne Fjord, but not as mappable units. Ravich (1960) records the presence of amphibolitic schists in the same area.

Near the head of Long Fjord, on its northern side, garnet-biotite-feldspar gneiss probably belonging to Unit 3 is apparently intruded by coarse-grained biotite granodiorite. The granodiorite is exposed as an irregular mass about 50 metres across, with numerous smaller veins. Parts of the granodiorite display a very poorly-developed foliation, trending about north. The granodiorite and country rock are cut by dykes, about 10 centimetres wide, of pink quartz-feldspar pegmatite.

The grain size of the gneiss varies considerably from area to area, ranging from fine to coarse, but in general it is fine to medium.

The dominant variations within Unit 3 are in the content, relative proportions, and mode of occurrence of pyroxene and biotite, and in the overall grainsize. The mafic grains form between 5 and 15 percent of the rock, and are dominantly fine-grained to medium-grained. They occur as disseminations of grains and crystals, as clots and schlieren of fine grains, as stringers or trails of grains, and as laths producing a finely-banded appearance.

The most prevalent texture is a well-foliated one in which the mafic minerals occur as thin streaks and trails in a matrix of quartz and feldspar grains. In most localities a particular texture predominates over a large area. Commonly the boundary between differing textures is gradational.

The rocks of Unit 3 generally are moderately to well jointed but no obvious pattern of joints was observed. The joints are normally open because of weathering effects. More numerous but weakly-developed joints were noted adjacent to a number of the dykes.

The quartz-feldspar joint fillings generally parallel the foliation of the enclosing gneiss, though some are perpendicular to it.

Deformation of this unit varies considerably and may be severe in places. Small-scale folding, with parallel axial planes, is common. Shears, often filled with coarse-grained quartz and feldspar crystals, are moderately common. Mylonites were recorded in minor amount.

DOLERITE DYKES

A dolerite dyke swarm, which intrudes the three rock units, is a prominent feature throughout the Vestfold Hills. Air-photo studies suggest that the dykes are less continuous and much thinner in the south and west, though possibly they are more densely developed there.

Lithologically they are composed of fine-grained dark grey to black dolerite, a specimen of which has been described by Crohn (1959 p.44) as "laths of andesine-labradorite and subhedral grains of augite, both up to 1 mm in size and occasionally showing ophitic texture, in a matrix of smaller plagioclase laths, interstitial granules of augite, and minor amounts of iron oxide (?magnetite), green amphibole, and biotite".

The width of the dykes is commonly 3 metres and ranges up to 25 metres, though a large proportion of the dykes are less than 2 metres wide. The majority of narrower dykes are traceable for less than 1½ kilometres, numerous dykes for between 3 and 6 kilometres, and a small number for up to 12 kilometres. One dyke 5 metres wide can be traced on the air photos for a distance of 25 kilometres from north to south.

Two major and two minor strike directions of these dykes exist. The two major directions are between 15° and 30° east of north (by far the most common) and between 35° and 45° west of north. One minor direction is north-south, and a fourth, but very minor direction, is east-west.

Limited ground observations suggest the dip of the dykes is generally within 25° of the vertical. Observation also suggest that at least some of the east-west striking dykes are slightly coarser in grain size than those of other directions.

The boundaries of the dykes are normally very sharp, though several were seen in which the pyroxene content of the country rock increased towards the dyke. For example, at the contact of country rock with a dyke 15 metres wide the pyroxene content was over 80 percent in the pyroxene-quartz-feldspar gneiss and decreased to normal proportions (20 to 25 percent) 2 metres away from the dyke. Within that distance of 2 metres, the foliation was more strongly marked than usual.

Three sets of joints were noted in the dykes: two strong sets, one sub-parallel and one perpendicular to the length of the dyke, and a third very weakly developed set at 45° to 50° to the length of the dyke. Some dykes exhibited a marked degree of shearing parallel to their length.

Although displacement of one dyke by another was visible in places, no systematic displacement of one set by another was observed in the time available.

NORITE

A roughly ellipsoidal outcrop of "norite-dolerite" occurs toward the entrance and on the north-west shore of Tryne Fjord. The outcrop is 400 metres long by 100 metres wide. It is a dark-coloured massive porphyritic rock containing medium-grained grains of pyroxene and laths of feldspar, the feldspar being the minor constituent; the groundmass is too fine-grained for hand-specimen identification of the mineral constituents. The texture of the rock is generally ophitic. Ravich (1960) has described a "norite-dolerite" from this general vicinity.

Two north-south trending dykes ½ and 25 metres across are apparently cut by the intrusion. The long axis of the intrusion is parallel to the trend of the dykes. No displacement is evident on either side of the intrusion and it is considered that the dykes are pre-intrusive, but no contacts could be found between the norite and the adjacent dykes. W.R. McCarthy (pers. comm.) has suggested that the intrusion may represent a feeder from which some of the dykes have originated.

STRUCTURE

The work done in the Vestfold Hills has not revealed any major structural features. The strike of the foliation of the gneisses is generally about east-west, although local variations are not uncommon. The dip is to the north, at angles ranging from 50° to 80°; vertical dips predominate in the western part of Long Peninsula.

Intense small-scale folding has been observed in many places, especially in the well-banded rocks of Unit 1.

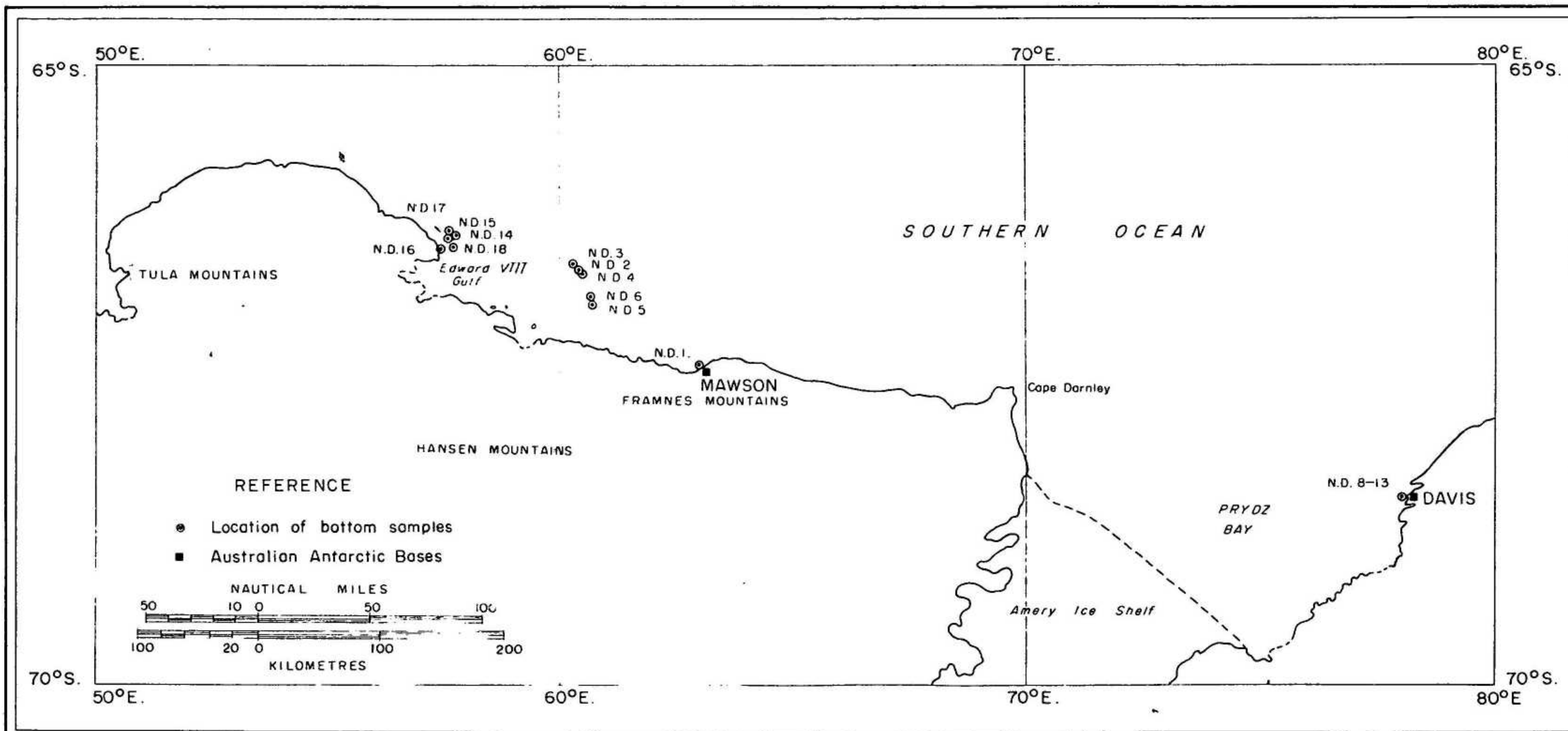
Zones of shearing and mylonitization, ranging in width from less than a centimetre to several metres, are common. Observed trends of these zones are north and north-east.

No direct evidence for large-scale faulting has been found. The many prominent valleys and inlets, trending about east or north-east, suggest lines of weakness trending in the same directions.

The remarkable dolerite dyke swarm indicates an episode of tensional stress in the history of the Vestfold Hills. Four sets of dykes can be distinguished, trending north-north-east (very common), north-west (common), north (minor), and east (very minor). No systematic displacement of one set by another has been observed. The dykes do not seem to have been displaced by faulting except to a very minor degree.

PLATE 8

LOCATION OF SEA BOTTOM SEDIMENT SAMPLING SITES



PART IV. RECENT MARINE SEDIMENTS, CONTINENTAL SHELF.

INTRODUCTION

During January and February 1965, bottom sediment samples were collected from 16 localities on the continental shelf of Antarctica between latitudes 66°25'S and 68°34'S and between longitudes 57°20'E and 77°56'E (Plate 8, Table 2). As there was no provision in the 1965 ANARE programme for systematic oceanographic work, bottom sampling could only be carried out when the ship was stationary in pack-ice or at anchor. This has inevitably resulted in an uneven distribution of samples.

TABLE 2

SEA FLOOR SAMPLE LOCALITIES

Specimen number	General Location	Latitude	Longitude	Depth (feet)	Length of Cores in inches
ND1	Mawson approaches	67°36'S	62°51'E	655	1
ND2	N.W. of Mawson	66°47'S	60°14'E	1550	10, 6
ND3	N.W. of Mawson	66°47'S	60°13½'E	1200	5, 2
ND4	N.W. of Mawson	66°48'S	60°18'E	1380	11
ND5	N.W. of Mawson	67°04'S	60°42'E	1740	10
ND6	N.W. of Mawson	66°59'S	60°47'E	1580	11
ND8	Davis approaches	68°33½'S	77°53'E	140	2
ND9	Davis approaches	68°34½'S	77°52'E	65	1
ND11	Davis approaches	68°34½'S	77°53'E	120	Bag sample
ND12	Davis approaches	68°34½'S	77°55'E	180	Bag sample
ND13	Davis approaches	68°34½'S	77°56'E	70	Anchor sample
ND14	Vicinity Cape Boothby	66°27'S	57°39'E	450	½
ND15	Vicinity Cape Boothby	66°25'S	57°36'E	540	10
ND16	Vicinity Cape Boothby	66°36'S	57°20'E	750	4
ND17	Vicinity Cape Boothby	66°36'S	57°31'E	790	½
ND18	Vicinity Cape Boothby	66°35'S	57°42'E	990	Rock chip

PREVIOUS WORK

The earliest known sampling of bottom sediments in the vicinity of Antarctica was carried out in 1873-1876 by the British "Challenger" Expedition (Murray and Renard, 1891). In 1898-1899 the German "Valdivia" Expedition (Murray and Philippi, 1908) carried out oceanographic work between Bouvet Island, Enderby Land and Kerguelen Islands. In 1901, a second German Expedition in the "Gauss" carried out bottom sampling in the Davis Sea (Drygalski, 1904; Philippi, 1912). The 1911-1914 Australasian Antarctic Expeditions undertook oceanographic work from Australia to Antarctica between longitudes 170°East and 90°East and collected over a hundred bottom samples, mainly to study the recent micro-organisms (Chapman, 1922). An oceanographic programme was initiated by the Discovery Committee (of Great Britain), and between 1925 and 1939 a total of fifteen oceanographic cruises were made, mainly off West Antarctica. Bottom sediment samples were collected on some of these cruises (Mackintosh, 1936; Deacon, 1939).

In the past decade a considerable amount of oceanographic work has been carried out by the Soviet and United States expeditions. The major Soviet work in Antarctic waters has been since 1955, from M/S "Ob" (Zhivago and Lisitsyn, 1957). The region investigated by Lisitsyn and Zhivago (1958) included the area lying between Enderby Land and Davis. Since 1961 the "Deep Freeze" operations of the United States have included numerous oceanographic programmes mainly utilizing the U.S.N.S. "Eltanin". Their investigations have been mainly concerned with Western Antarctic waters (Angino, 1964; Goodell and Osmond, 1964; Tierney, 1964).

The bottom sampling dealt with in this report represents the first work of its type carried out by Australia in Antarctic waters for more than fifty years.

SAMPLING PROCEDURES.

The method of bottom sampling used on the "Nella Dan" was basically that used by the Bureau of Mineral Resources in their bottom sampling in north Australian waters.

Severe limitations were placed on the type of equipment which could be used by the fact that the "Nella Dan" has not been designed specifically for oceanographic work. It was therefore impossible to use a large piston corer of the Kullenberg or Ewing type. An oceanographic winch was not available and therefore it was necessary to use one of the ship's mounted five ton winches.

The type of corer used was a modified type of Phleger Corer (see Fig. 20). A free fall of about 10 metres was achieved by means of a trigger arm with a 14 pound trip weight attached to one end by a 10 metre line. The corer is attached to the other end by 12 metres of wire rope (Fig. 21). There is theoretically no limit on the depth to which the corer may be used. The greatest depth of operation was 530 metres. A total of 550 metres of ½ inch circumference 6/19 galvanized steel wire rope was available.

The sample is retained in the corer by a plastic film lining (see Fig. 20). On removal from the corer, the sample is normally left in the plastic lining and put into a plastic bag which is then sealed, thus making the sample air-tight for transport back to Australia.

The depth of the bottom at the sampling point was obtained from a Kelvin Hughes MS26G Echo Sounder.

Theoretically it is possible to obtain cores of up to ½ metre or more but in fact the greatest length obtained was 28 centimetres. A greater penetration could probably be obtained by arranging for a free fall of more than 10 metres, or by making the corer heavier.

RECOMMENDATIONS

1. Whenever possible, oceanographic work should be carried out in Antarctic waters, because information, particularly from the Australian Antarctic Territory, is very sparse at present.

2. At least 1200 metres (4000 feet) of wire rope should be taken for any future work.

3. All screws, nuts, etc. on the bottom sampler should be as large as practicable, to facilitate handling of equipment in cold conditions.

4. Provision is made in the "Nella Dan" for adaptation of a compartment in the main body of the ship for oceanographic purposes. If possible this should be used in future. Some initial expense would be entailed in order to remove a plate in the hull and install an oceanographic winch. It would however, make any oceanographic work very much more efficient and make it possible to carry out sampling even under the most adverse conditions. Only a small corer could be used, however.

5. If possible a large piston corer should be taken, as this would give considerably more stratigraphic information than is obtained with the small corer.

6. Some difficulty was experienced with the tangling of the bottom 12 metres of the wire rope due to the necessity of coiling it. A 12 metre length of manilla rope should be spliced onto the end of the wire rope to overcome this tangling.

LABORATORY TECHNIQUE

Most samples were first quartered; one quarter was used for micropalaeontological work; one quarter for geochemical analysis; one quarter for sedimentological work and one quarter was retained.

The sedimentological work was done by P.J. Cook. Samples were compared with the United States Geological Survey Standard Colour Chart and then examined qualitatively under a binocular microscope. Core samples were then divided into lithological units where these were present; where no obvious breaks occurred, an arbitrary division into lower, middle and upper portions of the core was in general carried out. Samples were then dried at 40°C for several days.

Dry sieving was subsequently carried out for the range -2.0 Ø (phi) to +4.25 Ø (equivalent to the range 5 mesh to 270 mesh) at intervals of 0.25 Ø*. The sample from each 0.25 Ø interval was then weighed to an accuracy of 0.0002 gms. The tendency of silt particles to aggregate was overcome by carefully brushing each sample in the sieve until it could be seen by microscopic examination that all silt particles had disaggregated and had fallen through the sieve. The fraction below 270 mesh was collected and the textural analysis of this fraction is at present proceeding, using a sedimentation balance.

RESULTS OF SEDIMENTOLOGICAL WORK

It is at present impossible to do little more than draw very general conclusions from the sedimentological results, for work is still proceeding. Therefore comment is limited to the three major groups of grain size, i.e. rudite, arenite and lutite.

Table 3 gives a summary of the percentages of rudite, arenite, and lutite in each sea-bottom sample analysed. The average texture of the bottom samples is:

Rudite	10.39 percent
Arenite	45.11 percent
Lutite	44.50 percent

This contrasts markedly with a typical moraine sample from Stump Mountain near Taylor Glacier (see Fig. 5) which has a texture of:

Rudite	44.71 percent
Arenite	48.72 percent
Lutite	6.56 percent

Thus, considerable removal of the coarse ruditic fraction is apparently involved in the change from the terrestrial glacial deposit to the marine glacial deposit.

The ruditic fraction of a fluvio-glacial deposit was found to be intermediate between the marine and terrestrial glacial samples. A sample (C28) from a lake in the Vestfold Hills had a textural value of:

Rudite	29.77 percent
Arenite	35.61 percent
Lutite	34.62 percent

The arenite : lutite ratio is almost exactly 1:1 in both the average of marine samples and the lacustrine sample, although there is, however, considerable variation between the arenite : lutite ratios of individual marine samples. This suggests that in the finer size fractions the nature of the aqueous environments may have little or no influence on the degree of sorting.

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* a phi unit is equal to $-\log_2$ of the grain diameter in millimetres. (Krumbein, 1934)

Fig. 20 The oceanographic bottom sampler, showing: (a) bit; (b) core retainer; (c) plastic tubing for retaining core; (d) core barrel.

Fig. 21. The oceanographic bottom sampler being lowered through sea ice. (a) core barrel; (b) lead weighting; (c) canvas bag for retaining excess sample; (d) trigger arm; (e) rope attaching trip-weight to trigger arm.

A bottom sample (L1) from Deep Lake, one of the highly saline lakes in the Vestfold Hills, had the following texture:

Rudite	0.00 percent
Arenite	36.28 percent
Lutite	63.72 percent

These values further support the theory (McLeod 1964a) that the saline lakes are land-locked arms of the sea, for the evidence is that fluvio-glacial deposits would have a moderately high rudite content as opposed to the complete absence of a ruditic fraction in the Deep Lake sediments.

The sedimentological work will be discussed more fully in a later report.

PALAEONTOLOGICAL RESULTS

Quarterings of the sea bottom sediment samples were examined by Dr. G.R.J. Terpstra of the Bureau of Mineral Resources. A sample collected from the floor of Deep Lake, and three samples collected in earlier years by B.H. Stinear, were also examined by Dr. Terpstra. His report is quoted below:

Eighteen samples submitted by P.J. Cook and collected in the Antarctic region have been given preliminary examination for micro-organisms.

1. Thirteen core samples collected by P. J. Cook from the bottom of the ocean in the vicinity of Mawson and Davis bases contain Foraminifera, Ostracoda, Bryozoa, Radiolaria, Sponge-spiculae, Echinoid species, and small Mollusca.

The samples are numbered: *

ND1 (600'); ND4, A and B (1380'); ND5 (1740'); ND6 (1302'); ND8 (138'); ND11 (120'); ND12 (90'); ND15 (540') and ND16 (750')

The faunas present in these samples are in general not very rich except for those of ND4 and ND15, which contain a fair number of different species.

The faunal assemblages are marine, and the age of them is regarded as Recent.

2. The sample L1 collected by I.R. McLeod from Deep Lake, Vestfold Hills (180') contains a poor fauna consisting of a few Foraminifera, ?Radiolaria and Sponge-spiculae.

3. The samples E4 (East of head of Crooked Fjord, Vestfold Hills), V2 (Ellis Fjord, Vestfold Hills) and V4 (The Lookout, Vestfold Hills) collected by B.H. Stinear, do not contain micro-organisms.

4. No micro-organisms have been observed in any of the samples, which would indicate a geological age older than Recent.

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* Sample number system is as follows - lettered prefix (ND) relates to locality. Where two cores were obtained at the same locality the letters A & B were used (e.g. (ND4B). Where a core is divided into upper, middle or lower parts, the number 1, 2, or 3 is added (e.g. ND4B(1).)

TABLE 3.

GENERAL TEXTURAL PROPORTIONS OF RECENT MARINE SEDIMENTS FROM THE CONTINENTAL SHELF, ANTARCTICA.

General Number	Specific Number	Percentage Rudite	Percentage Arenite	Percentage Lutite
ND 1	ND1A	2.336	73.581	24.083
ND 2	ND2A	2.102	60.828	37.070
	ND2A(1)upper	34.247	46.347	19.406
	ND2A(2)lower	70.082	15.672	14.245
	ND2B	0.202	65.542	34.256
ND 3	ND3A	23.024	46.160	30.816
ND 4	ND4A(1)upper	31.264	33.670	35.066
	ND4A(2)lower	8.826	46.087	45.087
	ND4B(1)upper	18.029	57.934	24.036
	ND4B(2)middle	9.659	58.338	32.002
	ND4B(3)lower	59.347	25.090	15.562
ND 5	ND5(1)upper	1.155	45.803	53.042
	ND5(2)lower	0.839	49.242	49.919
ND 6	ND6(1)upper	0.471	57.159	42.370
	ND6(2) middle	0.902	43.314	55.784
	ND6(3)lower	0.459	44.249	55.292
ND 8	ND8	0	37.544	63.456
ND 11	ND 11	0	63.089	36.911
ND 12	ND12)Random)split of	13.683	21.460	64.858
	ND12)one sample	0	28.903	71.097
ND 14	ND14	0	55.388	44.612
ND 15	ND15(1)upper	0	45.686	54.314
	ND15(2)middle	0	33.041	66.959
	ND15(3)lower	0	43.952	56.048
ND 16	ND16(1)upper	0	38.479	61.521
	ND16(2)lower	0.599	39.456	59.949
ND 17	ND17	3.412	42.442	54.146

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