ROCKS FROM ANTARCTICA: THE *DISCOVERY* COLLECTION IN THE BRITISH MUSEUM (NATURAL HISTORY)

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CONTENTS

SYNOPSIS

A collection of rocks made by RRS *Discovery II* and RRS *William Scoresby* between 1932 and 1939 from the coast of continental Antarctica, from various islands, and from the bed of the Southern Ocean, is described. The petrography of the rocks is presented, with sixteen new chemical analyses and three (K/Ar) age determinations.

Leucocratic, and some basic and ultrabasic granulitic rocks from the coasts of Kemp and MacRobertson Lands, Australian Antarctic Territory, are described. The rocks have charnockitic affinities and are characterized also by an abundance of garnet and scarcity of sillimanite. A partial analysis of an almandine is reported. The five new chemical analyses of the granulites are plotted on FMA and lime-alkalis diagrams and show that the rocks resemble the Bunger Oasis (Queen Mary Land) and Madras charnockite series. Age determinations made on the hornblende and biotite from a basic granulite give 872 and 485 million years (m.y.), respectively. These are considered to be the ages of the major granulitization episode and of subsequent retrogressive metamorphism.

Greenschist facies rocks from Clarence Island, in the Scotia Arc, together with igneous and other metasedimentary rocks dredged from nearby, are described. The age of a quartz-muscovite-graphite schist from Clarence Island is determined as 28 m.y., and suggests a late Tertiary extension of the Andean orogeny, known to have affected the Antarctic Peninsula. The main Scotia Arc collection, however, comes from the South Orkney Islands. These high greenschist facies metasediments include garnet and hornblende schists, and also a group of altered microdiorites and andesites, hitherto unreported. Analyses of a schist, a microdiorite and two sediments (greywacke and conglomerate) are given ; the latter are from a later sedimentary sequence present only in the islands at the eastern end of the group.

The third part of the collection consists of basaltic and other rocks from Bouvet Island and several widely separated dredge stations. Two analyses of the Bouvet Island basalts match closely the earlier analyses, and are plotted on FMA and lime-alkalis diagrams. Differentiation curves are given for Bouvet and for other alkali basalt islands in the South Atlantic ; for comparison, curves of the tholeiitic basalt – andesite series of Deception and other South Shetland islands are given. An analysed olivine basalt from off the Balleny Islands shows a marked resemblance to the olivine basalts and ankaramites from the Tristan da Cunha group of islands, and an analysed picritic basalt dredged off Dronning Maud Land has strong affinities with the picrite basalt from Gough Island. The tholeiitic ophitic dolerites or coarse basalts from this station (one analysis) resemble dolerites from western Dronning Maud Land. Other dredged rocks include basic schists (one analysis), adamellitic granites, and greywackes.

I. INTRODUCTION

The purpose of this paper is to describe a heterogeneous collection of rocks made by RRS *Discovery II* and RRS *William Scoresby* between 1932 and 1939 from the coast of continental Antarctica, from some of the small islands, and from the bed of the Southern Ocean.* Many of these rocks were described some years ago but it would seem that an up-to-date account of the entire collection, together with chemical analyses and age determinations, would be a useful contribution, in view of the current interest in the geophysical, oceanographical and geological problems of this region resulting from improved accessibility and the concept of plate tectonics.

Table I is a catalogue of the rocks in the collection, together with their registered numbers and details of their collection. Those from the two continental localities were collected by the *William Scoresby* ; the remainder were collected by the *Discovery II*. Most of the collection falls into three main groups ; the remainder comes from two or three stations and merits less attention.

Of the main groups, the first comes from the two localities (Text-fig. 1) in Australian Antarctic Territory : Bertha Island, off Sheehan Nunatak, Kemp Land, and Scullin Monolith, MacRobertson Land.

The second group derives from islands forming part of the Scotia Arc : Clarence Osland (Pl. 1, 1), in the Elephant Island group, South Shetlands Islands, and the

* The rocks (144 numbered samples) are deposited in the collection of ocean bottom deposits in the Department of Mineralogy, British Museum (Natural History), from which subsamples can be supplied for specialist investigations.

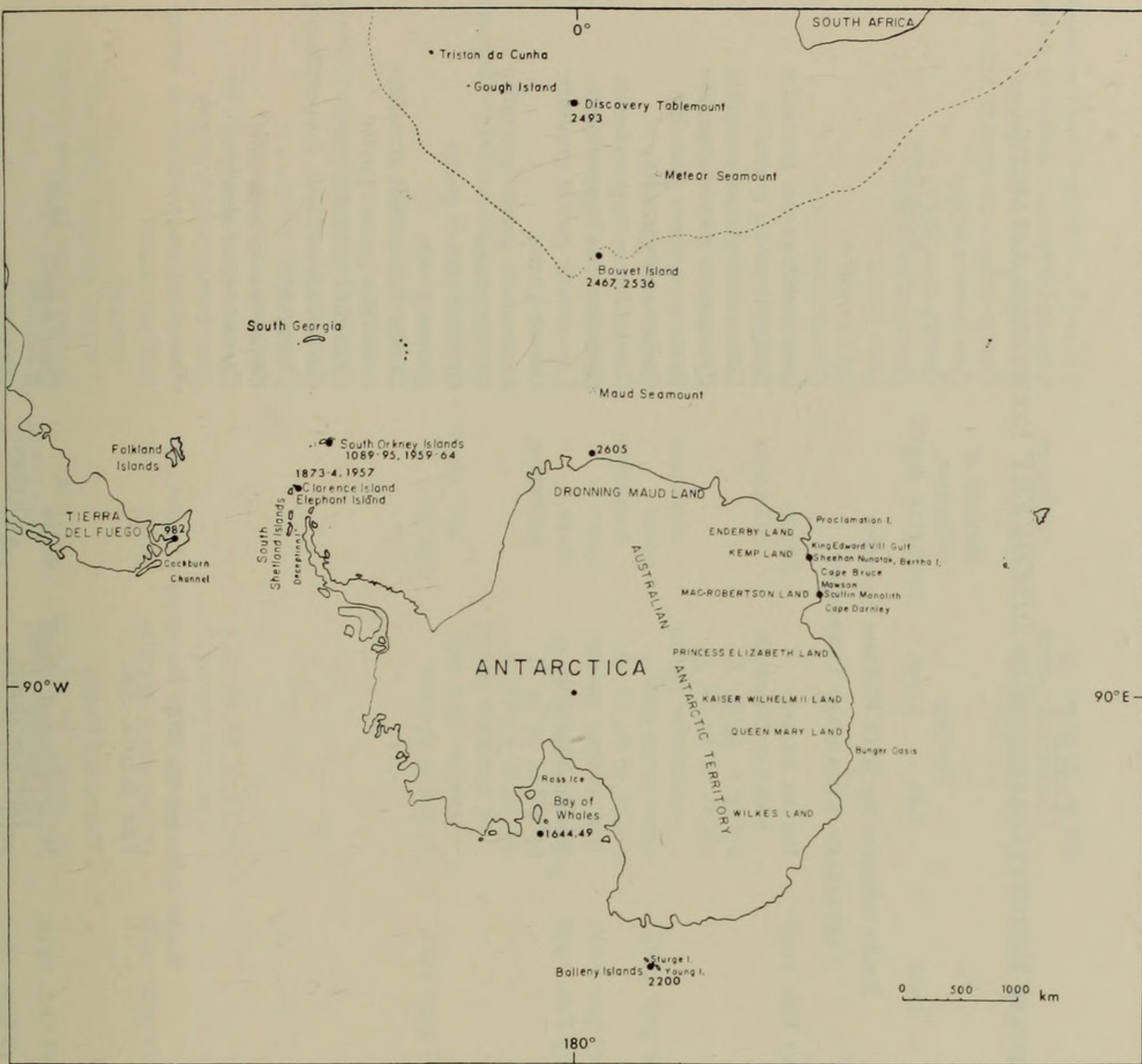


FIG. 1. Sketch map of Antarctica and the South Atlantic, to show the localities from which specimens were collected. Heavy numbers refer to Discovery Stations, listed in '*Discovery*' *Reports* **21** and **24**, and in Table I. Seamounts are shown as dotted lines and the dashed line represents the median rift valley of the Mid-Atlantic Ridge.

South Orkney Islands (Pls. 1, 2; 2; and 3, 1). The South Orkney rocks were collected on two separate cruises, in 1933 and 1937. With these is included a single specimen from Tierra del Fuego.

The third group, dredged off or collected from the Balleny Island group (Pl. 4), near longitude 180°; and the Discovery Tablemount, Bouvet Island (Pl. 3, 2), and off Dronning Maud Land, all near longitude 0°, are basalts. Included in this section are the remaining rocks, dredged from the Bay of Whales and, with the

Table I

The British Museum (Natural History) Collection of *DISCOVERY* Rocks from Antarctica

BM no		Station no	Field no (if any)	Date	Position Lat. Long.	Method of collection, including depth	Rock type
					Rocks collected by RRS *William Scoresby*		
					Australian Antarctic Territory		
1972, O, 129	(1)	(No number)	1	27 Feb. 1936	Bertha Island, Sheehan Nunatak 67°22′ S, 59°50′ E	Shore collection	Leucocratic garnet granulite
	(2)		2				Basic (diopside) granulite
	(3)		5				Leucocratic garnet granulite
	(4)		6				Leucocratic garnet granulite
	(5)		7				Basic (pyroxene) granulite
	(6)		8				Garnet-rich granulite
	(7)		9				Garnetiferous hypersthenite
	(8)		10				Garnetiferous hypersthenite
1972, O, 130	(1)	(No number)	1	25 Feb. 1936	Scullin Monolith 67°48′ S, 66°42′ E	Shore collection	Leucocratic garnet granulite
	(2)		2				Garnet gneiss
	(3)		3				Leucocratic garnet granulite
	(4)		4				Garnet gneiss
	(5)		5				Granitic garnet gneiss
	(6)		6				Garnet gneiss
	(7)		7				Leucocratic garnet granulite
	(8)		8				Granulitic garnet gneiss
	(9)		9				Granulitic garnet gneiss
	(10)		10				Garnetiferous basic (hypersthene) granulite
	(11)		11				Garnetiferous quartzite
	(12)		12				Garnetiferous quartzite
					Rocks collected by RRS *Discovery II*		
					The Scotia Arc		
					Tierra del Fuego		
1972, O, 131		982		18 Oct. 1932	Mt Boucheron, Shoal Bay, Cockburn Channel 54°25′ S, 72°00′ W	Shore collection	Quartz-mica schist

					Clarence Island		
1972, O, 132	(1)	1873	3	13 Nov. 1936	W of Cape Bowles,	DRR:	Epidosite
	(2)		4		off Clarence Island	180–210 m	Epidosite
	(3)				61°20·8′ S, 54°04·2′ W	117 m	Metamorphic pebbles (chlorite schist, phyllite, epidosite, marble)
1972, O, 133	(1)	1874		13 Nov. 1936	ca. 0·8 km E of Cape	Shore	Graphite schist
	(2)				Bowles, off	collection	Quartz-muscovite-graphite schist
	(3)				Clarence Island		Vein quartz with graphite
	(4)				61°17′ S, 45°03′ W		Quartz-mica-graphite schist
	(5)		3				Quartz-mica schist
	(6)						Quartz-mica schist
	(7)						Quartz-mica schist
	(8)		2				Quartz-epidote-muscovite-chlorite schist
	(9)						Quartz-mica schist
1972, O, 134	(1)	1957	1	3 Feb. 1937	11 km E of Cape	DLH:	Granodiorite
	(2)		2		Bowles, off S side	785–816 m	Granodiorite
	(3)				of Clarence Island 61°18′ S, 53°57′ W		Granitic and metamorphic pebbles
					South Orkney Islands		
1972, O, 135		1094	61	25 Jan. 1933	Inaccessible Islands 60°34′ S, 46°44′ W	Shore collection	Hornblende-epidote schist
1972, O, 136	(1)	1091	5	9 Jan. 1933	Sandefjord Bay,*	Shore	Quartz-muscovite schist
	(2)		11		Coronation Island	collection	Marble
	(3)		25		60°37′ S, 46°03′ W		Quartz-muscovite schist
	(4)		26				Quartz-muscovite schist
	(5)		33				Marble
	(6)		34				Vein quartz
	(7)		35				Quartz-mica schist
	(8)		36				Biotite schist
	(9)		39				Vein quartz
	(10)		44				Quartz-mica schist
	(11)		52				Quartz-mica schist
	(12)		59				Quartz-mica schist
	(13)		60				Quartz-muscovite-chlorite schist
1972, O, 137	(1)	1963	1	14 Feb. 1937	Sandefjord Bay,*	Shore	Altered quartz microdiorite
	(2)		2		Coronation Island	collection	Altered porphyritic quartz andesite
	(3)				60°37′ S, 46°03′ W		Altered porphyritic quartz andesite

TABLE I (*cont.*)

BM no		Station no	Field no (if any)	Date	Position Lat. Long.	Method of collection, including depth	Rock type
1972, O, 138	(1)	1964	1	15 Feb. 1937	NW corner of	Shore	Quartz-mica schist
	(2)		2		Coronation Island	collection	Chlorite-mica schist
	(3)				60°37′ S, 45°35′ W		Garnet-mica schist
1972, O, 139	(1)	1092	1	18 Jan. 1933	Borge Bay, Signy	Shore	Banded marble
	(2)		4		Island	collection	Garnet-hornblende schist
	(3)		6		60°43′ S, 45°38′ W		Quartz-mica schist
	(4)		7				Garnet-hornblende gneiss
	(5)		10				Garnet-hornblende gneiss
	(6)		15				Garnet-hornblende gneiss
	(7)		17				Quartz-garnet-hornblende gneiss
	(8)		18				Actinolite-chlorite-epidote schist
	(9)		19				Garnet-hornblende schist
	(10)		21				Quartz-mica schist
	(11)		28				Garnet-biotite schist
	(12)		30				Banded marble with garnet-hornblende schist
	(13)		37				Garnet-biotite schist
	(14)		40				Folded quartz-mica schist
	(15)		41				Garnet-mica schist
	(16)		42				Marble
	(17)		43				Hornblende schist
	(18)		46				Garnet-hornblende gneiss
	(19)		51				Chlorite schist
1972, O, 140	(1)	1962	1	13 Feb. 1937	Paal Harbour,	Shore	Garnet-mica schist
	(2)				Signy Island	collection	Micaceous quartz vein
					60°43′ S, 45°38′ W		
1972, O, 141	(1)	1961		12 Feb. 1937	60°49·5′ S, 45°27·5′ W	DLH :	Metacalcareous rocks
	(2)		2			340 m	Quartz-mica schist
	(3)						Quartzite
1972, O, 142	(1)	1089	2	3 Jan. 1933	Powell Island	Shore	Greywacke
	(2)		3		60°41′ S, 45°03′ W	collection	Greywacke
	(3)		8				Greywacke
	(4)		12		Michelsen Island		Conglomerate
	(5)		13		60°44′ S, 45°02′ W		Conglomerate
	(6)		22		Powell Island		Greywacke

	(7)		29		Michelsen Island		Greywacke
	(8)		31				Sandstone
	(9)		55		Powell Island		Conglomerate
	(10)		56				Conglomerate
	(11)		58		Michelsen Island		Greywacke
1972, O, 143	(1)	1090	8	4 Jan. 1933	Fredriksen Island	Shore	Greywacke
	(2)		9		and Holmen Gras	collection	Greywacke
	(3)		20		60°44′ S, 44°59′ W		Greywacke
	(4)		24				Greywacke-conglomerate
	(5)		38				Flaggy sandstone
	(6)		48				Shale
	(7)		49				Shale
	(8)		50				Greywacke
	(9)		54				Conglomerate
	(10)		62				Greywacke
1972, O, 144	(1)	1095	14	26–28 Jan.	Wilton Bay,	Shore	Coral
	(2)		16	1933	Laurie Island	collection	Greywacke
	(3)		23		60°44′ S, 44°37′ W		Greywacke
	(4)		27				Fine greywacke
	(5)		32				Slate
	(6)		36				Quartz-mica schist
	(7)		45				Fine greywacke
	(8)		47				Fine greywacke
	(9)		53				Quartzite
	(10)		57				Chlorite-mica schist
1972, O, 145	(1)	1959	1	8 Feb. 1937	Scotia Bay,	Shore	Greywacke-conglomerate
	(2)		2		Laurie Island	collection	Greywacke-conglomerate
	(3)				60°46′ S, 44°40′ W		Shale
	(4)						Conglomerate with calcite vein
1972, O, 146	(1)	1960	1	11 Feb. 1937	Graptolite Island	Shore	Greywacke
	(2)				60°44′ S, 44°28′ W	collection	Fine greywacke
	(3)						Greywacke-conglomerate
	(4)						Greywacke-conglomerate

Basaltic and other rocks

1954, 152		2493		29 Nov. 1938	Discovery	DLH :	Porphyritic basalt
					Tablemount	472 m	
					42°03·9′ S, 00°03·5′ E		
1972, O, 147	(1)	2493					Diopside-hornblende schist
	(2)						Conglomerate and argillite pebbles

TABLE I (*cont.*)

BM no		Station no	Field no (if any)	Date	Position Lat. Long.	Method of collection, including depth	Rock type
1972, O, 148	(1)	2467		28 Oct. 1938	Near Bouvet Island 54°24·1′ S, 03°15·2′ E	DLH : 119–124 m	Porphyritic basalt
	(2)						Porphyritic basalt
	(3)						Aphyric vesicular basalt
	(4)						Very fine-grained basalt
	(5)						Basalts
1972, O, 149	(1)	2536		17 Jan. 1939	Off Bouvet Island 54°23·8′ S, 03°28·4′ E	Shore collection	Porphyritic vesicular basalt
	(2)						Red-weathering porphyritic olivine basalt
	(3)						Basalt and weathered fragments
	(4)						Scoriaceous and porphyritic basalts
	(5)						Porphyritic olivine basalt
	(6)						Beach sand
1972, O, 150	(1)	2605		5 March 1939	Off Dronning Maud Land 70°03·2′ S, 04°12·9′ E	DLH : 214 m	Ophitic dolerite or coarse basalt
	(2)						Ophitic dolerite or coarse basalt
	(3)						Ophitic coarse basalt
	(4)						Ophitic coarse porphyritic basalt
	(5)						Ophitic coarse porphyritic basalt
	(6)						Coarse porphyritic olivine-enstatite basalt
	(7)						Adamellite
	(8)						Garnet-apatite gneissose adamellite
	(9)						Chlorite-hornblende schist
1972, O, 151		2200		21 Jan. 1938	Off Balleny Islands 67°09·6′ S, 163°27·7′ E	DLH : 512–532 m	Porphyritic olivine basalt
1972, O, 152		1644		16 Jan. 1936	Bay of Whales 78°24·8′ S, 164°10·3′ W	DC : 645 m	Greywacke
1972, O, 153		1649		21 Jan. 1936	Bay of Whales 78°24·8′ S, 164°10·3′ W	DLH : 695 m	Greywacke

Notes: Within each group the stations are arranged in clockwise geographical position.
* See p. 358 for correct localities.
Types of dredge used : DLH : Large dredge. Heavy pattern, 1·2 m long.
DC : Conical dredge. Mouth 40·5 cm in diameter, with a canvas bag.
DRR : Rectangular dredge bag bent on to a Russell frame with skids.

basalts, near the Discovery Tablemount and off Dronning Maud Land. Many of these are probably glacial erratics, including some transported by ice rafting.

The *'Discovery' Reports* by Rayner (1940) and Marr (1935) give full accounts, with historical backgrounds, of the *William Scoresby*'s visit to Australian Antarctic Territory and the *Discovery II*'s first expedition to the South Orkney Islands. In addition, full lists of relevant station numbers, with collection details, are given in volumes **21** and **24** of the *Reports*. Only a brief summary, therefore, of other relevant expeditions, both before and after that of the *Discovery II*, is given here.

Rock specimens, mainly basalts and other lavas, collected by the first RRS *Discovery* from the southern islands and South Victoria Land during the National Antarctic (*Discovery*) Expedition, 1901–4, are in the rock collections of the British Museum (Natural History). They were described by Prior (1907) and catalogued by Campbell Smith & Game (1954). The *Discovery* also dredged in 1927 a specimen of andesite from off the Palmer Archipelago, off Graham Land (Campbell Smith & Game, 1954, p. 167).

II. AUSTRALIAN ANTARCTIC TERRITORY

In 1936, the *William Scoresby*, whilst marking whales in the Southern Ocean, was near the newly explored coasts of Kemp Land and MacRobertson Land. Her captain, Lieut Cdr C. R. U. Boothby, R.N.R., took the opportunity of the very open ice conditions at that time to make two short 'unofficial' landings. These were made by Mr G. W. Rayner on Bertha Island and Scullin Monolith (Text-fig. 1).

Bertha Island, first thought to be part of the mainland, is 3 miles long, with a series of north–south ridges running normal to its length. It is near Sheehan Nunatak, in the Sheehan Island group, which forms part of the William Scoresby Archipelago, in William Scoresby Bay, between King Edward VIII Gulf and Mawson. Scullin Monolith, some 290 km to the east, is a crescent-shaped massif rising to 400 m or more, between Mawson and Cape Darnley.

The British, Australian, and New Zealand Antarctic Research Expedition (BANZARE) of 1929–31, under the leadership of Sir Douglas Mawson in the first *Discovery*, visited Scullin Monolith and also Cape Bruce, near Bertha Island. The rocks he collected from these localities are described by Tilley (1937). After the *William Scoresby* landings were made (Rayner, 1940), Mr Rayner sent the rocks to Tilley who again described them (1940) and compared them with the previous collections ; thus two granite gneisses taken from Scullin Monolith by BANZARE were compared with about a dozen varied rocks collected by the *William Scoresby* ; and some fifty rocks from Cape Bruce, acquired from two separate landing places by BANZARE, were compared with ten specimens from Bertha Island.

The Australian National Antarctic Research Expedition (ANARE), 1954, visited the same region in Kemp Land, but not Cape Bruce or Bertha Island ; it did, however, visit Scullin Monolith (Stinear, 1956, unpublished). Neither area was visited by the ANARE, 1955–57, but Crohn (1959), describing the results of this extended work season, has provided an up-to-date account of the regional geology of Australian Antarctic Territory, with notes on the petrology of the main rock types.

i Bertha Island, Sheehan Nunatak

Of the ten rocks collected by Rayner from this locality, and described by Tilley (1940), eight are in the British Museum collection.

Tilley (1940) refers to the chief rock type of the island as a garnet-hornblende-microperthite-quartz gneiss and compares two other specimens, rich in almandine garnet, with the gneisses of the Cape Bruce area (Tilley, 1937). These two rocks he names as a microperthite-quartz gneiss, with biotite, garnet and accessory xenotime ; and a quartz-plagioclase (andesine)-garnet gneiss with spinel enclosures in the garnet, both of igneous origin (1940, pp. 181–2). The basic rocks are named as hypersthenite and garnetiferous hypersthenite ; mangerite passing into quartz norite ; and bands of basic rock described as metamorphosed gabbros or norites.

Four of the specimens in the collection are *leucocratic garnet granulites* (Pl. 5, 1) ; two are *basic granulites* (metagabbro and metanorite) (Pls. 5, 2 and 3) ; and two are metamorphosed *ultrabasic* rocks (*garnetiferous hypersthenites*). Excluding the mangerite-norite category, these groups correspond with Tilley's and represent, respectively, the country rock ; basic bands within it, varying from a few centimetres to a metre or two in width ; and a small outcrop, 5 to 7 m in diameter, towards the western end of the island (Tilley, 1940, p. 182, based on field notes provided by Rayner).

The mineralogy of the rocks is given in Table II. In the leucocratic group the quartz is often strained and granulated, and the most common ferromagnesian mineral is an olive-green hornblende, sometimes derived by alteration of a diopsidic augite. Garnet, a partial analysis of which is given in Table III (analysis 1), is present in all but the basic granulites. It is a pale pink almandine, typical of granulite facies rocks and very similar to the pink almandine from a garnetiferous enderbite from Madras (analysis A) (Howie & Subramaniam, 1957). In the basic granulites, the plagioclase is andesine-labradorite, accompanied by hornblende, often retrogressive after clinopyroxene. Hypersthene occurs in one of the two rocks and it is notable that biotite is more abundant in the other. Both the ultrabasic rocks are stained green by copper mineralization and the hypersthene-plagioclase rock is heavily mineralized with marcasite (ca. 10% by weight).

ii Scullin Monolith

The twelve specimens from Scullin Monolith show a greater textural variation. Tilley (1940) grouped most of them as quartz-microperthite gneiss, and compared some, in which bands of dark smoky quartz are present, with rocks from the Cape Bruce area (Tilley, 1937). These twelve specimens include three *leucocratic garnet granulites* (Pl. 5, 4) and six *garnet gneisses*, of which two are granulitic and one granitic ; two *garnetiferous quartzites* (quartz veins) ; and a single *garnetiferous basic granulite* (the hornblende norite of Tilley, 1940, p. 181).

In the leucocratic rocks, the quartz is again usually strained and granulated, especially in the quartzites, and in some (e.g. 130 (2)) it occurs, as noted by Tilley, as bands of the dark smoky variety. The alkali feldspar is bleb or hair microperthite and in two specimens (130 (1) and (8)) forms large 'phenocrysts' or porphyroblasts reaching 2·5 cm in length. One leucocratic garnet granulite (130 (1)) contains

Table II

The Mineralogy of Rocks from Australian Antarctic Territory

	Bertha Island								Scullin Monolith											
	Leucocratic garnet granulites				Basic granulites		Garnetiferous hypersthenites		Leucocratic garnet granulites			Garnet gneisses			(granu-litic)		(gran-itic)	Gar-netiferous quartzites		Garnetiferous basic granulite
Field No	1	5	6	8	2	7	9	10	1	3	7	2	4	6	8	9	5	11	12	10
Quartz	c	a	a	a					c	a	a	a	c	c	a	c	a	a	a	
Microperthite :																				
bleb	a	a	a						a	a		a			a	a	a			
hair		c*							a	a	a	a	a	a				s	s	
Myrmekite	r		r						r		r	r	r	r	s	r	s			
Plagioclase :																				
andesine	a	s	a	a					c	c		s	s	s		c				
labradorite					a	a		c												a
Hypersthene						a	a	a												a
Clinopyroxene	r	s	r		a	a				s										
Hornblende :																				
olive-green	c	c			a	a														
brown																				a
Biotite :																				
foxy-red			s		a	a	s	s	s		s			s		c				s
brown				s						c		s	s		s		s			
Garnet	s	c	c	a			a	s	s	c	s	c	s	s	s	r	r	r	r	r
Sillimanite																		r		
Green spinel											r									
Iron ore	ac	ac	ac	ac	ac	ac	s	s	ac	ac	ac	ac	ac	ac	ac	ac	ac			ac
Apatite	ac	ac								ac			ac	s	ac	ac		ac	ac	
Sphene	ac	ac	ac	ac																
Zircon	ac			ac						ac	ac	ac		ac	ac	ac	ac		ac	

a abundant
c common
s sparse
r rare
ac accessory
* coarse anti-perthite

Table III

Analysis of a Garnet, with a Comparison

	1	A
SiO_2	38·6	38·02
TiO_2	n.d.	0·03
Al_2O_3	21·64	21·02
Fe_2O_3	–	1·98
FeO	29·35 (total)	28·12
MnO	n.d.	0·64
MgO	7·6	7·87
CaO	2·7	2·25
Na_2O	n.d.	0·11
K_2O	n.d.	0·01
H_2O^+	n.d.	–
H_2O^-	n.d.	0·09
Total	99·89	100·14
Numbers of ions on the basis of 24 oxygens		
Si	6·007 } 6·01	5·936 } 6·00
Al	–	0·064
Al	3·970 } 3·97	3·796 } 4·04
Ti	–	0·008
Fe^{3+}	–	0·240
Fe^{2+}	3·820 } 6·03	3·670 } 5·99
Mn	–	0·084
Mg	1·763	1·826
Ca	0·450	0·374
Na	–	0·036
K	–	0·002
Almandine	64	61·2
Andradite	–	6·2
Grossularite	7	0·7
Pyrope	29	30·5
Spessartine	–	1·4

1 Almandine garnet, leucocratic garnet granulite, Bertha Island, BM 1972, O, 129 (6). (Analyst: R. F. Symes.) (Partial analysis by electron microprobe; calculation ignores andradite and spessartine components.)
A Pink almandine garnet, garnetiferous enderbite (Ch 113) (charnockite series), Pallavaram, Madras, India (Howie & Subramaniam, 1957). (Analyst: R. A. Howie.)

white patches of feldspar with green irregular intergrown cores of quartz. The rocks, on the whole, contain lesser amounts of ferromagnesian minerals than their nearest equivalents from Bertha Island. Hornblende is virtually absent and a little clinopyroxene is found in only one specimen ; there is no hypersthene. Biotite is present in all except the quartzites, and garnet is found in every rock ; both these minerals are sparsely distributed (Table II) and the garnet is sieved with inclusions of quartz and biotite. Sphene does not occur amongst the accessory minerals, whilst apatite, in one rock, forms large widely disseminated oval blebs and localized crystal aggregates. Green spinel (near gahnite) is present in one granulite and the thin section of a quartzite contains a single cross-section of sillimanite.

Thus, the two groups of granulites, containing hypersthene in only four out of twenty rocks, are notable in that they lack garnet only in the two basic granulites from Bertha Island, this mineral being present in the single similar rock from Scullin Monolith. The scarcity of sillimanite in a suite of granulites is surprising and the apatite blebs are unusual.

iii Chemistry and discussion

In Table IV (analyses 1 to 4), chemical analyses, with their CIPW norms, are given of a leucocratic granulite and a basic granulite each from Bertha Island and Scullin Monolith. An analysis of the mineralized garnetiferous hypersthenite from Bertha Island, recalculated on a sulphide-free basis, is also presented (analysis 5) ; its relatively high SiO_2 content results from the presence of plagioclase. Three analyses are also presented in Table IV for comparison. Of these, the first is of a garnet granulite from Proclamation Island, Enderby Land, some 290 km west of Bertha Island (Tilley, 1937, p. 10). In SiO_2 content it lies between the two similar *Discovery* rocks but differs somewhat in its content of other oxides. This is not surprising since in rocks of this (granitic) composition slight variations in the modal content of the ferromagnesian minerals will result in proportionally large variations in certain elements.

TABLE IV

ANALYSES, SOME TRACE ELEMENTS, AND CIPW NORMS OF GRANULITES FROM AUSTRALIAN ANTARCTIC TERRITORY

	Leucocratic rocks				Basic and ultrabasic rocks			
	1	A	2	B	3	4	5	C
SiO_2	81·02	73·84	68·43	62·31	50·35	46·50	50·60	51·79
TiO_2	0·37	0·09	0·93	1·38	0·60	2·43	0·87	1·16
Al_2O_3	9·27	14·06	12·84	14·10	15·63	15·49	7·72	15·62
Fe_2O_3	0·51	tr	1·61	1·92	1·25	1·27	3·15	1·93
FeO	0·98	1·55	4·36	6·63	6·90	12·28	19·60	8·42
MnO	0·01	nil	0·11	0·20	0·16	0·23	0·30	0·25
MgO	0·38	0·41	1·22	1·71	8·61	7·68	13·45	7·00
CaO	1·14	1·65	2·92	4·80	9·90	9·42	2·26	9·79
Na_2O	1·61	2·72	2·00	2·72	3·40	2·61	1·50	2·29
K_2O	4·07	5·08	5·18	3·72	1·96	1·22	0·28	0·87
H_2O^+	0·59	0·25	0·37	–	0·87	0·59	0·41	–
H_2O^-	0·10	0·25	0·05	–	0·12	0·06	nil	–
P_2O_5	0·09	nil	0·26	0·36	0·06	0·30	–	0·16
S	0·02	–	0·04	–	0·08	0·13	–	–
CO_2	0·79	nil	0·35	–	0·58	0·32	0·27	–
Others	–	–	–	0·33	–	–	–	1·27
Less O≡S	0·01	–	0·02	–	0·04	0·06	–	–
Total	100·94	99·90	100·65	100·18	100·43	100·47	100·41	100·55

[*Continued overleaf*

TABLE IV (*cont.*)

				Trace elements (p.p.m.)				
Cr	20		120		nil	100	400	
Li	19		9		23	37	20*	
Ni	nil		15		50	100	2100	
Cu	10		5		5	15	20*	
Zn	280		230		280	400	780*	
V	25		40		250	400	300	
Zr	500		2000		70	400	50	
Y	nil		170		nil	80	nil	
Sr	100		250		200	325	tr	
Ba	400		500		100	400	50	
Rb	73		91		91	137	160*	
				Norms				
q	52·96	33·20	27·63	17·81	–	–	1·84	2·36
c	0·36	1·09	–	–	–	–	1·47	–
or	24·06	30·03	30·62	21·99	11·59	7·21	1·66	5·14
ab	13·62	23·01	16·92	23·01	20·20	20·84	12·69	19·38
an	5·07	8·19	10·76	15·28	21·61	26·95	9·51	29·78
ne	–	–	–	–	4·64	0·68	–	–
di	–	–	1·71	5·24	21·99	14·72	–	14·52
hy	1·73	3·72	7·52	10·28	–	–	66·01	22·74
ol	–	–	–	–	15·63	21·89	–	–
mt	0·74	–	2·33	2·78	1·81	1·84	4·57	2·80
il	0·70	0·17	1·77	2·62	1·14	4·62	1·65	2·20
ap	0·21	–	0·61	0·85	0·14	0·71	–	0·38
ct	–	–	–	–	–	–	0·61	–

1 Leucocratic garnet granulite, Scullin Monolith, BM 1972, O, 130 (3). (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)
A Garnet granulite, Proclamation Island, Enderby Land (no. 154) (Tilley, 1937, p. 10). (Analyst: C. E. Tilley.)
2 Leucocratic garnet granulite, Bertha Island, BM 1972, O, 129 (1). (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)
B Charnockite (granosyenite), Charnokitovyy Island, Bunger Oasis (no. 367) (Ravich & Kuno, 1961, p. 66).
3 Basic (diopside) granulite, Bertha Island, BM 1972, O, 129 (2). (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)
4 Basic (hypersthene) granulite, Scullin Monolith, BM 1972, O, 130 (10). (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)
5 Garnetiferous plagioclase hypersthenite, Bertha Island, BM 1972, O, 129 (8). (Analysts: C. J Elliott, V. K. Din and A. J. Easton; analysis carried out on sulphide-free fraction; * : determined on total rock.)
C Charnockite (quartzy gabbro-norite), Smelykh Island, Bunger Oasis (no. 446) (Ravich & Kuno, 1961, p. 66).

The second and third analyses are of two charnockites from Bunger Oasis, Eastern Antarctica (Ravich & Kuno, 1961). The first (B) resembles the garnet granulite from Bertha Island, the second (C) the more basic *Discovery* rocks ; in each case there are differences in the content of various elements. For example, the basic granulite from Bertha Island is somewhat deficient in iron. Both the basic granulites from Australian Antarctic Territory contain normative nepheline.

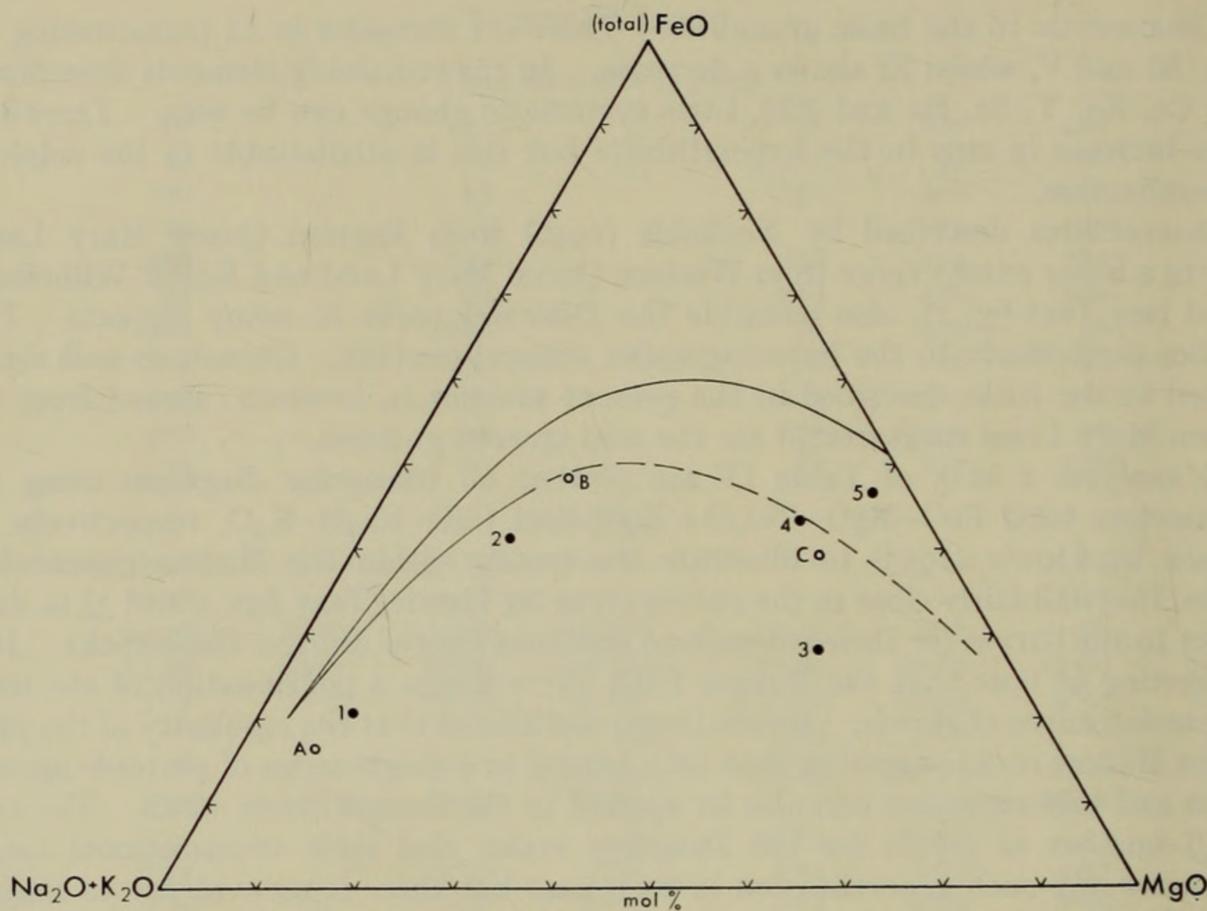
The trace elements, which in most cases are present in similar quantities to those in the Madras charnockite series (Howie, 1955), show limited patterns of change from the leucocratic to the basic granulites. There are increases in Li (substituting for Mg), Ni and V, whilst Zr shows a decrease. In the remaining elements determined (Cr, Cu, Zn, Y, Sr, Ba and Rb), little systematic change can be seen. There is a large increase in zinc in the hypersthenite but this is attributable to the sulphide mineralization.

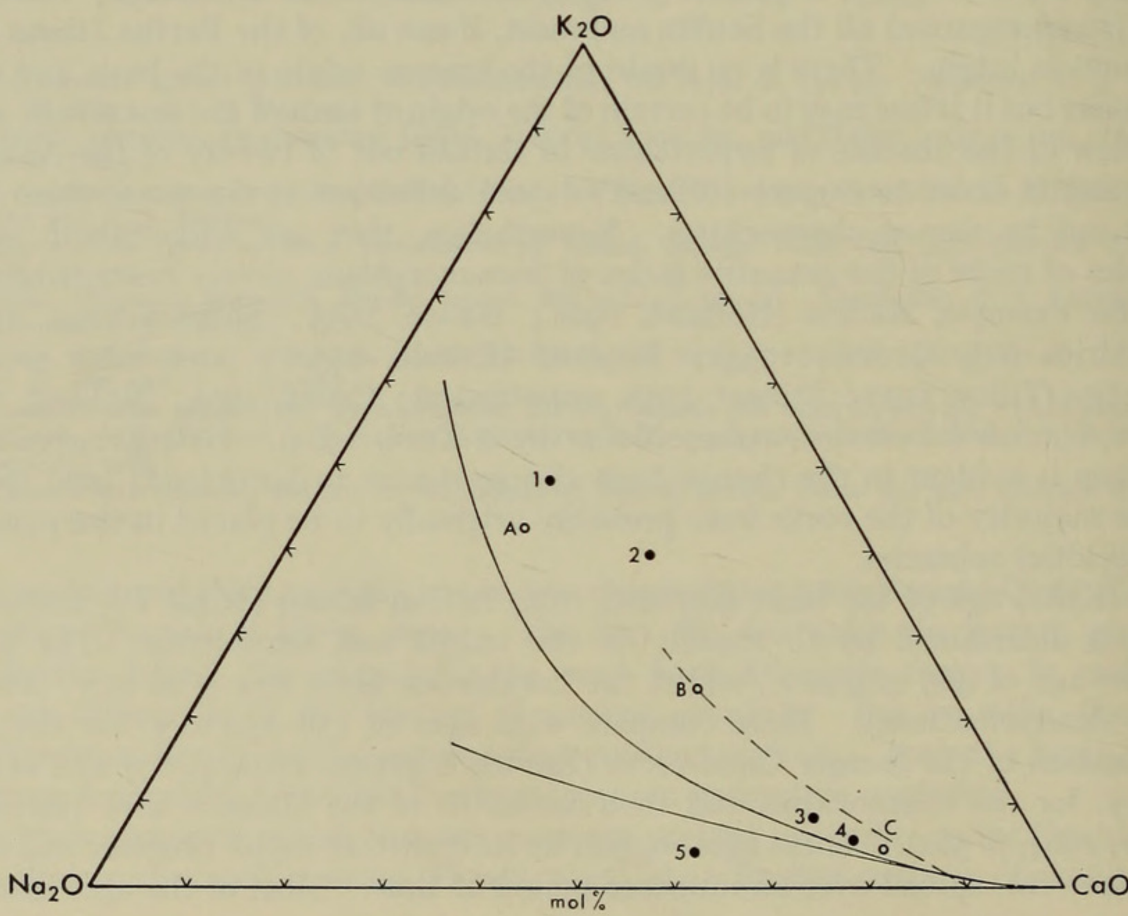
Charnockites described by Nockolds (1940) from Eastern Queen Mary Land, and to a lesser extent those from Western Queen Mary Land and Kaiser Wilhelm II Land (see Text-fig. 1), also resemble the *Discovery* rocks in many respects. This applies particularly to the ferromagnesian mineral content. Garnet, so well represented in the rocks described in the present account is, however, absent from the Queen Mary Land rocks except for the acid igneous gneisses.

If analyses 1 to 5 of Table IV are plotted on triangular diagrams using the parameters total FeO–MgO–(Na_2O+K_2O) and CaO–Na_2O–K_2O, respectively, as chosen by Howie (1955) to illustrate the trends within the Madras charnockite series, they fall fairly close to the curves given by Howie (Text-figs. 2 and 3) or even closer to the curves (or their extensions) obtained for the Bunger Oasis rocks. It is interesting to note that the Bunger FMA curve forms a continuation of the more magnesian curve of Howie. Howie (1955) considered that the regularity of the plots of the Madras rocks suggested that they belong to a single series of plutonic igneous rocks and this argument can also be applied to the Bunger Oasis series. The very small number of points for the *Discovery* rocks, and their compositional range, precludes any such generalization in their case but there is no evidence to suggest that they represent, say, a random group of metamorphosed sediments ; moreover, Tilley (1940) regarded all the Scullin and most, if not all, of the Bertha Island rocks as igneous in origin. There is no doubt of the igneous origin of the basic and ultrabasic rocks but it is less easy to be certain of the origin of some of the leucocratic rocks.

In view of the absence of hypersthene in sixteen out of twenty of the Antarctic rocks, and in order to respect Holland's (1900) definition of the term, these rocks should not be named charnockites. Nevertheless, they are undoubtedly typical examples of rocks of the granulite facies of metamorphism, closely resembling rocks from, for example, Madras (Holland, 1900 ; Howie, 1955 ; Subramaniam, 1959) ; East Africa (e.g. Groves, 1935) ; Lapland (Eskola, 1952) ; and other parts of Antarctica (Tilley, 1937 ; Stinear, 1956, unpublished ; Crohn, 1959 ; McLeod, 1964 ; Klimov, Ravich & Soloviev, 1964 ; McCarthy & Trail, 1964). Retrogressive metamorphism is evident in the change from clinopyroxene to hornblende (and biotite) but the majority of the rocks were probably originally to be placed in the pyroxene (charnockitic) subfacies.

The (K/Ar) age of the basic granulite from Bertha Island (Table IV, analysis 3) has been determined by C. Rundle on the biotite and hornblende. The biotite gives an age of 485 ± 9 m.y., whilst the hornblende gives 872 ± 21 m.y. (average of two determinations). These compare with ages of 750–650 m.y. for the charnockitisation of the Bunger Oasis rocks (Ravich & Kuno, 1962, p. 67) and of 650–490 m.y. for the charnockites and their xenoliths of the Mawson area (Ravich & Krylov, 1964, p. 582). These ages suggest an intermittent major orogenic and metamorphic event, spread over an immense period of time. Most of the ages listed by


(total) FeO
Na2O+K2O
MgO
mol %
1
2
3
4
5
A
B
C


K2O
Na2O
CaO
mol %
1
2
3
4
5
A
B
C

Ravich and Krylov (1964) were determined on whole rocks, determinations on which almost invariably yield younger ages than those given by individual minerals (p. 579). Probably the older (hornblende) age on the Bertha Island granulite gives a fair estimate of the age of much of the original granulite facies metamorphism, whilst that of the biotite relates to the retrogressive phase some 400 m.y. later. The general ages of the later stages of metamorphism compare fairly closely with the last regional metamorphic ages of similar rocks from Madras – 500 m.y. (Aswathanarayana, 1964) and 550–600 m.y. (Sarkar *et al.*, 1964, p. 536) – and the East African region.

III. THE SCOTIA ARC

In 1932 *Discovery II* visited Mount Boucheron, Shoal Bay, in the Cockburn Channel, Tierra del Fuego (Text-fig. 1) ; a single specimen of quartz-mica schist was collected and is included in the British Museum collection.

In 1936 she called at Clarence Island, in the Elephant Island group, South Shetlands (Text-fig. 1), where a collection of nine rocks was made. On the same occasion, rocks were dredged off Cape Bowles (on the southern side of the island) ; 3 months later, early in 1937, further dredging took place to the south-east of the island. Prior to this, in 1928, Professor Holtedahl landed briefly on the island and made the first collection (see Holtedahl, 1929, and Barth & Holmsen, 1939), whilst limited collections were made from Elephant Island (by Mr G. V. Douglas in the *Quest*, 1922) and from Gibbs and Narrow Islands (by Mr J. W. Marr in the *Discovery II*, February (sic) 1937 ; these rocks are not in the British Museum collection). Recently, the Joint Services Expedition to Elephant Island, 1970–71, made a thorough collection from that island and limited collections from the remainder of the group (Roxburgh & Burkitt in Burley, 1971, pp. B1–2). This collection has been deposited with Dr R. J. Adie, of the British Antarctic Survey, at the University of Birmingham.

Rocks dredged from near Clarence Island were described by Tyrrell (1945) and are presumably those collected by *Discovery II* in 1937. This material, together with many other specimens collected by *Discovery II* in 1934 and 1937 from West Antarctica and the Scotia Arc, which are housed elsewhere, were submitted to Professor Tyrrell for description. He does not appear to have received the shore collection from Clarence Island made in 1936, reference to which is omitted from Roxburgh & Burkitt's (1971, p. B1) account of previous landings on the Elephant Island group. Rocks from Elephant Island collected by Douglas during the Shackleton–Rowett Expedition in the *Quest* were described by Tilley (1930) and a full bibliography of other early works on the geology of the Scotia Arc is given by Tyrrell (1945) or in papers listed therein.

FIGS. 2 and 3. Triangular diagrams (molecular percentages) for analysed granulites from Australian Antarctic Territory. 2 : (total) FeO–MgO–(Na_2O+K_2O). 3 : CaO–Na_2O–K_2O. Solid lines, curves for the Madras charnockite series from Howie (1955) ; dashed lines, curves plotted from analyses of the Bunger Oasis charnockites given by Ravich & Kuno (1961). Numbers (solid circles) and letters (open circles) refer to analyses of rocks from A.A.T. and Bunger Oasis given in Table IV.

The earliest collection from the South Orkney Islands was made in 1838 by members of d'Urville's expedition (d'Urville, 1842, pp. 70 and 316–17). The Scottish National Antarctic Expedition spent the winter of 1903–4 on Laurie Island (cf. Pirie, 1905 and 1913) ; and Signy Island was visited by Holtedahl in 1928 (Holtedahl, 1929 ; Barth & Holmsen, 1939).

Separate major collections of rocks from the South Orkney Islands were made by *Discovery II* in 1933 and 1937. The earlier collection only is described by Tilley (1935) ; possibly it was considered that no further comment was needed on the second collection (Wordie in Tyrrell, 1945, p. 40). Nine mainly metamorphic rock specimens from the South Orkney Islands, collected in 1915 by A. G. Bennett and similar to many collected by *Discovery II*, are in the rock collections of the British Museum (Natural History) (Campbell Smith & Game, 1954, p. 166).*

More recently, the geology of some of the South Orkney Islands has been systematically described by members of the British Antarctic Survey. The geology of Signy Island, on which is maintained a field station, is well known (Matthews & Maling, 1967 ; Thompson, 1968), and the petrography of the metamorphic rocks from the Inaccessible and Larsen Islands has been described by West (1968). Considerable further work is in progress.

i Clarence Island

The shore collection made from Clarence Island (Pl. 1, 1) in 1936 by Dr F. D. Ommanney consists of nine low-grade (greenschist facies) metasediments. They were collected from the scree slope on an exposed cliff rising sheer about 245 m above the landing place (detail from the Biological Log) ; the bedding was marked, dipping some 15° to the east. The phyllites are quartz-rich and more than half are graphitic : clearly they derive from impure carbonaceous sandstones (? greywackes).

Of the nine rocks, collected at various levels between 10 and 150 m above sea level, three were selected for sectioning as being typical of the group ; petrographic descriptions are given below.

BM 1972, O, 133 (2) *Quartz-muscovite-graphite schist* (Station 1874). A corrugated phyllitic rock, containing some epidote, and a little brown and green tourmaline and sphene. The rock is veined by quartz, running parallel to the schistosity. From about 30 m above sea level.

1972, O, 133 (4) *Quartz-mica-graphite schist* (Pl. 6, 1). A highly corrugated phyllite, in which muscovite, biotite and chlorite are present, with some epidote, sphene and iron ore, including hematite. From about 30 m above sea level.

1972, O, 133 (8) *Quartz-epidote-muscovite-chlorite schist*. A compact, slightly schistose, fine-grained rock, with micro-corrugations ; it is cut by a mosaic of fine quartz veins. The main minerals are accompanied by some potassium feldspar and a little sphene. From 1 to 150 m above sea level.

These rocks strongly resemble some of the metamorphic types described by Tyrrell (1945) from the dredged (1937) collection ; one such example is illustrated by him (p. 82, fig. 11).

* Sandstone from Powell Island [BM 1920, 139]; garnet-hornblende schist, garnetiferous schists, epidote-hornblende schist, and crystalline limestone, from the north end of Signy Island [BM 1920, 276; 1921, 700].

Two sets of dredged rocks and pebbles are in the British Museum, collected, as mentioned above, in 1936 and 1937. The earlier group (Station 1873) consists of several hundred pebbles, ranging from less than 2 to 20 cm in diameter, of metamorphic rocks : phyllites, chlorite schists, marbles and (metacalcareous) epidosites. Two were sectioned for closer examination.

The second batch from Station 1957 comprises two specimens of granite and many very small granitic and low-grade metamorphic pebbles. Many of these may be glacial erratics. One of the larger specimens, a granodiorite, was sectioned.

1972, O, 132 (1) *Epidosite* (Station 1873). A metamorphosed calcareous sandstone now comprising epidote and quartz, with lesser chlorite and some iron ore.
1972, O, 132 (2) *Epidosite.* A banded, somewhat schistose rock, in which layers of fine-grained epidote and quartz alternate with coarser layers of quartz with biotite, chlorite and calcite.
1972, O, 134 (1) *Granodiorite* (Station 1957). A typical oligoclase-quartz rock, with slight alteration resulting in sericitization of the feldspar. The ferromagnesian mineral is biotite, largely chloritized, and there is some epidote and sphene. The quartz shows local granulation resulting from shear stress.

The porphyries or microgranites and rhyolite described by Tyrrell (1945) are not present : nor are the unmetamorphosed greywackes or amphibole-bearing metamorphic rocks. The latter – quartz-epidote-amphibole schists – are apparently similar to those collected by Holtedahl in 1928 and described by him (1929) and by Barth & Holmsen (1939) ; they were considered by Tyrrell to be derived from basic igneous rocks or their tuffs. Two analyses of these greenschists are given by Barth & Holmsen and are reproduced here (Table V).

Table V

Analyses and CIPW Norms of Greenschists from Clarence Island

	A	B
SiO_2	57·66	47·37
TiO_2	0·85	1·20
Al_2O_3	16·30	16·46
Fe_2O_3	3·46	1·92
FeO	2·46	7·41
MnO	0·11	0·15
MgO	3·95	8·64
CaO	6·01	10·19
Na_2O	4·39	2·74
K_2O	2·68	0·06
H_2O^+	0·98	3·38
H_2O^-	0·10	0·10
P_2O_5	0·55	0·14
S	0·19	0·02
CO_2	0·12	0·21
Cl	0·02	nil
BaO	0·08	–
Less O≡S, Cl	0·10	0·01
Total	99·81	99·98

[*Continued overleaf*

TABLE V (*cont.*)

	Norms	
q	6·63	–
or	15·84	0·36
ab	37·14	23·18
an	16·86	32·44
di	6·73	12·84
hy	7·16	11·81
ol	–	10·01
mt	5·02	2·78
il	1·61	2·28
ap	1·30	0·33
ct	0·27	0·48

A Biotite-epidote-actinolite schist (no. 22) (not very schistose). (Analyst: E. Klüver.)
B Chlorite-actinolite-clinozoisite-albite schist (no. 23) (very schistose). (Analyst: E. Klüver.)
(From Barth and Holmsen, 1939, p. 60.)

Tyrrell summarizes the geology of the Elephant and Clarence Island group, together with that of the South Orkneys, as a typical geosynclinal greenstone-greywacke-mudstone association (1945, p. 88).

The age of the quartz-muscovite-graphite schist (1972, O, 133 (2)) has been determined (K/Ar) by C. Rundle at 28 ± 3 m.y. This is very young in comparison with, for example, the South Orkney Islands quartz-mica schists (ca. 187 m.y.), discussed on p. 360. Angino & Turner (1964) quote examples of Cenozoic (Tertiary) metamorphic and orogenic activity, ranging from 100 down to 6 m.y. (pp. 554–5). The most likely explanation for the Clarence Island age is that it represents a late Tertiary extension of the Andean orogeny (75–110 m.y.), which is known to have affected the Antarctic Peninsula.

ii South Orkney Islands

The South Orkney Islands (Text-fig. 4) were visited by the *Discovery II* in 1933 and 1937, and shore collections were made by Mr J. W. S. Marr. In 1933 the ship visited Inaccessible, Coronation, Signy, Powell and Michelsen, Fredriksen and Laurie Islands ; in 1937 Inaccessible, Powell and Michelsen, and Fredriksen Islands were not visited, but a few rocks were dredged from a station to the south of Coronation Island, and landing was made on Graptolite Island.

The earlier collection of rocks was described by Tilley (1935), so that the greatest interest lies in the hitherto undescribed 1937 collection. The rocks correspond well with the general geology of the South Orkney Islands (Tilley, 1935 ; Matthews & Maling, 1967 ; Thompson, 1968). This is shown in Table VI (and see p. 360) and Text-fig. 4 : a metasedimentary Basement Complex to the west, possibly rising in grade to the south and west, with a greywacke–shale series, surmounted unconformably by a younger conglomerate, to the east.

Correlation with Clarence Island and others in that group is not possible on present evidence, but similarities in the geology of the Elephant Island group and the South Orkneys have been noted by Tyrrell (1945), Matthews & Maling (1967), Thompson (1968), West (1968) and Harrington *et al.* (1972).

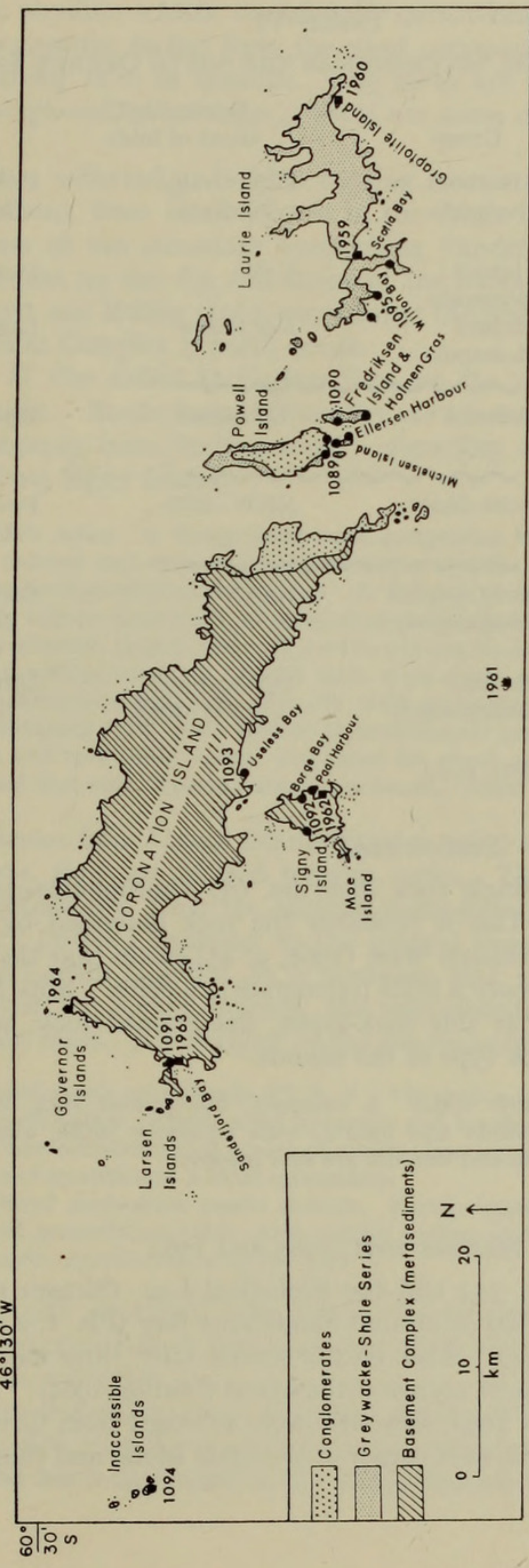


FIG. 4. Geological map of the South Orkney Islands, after Matthews & Maling (1967). Heavy numbers refer to Discovery Stations (Table I) visited in 1933 (solid circles; in some cases there were several collection points) and 1937 (solid squares).

TABLE VI

STRATIGRAPHICAL SUCCESSION IN THE SOUTH ORKNEY ISLANDS

Age	Group	Generalized trend of folds	Outcrop areas
	Spence Harbour Conglomerate	E-W (insignificant)	East end of Coronation Island
? Cretaceous	Powell Island Conglomerate	E-W	Powell Island
	Laurie Island Conglomerate	*Not known*	Laurie Island (?)
? Jurassic	Derived Series	*Not known*	Known only as boulders in conglomerate
? Carboniferous	Greywacke-Shale Series	NNW-SSE	Powell and Laurie Islands
? Precambrian	Basement Complex (metasediments)	N-S	Coronation and Signy Islands
Post-Basement Complex	Dolerites (not metamorphosed)	Dykes trend WNW-ESE	Intrude Basement Complex

(From Matthews & Maling, 1967, p. 2.)

(*a*) Inaccessible Islands : Station 1094

Several samples of a single rock (field no. 61) – hornblende-epidote schist – are in the 1933 collection. This is probably the rock described by Tilley (1935) as chlorite-epidote schist, although West (1968, p. 45) states that the commonest type contains hornblende and only a little (retrograde) chlorite. Note No. 256 (from the Biological Log) states that this dark-green, fine-grained rock, with some quartz veins, forms the main rock type of the islands.

1972, O, 135 *Hornblende-epidote schist.* A compact, fine-grained rock consisting of bluish-green hornblende, epidote, albite and quartz, with accessory rutile, altering to, and often mantled by, sphene. Apatite and iron ore are also present.

(*b*) Coronation Island : Stations 1091, 1963 and 1964

According to Note No. 253 and the Biological Log, thirteen single or multiple samples were collected from or around Sandefjord Bay (Pls. 1, 2 and 2, 1) in 1933, and a further three in 1937. Also, on the second visit, three more specimens were collected from the north-west corner of the island (Station 1964). Most of the specimens accorded to Station 1091, however, were collected from Governor [Guvernen] Island(s), also off the north-west corner of the main island and those of Station 1963 from Larsen Island.

Grey, graphitic phyllitic schists, occasionally garnet-bearing, and epidote-chlorite schists (of the greenschist facies) form the most common rocks, plentifully cut by quartz veins reaching 10 m in breadth. The rocks are quartz-rich and probably represent metamorphosed greywackes ; there are some marble bands interbedded with the schists.

Mica schists were collected at heights ranging from sea level up to about 30 m from Governor Island, from small islands in the strait north of Governor Island, and from the base of the mountain overlooking Sandefjord Bay, on Coronation Island. Observations on the dip and strike of the rocks are too variable to be of value but Matthews and Maling (1967) record that the generalized trend of the folds within the Basement Complex is north–south.

The *Discovery II* also called at Useless Bay, on the south coast of Coronation Island (Station 1093). Rocks from this locality are absent from the British Museum collection (as are many from Station 1092) ; according to Note No. 255 they are similar to those from Signy Island.

1972, O, 136 (8) *Biotite schist.* A fine-grained rock comprising quartz, biotite and graphite, with some epidote, chlorite and muscovite, and accessory apatite, allanite and iron ore.

1972, O, 136 (13) *Quartz-muscovite-chlorite schist.* A layered rock in which quartzitic layers alternate with bands rich in muscovite, chlorite, quartz and epidote. Perthite and potassium feldspar, and a little allanite, apatite and iron ore are present, as are occasional lenses of calcite.

1972, O, 138 (3) *Garnet-mica schist.* A layered rock, typical of a phyllitic schist derived from a mixed arenaceous sedimentary sequence. Quartz, with muscovite, brown biotite and chlorite, form the main constituents, with some epidote in boat-shaped grains. Locally, layers rich in calcite, with quartz and muscovite, occur, and there are small amounts of sphene, potassium feldspar, graphite and iron ore. Sparse garnets are found, 'rolled' in envelopes of chlorite.

The three specimens from Larsen Island (Station 1963) are notable in that, unlike most of the others, they are altered igneous rocks. They consist of a greenish altered quartz microdiorite 'from the outcrop immediately above that of the fine-grained green rock [altered andesite] in the general gneissose mass at the south-western corner of Larsen Island'. It is probable that they represent a volcanic interpolation within the metasediments, the microdiorite being a coarse-grained variant of the main mass. An analysis of the microdiorite is given in Table VII.

1972, O, 137 (1) *Altered quartz microdiorite* (Pl. 6, 2). The rock mainly consists of saussuritized plagioclase and greenish-yellow chlorite after pyroxene and hornblende, of each of which a few crystals remain. There are interstitial grains of quartz, iron ore, some yellow epidote, calcite, long acicular needles of apatite and a little myrmekite.

1972, O, 137 (2) *Altered porphyritic quartz andesite.* Mainly saussuritized plagioclase forming both phenocrysts and groundmass laths, with patchy yellow epidote and chlorite. Iron ore, calcite and a few quartz crystals make up the rock.

Tilley (1935, p. 386) described from Larsen Island grey phyllitic rocks, similar to those from Coronation Island, but examples of these also are not represented in the British Museum collection.

No igneous rocks resembling those described above are recorded from the Larsen Islands by West (1968), with the possible exception of the grey-green altered doleritic dyke rock from the north-east coast of the southernmost of the Larsen Islands.

(*c*) Signy Island : Stations 1092 and 1962

The *Discovery II* collected more rocks from this, the best known geologically, than from any other island (nineteen in 1933, two in 1937) ; in 1933, according to Note No. 254, they were recorded as crystalline limestone and, chiefly, gneissose rocks such as garnet-bearing dark-green mica schists. Tilley (1935) grouped the Signy Island rocks into marbles ; garnet-hornblende schists ; garnet-hornblende-biotite schist ; and garnet-mica schists.

Miller (1960) and Rex (1967, unpublished) have determined the ages (K/Ar, on biotite) of the (? latest) metamorphism affecting the quartz-mica schists of Coronation, Signy and Moe Islands. They obtained ages varying between 176 and 199 m.y. (Lower Jurassic to Upper Trassic), but Rex's mean age (183 m.y.) corroborates Miller's (187 m.y.).

Matthews & Maling (1967, p. 8) give a detailed succession for the south-west part of the island, of which the rock types are discussed in detail by Thompson (1968). The outline succession comprises :

Moe Island Series (quartz-mica schists)
Amphibolite Series (includes some garnetiferous types)
Marble Series (upper part : highly variable)
Marble Series (lower part)

Below are brief petrographic descriptions of representative rocks in the British Museum collection. With the exception of quartz-mica schists, which are similar to the garnet-mica schists, they include the most common types and suggest that a metamorphic grade approaching the amphibolite facies (the highest in the South Orkney group) is reached at this locality. The rocks of Borge Bay are notable for the size of their garnets (up to 2·5 cm in diameter) and were distinguished by Tilley (1935, p. 388) because of their richness in biotite. However, it would seem that this is not invariably the case and that Tilley's garnet-hornblende schists and garnet-hornblende-biotite schist are merely variants of the same rock type.

An analysis of the actinolite-chlorite-epidote schist, 1972, O, 139 (8), is given in Table VII. The rock is a typical greenschist, probably derived from a basaltic igneous rock, and similar to those from Clarence Island (Table V) and, to a lesser extent, the chlorite-hornblende schist amongst the rocks dredged off Dronning Maud Land (pp. 368, 373 and Table IX).

The chlorite from this rock has been examined by X-ray diffraction using part of the technique of Brindley & Gillery (1956). Accurate measurement of the $^{d}001$ spacing gives 14·160 Å, from which can be estimated the amount of Al^{IV} replacing Si in the structure. This determination was made in order to compare this chlorite with other chlorites from a chlorite-mica schist from Laurie Island, 1972, O, 144 (10), and with a chlorite in the chlorite-hornblende schist from off Dronning Maud Land (Table IX, analysis 3), mentioned above. The Laurie Island chlorite, with $^{d}001$ of 14·156 Å, is not significantly different, whilst that from off Dronning Maud Land, with $^{d}001$ of 14·204 Å, can be regarded as different in having less Al^{IV} in the structure. This mineral is seen in thin section to differ

Table VII

Analyses, some Trace Elements and CIPW Norms of Rocks from the South Orkney Islands

	1	2	Norms			3	A	4	B
SiO_2	55·18	47·47				64·68	64·7	78·52	76·84
TiO_2	1·52	2·03		1	2	0·74	0·5	0·46	–
Al_2O_3	15·09	16·79	q	8·48	6·54	15·89	14·8	10·43	11·76
Fe_2O_3	3·05	3·15	or	3·84	3·61	0·36	1·5	0·15	0·55
FeO	6·90	5·85	ab	37·47	9·14	3·94	3·9	2·88	2·88
MnO	0·17	0·18	an	19·32	39·17	0·07	0·1	0·05	tr
MgO	3·60	7·84	di	4·30	5·08	2·60	2·2	1·13	1·39
CaO	5·92	10·64	hy	14·81	22·23	1·36	3·1	1·16	0·70
Na_2O	4·43	1·08	mt	4·43	4·57	3·35	3·1	2·90	2·57
K_2O	0·65	0·61	il	2·89	3·86	3·06	1·9	1·55	1·62
H_2O^+	2·78	2·71	ap	0·57	0·54	2·24	2·4	1·41	1·87
H_2O^-	0·09	0·02	ct	1·23	2·07	0·10	0·7	0·01	–
P_2O_5	0·24	0·23				0·16	0·2	0·15	–
S	–	0·05				0·07	0·6	0·07	–
CO_2	0·54	0·91				0·76	1·3	0·34	–
Less O ≡ S	–	0·02				0·03	0·3	0·03	–
Total	100·16	99·54				99·35	100·7	101·18	100·18

Trace elements (p.p.m.)

	2	3	4
Cr	500	60	15
Ni	120	50	< 5
V	200	100	75
Zr	150	400	400
Y	25	50	20
Sr	750	430	200
Ba	200	650	400
Rb	9	55	14

1 Altered quartz microdiorite, Larsen Island, BM 1972, O, 137 (1). (Analyst : V. K. Din.)
2 Actinolite-chlorite-epidote schist, Borge Bay, Signy Island, BM 1972, O, 139 (8). (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)
3 Greywacke, Wilton Bay, Laurie Island, BM 1972, O, 144 (8). (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)
A Average of 23 greywackes (Pettijohn, 1957, Table 52, analysis A).
4 Greywacke-conglomerate, Scotia Bay, Laurie Island, BM 1972, O, 148 (2). (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)
B Subgreywacke from Tyler Slate (Precambrian) near Hurley, Wisconsin (Diller, 1898, p. 87). (Analyst: H. N. Stokes.)

from the other two and corresponds to a higher sub-facies within the greenschist metamorphic facies.

1972, O, 139 (1) *Banded Marble.* A typical mosaic-textured marble with indistinct banding. A few accessory minerals are present, notably muscovite, monticellite and sphene.

1972, O, 139 (4) *Garnet-hornblende gneiss.* A coarse-grained gneissose rock, mainly composed of large garnets and olive-green hornblende. Carlsbad-twinned orthoclase and yellow biotite are common, and there is some quartz, epidote, abundant well-shaped sphene, apatite and iron ore. The garnets are richly sieved with sphene and, to a lesser extent, epidote.

1972, O, 139 (8) *Actinolite-chlorite-epidote schist.* A greenschist with patchily developed layers of chlorite and blue-green actinolite, and finer-grained lenses of epidote, quartz and clouded feldspar. Some of the amphibole occurs in long, bent acicular crystals whilst the chlorite forms dense patches. Yellow-brown biotite is common and there is abundant well-shaped sphene. Locally, patches of calcite are developed and apatite is fairly common.

1972, O, 139 (9) *Garnet-hornblende schist.* This compact, dark grey rock is typical of those from Borge Bay. The large garnets (up to 1 cm across) are set in a matrix of olive-green hornblende crystals in which are also crystals of oligoclase. The garnet, and to a lesser extent the feldspar, is sieved with sphene and epidote. There is a little quartz, calcite, biotite and iron ore.

1972, O, 139 (15) *Garnet-mica schist* (Pl. 6, 3). From the landing opposite the old wreck, this rock type forms the main mass of much of the island. It comprises muscovite and quartz, with less red-brown biotite and chlorite. There are some crystals of feldspar (mainly sodic plagioclase), apatite, iron ore and sparse rotated, sometimes altered garnets. In addition to the garnets, an augen-like texture is produced in the rock by pods or clusters of quartzo-feldspathic material.

The garnet-free members of this group form the quartz-mica schists, which are also abundant on the island.

Quartz-mica schist is the common rock type from Paal Harbour (Station 1962), of which specimens were collected in 1937. Similar rocks were dredged in the same year from Station 1961, to the south of Coronation Island, together with quartzite and some metacalcareous rocks.

(*d*) Powell and Michelsen Islands : Station 1089

From the eastern end of Coronation Island eastwards, the Basement Complex of metasediments is unconformably overlain by a greywacke–shale series, which is in turn overlain unconformably by conglomerates (Text-fig. 4).

On Powell and Michelsen Islands (Pl. 3, 1) greywackes and conglomerates were the only rock types collected by *Discovery II*. The ship anchored in Ellefsen [Ellersen] Harbour, at the southern end of Powell Island, and six specimens were collected from the south-west corner of Powell Island, and five from Michelsen Island. The Biological Log notes that the smaller island is composed of low-lying rocks, rising at their highest to ca. 30 m. The rock, which throughout is a coarse conglomerate, rests at one point on a horizontal bed of greywacke, some 5 m above sea level. The dip of the conglomerate is south-west at an angle of 30°, the strike running NW–SE.

(*e*) Fredriksen Island : Station 1090

The ten specimens from Fredriksen Island show more variety than those from Station 1089. There are two conglomerates, five greywackes, one flaggy sandstone and two shales. The shales appear to be locally interbedded and are found infilling vertical cracks in the sandstone. Narrow ramifying quartz veins penetrate the rocks throughout.

Rocks were collected from two localities on the west coast, from points up to 180 m above sea level, and also from the small islet of Holmen Gras. The rocks dip generally southwards at angles ranging from 30° to 40° and even steeper.

(*f*) Laurie Island : Stations 1095 and 1959

Ten specimens were collected from Wilton [Whitton] Bay in 1933 and four from Scotia Bay in 1937. They consist of greywackes, quartzites, shales and less coarse conglomerates but with some slate and chlorite-mica schist. It thus seems that dynamic or very low-grade greenschist facies metamorphism affected the sediments at the eastern end of the South Orkney Islands.

Two small rocky islets in Wilton Bay were also visited in 1933. The rocks on one are of the usual grey type (greywacke), interbedded with a more or less vertical band of slate, over 1 m thick. The thin, ramifying quartz veins again cut through in all directions.

Descriptions of a greywacke and a conglomerate typical of those from the east end of the South Orkney group are given below, together with that of the chlorite-mica schist from Wilton Bay, Laurie Island. Analyses of the sediments are given in Table VII, and the type of chlorite in the schist is discussed on p. 360.

The composition of the greywacke (analysis 3) is close to that of an average greywacke (analysis A), except that it contains less CaO and more K_2O, whilst the greywacke-conglomerate (analysis 4) resembles a typical subgreywacke (analysis B).

1972, O, 144 (8) *Greywacke.* A typical rock of this type, with angular grains of quartz, altered feldspars, muscovite, chlorite and biotite, and a few grains of apatite and iron ore, in a matrix of fine-grained micas and clay minerals.

1972, O, 145 (2) *Greywacke-conglomerate* (Pl. 6, 4). A 'fine-grained' conglomerate, with well-rounded fragments reaching 5 mm in diameter, which consist of quartzite, rhyolite, basalt, variolitic basalt, andesite, silt- and fine-grained sandstone and greywacke. The latter is possibly of the type described above, and the matrix of the conglomerate is closely similar, with, in addition, abundant epidote crystals.

1972, O, 144 (10) *Chlorite-mica schist.* A very low-grade schist comprising lenses of quartz and potassium feldspar within layers of chlorite and muscovite, with a little biotite, epidote and iron ore. The presence of one or two tight folds in the fabric suggests that the metamorphism was dynamic rather than of low-grade regional type ; the original sediment was probably a greywacke.

(*g*) Graptolite Island : Station 1960

Four specimens were collected from Graptolite Island in 1937. Two are greywackes – the dominant rock mass – taken from 45 m above sea level. The greywackes are nearly vertical, the dip being southerly, with conglomerate (two specimens) resting unconformably on the top.

IV. BASALTIC AND OTHER ROCKS FROM BOUVET ISLAND AND VARIOUS DREDGE STATIONS

i Discovery Tablemount area

The basalt (BM 1954, 152) forming the Discovery Tablemount, which lies some 850 km east of Gough Island and the eastern flank of the Mid-Atlantic Ridge, was collected by *Discovery II* but had been registered previously by the British Museum (Natural History). It is described in detail elsewhere (Schilling & Kempe, in preparation) but is mentioned here since it forms part of the *Discovery II* collection and was dredged from the same station (2493) as other rocks described below (Text-fig. 1).

The small boulder of the basalt, weighing more than 5 kg, has a pale-grey alteration rind, approximately 1 cm thick, mantling dark-grey fresh basalt. The alteration is apparent from a comparison of the chemical compositions of the inner and outer parts but in thin section is barely discernible. Chemically, the rock appears to be tholeiitic, since it contains normative quartz and hypersthene, but there is strong evidence, discussed below, to show that it belongs to an alkali basalt series.

It is a *porphyritic basalt* (Table VIII, analysis B) with large glomerophyric phenocrysts of zoned labradorite ; some augite phenocrysts occur enmeshed subophitically within the plagioclase, and the rock has a slight flow texture. There are small olivine crystals and a very occasional large phenocryst, all completely altered to iddingsite. Most of the rock comprises small plagioclase laths and augite grains in a pilotaxitic groundmass of very small labradorite crystals, augite grains and rod-like iron ore. Some areas of the rock are finer-grained than the rest, with glassy patches, and there are almost totally digested patches of a black (? cognate) xenolithic glassy basalt, which are similar to the Balleny Group basalt described below.

Another rock from this station is a pebble (glacial erratic) of *diopside-hornblende schist.* The main constituents are olive-green hornblende and plagioclase (andesine-labradorite), with some pale diopside and brown biotite. The pyroxene occurs as cores, largely altered to hornblende, or as new growths; the biotite is patchily developed. The texture is schistose and granular, with some layering : hornblende only is found in some layers, whilst pyroxene is also present in others ; some iron ore also occurs. In origin it was probably a doleritic igneous rock, metamorphosed to the amphibolite facies, but could possibly be of sedimentary derivation (e.g. a marl), especially since one end of the specimen shows an interlayered leucocratic band.

Ten other erratic pebbles were dredged from the station consisting of conglomerate and lithified clays and marls (argillites).

ii Bouvet Island (Bouvetøya)

The earliest knowledge of rocks from Bouvet Island, the southernmost volcanic island of the Mid-Atlantic Ridge (Text-fig. 1), derived from specimens dredged some 5 km east of the island by the *Valdivia* expedition and described by Reinisch (1907). Between 1927 and 1929 the *Norvegia* expeditions made the first shore collections ; the geology of the island was described by Holtedahl (1929) and a detailed account of the petrology was given by Broch (1946).

Eighteen pebbles were dredged to the west of Bouvet Island (Pl. 3, 2) in 1938 and consist of basalts and related volcanic material, some of it deeply weathered. The following year a landing was made on Bouvet Island and a dozen rocks and a sample of beach sand collected.

Following reports of the appearance of a new volcanic platform on the island, Baker & Tomblin (1964) described a visit to the island and concluded that renewed volcanic activity must have taken place between 1955 and 1958, during which lava of a trachyandesitic nature was extruded.

Broch (1946) described rocks from Lars Island, a low islet off the south-western corner of Bouvet, from the sea elephant beach of the main island (opposite Lars

TABLE VIII

ANALYSES, SOME TRACE ELEMENTS AND CIPW NORMS OF LAVAS FROM BOUVET ISLAND

	1	2	A	B	C
SiO_2	49·30	49·89	49·68	50·31	70·47
TiO_2	3·25	3·38	2·28	2·69	0·29
Al_2O_3	14·20	14·63	18·38	15·48	12·28
Fe_2O_3	7·97	4·46	2·70	3·67	2·96
FeO	5·07	7·33	6·69	6·29	1·99
MnO	0·18	0·19	0·14	0·16	0·06
MgO	4·00	4·89	3·97	4·87	0·18
CaO	8·60	8·65	10·62	9·06	0·44
Na_2O	3·38	3·43	3·09	3·03	4·91
K_2O	1·31	1·08	0·86	1·40	4·85
H_2O^+	1·24	0·90	0·32	1·05	0·50
H_2O^-	1·02	0·47	0·52	1·06	0·42
P_2O_5	0·59	0·55	0·35	0·42	0·05
S	0·07	0·04	0·02	0·03	0·01
Cl	–	–	0·10	–	0·07
CO_2	0·53	0·27	0·06	0·23	0·11
Less O≡S, Cl	0·03	0·02	0·04	0·01	0·02
Total	100·68	100·14	99·74	99·74	99·57
		Trace elements (p.p.m.)			
Ni	20	10	–	100	–
V	400	550	–	400	–
Zr	250	200	–	250	1800
Y	20	25	–	50	–
Sr	520	570	–	> 1000	–
Ba	300	200	1200	600	300
Rb	nil	nil	–	22	–
		Norms			
q	6·75	3·71	1·42	3·98	23·06
or	7·74	6·38	5·08	8·28	28·67
ab	28·60	29·02	26·14	25·64	36·17
an	19·71	21·34	33·75	24·51	–
ac	–	–	–	–	4·74
di	12·26	13·08	13·29	13·04	1·01
hy	4·28	10·44	9·94	10·24	2·12
mt	7·51	6·47	3·91	5·32	1·92
hm	2·79	–	–	–	–
il	6·17	6·42	4·33	5·11	0·55
ap	1·39	1·30	0·88	0·99	0·12
ct	1·21	0·61	0·14	0·52	0·25

1 Porphyritic basalt, near Bouvet Island (Station 2467), BM 1972, O, 148 (2). (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)

2 Porphyritic vesicular basalt, landing place, Bouvet Island, BM 1972, O, 149 (1). (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)

A Basalt, sea elephant beach, Bouvet Island (Broch, 1946, p. 24, rock no. 10). (Analyst: E. Klüver.)

B Porphyritic basalt, Discovery Tablemount (Schilling & Kempe, in preparation). (Analysts: C. J. Eliott, V. K. Din and A. J. Easton.)

C Alkali rhyolite, Lars Island, near Bouvet Island (Broch, 1946, p. 24, rock no. 4). (Analyst: E. Klüver.)

Island and almost certainly the landing place for the *Discovery II* collection), from dredging south-west of the island, and from Cape Norvegia and the surrounding area, on the western side of the island. He divided the rocks into four groups: basalts, rhyolites, obsidian, and pumice and scoria.

Three of the dredged basalts have been sectioned, as have four of the basalts collected from or near the landing place (? sea elephant beach) on the island. The remaining rocks also are either basalts or scoria. Some of the rocks closely resemble those described by Broch (1946), but since his material derives from a wider area, exact correlation is not attempted. No rhyolite, obsidian or true pumice is present in the *Discovery II* collection. It is notable that the texture of all the basalts is equigranular or possibly sub-trachytic, but none of them exhibits any sign of a poikilitic or ophitic texture.

Brief descriptions of the sectioned rocks are given below.

1972, O, 148 (1) *Porphyritic basalt.* This dredged grey rock is characterized by many large (ca. 8 mm) zoned labradorite phenocrysts. They are not glomerophyric, as is the Discovery Tablemount basalt (see p. 364), which this rock, although slightly coarser-grained, resembles. There are also a few small augite phenocrysts, contained mostly within the feldspars. Small, completely altered olivine crystals and laths of plagioclase are scattered throughout the granular groundmass, which comprises plagioclase crystals, skeletal iron ore crystals, and augite and hematite grains. Glass is absent. This rock resembles Broch's (1946) specimen no. 10, from the sea elephant beach (Table VIII, analysis A).

1972, O, 148 (2) A second dredged *porphyritic basalt,* also dark-grey, has far fewer and smaller reverse-zoned labradorite phenocrysts and none of pyroxene. There are traces of altered olivine, laths of plagioclase and granular augite in an aphanitic groundmass of pyroxene, equigranular ore and yellowish alteration material. The texture is sub-trachytic in its arrangement of the feldspar laths. An analysis of this rock is given in Table VIII (analysis 1) and discussed on page 371.

1972, O, 148 (3) A dredged, grey, *aphyric vesicular basalt.* Lacking phenocrysts, this rock has small laths of plagioclase in an aphanitic groundmass of augite grains, granular iron ore and yellow alteration products. Its many round vesicles (ca. 1 mm) are filled with pinkish rhodochrosite ($MnCO_3$), characteristically structured with 'layering' and chevron markings picked out in iron staining; the manganese presumably derives from solution in the sea water. This rock resembles Broch's specimen no. 2 from Lars Island.

1972, O, 148 (4) A dredged, grey-black, fine-grained *basalt,* aphyric, highly aphanitic and flow-banded. It consists of tiny feldspar laths, pyroxene grains and abundant iron ore, with some calcite and yellow alteration material.

1972, O, 149 (1) This grey-black *porphyritic vesicular basalt* (Table VIII, analysis 2) was collected from the cliff behind the landing place on Bouvet Island, some 10 m above sea level, and was considered to be the typical country rock of the island. The thin section is black and aphanitic to the point of glassiness, and shows flow texture. It contains a few zoned labradorite phenocrysts and pyroxene microphenocrysts, together with small plagioclase laths and augite grains, in the black groundmass, which contains many round vesicles, unfilled by secondary minerals. There is no trace of fresh or altered olivine.

1972, O, 149 (2) A fragment of a red-weathering *porphyritic olivine basalt* from an isolated boulder on the landing place. There are fairly sparse phenocrysts of labradorite and some small crystals of olivine. The latter are sometimes fresh but often have an iddingsitized rim. Some are notable for their long, acicular habit. Together with laths of plagioclase and grains of augite, they are embedded in an aphanitic, partly glassy, iron-rich matrix.

1972, O, 149 (4) A grey *porphyritic basalt* resembling the dredged sample (148 (2)), described above. The section shows two or three small labradorite phenocrysts, with many tiny plagioclase laths, in a groundmass of even smaller feldspar, pyroxene and iron ore grains. There is a

Table IX

Analyses, some Trace Elements and CIPW Norms of Basic Rocks Dredged off Dronning Maud Land

	1	A	2	B	3
SiO_2	49·79	46·57	48·21	51·92	49·08
TiO_2	1·93	1·85	2·27	0·96	1·23
Al_2O_3	8·74	8·20	13·35	12·87	18·43
Fe_2O_3	1·33	1·20	4·43	2·89	1·90
FeO	11·11	9·75	8·29	9·42	8·51
MnO	0·19	0·14	0·21	0·21	0·22
MgO	15·94	19·65	7·35	6·93	5·54
CaO	7·80	9·43	10·56	10·68	7·28
Na_2O	1·29	1·56	2·49	1·50	3·43
K_2O	0·64	1·18	0·16	0·84	1·20
H_2O^+	1·34	0·11	1·30	1·81	2·56
H_2O^-	0·12	0·12	0·41	0·06	0·02
P_2O_5	0·20	0·26	0·26	0·09	0·35
S	0·02	–	0·22	–	0·14
CO_2	0·18	–	0·88	–	0·90
Less O≡S	0·01	–	0·11	–	0·07
Total	100·61	100·02	100·28	100·18	100·72
		Trace elements (p.p.m.)			
Cr	1800	1250	–		25
Ni	450	465	70		25
V	300	100	350		300
Zr	200	100	150		120
Y	25	10	40		50
Sr	260	450	280		370
Ba	300	340	200		700
Rb	nil	30	nil		18
		Norms			
q	–	–	3·32	6·49	–
c	–	–	–	–	1·18
or	3·78	7·23	0·95	4·97	7·09
ab	10·92	11·00	21·07	12·69	29·02
an	16·17	11·68	24·78	25·91	28·14
ne	–	1·14	–	–	–
di	16·18	26·84	16·43	21·75	–
hy	38·51	–	18·58	20·28	20·42
ol	7·12	36·11	–	–	4·27
mt	1·93	1·86	6·42	4·19	2·78
il	3·67	3·50	4·31	1·82	2·34
ap	0·47	0·67	0·61	0·21	0·83
ct	0·41	–	2·00	–	2·05

1 Coarse porphyritic olivine-enstatite (picritic) basalt, off Dronning Maud Land (Station 2605), BM 1972, O, 150 (6). (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)

A Picrite basalt, mouth of Deep Glen, Gough Island, G 121 (Le Maitre, 1962, Table 10).

2 Ophitic dolerite or coarse basalt, off Dronning Maud Land (Station 2605), BM 1972, O, 150, (3). (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)

B Dolerite, western Dronning Maud Land, 71°15′ S, 3°00′ W (von Brunn, 1964, Table 1, analysis 3).

3 Chlorite-hornblende schist, off Dronning Maud Land (Station 2605), BM 1972, O, 150 (9). (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)

trace of calcite and yellow alteration material. The rock is not dissimilar from those considered by Broch (1946) as typical of the island – no. 1, from Lars Island, and no. 9, from sea elephant beach – except for the apparent absence of olivine.

1972, O, 149 (5) *Porphyritic olivine basalt.* A very pale-grey rock containing sparse, slightly zoned phenocrysts of labradorite, fresh olivine and pyroxene. The crystals of pyroxene are small and, with small olivines, lie in a matrix of pyroxene and sub-trachytically arranged plagioclase laths. The pyroxene is patchily hematized and there is abundant skeletal iron ore.

iii Off Dronning Maud Land

A collection of nine basic, and fourteen acidic and metamorphic, rocks was dredged off Dronning Maud Land (Station 2605), some 600 km south of the Maud Seamount, early in 1939 (Text-fig. 1); they must include glacial erratics.

The basic rocks are coarse basalts or dolerites and, in contrast to the basalts previously described, they are all highly ophitic or poikilitic. The six basic samples sectioned fall into three groups.

Ophitic dolerite or coarse basalt (Table IX, analysis 2). This type consists largely of prisms of titaniferous augite ophitically penetrating labradorite laths. The remainder of the rock is made up of abundant skeletal iron ore and traces of brown hornblende, and chlorite and/or brown biotite. In at least two of the sections, the biotite appears on morphological grounds to be pseudomorphing olivine.

Coarse ophitic porphyritic basalt (Pl. 7, 1). In this group, a similar mineralogy to that above is accompanied in one sample by abundant phenocrysts of zoned labradorite and augite. In the other, the phenocrysts present are of plagioclase only. Here also, biotite appears to be pseudomorphing olivine.

Coarse porphyritic olivine-enstatite (picritic) basalt (Table IX, analysis 1; Pl. 7, 2). In the one sectioned specimen of this type, the texture is sub-ophitic and a different mineralogy is found. Early formed orthopyroxene (2V $\sim$ 90°) and, to a lesser degree, clinopyroxene are ophitic towards altered olivine, which has been totally altered to talc and skeletal and dusty iron ore. Labradorite, showing slight zoning; small crystals of clinopyroxene and iron ore, filling in the gaps between the ferromagnesian minerals; and a little green chlorite, are the other constituents of the rock.

The acidic and metamorphic group (? erratics) consists of adamellitic and gneissose adamellitic rocks, quartzites, and a single chlorite-hornblende schist. Examples of these are described below.

1972, O, 150 (8) *Garnet-apatite gneissose adamellite.* This rock has alternate coarse and fine layering, giving it a gneissose appearance, but is undoubtedly of igneous origin. It comprises mainly sericitized sodic plagioclase, quartz and microcline, with a few per cent of muscovite and a brown biotite, largely altered to chlorite. Accessory iron ore and zircon are present and there are a few small garnets. The rock is notable for its high content of apatite, both as aggregated patches or segregations and as large individual crystals. A similar occurrence of apatite was observed in a garnet gneiss from Scullin Monolith (p. 348).

A similar mineralogy is found in the non-gneissose adamellite, 1972, O, 150 (7), which is moderately fine-grained: microcline, albite and quartz, accompanied by partly chloritized brown biotite. There is also a little muscovite, iron ore, apatite, altered allanite and zircon.

It may be mentioned that small pebbles of aegirine granite were dredged from approximately 67°48′ S, 16°01′ E and 69°18′ S, 17°09′ E in 1922, by the *Quest* (Douglas, 1930, p. 152).

1972, O, 150 (9) *Chlorite-hornblende schist* (Table IX, analysis 3; Pl. 7, 3). This high greenschist facies ? metabasalt, resembling, although less basic, the diopside-hornblende schist from the Discovery Tablemount area (p. 364), is comprised essentially of three minerals. Slightly altered andesine, olive-green hornblende and green chlorite are disposed in a compact granular texture, the chlorite aligned parallel to the schistosity. Small amounts of quartz, with a little sphene, epidote, apatite and iron ore, are also present. The type of chlorite in this rock is discussed on p. 360), where it is compared with that from a lower grade greenschist.

iv Balleny Islands

A single large boulder of ***porphyritic olivine basalt*** (Table X, analysis 1 ; Pl. 7, 4), weighing 37 kg, was dredged in 1938 from the area between Young and Sturge Islands, in the Balleny Group (Text-fig. 1 and Pl. 4).* The Biological Log, reporting a previous passing visit (3 February 1936) when no rocks were collected, gives the following description of the Balleny Islands. 'None of them possesses a single peak but they have ice-mantled plateau-like summits, rising to some 750 m. The cliffs are often sheer at one end, with considerable exposures of rock, whilst the other end forms a gentle plateau slope dropping to 100 m or so above sea level.'

The fine-grained glassy basalt contains numerous small phenocrysts of fresh olivine, and a few of plagioclase. These, together with aggregates of augite grains, are set in a dark slightly flow-textured pilotaxitic groundmass of magnetite octahedra, augite and dark glass.

Pebbles of dolerite and 'black slaty rock' dredged near the Balleny Islands are amongst the first *Discovery* collections of 1901–4 (see p. 345).

v Bay of Whales

Two large boulders of ***greywacke***, weighing 40 and 21 kg, were dredged from the Bay of Whales, on the edge of the Ross Ice Shelf, in 1936 (Text-fig. 1).

Both are poorly sorted, consisting of angular quartz grains, accompanied by flakes of calcite and muscovite, in a heterogeneous, relatively fine-grained groundmass which consists of quartz, chlorite, sericite, calcite, biotite, epidote and hematite, with lesser amounts of tourmaline, apatite and iron ore. There is little feldspar in either rock. One specimen contains chlorite pseudomorphs after ?hornblende and the groundmass is patchily developed : a single fragment of garnet-hornblende-quartz schist is present and the rock has a slight schistosity. The second specimen has hardly any orientation although the groundmass shows the same patchy development of, for example, green biotite and epidote.

Geological investigations on land across the Shelf show the presence of formations which include greywacke, from which the present examples might derive by glacial action (cf. Grindley, McGregor & Walcott, 1964 ; Laird, 1964).

vi Miscellaneous

The *Discovery II* collection includes a few rocks for which, unfortunately, no localities are given. Noteworthy amongst these is a porphyritic olivine basalt, a

* A trachybasalt from Buckle Island, in the Balleny Group, is included in the rock collections of the British Museum (Natural History) [BM 1967, P 10].

Table X

Analysis, some Trace Elements and CIPW Norm of a Basalt dredged off the Balleny Islands

	1	A
SiO_2	44·99	47·7
TiO_2	2·70	3·2
Al_2O_3	15·51	15·2
Fe_2O_3	3·43	2·3
FeO	7·27	8·7
MnO	0·19	–
MgO	9·29	9·7
CaO	9·63	8·9
Na_2O	4·32	2·7
K_2O	1·13	1·6
H_2O^+	0·32	–
H_2O^-	0·01	–
P_2O_5	0·70	–
S	0·05	–
CO_2	0·13	–
Less O≡S	0·02	–
Total	99·65	100·0
	Trace elements (p.p.m.)	
Cr	200	245
Ni	200	210
V	300	160
Zr	350	123
Y	50	16
Sr	800	725
Ba	450	850
Rb	14	65
	Norms	
or	6·68	9·5
ab	17·58	22·1
an	19·60	24·6
ne	10·28	0·4
di	18·19	15·7
ol	14·95	18·3
mt	4·97	3·3
il	5·13	6·1
ap	1·65	–
ct	0·30	–

1 Porphyritic olivine basalt, off Balleny Islands (Station 2200), BM 1972, O, 151. (Analysts: C. J. Elliott, V. K. Din and A. J. Easton.)

A Average porphyritic olivine basalt, Gough Island (Le Maitre, 1962, Table 13, area 5). (Recalculated on an MnO-, H_2O- and P_2O_5-free basis to 100%.)

very dark granular variety in which small phenocrysts of fresh olivine occur in a groundmass of plagioclase laths, grains of augite and iron ore.

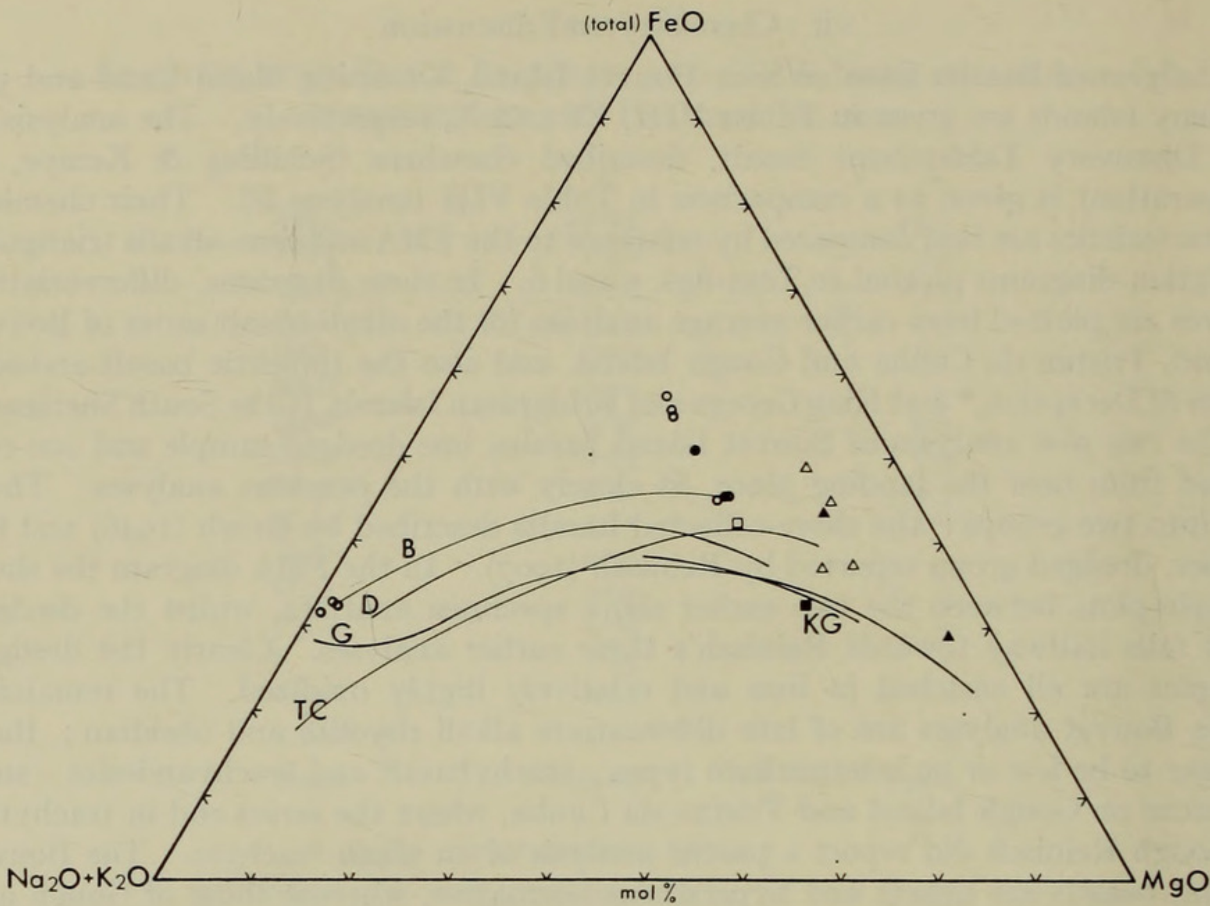
vii Chemistry and discussion

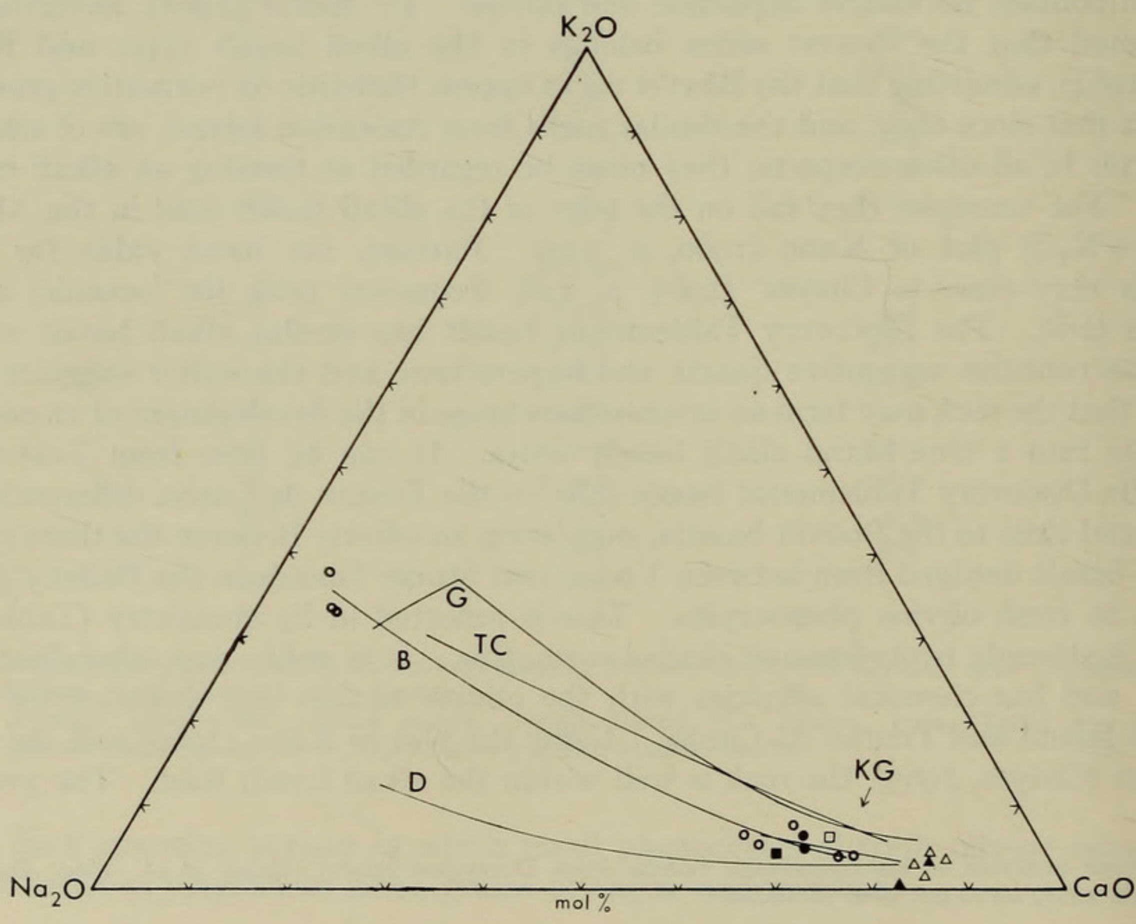
Analyses of basalts from or near Bouvet Island, Dronning Maud Land and the Balleny Islands are given in Tables VIII, IX and X, respectively. The analysis of the Discovery Tablemount basalt, described elsewhere (Schilling & Kempe, in preparation) is given as a comparison in Table VIII (analysis B). Their chemical characteristics are best compared by reference to the FMA and lime-alkalis triangular variation diagrams plotted in Text-figs. 5 and 6. In these diagrams, differentiation curves are plotted from earlier average analyses for the alkali basalt series of Bouvet Island, Tristan da Cunha and Gough Island, and also the tholeiitic basalt-andesite series of Deception,* and King George and Bridgeman Islands, in the South Shetlands.

The two new analyses of Bouvet Island basalts, one dredged sample and one collected from near the landing place, fit closely with the previous analyses. These fall into two groups : the shore-collected basalts described by Broch (1946) and the earlier, dredged group reported by Reinisch (1907). In the FMA diagram the shore sample plots between the two earlier shore specimen analyses, whilst the dredged rock falls halfway towards Reinisch's three earlier analyses. Clearly the dredged samples are all enriched in iron and relatively highly oxidized. The remaining three Bouvet analyses are of late differentiate alkali rhyolite and obsidian ; there appear to be few or no intermediate types – trachybasalt and trachyandesite – such as occur on Gough Island and Tristan da Cunha, where the series end in trachytes, although Reinisch did report a partial analysis of an alkali trachyte. The Bouvet Island basalts are quartz and hypersthene normative, whereas those of Gough and Tristan contain normative nepheline and olivine. Le Maitre (1962), nevertheless, considered that the Bouvet series belongs to the alkali basalt type, and Baker *et al.* (1964), admitting that the Bouvet rocks appear tholeiitic on normative grounds, suggest that since they, and the similar rocks from Ascension Island, are of alkaline character in all other respects, they must be regarded as forming an alkali basalt series. For example, they fall on the edge of the alkali basalt field in the Al_2O_3–(Na_2O+K_2O) plot of Kuno (1960, p. 127). Further, the mean value for TiO_2 (3·0) is very close to Chayes' (1965, p. 128) frequency peak for (oceanic) alkali basalts (2·8). The Discovery Tablemount basalt has similar alkali basalt values but also contains normative quartz and hypersthene and the writer suggests elsewhere that the rock may form an intermediate stage in the development of an oceanic tholeiite into a true island alkali basalt series. It can be seen from Text-fig. 5 that the Discovery Tablemount basalt falls on the Tristan de Cunha differentiation curve and close to the Bouvet basalts, suggesting an affinity between the three types.

The basalt dredged from between Young and Sturge Islands in the Balleny group is rich in fresh olivine phenocrysts. This is reflected in its chemistry (Table X), which is strongly nepheline and olivine normative. It is unlike any other *Discovery* basalt and has chemical affinities with the olivine basalts and ankaramites from Gough Island and Tristan da Cunha. Using the plot of Kuno (1960) and the TiO_2 content (Chayes, 1965), the rock is well within the alkali basalt field. The average

* Recent analyses of trachyandesite bombs from Deception Island (Baker *et al.*, 1969; Baker & McReath, 1971) have not been included.


(total) FeO
Na2O+K2O
MgO
mol %
B
D
G
TC
KG


K2O
Na2O
CaO
mol %
G
TC
B
D
KG

olivine basalt from Gough Island, near to which the Balleny rock plots in Text-fig. 5, is given as a comparison (Table X, analysis A).

The olivine-enstatite (picritic) basalt dredged from off Dronning Maud Land is olivine normative (Table IX, analysis 1) and resembles the picrite basalt from Gough Island (analysis A). The two analyses are notable for the closely similar content of most of their trace elements. The *Discovery* rock plots in Text-fig. 5 between the Gough picrite and olivine basalts, but in Text-fig. 6 it lies, oddly, within the cluster of western Dronning Maud Land rocks referred to below.

The tholeiitic ophitic dolerite or coarse basalt dredged from the same station (Table IX, analysis 2) plots in Text-fig. 5 within or (6) close to a group of three tholeiitic ophitic dolerites, and one basalt vein within them, from western Dronning Maud Land, described by von Brunn (1964) ; the nearest comparable analysis is given as analysis B, although the dredged rock is notably poorer in K_2O. The land rocks form isolated groups of massifs or nunataks 10 to 30 km apart, rising 200 m above the surrounding snow surface, and are characterized by vertical columnar jointing. Von Brunn described the rocks as typical tholeiitic dolerites and the derivation of the dredged rocks from such a group, some 300 km to the south-west, is a strong possibility. Application of the chemical criteria of Kuno (1960) and Chayes (1965) leaves little doubt that the dolerites described by von Brunn, and the dredged samples, are of the circumoceanic tholeiitic type.

Finally, the chlorite-hornblende schist (Table IX, analysis 3), although of different chemical and normative composition, would plot in Text-figs. 5 and 6 close to the Bouvet Island basalts, whilst the greenschist from Signy Island, South Orkneys (Table VII, analysis 2, and p. 360), apparently derived from a basic igneous rock, is low in iron and consequently would plot as a magnesian tholeiite.

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FIGS. 5 and 6. Triangular diagrams (molecular percentages) for analysed basaltic rocks. 5 : (total) FeO–MgO–($Na_2O + K_2O$). 6: CaO–Na_2O–K_2O. Open square, Discovery Tablemount basalt (Table VIII, analysis B). Solid circles, Bouvet Island basalts (Table VIII, analyses 1 and 2) and open circles, Bouvet Island basalts and rhyolites (Reinisch, 1907 ; Broch, 1946, p. 24). Solid triangles, basalts dredged off Dronning Maud Land (Table IX) and open triangles, dolerites and basalt from western Dronning Maud Land (von Brunn, 1964). Solid square, basalt dredged off the Balleny Islands (Table X).

Curves are basalt series differentiation trends for Bouvet Island, B, and for other Atlantic islands from averages of analyses : TC, Tristan da Cunha (Baker *et al.*, 1964, p. 531) ; G, Gough Island (Le Maitre, 1962, p. 1328) ; D, Deception Island and K.G., King George Island and Bridgeman Island, South Shetlands, both compiled by Tyrrell (1945, pp. 58–59).

Antarctic localities and for the loan of some of the Biological Logs, from the *Discovery* Collection. The *Discovery* photographs are copyright of the National Institute of Oceanography.

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PLATE I

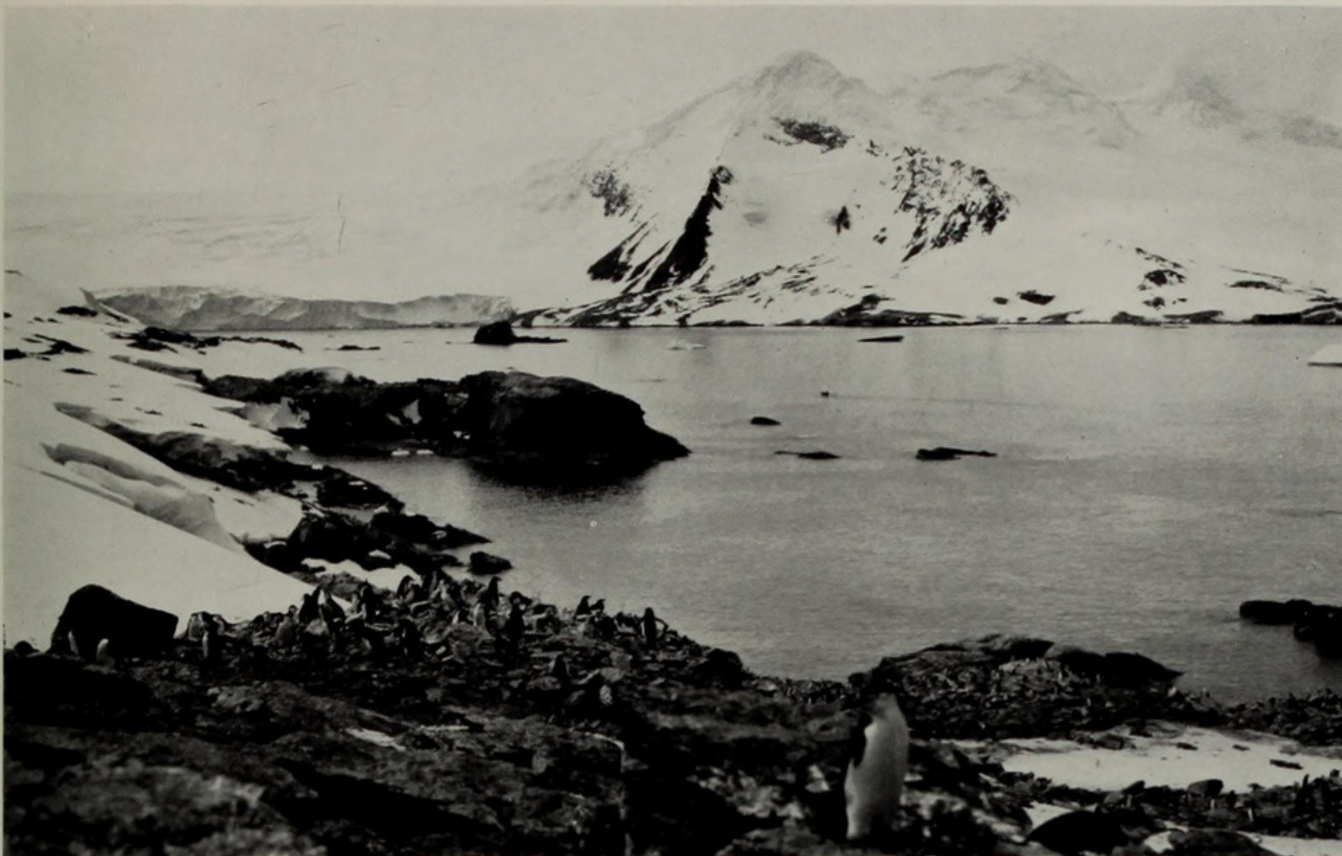
FIG. 1. Clarence Island Peak.

FIG. 2. RRS *Discovery II* at Sandefjord Bay, Coronation Island, South Orkneys, 1937.

PLATE 2

FIG. 1. Sandefjord Bay, Coronation Island.

FIG. 2. North coast, Coronation Island.



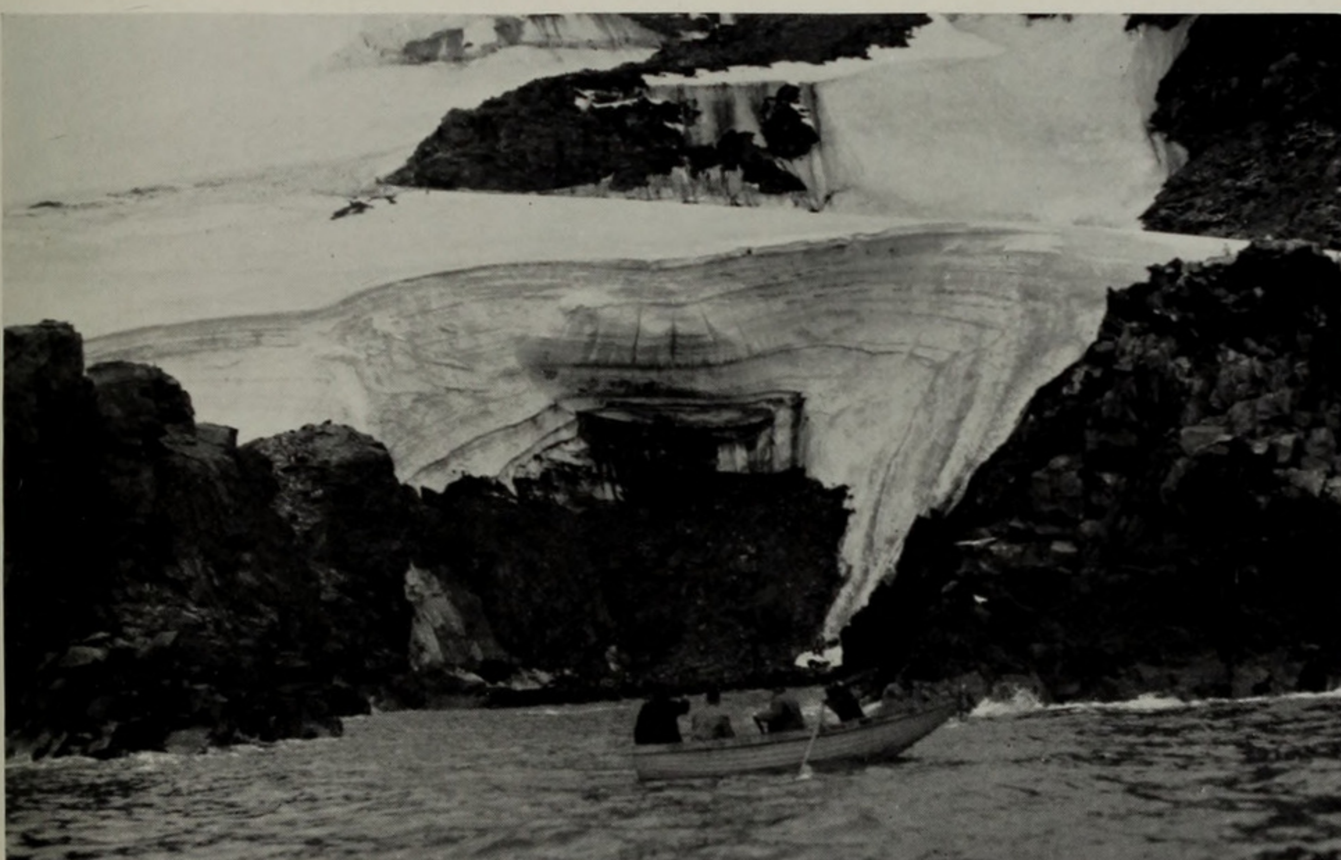


PLATE 3

FIG. 1. Archway formed by boulders of conglomerate, Powell Island, 1933.

FIG. 2. Basalt, Bouvet Island.

PLATE 4

FIG. 1. The Monolith, Balleny Islands.

FIG. 2. Young Island, Balleny Islands.

PLATE 5

FIG. 1. Photomicrograph of leucocratic granulite, Bertha Island, Sheehan Nunatak (BM 1972, O, 129 (1)). Perthite, quartz and (diagonally from lower right) biotite and garnet. Upper left centre, apatite.

Plane polarized light, × 28.

FIG. 2. Basic (diopside) granulite, Bertha Island, Sheehan Nunatak (BM 1972, O, 129 (2)). Clinopyroxene, sometimes symplectically intergrown with plagioclase, (darker) hornblende and (paler) biotite.

Plane polarized light, × 28.

FIG. 3. Basic (pyroxene) granulite, Bertha Island, Sheehan Nunatak (BM 1972, O, 129 (5)). Clinopyroxene, hypersthene and (darker) hornblende.

Plane polarized light, × 15.

FIG. 4. Leucocratic garnet granulite, Scullin Monolith (BM 1972, O, 130 (3)). Garnet, perthite, quartz and a little biotite.

Plane polarized light, × 14.

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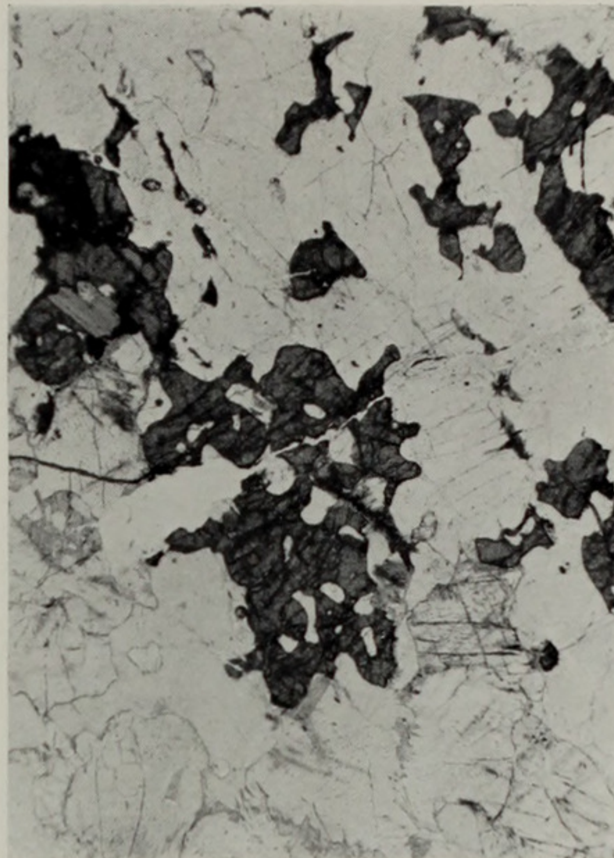

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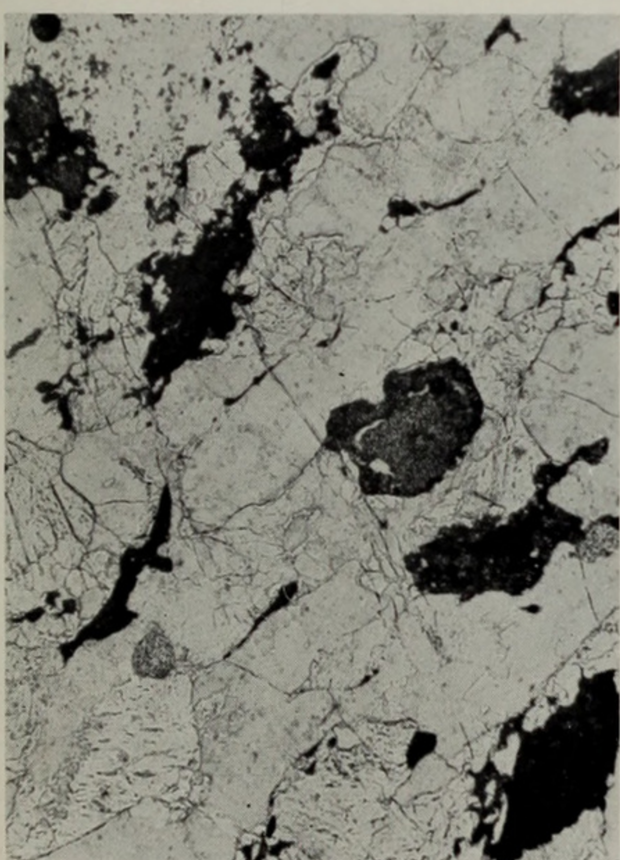

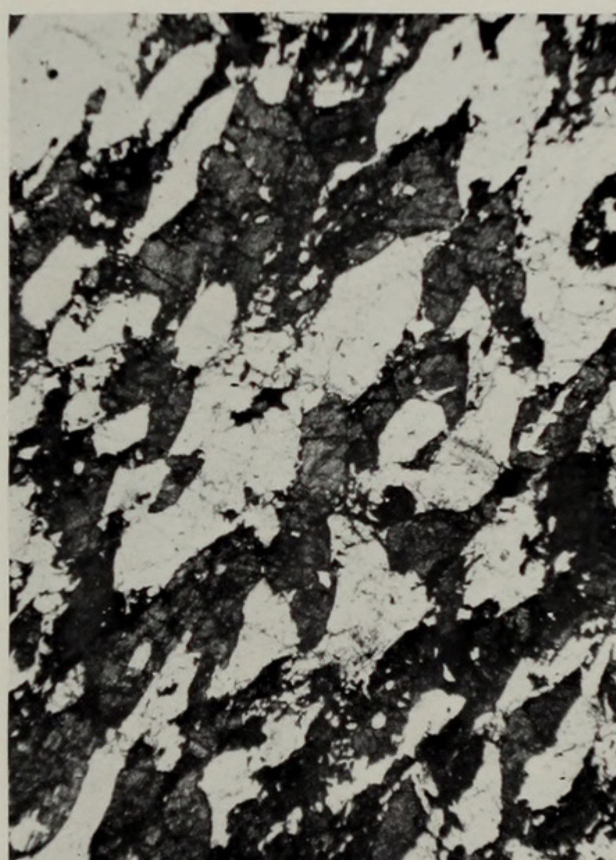

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PLATE 6

Fig. 1. Quartz-mica-graphite schist, Clarence Island (BM 1972, O, 133 (4)).

Plane polarized light, × 13.

Fig. 2. Altered quartz microdiorite, Larsen Island, off Coronation Island (BM 1972, O, 137 (1)).

Plane polarized light, × 16.

Fig. 3. Garnet-mica schist, Borge Bay, Signy Island (BM 1972, O, 139 (15)). Garnet (lower left) with muscovite, and lesser biotite, chlorite and apatite.

Plane polarized light, × 14.

Fig. 4. Greywacke-conglomerate, Scotia Bay, Laurie Island (BM 1972, O, 145 (2)). Pebbles of quartz (top), greywacke (upper left), chert (bottom), basalt (right), and rhyolite (centre), in an epidote-rich matrix.

Plane polarized light, × 12.

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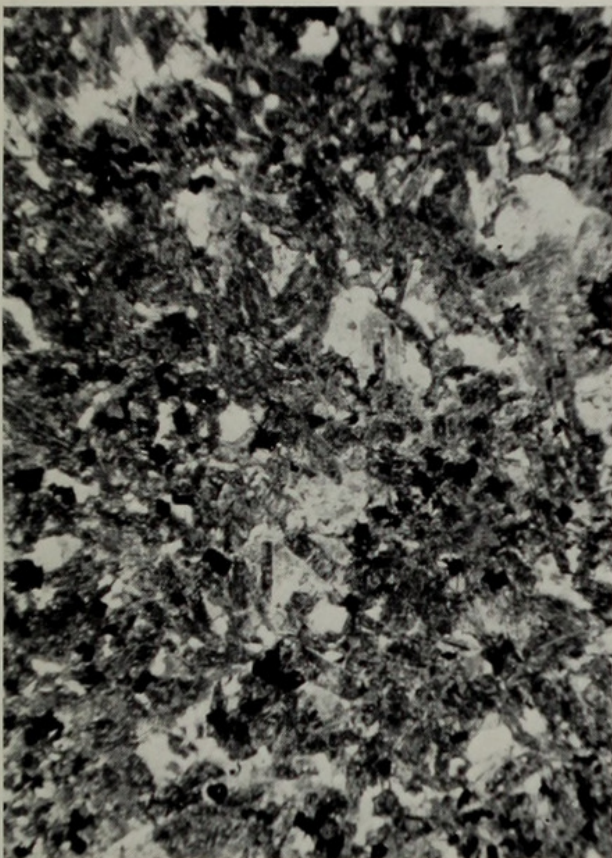

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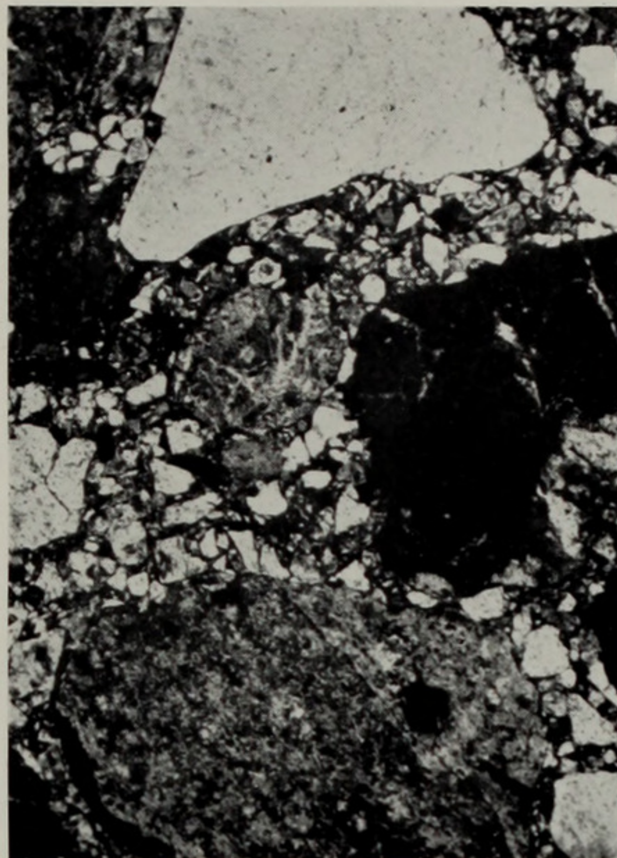

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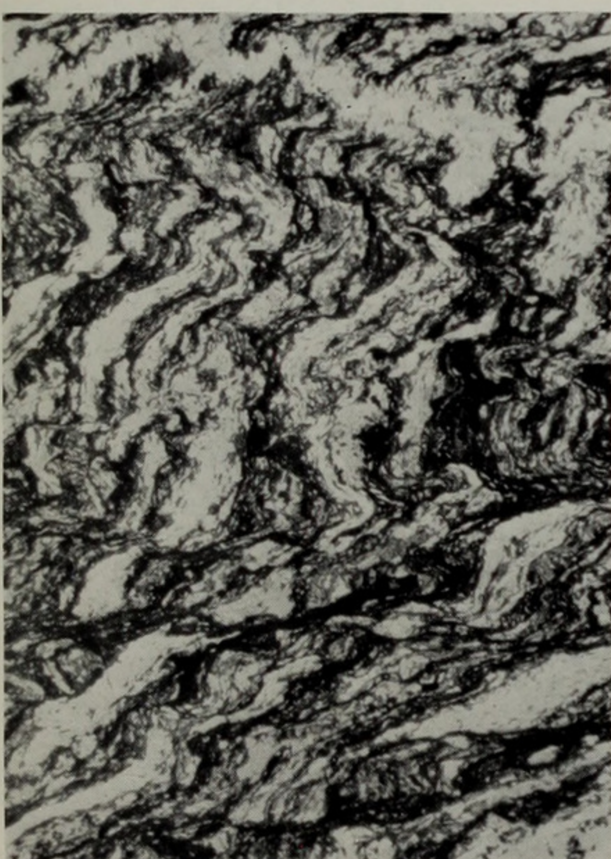

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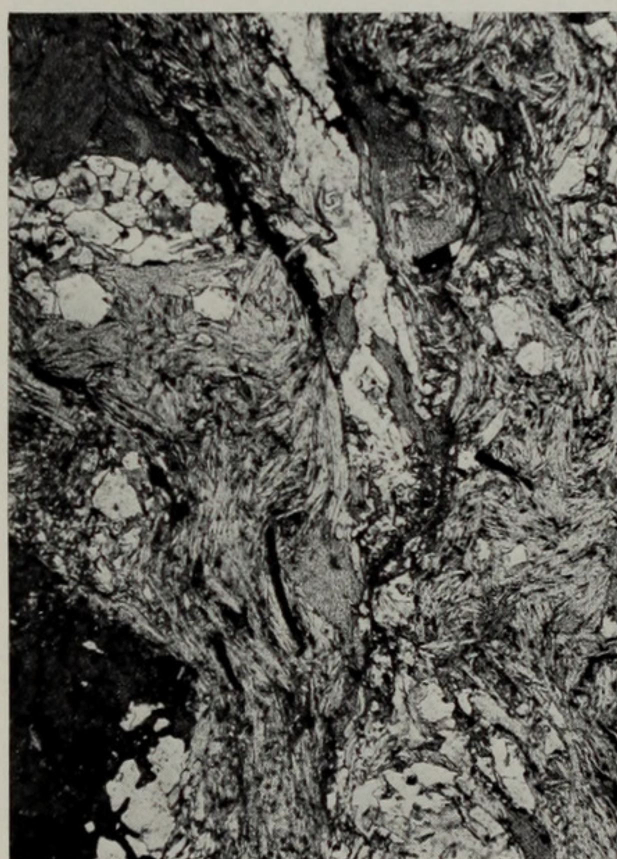


PLATE 7

FIG. 1. Ophitic coarse porphyritic basalt, off Dronning Maud Land (Station 2605) (BM 1972, O, 150 (5)).

Plane polarized light, × 31.

FIG. 2. Coarse porphyritic olivine-enstatite (picritic) basalt, off Dronning Maud Land (Station 2605) (BM 1972, O, 150 (6)). Phenocrysts of enstatite, with several crystals of olivine altered to talc and skeletal iron ore.

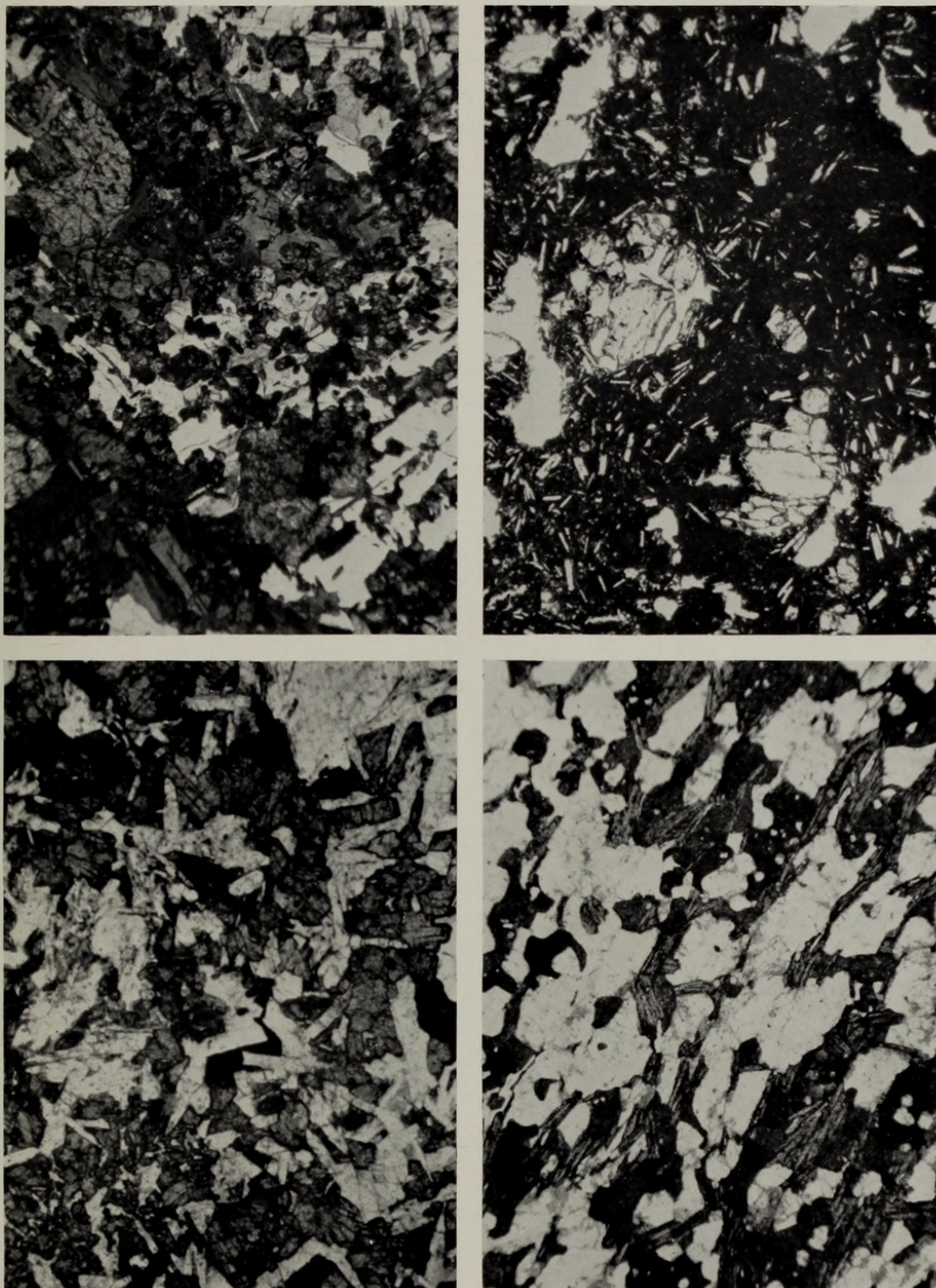
Crossed polars, × 14.

FIG. 3. Chlorite-hornblende schist, off Dronning Maud Land (Station 2605) (BM 1972, O, 150 (9)).

Plane polarized light, × 15.

FIG. 4. Porphyritic olivine basalt, off Balleny Islands (Station 2200) (BM 1972, O, 151). Showing large olivine phenocrysts.

Plane polarized light, × 31.



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