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THE GEOLOGY OF THE DUSE BAY–LARSEN INLET AREA, NORTH-EAST GRAHAM LAND

(WITH PARTICULAR REFERENCE TO THE TRINITY PENINSULA SERIES)

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ABSTRACT

SEDIMENTARY, metamorphic and igneous rocks, ranging in age from (?) Carboniferous to Tertiary, occur as scattered exposures in the mountainous ice-covered area of north-east Graham Land which forms part of a discontinuous orogenic belt linking western Antarctica with the South American Andes. The oldest rocks known in this area form the Trinity Peninsula Series, a major group of (?) Carboniferous geosynclinal sediments and their metamorphic equivalents approximately 45,000 ft. (13,715 m.) thick, comprising greywackes and siltstones intercalated with grey shales and laminated mudstones. Conglomerates, pebbly mudstones, red and green shales, cherts and greenschists occur locally. The greywackes exhibit two broad regional variations: feldspar-rich types and quartz-rich types with siliceous matrices. Parts of this succession are intruded by dykes of a peculiar composition which are probably associated with the greenschists.

The sedimentary structures are tentatively interpreted as an indication that the majority of the sediments were deposited by turbidity currents. The palaeogeography of the source area is unknown, but a study of the sand and gravel fractions of the sandstones and conglomerates shows that it largely comprised granite-gneisses, quartzites and subarkoses, and acid volcanic rocks. Structurally, the Trinity Peninsula Series rocks mostly form the south-east limb of an anticlinorium whose axis trends sub-parallel to Trinity Peninsula. The steeply dipping, well-indurated sediments with isolated disharmonic folds in the north-east show a gradual transition into low-grade metasediments with more intense and complex deformation towards the south-west. A second minor phase of deformation in the south-western area is indicated by puckering almost perpendicular to the major fold axes. Thermal metamorphism, superimposed on the earlier regional metamorphism, has resulted in quartz-biotite-hornfelses and mica-cordierite-andalusite-schists in aureoles around plutons of the Upper Cretaceous to early Tertiary Andean Intrusive Suite. Localized deformation in the Sjögren Glacier area is attributed to early phases of these intrusions. Although the absence of identifiable fossils limits stratigraphic correlation within the succession, the Trinity Peninsula Series has structural and compositional features which reinforce existing correlations with geosynclinal sediments on Livingston Island, the South Orkney Islands and South Georgia.

A distinctive group of banded hornfelses, of uncertain age and with a minimum thickness of 2,000 ft. (610 m.) is exposed in the central part of Trinity Peninsula. These rocks have been thermally metamorphosed

by intrusions of the Andean Intrusive Suite but they show no evidence of deformation by the major pre-Jurassic orogeny which folded the Trinity Peninsula Series.

Sediments, which grade upwards into volcanic rocks, occur in the Sjögren Glacier–Larsen Inlet area and are correlated on their fossil flora and petrographic characteristics with the Middle Jurassic beds and Upper Jurassic Volcanic Group established in adjacent areas of Trinity Peninsula. In two localities (Bald Head and Tower Peak) these rocks rest with strong unconformity on deformed Trinity Peninsula Series metasediments. The sediments comprise basal conglomerates, plant-bearing mudstones and sandstones with a total thickness of about 200 ft. (61 m.). The volcanic group comprises about 3,500 ft. (1,066 m.) of lavas, crystal tuffs, agglomerates and quartz-plagioclase-porphyries of andesitic to rhyodacitic composition in which resorbed quartz phenocrysts are ubiquitous in all but the most basic types. Dykes of a similar composition are common over most of this area, and they include a remarkable quartz-plagioclase-porphyry dyke swarm cut by Andean granite near Pitt Point.

Several plutons and complexes of the Andean Intrusive Suite ranging from tonalite to granite are exposed in Trinity Peninsula. The tonalites form relatively small intrusions cut by the major granodiorite-granite plutons. A few hypabyssal rocks of intermediate to acid composition are associated with the Andean Intrusive Suite and they include an aegirine-riebeckite-granite. There is little evidence of associated metasomatism or pneumatolytic mineralization.

Two outliers of basaltic tuffs and breccias, together with several olivine-dolerite dykes, are the only representatives of the Miocene James Ross Island Volcanic Group which is fully developed in the type locality to the east.

CONTENTS

I. INTRODUCTION

1. *Location*

This report describes the geology of an area about 2,000 sq. miles (5,180 km.^{2}) in extent near the northern extremity of Graham Land, between Duse Bay (lat. 63°35′S., long. 57°15′W.) and Larsen Inlet (lat. 64°30′S., long. 59°30′W.), including the greater part of Trinity Peninsula. This area forms part of the complex and discontinuous orogenic belt which curves southwards along the length of the Antarctic Peninsula and across the western part of the Antarctic continent. To the north it is linked by the scattered island groups and submarine ridges of the Scotia arc to the South American Andes. This geographical setting is shown in Map 1.

2. *Previous investigations*

North-east Graham Land is relatively easily accessible by sea during the summer months and consequently is one of the best-known areas of the Antarctic continent. The discovery by J. G. Andersson, O. Nordenskjöld and other members of the Swedish South-Polar Expedition, 1901–03, of Middle Jurassic plant fossils at Hope Bay, and Upper Cretaceous and Tertiary invertebrate fossils on Cockburn, James Ross, Seymour and Snow Hill Islands greatly stimulated the interest of geologists in this area. A comprehensive review of these and other geological investigations in north-east Graham Land has been given by Adie (1957*a*, p. 507–08; 1958, p. 6–10).

On the mainland, most of the work of the Swedes (Nordenskjöld, 1905; Andersson, 1906) and the later work of the Falkland Islands Dependencies Survey geologists was concentrated in the Hope Bay area and on coastal exposures between View Point and Church Point. They paid particular attention to the Middle Jurassic plant-bearing strata. More extensive observations were made in 1947–48 by Adie who recognized the importance and widespread development of the (?) Carboniferous geosynclinal sediments which he named the Trinity Peninsula Series. He also investigated the petrology of some of the plutonic intrusions of the Andean Intrusive Suite and the associated thermally metamorphosed rocks of the Trinity Peninsula Series.

Recent work in this area includes geological and geophysical surveys by British Antarctic Survey personnel in and adjoining Trinity Peninsula, and investigations on the coast and offshore islands near Cape Legoupil by United States geologists (p. 55).

3. *Present work*

The field work on which this report is based was undertaken by the author from the British Antarctic Survey's Hope Bay scientific station between March 1960 and January 1962. The field notes and specimens collected by D. H. Elliot and M. Fleet in the area between Camel Nunataks and Cape Legoupil have also been made available to the author. The primary purpose of the field work was to map the area geologically on a scale of 1 : 25,000. Full air-photograph coverage proved very useful both for route finding and for mapping purposes.

The rocks of the Trinity Peninsula Series were selected for special study not only because they are the least known but the most widespread in this area. The total area mapped was about 2,000 sq. miles (5,180 km.^{2}) of which the Trinity Peninsula Series rocks occupy about two-thirds (Maps 2 and 3). As can be readily seen from the geological maps, rock exposures are most abundant in the south-eastern parts of Trinity Peninsula where there is less ice cover than elsewhere.

The following areas have been described or are at present being described by other British Antarctic Survey geologists, and therefore they have not been dealt with in any detail in this account: Tabarin Peninsula and the northern extremity of Trinity Peninsula, the west side of Trinity Peninsula between Cape Ducorps and Marescot Ridge, the west side of Trinity Peninsula between Russell West Glacier and Charcot Bay, the south-east coast of Trinity Peninsula including Bald Head, Camp Hill and Church Point, and the area between Longing Gap and Cape Longing.

4. *Physiography*

Koerner (1964, p. 4), describing Trinity Peninsula, wrote: "it consists basically of east and west coast ice piedmonts which are separated by the plateau". These landforms continue south-westwards and broaden as the general width of the peninsula increases to over 50 miles (80 km.) between Cape Longing and Charcot Bay (Map 1). The plateau level rises very gently to a height of nearly 7,000 ft. (2,135 m.) north of Larsen Inlet. The south-eastern ice piedmont is discontinuous in the Mount Roberts area, where rocky ridges separated by valley glaciers descend from the plateau and almost reach the coast. Farther south the ice piedmont is again interrupted by Sjögren Glacier which is about 17 miles (27 km.) long and up to 5 miles (8 km.) wide. This glacier continues eastwards as a glacier tongue, completely blocking the southern part of Prince Gustav Channel and contributing ice to form a small ice shelf whose low front trended north to north-east from Cape Longing to Cape Broms in 1961. Between Sjögren Glacier and Larsen Inlet there is a broad upland at the same general level as the ice piedmont to the north but cut off from the plateau scarp by Shortcut Col. Several nunataks and ridges project above the general plateau level, notably Tower Peak, Mount Tucker and Mount Brading, while three small nameless valley glaciers cut deeply into this upland area on its north-east and east sides.

Over Trinity Peninsula as a whole most of the accessible rock exposures occur along the base of the rock ridges which descend from the plateau and flank the more vigorous valley glaciers (Plate Ib). The scattered and isolated nunataks provide excellent exposures but the most accessible areas of bare rock surface occur on the relatively flat-topped windswept promontories which project into Prince Gustav Channel. There are eleven examples of this type of feature, including View Point in the north-east and the broad promontory overlooking the Sjögren Glacier tongue 9 miles (14·5 km.) north of Longing Gap. The surfaces of all these promontories have been glaciated, a fact that supports Croft's (1947) view that they were formerly covered by extensions of the ice piedmont.

Even where there are broad uninterrupted stretches of ice piedmont, small scattered rock exposures occur at or near the coast. Moreover, the terminal cliffs of the ice piedmonts are relatively low in comparison with those of adjacent valley glaciers and ice streams. These facts support the idea that the ice piedmonts consist of a thin and essentially protective ice cover underlain by a planation surface. The question is still open as to whether this surface has resulted mainly from subaerial, marine or glacial erosion, because so little is known about the rate and effectiveness of such processes in these particular climatic conditions.

In addition to these major landforms there are numerous minor bench features at varying heights on the ice-free promontories flanking Prince Gustav Channel. For instance, at View Point there are distinct benches at approximately 200, 400, 500 and 600 ft. (61, 122, 152 and 183 m.) but it is uncertain whether these are a result of ice erosion, or marine erosion followed by ice erosion.

II. GENERAL STRATIGRAPHY

THE general stratigraphy of this area is given in Table I and the distribution of the major rock groups is shown in the geological maps (Maps 2 and 3). The Trinity Peninsula Series, of (?) Carboniferous age, is the oldest and the most widespread group of rocks. Sedimentary and volcanic rocks of Middle and Upper Jurassic age are restricted to the south-east coastal areas of Crystal Hill, Camp Hill and Church Point, and the broad upland between Sjögren Glacier and Larsen Inlet. Cretaceous sediments of differing facies occur in the islands off Cape Legoupil and possibly at Cape Longing. Apart from a small grit outcrop of unknown age at View Point, the youngest rocks in this area are basaltic tuffs and breccias of the Miocene James Ross Island Volcanic Group, forming two small outliers in Broad Valley. A distinctive group of banded hornfelses of indeterminate age is exposed near Mount Bradley between two plutons of the late Cretaceous to early Tertiary Andean Intrusive Suite. Large plutons of this suite also occur north-west of Louis-Philippe Plateau and in the Sjögren Glacier area. Dykes, mainly associated with the Upper Jurassic and Miocene volcanic rocks, are widely distributed over this area.

A. TRINITY PENINSULA SERIES

The Trinity Peninsula Series of north-east Graham Land comprises numerous sequences of sedimentary rocks and their metamorphic equivalents, amounting to an estimated total thickness of at least 45,000 ft. (13,715 m.). Many features of this series are characteristic of geosynclinal deposits of the flysch type (Bouma, 1962). Although many different rock types make up these sequences, they are all (with rare

TABLE I

GENERAL STRATIGRAPHIC SUCCESSIONS IN NORTH-EAST GRAHAM LAND
(after Adie, 1953)

Age		*Hope Bay Area*	*Area North of Laclavère Plateau*	*Laclavère Plateau–Sjögren Glacier Area*	*Sjögren Glacier–Longing Gap–Larsen Inlet Area*
Pleistocene to Recent		Moraines Raised beaches Moraines	Moraines	Moraines	Moraines
Pliocene Miocene Oligocene Eocene				James Ross Island Volcanic Group ~~~~~~~~ Cape Roquemaurel, Mount Reece and Tufft Nunatak granodiorite and associated tonalite	Sjögren Glacier igneous complex
Cretaceous	Upper	Tabarin Peninsula diorite Nobby Nunatak and other gabbros	Quartz-diorite; andesitic lavas (?) *disconformity* Cretaceous sediments of the Cape Legoupil area ~~~~~~~~		
	Lower		? Diorite ? Gabbro		
Jurassic	Upper	? Upper Jurassic Volcanic Group		? Upper Jurassic Volcanic Group	? Upper Jurassic Volcanic Group
	Middle	Middle Jurassic beds ~~~~~~~~		Middle Jurassic beds ~~~~~~~~	Middle Jurassic beds ~~~~~~~~
	Lower				
(?) Carboniferous		Trinity Peninsula Series	Trinity Peninsula Series	Trinity Peninsula Series	Trinity Peninsula Series

exceptions) clastic sediments ranging in grain-size from mudstone to conglomerate. The characteristic succession consists of mudstone or shale alternating with beds, or groups of beds, of siltstone or sandstone with monotonous repetition for thousands of feet of strata. Some sequences are predominantly argillaceous with thinly laminated siltstone beds instead of sandstones.

This general lithological monotony is further exemplified by the fairly limited compositional and textural range of the rocks. Most of the shales and mudstones are dark grey in colour, while the moderate to poorly sorted sandstones generally fall into the lithic greywacke or feldspathic greywacke classes.*

The unusual rock types in these sequences, such as the conglomerates or the red and green shales, occur only locally and are therefore of little stratigraphic use. However, they are of great palaeogeographical significance. Stratigraphical correlation is made even more difficult by the almost complete absence of identifiable fossils and by the lateral changes in metamorphic grade resulting from plutonic intrusion (p. 43). No further palaeontological evidence has been found either to support or modify the (?) Carboniferous age suggested by Adie (1957*b*) for fragmentary fossil plant material in the greywacke-shale sediments at Hope Bay, which has been designated the type locality for the Trinity Peninsula Series.

In view of these difficulties, it was decided to describe and subdivide the Trinity Peninsula Series on an areal rather than a stratigraphical basis (Fig. 1). The rocks within these areal sub-divisions form

* The sandstone classification of Pettijohn (1957) is followed throughout this report.

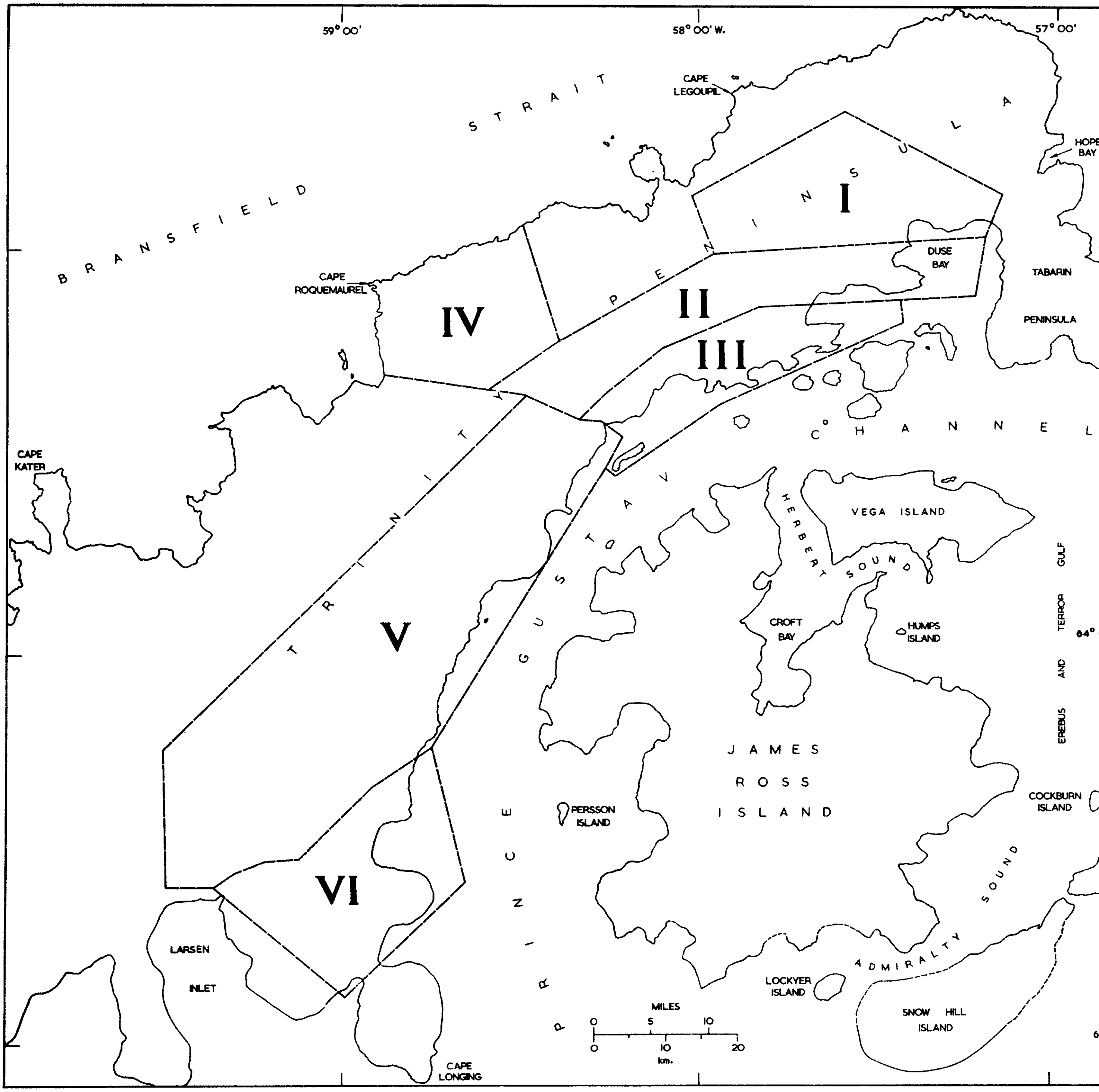

FIGURE 1

Map of Trinity Peninsula showing regional sub-divisions based on lithologies and structures in the Trinity Peninsula Series.

natural groups with certain affinities, such as common topographical expression or similar strike directions, lithology or metamorphic grade. These areas and the named features to which they are referred are easily discernible on the geological maps (Maps 2 and 3). A brief description of the extent and distinguishing features of each area is set out below.

1. *Laclavère Plateau (Fig. 1, area I)*

This area includes all the buttresses and ridges leading up to the Laclavère Plateau, together with outlying peaks and nunataks such as Fidase Peak and Camel Nunataks. The alternating beds of sandstone and shale or mudstone, which are so characteristic of the Trinity Peninsula Series, are present in all the outcrops of this area and no other sedimentary rock types have been found.

Little is known of the structure of this area, except that large-scale overfolding is probably present, but the total thickness of the strata must be several thousand feet.

2. *View Point and the south flanks of Broad Valley and Louis-Philippe Plateau (Fig. 1, area II)*

The outcrops in this area are distributed roughly along the direction of the regional strike (east-north-east to west-south-west). As well as the usual sandstone-shale alternations, important beds of conglomerate crop out in the View Point area (D.3820, 3877). South of Broad Valley and Louis-Philippe Plateau, there are thick mudstones and occasional beds of conglomeratic mudstone. The estimated total thickness of this succession is about 5,000 ft. (1,525 m.).

3. *Jade Point–Russell East Glacier area (Fig. 1, area III)*

This area includes all the outcrops of the Trinity Peninsula Series south of Cugnot Ice Piedmont.

There are considerable local variations in lithology in this area. On the nunataks north of Church Poin, (D.3634, 3635, 3650) red and green shales, pale green cherts and finely laminated siliceous mudstonet are present, while pebbly mudstone crops out south-east of Benz Pass (D.3801). In addition, trace fossils were found on the coast near Crystal Hill (D.3651) and at Panhard Nunatak (D.4273) (p. 38; Plate IVd).

The rock sequences exposed on Azimuth Hill, Panhard Nunatak, the ridges on the east flank of Russell East Glacier and the south-west scarp of Louis-Philippe Plateau provide the most continuous cross-section of Trinity Peninsula Series strata in the whole area (Map 2). The individual sequences which comprise the whole succession, from the youngest beds of Long Island to the oldest beds of Louis-Philippe Plateau, are summarized in Table II.

The total length of actual rock outcrop in this section is about 7 miles (11·3 km.), representing a maximum total thickness of 39,200 ft. (11,945 m.). Apart from isolated minor folds and zones of crumpling (p. 51), no evidence was found of any significant deviation from the general direction of "younging" of the beds towards the south-east. Neither were any faults found, apart from two minor thrusts, which would affect the estimated total thickness by causing repetition or cutting out of the strata. In any case, the error in the thickness estimate resulting from hidden high-angle normal faults would be small in these steeply dipping beds compared with the total known thickness. The effect of isolated minor folding and zones of crumpling on the estimated total thickness cannot be assessed with any accuracy. However, it is clear that a reduction of several thousand feet must be allowed for repetition by folding.

3·5 miles (5·6 km.) of the section are hidden under ice and beneath the channel between Long Island and Azimuth Hill. Therefore, assuming continuous "younging" to the south-east with an average dip of 70° in these hidden beds, a further 17,400 ft. (5,305 m.) of strata must be added to the estimate.

Bearing these factors in mind, it is considered that 45,000 ft. (13,715 m.) is a reasonable estimate for the thickness of the Trinity Peninsula Series in this area.

4. *North of Louis-Philippe Plateau (Fig. 1, area IV)*

Most of the outcrops which have been examined in this area are in the vicinity of Marescot Ridge. Sandstones of the type found in the other areas occur at only one locality (D.3842). The predominant rock types are metasiltstones and dark phyllitic mudstones. Most of this area lies within the aureoles of Andean intrusions and the rocks have been affected by thermal metamorphism.

5. *Russell East Glacier–Polaris Glacier area (Fig. 1, area V)*

South-east of Russell East Glacier the usual greywacke-shale lithology predominates except for three isolated conglomerate exposures of limited extent (p. 26). In the Mount Roberts area, where the thickest sequences are exposed, the estimated total thickness is about 12,000 ft. (3,660 m.). The rocks have a low

TABLE II

SUCCESSION FROM LONG ISLAND TO LOUIS-PHILIPPE PLATEAU

Area	*Lithology*	*Thickness*	
		(ft.)	(m.)
Long Island	Greywackes, siltstones and dark slaty shales	2,600	795
	?		
Azimuth Hill	Siltstones and occasional greywackes interlaminated with phyllites. Beds often highly contorted (Plate Vb)	6,500	1,980
Panhard Nunatak	Contorted shales and interlaminated siltstones. Massive greywackes showing some graded bedding with rare sole markings (Plates IVa, b and c)	6,100	1,860
	?		
Nunatak north-west of Panhard Nunatak	Greywackes (with occasional graded beds) interbedded with dark grey or green slaty shales	2,600	795
	?		
Long ridge south-east of Benz Pass	Greywackes (with occasional graded beds) interbedded with slaty shales. Interbedded slaty shales, siltstones and mudstones (occasionally conglomeratic). Pebbly mudstones (Plate IIIb) and interbedded siltstones	7,500	2,285
	?		
South-west scarp of Louis-Philippe Plateau	Metasiltstones and dark phyllites. Metagreywackes (with graded bedding) and thin phyllites (Plate Vc); base not exposed	13,900	4,235

grade of regional metamorphism which shows a definite but slight increase towards the south-west. In the Sjögren, Eliason and Polaris Glaciers areas, thermal metamorphism resulting from extensive Andean plutonic intrusion has further altered these rocks and their original sedimentary characteristics are often obscure.

6. *Longing Gap–Mount Wild–Shortcut Col area* (*Fig. 1, area VI*)

The Trinity Peninsula Series rocks of this area are distinguished by the occurrence of greenschists and unusually chloritic metagreywackes, metasiltstones and phyllites which are often poor in quartz. A 15,000 ft. (4,570 m.) sequence of these rocks occurs on the long isolated ridge of Mount Wild, flanking the lower north side of Sjögren Glacier. This sequence is thrust over highly contorted metasiltstones and slates forming the north-west end of the ridge (Fig. 2; Plate VIIc). Though it is probable that the rocks above the thrust plane are younger than those below, it is assumed (on lack of evidence to the contrary) that both sequences belong to the Trinity Peninsula Series.

7. *Associated minor intrusive rocks*

Two fine- to medium-grained dykes, situated respectively on the north side of Victory Glacier (D.4268) and on the north side of the glacier 6 miles (9·7 km.) west-north-west of Mount Wild (D.3993), are of stratigraphical importance because their unusual mineral composition shows several similarities to the

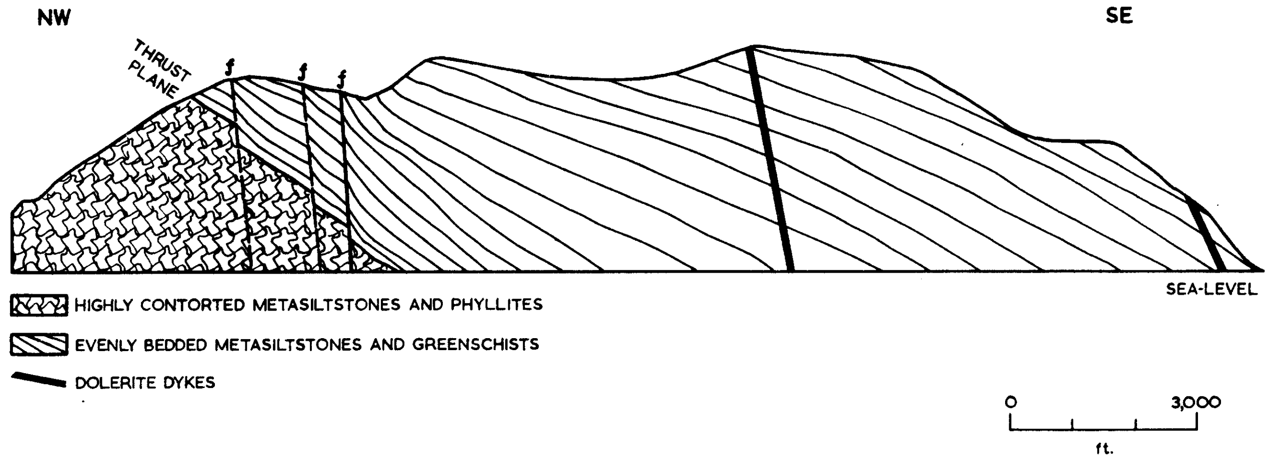

FIGURE 2

Diagrammatic cross-section of Mount Wild.

greenschist rocks in the Tower Peak area (p. 42). These dykes are variable in composition but they are composed essentially of albite or albite-oligoclase, augitic pyroxene and ilmenite, with minor quartz and secondary chlorite, epidote, leucoxene and tremolite. In one thin section (D.4268.3) stilpnomelane is abundant.

These dykes are broken and flexured, suggesting that they were deformed at the same time as the metasediments into which they are intruded. In thin section, augite is shattered and granulated to varying degrees, and the plagioclase twin lamellae are also bent and fractured (Plate VIIIa). However, it is not certain that the degree of deformation of the dykes is as advanced as that of the adjacent metasediments and their intrusion may have occurred after some compression of the Trinity Peninsula Series had already taken place.

B. Banded Hornfelses

Between the Andean intrusions of Mount Reece and the Tufft Nunatak area there is a group of banded hornfelses with a total exposed thickness of about 2,000 ft. (610 m.) on the long ridge trending north-west from Mount Bradley and the peaks flanking the south-western part of the upper amphitheatre of Victory Glacier. Two distinctive features of these rocks, which suggest that they are younger than both the Trinity Peninsula Series and the major orogeny which folded that series (p. 54), are the absence of sandstones and the very even and relatively undeformed nature of the bedding. There is no other direct evidence of their age, except the fact that they are clearly older than the adjacent plutonic rocks. However, similar banded hornfelses on the western side of Detroit Plateau are intruded by a dyke of possible Upper Jurassic affinity (personal communication from D. H. Elliot). The banded hornfelses are described in detail on p. 48.

C. Middle to Upper Jurassic Rocks

With the possible exception of the banded hornfelses, no rocks have been found in this area which are younger than the Trinity Peninsula Series but older than the plant-bearing Middle Jurassic beds.

Middle Jurassic beds, conformably overlain by Upper Jurassic volcanic rocks, occur in three main areas of north-east Graham Land: Hope Bay (Mount Flora), the coast between Bald Head and Church Point, and the area between Longing Gap and Shortcut Col. Generalized stratigraphic successions in these three areas are given in Table III. The most recent detailed descriptions of the first two successions have been given by Adie (1953) and Bibby (in press), while the various successions in the third area are described below (Table IV). In addition, several ammonites collected from surface detritus on the south-east side of Longing Gap have been dated by Dr. M. K. Howarth as possibly having a Kimmeridgian or Oxfordian age, but these rocks are beyond the scope of this report.

TABLE III

TENTATIVE CORRELATION BETWEEN THE THREE MAIN SUCCESSIONS OF JURASSIC ROCKS IN NORTH-EAST GRAHAM LAND

	Hope Bay (Mount Flora)	*Bald Head, Camp Hill, Botany Bay and Church Point*	*The Area North of Longing Gap, Tower Peak, Mount Tucker and the East Side of Larsen Inlet*
Upper			Quartz-plagioclase-porphyries
			Quartz-plagioclase crystal tuffs
Jurassic			Rhyolitic lavas
		Andesites and associated tuffs	Andesitic lavas
Volcanic	Rhyolites	Rhyolites and associated tuffs	Rhyolitic lavas and agglomerates
	Acid tuffs and agglomerates	Agglomerates and tuffaceous conglomerates	
Group	Quartzites with thin intercalations of acid tuff		
Middle		Sandstones and conglomerates with fossil plants	
Jurassic	Shales with an abundant Middle Jurassic flora and a few beetle remains	Shales with a fairly abundant Middle Jurassic flora interbedded with marine sandstones and current-bedded quartzites	Shales and mudstones with Middle Jurassic flora
Beds	Massive basal conglomerates with a few plant remains	Massive conglomerates	Basal conglomerates and sandstones
(?) Carboniferous	Trinity Peninsula Series	Trinity Peninsula Series	Trinity Peninsula Series

In all three areas where Jurassic rocks occur they are seen, or inferred, to rest with strong unconformity on folded or steeply dipping beds of the Trinity Peninsula Series. The actual plane of unconformity is exposed 9 miles (14·5 km.) north of Longing Gap (at Tower Peak (Plate Ia)) and at Bald Head, where the Middle Jurassic sedimentary rocks are absent and andesitic lavas of the volcanic group lie directly on the Trinity Peninsula Series (Bibby, in press).

1. *Outlier 9 miles (14·5 km.) north of Longing Gap*

Plant-bearing shales and siltstones with conglomerates form a small outlier of Middle Jurassic beds resting unconformably on heavily veined and shattered rocks of the Trinity Peninsula Series. These beds dip gently and uniformly east-south-eastwards and, although the phenoclasts in the conglomerates include many pebbles of vein quartz and greywacke clearly derived from the underlying Trinity Peninsula Series, the actual plane of unconformity has not been seen.

A preliminary identification of 15 fossil plants from these beds shows them to be species of the fern *Cladophlebis*, the Cycadophytes *Nilssonia* and *Pseudoctenis*, and the conifer *Elatocladus*. The specific identifications have not been determined but the material probably includes no species which are not present in the Middle Jurassic beds of Mount Flora, Hope Bay.

These beds were probably deposited in lacustrine conditions, because some of the plants are relatively unfragmented and there is little evidence of current-sorting or winnowing of the predominantly muddy sediments.

TABLE IV

TENTATIVE CORRELATION OF JURASSIC STRATA IN THE SJÖGREN GLACIER–LARSEN INLET AREA

General Succession	*Outlier 9 Miles (14·5 km.) North of Longing Gap*	*Tower Peak and Mount Tucker Areas*	*Ridge 2 Miles (3·2 km.) South of Holt Nunatak*	*Porphyry Nunatak–Hampton Bluffs Area*
Upper				"Quartz-plagioclase-porphyries" and laminated crystal tuffs; > 200 ft. (61 m.)
Jurassic				Massive crystal tuffs and agglomerates; > 300 ft. (91 m.)
				Rhyodacitic lavas; > 100 ft. (30·5 m.)
Volcanic		Andesitic lavas; > 2,000 ft. (610 m.)		? *base not exposed*
Group		Mainly andesitic blocky lavas and agglomerates; > 420 ft. (128 m.)	Flow-banded rhyodacites and (?) andesitic blocky lavas; > 1,500 ft. (455 m.)	
Middle Jurassic Beds	Conglomerates and plant-bearing shales and siltstones; >200 ft. (61 m.)	Conglomerates and plant-bearing sandstones; 85 ft. (26 m.)	Sandstones and shales; > 75 ft. (23 m.) ? *base not exposed*	
(?) Carboniferous	Trinity Peninsula Series	Trinity Peninsula Series		

2. *Tower Peak and Mount Tucker*

The Jurassic succession at Tower Peak is the most complete in this area and it shows a transition upwards from basal conglomerates and sandstones to volcanic rocks, but at Mount Tucker and other nearby nunataks only andesitic lavas are exposed.

a. *Sedimentary rocks.* The succession on the west ridge of Tower Peak (Plate Ia) begins with a 25 ft. (7·6 m.) basal conglomerate resting unconformably on Trinity Peninsula Series metasediments. This is followed by 40 ft. (12·2 m.) of light-brown fissile sandstone containing fragmentary unidentified plant axes. The sandstone is overlain by an intrusion of porphyritic microdiorite which probably has a laccolithic form (p. 15). The succeeding 20 ft. (6·1 m.) bed of conglomerate grades to coarse sand size at the top and is remarkably rich in detrital garnet. A thin section (D.4325.4) shows that many of the garnets are anhedral or broken with little sign of abrasion. They are vermillion to amber-red in colour, up to 1·0 mm. in diameter, contain cracks infilled with quartz and calcite, and have a specific gravity of 3·9 and a refractive index of $1{\cdot}804 \pm 0{\cdot}003$, suggesting an almandine-spessartine composition. The other clastic constituents of the conglomerate mainly comprise fragments of Trinity Peninsula Series metasediments and a variety of volcanic debris, including acid lava and crystals of quartz, plagioclase and highly altered ferromagnesian minerals. Garnets were seen in neither the volcanic nor the metasedimentary rock fragments in the conglomerate. Garnets are also absent from thin sections of the local regionally metamorphosed Trinity Peninsula Series rocks and rocks of the Upper Jurassic Volcanic Group, though Adie (1953, p. 159) reported pale pink almandine garnet from the rhyolitic tuffs of Crystal Hill.

b. *Andesites.* There is no clearly defined boundary between the sedimentary beds and the volcanic group at Tower Peak. Two beds of conglomerate, both about 10 ft. (3·0 m.) thick and containing volcanic and metasedimentary phenoclasts, are interbedded with the lavas and agglomerates. It is concluded from this evidence that the volcanic group is diachronous.

Both lavas and agglomerates are present in the volcanic group but the lavas are blocky and the two rock types are difficult to distinguish in the field, since both are brown or greyish brown in colour and deeply weathered. A thin section of the lowest 80 ft. (24·4 m.) blocky lava consists essentially of anhedral oligoclase phenocrysts (An_{28}), together with chlorite and serpentine forming conspicuous pseudomorphs after pyroxene, set in a very fine-grained groundmass containing small tabular plagioclase laths and scattered iron ore granules. Secondary calcite is abundant in the plagioclase and in the groundmass, and it also forms irregular rims around the pyroxene pseudomorphs. This rock is classified as a carbonatized pyroxene-andesite.

The group of nunataks (including Mount Tucker) to the west-north-west of Tower Peak are all formed of andesitic lavas. The tops and bottoms of the individual flows are indistinct but there are probably many thick flows dipping south-westwards at a low angle, with a total estimated thickness of about 2,000 ft. (610 m.). Thin sections of lavas from two of these nunataks (D.3901, 4312) also consist of carbonatized pyroxene-andesite. In specimen D.4312.1 the plagioclase is present as zoned and sericitized phenocrysts with a composition range from centre to rim of An_{65} to An_{30}, and also as small tabular crystals which are quite fresh. The groundmass has a flow texture. Specimen D.3901.1 is highly carbonatized and vesicular.

Small exposures of andesite also occur south of Tower Peak. Some of these represent part of the lava sequence, while others are probably plugs or sills.

3. *Coastal ridge 2 miles (3·2 km.) south of Holt Nunatak*

a. *Sedimentary rocks.* About 75 ft. (22·8 m.) of coarse sandstones with thin interbedded shales are exposed beneath rhyodacitic lavas at the foot of the conspicuous cliff which forms the coastal termination of the ridge trending south-west from Mount Brading. These beds dip at 30° to the north-north-west and they appear to be conformable with the overlying lavas, but the base of the sequence is not exposed and no fossils were found. This conformable relationship with the volcanic rocks, together with the presence of abundant volcanic detritus in a thin section of sandstone (D.4310.1) from the sequence, strongly suggests that they are Jurassic sediments.

b. *Rhyodacitic lavas and agglomerates.* The volcanic sequence overlying the sedimentary succession described above has been traced for 3 miles (4·8 km.) up the ridge trending north-west from the coast but the nature of the exposed junction with the Trinity Peninsula Series has not been discovered in this area. The sequence, estimated to have a total exposed thickness of 1,500 ft. (457 m.), is composed of at least two groups of rhyodacitic lava flows together with some agglomerates of more basic appearance. The lavas are light greenish grey in colour and usually show flow structures. A thin section (D.4304.1) from one of the lowest flows in the sequence consists of small phenocrysts of partially resorbed quartz and highly altered plagioclase, and potash feldspar, set in a quartzo-feldspathic groundmass with an irregular spherulitic texture. Secondary calcite and pyrite are also present.

4. *Porphyry Bluff–Hampton Bluffs area*

The volcanic rocks of this area, unlike those described above, are mainly pyroclastic, though the true nature of the "quartz-plagioclase-porphyries" is still in doubt. The only flow-banded rhyodacitic lavas comparable to those previously described form an isolated cliff about 100 ft. (30·5 m.) high which is the northernmost exposure in this area.

The north-west scarp of Hampton Bluffs is composed of apparently unbedded crystal tuffs, with a few coarse agglomeratic bands, overlapped by laminated crystal tuffs. The unbedded crystal tuffs vary from very siliceous and light in colour with irregular limonitic cavities to greenish brown rocks with clearly discernible individual pyroclastic constituents. A specimen from one of the agglomeratic bands (D.4317.2) is composed mainly of fragments of flow-banded rhyodacitic lava and "quartz-plagioclase-porphyry". This group of crystal tuffs is estimated to be about 300 ft. (91·5 m.) thick.

The overlying group of volcanic rocks is much more homogeneous in grain-size and cementation, and shows a conspicuous parallel lamination on weathered surfaces (Plate IIa). This lamination is thought to represent varying degrees of welding of the crystal debris similar to that described by Ross and Smith (1961, p. 20) in welded ash-flow tuffs. However, in a thin section of the laminated rock (D.4319.2), there is no sign of glassy or devitrified shards and most of the crystals, consisting mainly of partially resorbed quartz, highly altered oligoclase and serpentinized orthopyroxene, are anhedral and unbroken showing little evidence of abrasion. The crystals are set in a cloudy indeterminate quartzo-feldspathic mosaic which could be a devitrified acid glass. The exposed laminated rocks are about 200 ft. (61 m.) thick.

The "quartz-plagioclase-porphyries" are closely associated with the laminated crystal tuffs but they differ in being massive, structureless and having a more acid composition. They form prominent north-facing scarps on Porphyry Bluff and the southernmost of Hampton Bluffs. The Porphyry Bluff rock contains crystals of vitreous quartz and white feldspar set in a cryptocrystalline pink groundmass. A thin-section examination of specimen D.3926.1 reveals that the feldspar is partially albitized patch microperthite. Again, there are no textures or constituents present to suggest that this is a tuffaceous rock. Coarse, deeply weathered and very friable "quartz-plagioclase-porphyry" forms a circular plug-like intrusion about 100 ft. (30·5 m.) across, with margins chilled against andesitic lavas at station D.3933, 4·5 miles (7·2 km.) south of Tower Peak. This rock probably represents the acid magma, highly charged with crystals, that gave rise to the distinctive but problematical rocks described above. The field relations and structural evidence both indicate that the "quartz-plagioclase-porphyries" are the youngest rocks in the Jurassic volcanic succession of this area.

5. *Minor intrusive rocks*

Minor intrusive rocks, with a close petrographical resemblance to the andesites and rhyodacites of the Upper Jurassic Volcanic Group, form dykes scattered throughout Trinity Peninsula. Sixteen of these dykes have been mapped, not counting the very dense swarm of acid dykes near Pitt Point (Maps 2 and 3). Of these, only four are of intermediate composition and the others are felsites and "quartz- or quartz-plagioclase-porphyries". The intermediate rocks comprise altered porphyritic microdiorites containing phenocrysts of intermediate plagioclase and pseudomorphs after hornblende and orthopyroxene. Quartz is present as small partially resorbed phenocrysts in two cases (D.3928.1, 4215.1) and it is generally present as an interstitial mineral. The least altered specimen is D.4215.1, which consists of anhedral phenocrysts of andesine and partially altered orthopyroxene set in a pilotaxitic groundmass containing abundant small carbonate aggregates (Plate VIIIb). The orthopyroxene has a positive sign and is non-pleochroic, suggesting an enstatitic composition. The plagioclase is zoned with highly saussuritized cores.

The laccolith on the west ridge of Tower Peak is also composed of microdiorite (D.4325.6), which is generally altered and non-porphyritic but containing a few dispersed phenocrysts of hornblende.

The acid dyke rocks are classified into non-porphyritic felsites and "plagioclase- or quartz-plagioclase-porphyries". The felsites are very fine-grained and generally pale greenish or pinkish grey in colour. In thin section they usually show a felsitic devitrification texture consisting of a grey-polarizing mosaic in which tiny albite laths are scattered. In several specimens these laths have forked terminations.

In nearly all of these acid rocks secondary calcite is abundant, either partially or completely replacing the plagioclase phenocrysts in most of the thin sections of acid porphyry that have been examined. In dykes near the Sjögren Glacier igneous complex, carbonatization is advanced and is accompanied by deformation textures with small orientated flakes of sericite and chlorite (D.3991.1, 3993.2, 4203.2). Ferromagnesian minerals are usually rare or absent but chloritized biotite occurs in some specimens.

The swarm or multiple series of "quartz-plagioclase-porphyry" dykes, which is cut by the Mount Reece granite 4 miles (6·4 km.) west of Pitt Point, is a remarkable and unusual feature. These dykes are up to 20 ft. (6·1 m.) wide, and near the granite contact where they dip at 35° to the south-east they are so closely spaced as to be partially adjacent to each other, with only thin wedges of country rock separating them (Plate IIb). The dip of the dykes steepens and they become more widely spaced towards Pitt Point. The "quartz-plagioclase-porphyry" forming these dykes is unlike that described above from Porphyry Bluff. A thin section of specimen D.3679.1 contains partially resorbed anhedral quartz phenocrysts (characteristic of Upper Jurassic volcanic rocks of this area) together with albite and a few potash feldspar phenocrysts. The groundmass is formed mainly of microspherulitic or feathery granophyric intergrowths of quartz and alkali-feldspar. A few narrow phenocrysts of chloritized biotite are also present.

There is no evidence to suggest why this unusual dyke swarm should be confined to this particular locality.

D. Andean Intrusive Suite

Plutonic rocks of the Andean Intrusive Suite are abundant and widely distributed in north-east Graham Land (Maps 2 and 3). The intrusions are generally in the form of stocks and bosses of oval-shaped plan, but in the area between Marescot Ridge and Russell West Glacier, and round the upper part of Sjögren Glacier, multiple intrusion has resulted in intrusive complexes. Adie's (1955) account of the petrology of the Andean Intrusive Suite of Graham Land includes details of biotite-granites from Mount Reece and Cape Roquemaurel. He deduced, from indirect evidence, a late Cretaceous to early Tertiary age for this suite and concluded that the rocks, ranging from gabbro to granite, form a differentiation series derived from a common parental magma. Recent radiogenic age determinations (Halpern, 1962; personal communication from R. J. Adie) indicates that this plutonic activity perhaps spanned a greater period of time than suggested by the indirect evidence.

The Andean intrusions in this area are described briefly below and modal analyses of some of the rocks are given in Table V. It should be noted that the rock names applied to the various intrusions are open

Table V

MODAL ANALYSES OF SOME ROCKS OF THE ANDEAN INTRUSIVE SUITE FROM THE AREA BETWEEN MOUNT BRADLEY AND SJÖGREN GLACIER

	1	2	3	4	5	6	7	8	9	10
Quartz	23·7	43·3	17·2	40·7	26·2	15·9	40·6	30·2	26·8	31·8
Potash feldspar	6·3	44·6	0·9	32·7	14·5	63·3	37·0	14·0	1·2	22·7
Plagioclase	47·9	12·0	66·6	23·9	54·8	17·3	19·6	36·6	46·3	40·7
Biotite/chlorite	22·0	0·1	5·4	2·3	4·5	3·2	2·7	17·1	17·2	4·8
Hornblende	—	—	8·8	—	—	—	—	2·4	8·5	—
Accessories	0·1	*	1·1	0·4	*	0·3	0·1	*	*	*
Plagioclase composition	An_{24-47}	An_{11}	An_{35-45}	An_{16-22}	An_{20-26}	An_{20}	An_{13-33}	An_{33-43}	An_{6-40}	An_{12-42}

* Present but not recorded.

1. D.3663.1 Granodiorite, Mount Bradley.
2. D.3951.1 Granite, 4 miles (6·4 km.) north-east of Mount Tucker.
3. D.3961.1 Tonalite, Sjögren Glacier igneous complex.
4. D.3967.1 Adamellite, Sjögren Glacier igneous complex.
5. D.3971.1 Granodiorite, Sjögren Glacier igneous complex.
6. D.3974.1 Granite, Sjögren Glacier igneous complex.
7. D.3975.1 Granite, Sjögren Glacier igneous complex.
8. D.3983.1 Granodiorite, Sjögren Glacier igneous complex.
9. D.4257.1 Tonalite, intrusion between Aitkenhead Glacier and Mount Bradley.
10. D.4259.1 Granodiorite, intrusion between Aitkenhead Glacier and Mount Bradley.

to revision, because they are based on only one or two specimens from each intrusion. Where there is doubt about these specimens being representative of the whole intrusion, the rocks are classified as undifferentiated granite.

1. *Intrusions in the Marescot Ridge–Russell West Glacier area*

Rock exposures in this area are widely scattered and isolated. Biotite-granites, similar to those from Cape Roquemaurel, form a ridge trending westwards to the coast from Wimple Dome. A small exposure of granite-pegmatite very rich in potash feldspar occurs about 2·5 miles (4 km.) west of Crown Peak, while at Crown Peak itself there is a small inaccessible intrusion of grey-weathering rock, rich in xenoliths and containing several large rafts of country rock. The southern contact of the intrusion is sharp against upturned beds of the Trinity Peninsula Series but the northern one is broken with several stringers and dykes.

The only other plutonic rock found in this area is quartz-gabbro exposed on the coast 1·5 miles (2·4 km.) west of Thanaron Point, which is probably also formed of the same rock.

It is probable that the various intrusions mentioned above are part of a single igneous complex underlying the whole area. The metamorphism of the scattered exposures of Trinity Peninsula Series rocks in this area supports this contention (p. 43).

2. *Tufft Nunatak granodiorite and associated tonalite*

Four intrusions are exposed in the area between Victory and Aitkenhead Glaciers. They comprise the Mount Reece granite, the small granodiorite-granite complex near Mount Bradley and the Tufft Nunatak granodiorite, which is flanked by a relatively small tonalite intrusion.

a. *Mount Reece granite.* A pink biotite-granite, whose petrology has been described by Adie (1955, p. 6–7), forms the intrusion centred on Mount Reece. Where the margin is exposed on the south-west side of Victory Glacier, the contact is always sharp with granite stringers ramifying through the country rock, which at one locality (D.3674) contains a swarm of "quartz-plagioclase-porphyry" dykes (p. 15). Though the granite is poor in xenoliths, in some places rafts of country rock appear to be frozen in a position of partial detachment from the margin. The marginal zone of the granite appears to be richer in biotite and poorer in quartz than the rest of the intrusion. A few late-stage quartz-chlorite veins cut both the granite and the country rock.

b. *Small intrusive complex near Mount Bradley.* A small granodiorite intrusion cut by granite stringers occurs on the long ridge 1 mile (1·6 km.) north-west of Mount Bradley and at about the same distance from the nearest exposure of Mount Reece granite. The stringers probably represent the uppermost part of this granite. The granodiorite is a heterogeneous, medium-grained grey rock, containing abundant xenoliths in various stages of digestion. A thin section of specimen D.3663 shows a hypidiomorphic granular texture and it contains tabular, zoned plagioclase crystals (An_{24-27}) with a complex zone/twinning relationship and an unusual abundance of chloritized biotite.

c. *Intrusions in the Mount Bradley–Aitkenhead Glacier area.* Conspicuous exposures of pink-weathering granodiorite form the scarps and ridges flanking Detroit Plateau south-west of Mount Bradley. The granodiorite contains aplite and pegmatite veins, and enormous rafts of dark country rock up to 400 ft. (122 m.) across, which are well exposed on the plateau edge west of Mount Bradley. In the hand specimen the granodiorite (D.4259.1) differs from the Mount Reece granite in containing white rather than pink potash feldspar. The potash feldspar is microperthitic and is present as crystal aggregates. There appears to be a higher proportion of potash feldspar than that given in the mode and the rock could well be classified as an adamellite. Other petrographic features are strong oscillatory zoning in the plagioclase with a range An_{12-42} and the presence of partially chloritized biotite. The main accessory minerals are zircon and apatite.

A sharp contact between the granodiorite and the Trinity Peninsula Series metasediments is exposed at the north-east end of a nunatak 2 miles (3·2 km.) south-west of Tufft Nunatak. The south-western end of this nunatak consists of a tonalite intrusion which is cut by undifferentiated granitic dykes at station D.4257. The tonalite is somewhat altered with the hornblende bleached a pale brownish yellow to pale yellowish green; most of the plagioclase is highly saussuritized and the biotite is almost completely chloritized. The rock varies in appearance and it contains a moderate number of xenoliths in various stages of digestion.

3. *Sjögren Glacier igneous complex*

An intrusive complex of plutonic and minor hypabyssal rocks is exposed over an area of about 60 sq. miles (155 km.^{2}) round the upper parts of Sjögren, Eliason and Polaris Glaciers (Map 2). The northerly extent of this complex is unknown as it is hidden beneath the ice cover of Detroit Plateau. At least three major intrusions are represented in this area, as well as several minor ones. The rocks range from tonalite to granite and the order of intrusion, indicated by the field relations, is from intermediate to acid. Intermediate and variable undifferentiated granitic rocks form the southern part of the complex with younger and more homogeneous granitic rocks to the north.

a. *Tonalite*. A relatively small tonalite intrusion occurs over an area of about 1 sq. mile (2·6 km.^{2}) on the south-west flank of Sjögren Glacier at the southern margin of the igneous complex. The contact with the Trinity Peninsula Series is gradational and the tonalite contains numerous strongly orientated and partially digested metasedimentary xenoliths. There is also a strong planar parallelism of the hornblende and plagioclase crystals. A thin section of specimen D.3981.1 shows a hypidiomorphic granular texture with plagioclase (An_{35-45}) showing oscillatory zoning, and hornblende associated with small amounts of epidote, as the most prominent minerals. Quartz is mainly interstitial, though it amounts to 17·2 per cent of the mode.

b. *Undifferentiated granitic rocks*. West of the tonalite intrusion, and separated from it by a narrow belt of country rock, there is an extensive zone of undifferentiated granitic rock forming the high ridges and shear walls flanking Mount Hornsby. In the southern part of this zone the rock is an undifferentiated pink biotite-granite or adamellite with a few small xenoliths and a homogeneous appearance. However, farther to the north, the undifferentiated granite becomes increasingly variable, richer in xenoliths and large irregular rafts of metasedimentary and amphibolitic rock (Plate IIc). This variable zone probably extends westwards to form the head walls of Eliason and Polaris Glaciers.

The rafts of metasedimentary rocks are characterized by the presence of relict sedimentary banding but the more irregularly shaped amphibolitic rafts appear to be structureless, suggesting a possible igneous origin. A thin section from a specimen of amphibolite (D.3966.1) contains about 70 per cent of hornblende and 20 per cent of strongly zoned plagioclase with highly sericitized cores. Some of the hornblende is also markedly zoned. Three other specimens from different rafts appear to contain less hornblende (40–60 per cent) and in the hand specimen they more closely resemble the earlier Andean tonalites from which they may have been derived.

Xenolith-rich, undifferentiated granitic rocks exposed round the eastern walls of the great upper amphitheatre of Sjögren Glacier also belong to the variable zone. The rock types range from granodiorite (D.3983.1) to potassic granite (D.3974.1). In thin section the granodiorite has a hypidiomorphic granular texture with hornblende (pleochroism α' = pale brownish yellow, β' = brownish green, γ' = olive-green) ophitically enclosing biotite and plagioclase. Some of the plagioclase (An_{33-43}) shows oscillatory zoning and complex twinning. Myrmekite is common at the boundaries between potash feldspar and plagioclase grains. The potassic granite is a coarse-grained leucocratic rock with an abundance of pale grey microperthitic potash feldspar amounting to 63·3 per cent of the mode, but the proportion in the rock as a whole is probably rather less than this.

c. *Granodiorite, adamellite and granite*. Situated to the north of and intruding the undifferentiated granites of the variable zone are granitic rocks which have no rafts and very few xenoliths; they were classified as homogeneous pink biotite-granites in the field. However, an examination of three representative thin sections (D.3967.1, 3971.1, 3975.1) reveals mineral compositions ranging from those of granodiorite to granite (Table V). Specimens D.3967.1 and 3975.1 are from the central part of the intrusion and are regarded as reasonably representative of the intrusion as a whole. They are medium- to coarse-grained rocks with visible pink potash feldspar. It is microperthitic with albite forming very fine parallel lamellae as well as broader and more irregular cross veins. These homogeneous granitic rocks are the youngest of the igneous complex.

d. *Associated minor intrusions*. Within the intrusive complex are dykes, including aplite, pegmatite, microgranite and microdiorite, which are largely inaccessible (Plate IIc) and have not been studied in detail, except for one unusual dyke of "quartz-plagioclase-porphyry" which has a width of about 750 ft. (228 m.). This rock is normally light grey in colour but it becomes dark brown in the chilled marginal zone. Flow-banding and small streaked-out schlieren composed of partially re-mobilized granitic xenoliths are abundant, particularly near the dyke margins.

Phenocrysts are small and dispersed, and consist mainly of clouded plagioclase with a vague twinning and a probable soda-oligoclase composition, quartz showing partial resorption and a few relict biotite crystals. The quartzo-feldspathic groundmass has a very fine granular texture.

The intrusion of this dyke was probably accompanied by faulting, because there is a wide zone of breccia at the margins in which corroded blocks of "porphyry" occur in a feldspathic matrix. On the south side of the dyke, beyond the zone of crush breccia, is a very coarse granite with large zoned plagioclase phenocrysts over 2 in. (5 cm.) long. This granite becomes progressively finer until about 300 ft. (91 m.) from the dyke margin the normal homogeneous type of granite is present. On the north side of the dyke the little granite that is exposed is also somewhat shattered with fine black net veins very rich in magnetite.

A dyke of labradorite-microdiorite, which intrudes granite at the end of the long south-west ridge of Mount Hornsby (D.4286), is of some importance because the rock shows close similarities to a dyke intruding the Trinity Peninsula Series near the junction of Shortcut Col and Sjögren Glacier (D.3960). These two dykes are quite different from the orthopyroxene-microdiorites of Jurassic affinity (p. 15). The rock is fine- to medium-grained and it is distinguished in thin section by an abundance of subhedral to anhedral hornblende and by the more calcic composition of the plagioclase (labradorite). The pleochroism of the hornblende is from pale brownish yellow to grey-brown.

4. *Granite north-east of Mount Tucker*

A small stock of biotite-granite is exposed over an area of about 2 sq. miles (5·2 km.^{2}) 4 miles (6·4 km.) north-east of Mount Tucker (Map 3). The contact with the Trinity Peninsula Series metasediments is exposed at the north-eastern margin of the intrusion (D.3951), where it is sharp and regular, dipping to the north-east at about 30°. The granite is rich in pink microperthitic potash feldspar and has a homogeneous appearance. Xenoliths are small and scarce. However, the marginal zone of the granite is richer in quartz and poorer in biotite than the central part of the intrusion.

5. *Minor intrusions*

Only two other possible representatives of the Andean Intrusive Suite have been mapped apart from the major plutonic intrusions described above. These are two dykes, one of alkali-granite and the other of quartz-microdiorite. The possible affinity of these rocks with the Andean Intrusive Suite is based more on their grain-size and general appearance than on any mineralogical similarity.

The quartz-microdiorite (D.3911.2) forms a dyke 8 ft. (2·4 m.) wide crossing the nunatak north-west of Tower Peak. The rock is grey in colour and contains conspicuous dark xenoliths. Though it has a medium-grained appearance, thin-section examination shows it to have a porphyritic texture with abundant phenocrysts of sericitized oligoclase and chlorite/calcite pseudomorphs after (?) hornblende. The groundmass is fine-grained and of an indeterminate quartzo-feldspathic composition, containing irregular aggregates of chlorite and calcite.

The alkali-granite forms a dyke of unknown width in Trinity Peninsula Series metasediments 8 miles (12·9 km.) north-east of Tower Peak (D.3896.1). Its mineral composition is unique in this area of Graham Land. A specimen (D.3896.1) is medium-grained, pinkish grey in colour and has a porphyritic texture with phenocrysts of pink potash feldspar up to 1·0 cm. in length. The potash feldspar phenocrysts are microperthitic and show Carlsbad twinning and highly altered margins. The groundmass consists of a fine- to medium-grained granular mosaic of quartz, clouded potash feldspar and albite. Two unusual ferromagnesian minerals, riebeckite and aegirine, form dispersed aggregates or single anhedral crystals poekilitically enclosing subhedral feldspar crystals. These two minerals show a complex spongy intergrowth and appear to have the same maximum extinction angle of 0–5°. The riebeckite pleochroism is from pale purplish brown to very dark brownish purple and that of the aegirine is light yellowish green to bright green. Iron ore and a few subhedral epidote crystals are associated with the riebeckite-aegirine aggregates.

E. James Ross Island Volcanic Group

1. *Outliers in Broad Valley*

Two isolated nunataks, Cain and Abel Nunataks, are situated on the south side of Broad Valley and, although only Cain Nunatak is accessible, it is probable that both are formed of rocks of the James Ross Island Volcanic Group. These two outliers are the only exposures of these volcanic rocks on the mainland of Graham Land, apart from those on Tabarin Peninsula north-east of Duse Bay. Specimens from Cain Nunatak have been identified by P. H. H. Nelson (personal communication) as palagonite-tuffs and breccias formed from olivine-basalt, and they are similar to those forming thick sequences on the nearby islands in Prince Gustav Channel and the James Ross Island group which could be of Middle to Upper Miocene age. The total thickness exposed at Cain Nunatak is about 900 ft. (274 m.); most of the upper part of the succession shows conspicuous bedding (Plate IId) which is apparently absent in the lower part.

2. *Associated minor intrusions*

Nine dykes of olivine-dolerite were mapped in this area. They generally trend in a direction approximately parallel to Prince Gustav Channel. Their mineral composition and texture show a very close similarity to hypabyssal rocks associated with the James Ross Island Volcanic Group in the type area. These rocks are dark grey in colour, and several specimens are porphyritic with plagioclase phenocrysts up to 9·0 mm. in length. The plagioclase is always labradorite (An_{58-66}), showing slight marginal zoning and, in some cases, partial replacement by calcite. Labradorite also occurs as corroded xenocrysts (Plate VIIIc). In the groundmass the labradorite has a subophitic textural relationship with titanaugite which generally occurs as long subhedral or anhedral crystals showing the characteristic pale purplish brown colour and slight pleochroism. In the finer-grained rocks such as specimen D.3880.2 (Plate VIIIc) the titanaugite is barely distinguishable in the brown cryptocrystalline groundmass. No fresh olivine has been recorded in these dykes but pseudomorphs of brownish or green (?) serpentine and calcite are common. Amygdales of chlorite and calcite are abundant in some of the dykes, and irregular granules of iron ore are generally dispersed throughout the rock. Some of the more altered dykes are highly carbonatized.

F. Other Rocks

1. *View Point grit*

The only other consolidated deposit occurs on the edge of an elevated platform, 400 ft. (122 m.) above sea-level at View Point (D.3818). This deposit consists of a tiny patch of unfossiliferous, poorly consolidated conglomerate about 12 ft. (3·6 m.) thick, lying horizontally on steeply dipping beds of the Trinity Peninsula Series. Pebbles in the conglomerate are exclusively derived from the underlying rocks and the only deduction that can be made about its age is that it must be younger than the Trinity Peninsula Series.

2. *Dykes of uncertain affinity*

A few dykes have been mapped which have either not been sampled or which in two instances, from Corner Peak (D.3840.2) and 10 miles (16 km.) north-east of Tower Peak (D.3881.1), show no similarity to the main groups described above.

Specimen D.3840.2 is a fine-grained greyish green microdiorite consisting essentially of randomly orientated laths of soda-oligoclase showing a coarse felted texture with some interstitial quartz and abundant chlorite and calcite. In addition, there are small aggregates of leucoxene and dispersed subhedral crystals of epidote. Specimen D.3881.1 is a light grey "porphyry" with abundant pale yellow phenocrysts of potash feldspar up to 7·0 mm. long in the form of patch microperthite containing aggregates of haematite in a few cases. The groundmass is trachytic and formed mainly of albite laths with interstitial quartz.

III. TRINITY PENINSULA SERIES

A. Conglomerates and Pebbly Mudstones

Rudaceous rocks are not common in the Trinity Peninsula Series but a special study has been made of those that are present, because they indicate some of the main rock types that occurred in the source area. Moreover, they are themselves unusual deposits, the mode of deposition of which is not very well understood.

1. *Conglomerates*

Conglomerates, containing phenoclasts of several different rock types, are exposed in the View Point area, at a knoll below the south-east face of Mount Bradley (D.3660) and on a hill 7 miles (11·3 km.)

north of Longing Gap (D.3881). The conglomerate from the last locality is poorly exposed and, because only one specimen was collected, it is dealt with briefly here. It is interbedded with contorted grey phyllites and metagreywackes, and the rocks are in general strongly sheared, veined and encrusted with quartz and calcite, obscuring the bedding and field relationships.

In the hand specimen (D.3881.1) all size grades are present, from granules to pebbles with a maximum diameter of 5 cm., and this size range appeared to be typical of the rock as a whole. The phenoclasts are flattened and they generally have a rounded oval shape with a strong orientation parallel to the cleavage. At least part of this orientation must be due to rotation under shearing stress. The matrix, which comprises 30–40 per cent of the rock, consists of dark, strongly sheared, chloritic phyllite with silty bands and dispersed silt-sized quartz grains, indicating that it was originally silty muddy material. The phenoclasts include a higher estimated proportion (76 per cent) of mainly acid volcanic rocks than any other rudaceous rocks from the Trinity Peninsula Series (Table VI). The predominantly volcanic

TABLE VI

PHENOCLAST AND ROCK FRAGMENT CONTENTS OF SOME RUDACEOUS AND ARENACEOUS ROCKS FROM THE TRINITY PENINSULA SERIES

(Expressed as percentages of the total number of phenoclasts or rock fragments counted in each rock or group of rocks)

Rock Type	1*	2†	3†	4†	5†	6†	7†	8†	9†
Sedimentary	55·6	26·8	12·0	33·4	31·4	43·3	11·0	11·7	46·9
Low-grade metamorphic	4·3	12·2	10·0	—	20·0	17·4	8·7	11·6	9·2
Volcanic (mainly rhyolites and acid porphyries)	35·7	48·8	76·0	66·6	45·7	26·1	45·5	51·1	28·8
Plutonic and medium- to high-grade metamorphic (mainly granitic)	4·4	12·2	2·0	—	2·9	13·2	34·8	25·6	15·1
Actual number of phenoclasts counted	115	41	50	6	105	23			
Actual number of thin sections examined		8	2	1	3	3	9	2	4

* From a polished specimen.
† From thin sections.

1. View Point conglomerate (D.3820.4).
2. View Point conglomerate, stations D.3820 and 3877.
3. Metaconglomerate, near Longing Gap (D.3881).
4. Metaconglomerate, Mount Bradley (D.3660).
5. Pebbly mudstones, near Benz Col (D.3801 and 4276).
6. Pebbly mudstones, north side of Cugnot Ice Piedmont (D.3808).
7. Greywackes from 9 stations in the Laclavère Plateau area.
8. Greywackes from 2 stations on the north-west side of Cugnot Ice Piedmont.
9. Greywackes from 4 stations in the area between Jade Point and Russell East Glacier.

provenance is also indicated by the high chlorite content of the other metasediments in this area. However, no phenoclasts have been recorded which show any definite resemblance to the greenschists which also occur locally (p. 42). The very angular dark shale and mudstone fragments (now represented by phyllite) that are characteristic of Trinity Peninsula Series conglomerates and greywackes are also prominent in this rock, and it is possible that all these rocks had a common mode of origin (p. 26).

The Mount Bradley conglomerate is even more sheared and stretched but again the phenoclasts appear to be predominantly of acid volcanic rock types. The field relations are obscure, particularly as most of the non-plutonic rocks in this area belong to the banded hornfelses (p. 48).

The conglomerates in the View Point area (D.3820, 3877) have suffered less metamorphism than those described above and they are fairly well exposed.

a. *Field relations*. At station D.3820 conglomerates occur in a cliff section 40 ft. (12·2 m.) high. They form well-defined beds, which in the limited area of the exposure are remarkably thin (3–20 ft.; 0·9–6·1 m.) and persistent but they have not been traced outside the View Point area. Beds of characteristic Trinity Peninsula Series sandstones and argillaceous rocks occur in the same sequence as the conglomerates.

At station D.3877 the rocks are very broken and no bedding was observed. From the general strike direction it seems likely that they are part of the same horizon as the conglomerates at station D.3820, 2·5 miles (4 km.) to the west.

b. *Lithology*. Like all the arenaceous and rudaceous rocks of the Trinity Peninsula Series, this conglomerate is well-indurated and mechanical separation of the phenoclasts is too difficult to attempt. The following description, therefore, is based on polished and thin-section examination.

Phenoclasts comprise about 85–90 per cent of the rock, while the remaining 10–15 per cent consists of a sandstone matrix with a greywacke composition. This high proportion of phenoclasts reflects their broad size range, poor sorting and the fact that most of them are in partial contact with each other (Plate IIIa). The interstices between the larger pebbles are occupied by small pebbles and their interstices are in turn occupied by granules and sand in a siliceous muddy matrix. Despite the poor sorting, there is a distinct size grading in several beds and in the largest hand specimen (D.3820.4). Though the size range is broad, no phenoclasts over 30 cm. in diameter were seen and the average size appeared to be between 10 and 15 mm. As well as grading, there is a distinct preferred orientation of the long axes of the phenoclasts sub-parallel to the bedding. The rock is also cut by numerous quartz veinlets, and where they cross phenoclasts the two halves show relative displacement indicative of shear.

Pebble counts and roundness estimates from thin and polished sections are shown in Table VII. Roundness was estimated visually from Powers's photographic chart (Folk, 1959, p. 156). Field observations

TABLE VII

PEBBLE COUNT FROM A POLISHED SPECIMEN AND THIN SECTIONS OF VIEW POINT CONGLOMERATE

Lithology	*Actual Totals*						
	Well-rounded	*Rounded*	*Sub-rounded*	*Sub-angular*	*Angular*	*Very angular*	TOTAL
Granite, granite-gneiss and *para*gneiss	2	4	3	1			10
Rhyolites, acid porphyries and associated pyroclastic rocks	2	14	13	6			35
Sandstones and siltstone, mainly quartzite or subarkose	1	23	26	5			55
Schist and low-grade metamorphic rocks		6	3	1			10
Coarse dark tuff		4	4	8			16
Mudstone		1	2	4	2	1	10
Black shale or phyllite			1	1		8	10
Porphyritic or trachytic lavas and hypabyssal rocks		3	3	2	1	1	10
TOTAL	5	55	55	28	3	10	156

show that granitic rocks constitute most of the cobble-sized phenoclasts and therefore the comparative scarcity of these rocks in the pebble counts is misleading. The majority of the phenoclasts, including granites and gneisses, rhyolites and quartzites and subarkoses, are either rounded or sub-rounded. In contrast, black shale or phyllite phenoclasts are usually very angular. This difference in roundness reflects a difference in the source of the phenoclasts (p. 35).

c. *Petrography*

i. *Quartz overgrowths.* Most of the rounded and sub-rounded phenoclasts have narrow overgrowths of quartz around their margins. Where they are not present, the rock is generally one that is poor in quartz, such as a phyllite. Where phenoclasts have been sheared, the margin is irregular and overgrowths are not present. Similar overgrowths have formed round many quartz grains in the sandstone matrix and in some cases the overgrowth of a phenoclast is in optical continuity with that of an adjacent quartz grain, strongly suggesting a post-depositional origin for this feature. However, the overgrowths are sheared and cut by quartz veins; if they are post-depositional, they probably formed during the initial induration of the sediment. Another curious feature is that where the quartz overgrowth is adjacent to the matrix of the sandstone matrix, some of this matrix occurs between the overgrowth and the host phenoclast. No examples of this overgrowth phenomenon have been noted by the author in other conglomerates.

ii. *Matrix.* The sandstone matrix of these conglomerates is apparently similar both in composition and texture to that of the local greywacke sandstones. The estimated mineralogical composition of the matrix in one specimen of conglomerate (D.3877.3) is given in Table IX and shows that it is the equivalent of a quartz-rich feldspathic greywacke. An unusual feature of this specimen is the high proportion of garnet among the heavy minerals (Table X), but the garnet has the same appearance as that commonly present in the greywackes (p. 34). None of the phenoclasts contains garnet and therefore its origin remains uncertain. Another similarity with the greywackes is in the degree of sorting of the sandstone matrix; this conglomerate probably has at least three modes in its size distribution curve but a complete estimate of the size distribution cannot be obtained from thin-section analysis. The fine matrix of the sandstone matrix appears to be richer in leucoxene and chlorite at the expense of sericite compared with the greywacke matrices.

d. *Phenoclasts.* Although little is known of the palaeogeography of the source area, the composition of some of the source rocks has been determined by petrographical examination of the phenoclasts from the conglomerates, and of mineral grains and rock fragments from the sandstones. These phenoclasts are described below.

i. *Granite-gneiss.* Modal analyses of four phenoclasts show that they have a mineral composition equivalent to that of granite (Table VIII). Potash feldspar is absent from one specimen (D.3877.5) and the composition is probably very unusual. However, this phenoclast is only about 20 mm. in diameter and therefore it may not be truly representative of the rock from which it was derived.

Most of the quartz in the granite-gneisses shows strongly undulose to semi-composite extinction, and abundant inclusions (mainly vacuoles) are either irregularly dispersed throughout the mineral or arranged in trains (Plate VIIId). A subordinate type of recrystallized quartz which shows slightly undulose extinction and fewer inclusions is common in small amounts. Intergranular boundaries between quartz grains are sutured and irregular, indicating recrystallization accompanied by shear. However, the most important metamorphic feature of these rocks is the presence of interlobate margins between the quartz and feldspar.

In addition, discrete blebs of quartz are common in both potash feldspar and plagioclase, and it is clear that there has been replacement of feldspar by quartz (Plate VIIId). This feature is common in granite-gneisses of the Basement Complex in the Neny Fjord area of Marguerite Bay (Hoskins, 1963, p. 36).

Quartz showing strain lamellae, which is often present in the sandstones of the Trinity Peninsula Series (Plate IXb), occurs in one of the granite-gneisses (D.3877.6b).

Potash feldspar in the form of patch microperthite is present in three of the specimens. The patches are irregular and consist of albite which has partially or completely replaced the potash feldspar. Calcite is often associated with both types of feldspar. In specimen D.3820.1b some of the microperthitic potash feldspar is microcline, showing very fine cross-hatched twinning. The absence of potash feldspar in specimen D.3877.5 may be accounted for by its complete replacement by albite.

TABLE VIII

MODAL ANALYSES OF GRANITE-GNEISSES FROM VIEW POINT CONGLOMERATES COMPARED WITH THOSE OF SIMILAR ROCKS FROM THE BASEMENT COMPLEX AND ORFORD CLIFF SUITE OF SOUTH-WEST GRAHAM LAND

	View Point Conglomerates				*South-west Graham Land*		
	D.3820.1(a)	D.3820.1(b)	D.3877.5*	D.3877.6	E.1553.1	Y.617.6	W.310.1
Quartz	32·1	41·4	45–50	47·3	33·2	45·7	36·7
Potash feldspar	7·1	12·1	—	25·2	31·4	22·0	45·8
Plagioclase	50·4	43·5	45–50	21·2	32·1	27·1	15·2
Biotite / Chlorite	8·1	1·7	5	2·8	2·0	4·3	1·5
Accessory minerals	3·3	1·3	†	3·5	1·3	0·9	0·8
Average plagioclase composition	An_9	An_8	albite	An_8	An_{15}	An_{32}	An_{32}

* Visual estimation.
† Present but not recorded.

E.1553.1 Pink granite-gneiss, eastern side of Roman Four Promontory (Hoskins, 1963, p. 25).
Y. 617.6 Granite-gneiss, east end of Brian Island, Debenham Islands (Hoskins, 1963, p. 25).
W.310.1 Granite, 1·5 miles (2·4 km.) east-south-east of Orford Cliff (Goldring, 1962, p. 11).

Plagioclase occurs in the following main forms:

i. Small to very large anhedral grains with abundant inclusions of sericite flakes. Twinning varies from a weak to strong development of albite and occasionally Carlsbad and pericline twins. Polysynthetic twinning with bending and fracturing of the twin lamellae is common (p. 32). A composition of An_8 has been measured in several grains.
ii. Chequer-board albite occurring in relatively small grains less than 0·5 mm. in diameter. Often the chequer-board albite is surrounded by untwinned albite, suggesting only partial replacement by the chequer-board form.
iii. Relatively small grains of albite containing few inclusions and with strong albite twinning. This albite appears to replace potash feldspar and may also be converted to the chequer-board form.

The last two forms comprise only a small proportion of the total feldspar content. A little calcite is generally associated with the feldspar. Zoning is rare and, when it is present, it is only slightly developed.

The main ferromagnesian mineral in all the granite-gneisses is biotite, which is often partially to completely chloritized. The biotite occurs as irregular aggregates containing inclusions of leucoxene and occasional subhedral zircon.

Accessory minerals are few, both in amount and variety. Leucoxene, zircon and calcite are common, while in specimen D.3820.1a altered amphibole and sphene have been recorded. Leucoxene occurs both along the cleavages and around the margins of the chloritized biotite. A little pyrite is also generally present.

Four features of these granite-gneisses suggest that a tentative correlation might be made with those of the Basement Complex of the Marguerite Bay area:

i. Replacement of feldspar by quartz.
ii. Replacement of plagioclase by potash feldspar.
iii. The presence of rims of clear albite round sericitized and slightly more calcic plagioclase adjacent to potash feldspar.
iv. Fractured and bent polysynthetic albite twin lamellae in plagioclase.

However, antiperthitic plagioclase, which is a very common feature of the Basement Complex gneisses, is absent from these rocks. Another difference is that the replacement of potash feldspar by albite and its subsequent conversion to chequer-board albite has not been recorded in the Basement Complex. Published modal analyses also show a consistently higher proportion of potash feldspar (Table VIII).

ii. *Paragneiss.* One specimen (D.3820.3) contains a small fragment (2·5 mm. in diameter) of a fine-grained rock consisting of about 65 per cent of (?) albite, 30 per cent of chlorite and a little quartz. The (?) albite has a markedly lower refractive index than the interstitial quartz and it occurs as subidioblastic crystals showing Carlsbad twinning and dusty alteration. Two types of chlorite are present, one of which is chloritized biotite, similar to that of the granite-gneisses, except that it encloses rounded crystals of (?) albite. Most of the chlorite belongs to a paler green variety occurring in rounded aggregations enclosing (?) albite crystals, or as narrow interstitial patches between the plagioclase crystals. The mineralogy and texture of this rock suggest that it is a *para*gneiss.

Petrographical examination of sand grains and rock fragments in the greywacke sandstones reveals many minerals which are clearly derived from granite-gneisses similar to those in the View Point conglomerates. This is particularly true of the more feldspathic greywackes which occur north of Cugnot Ice Piedmont.

iii. *Alkali-rhyolites and associated pyroclastic rocks.* Sub-rounded to well-rounded phenoclasts of acid volcanic rocks are abundant in the conglomerates. Fragments and mineral grains, clearly derived from a similar source, are also abundant in the sandstones (Tables VI and XI).

These volcanic rocks fall into four main categories:

- i. Alkali-rhyolites.
- ii. Porphyritic alkali-rhyolites.
- iii. Rhyolitic vitric and crystal tuffs.
- iv. Volcanic sandstones.

In the hand specimen the alkali-rhyolites are pale green and translucent. In thin section they consist mainly of a very fine-grained intergrowth of quartz and plagioclase, with varying amounts of chlorite and leucoxene, forming scattered aggregations. Also, tiny cubes of pyrite are often present. The plagioclase has a refractive index less than that of quartz and generally very near that of Canada balsam; it is therefore albite or soda-oligoclase. The plagioclase often contains tiny specks of sericite and it occasionally shows poorly developed twinning.

Subhedral phenocrysts of sodic plagioclase are present in most of the rhyolites and they show a moderate to heavy degree of alteration (Plate VIIIf). Some of the larger phenocrysts have secondary rims of relatively unaltered, slightly more sodic plagioclase. Quartz phenocrysts are less common. They generally have a characteristically rounded and corroded appearance, show straight extinction and contain few inclusions.

Flow-banding is present in one thin section, while others have a tuffaceous texture in reflected light, which reveals the outlines of devitrified glass shards, and other vitric and crystalline tuffaceous debris. It is clear that a certain amount of devitrification and recrystallization has taken place in these rocks, but it is not certain whether this occurred before or after deposition of the present rocks. Small amounts of muscovite, calcite and zircon are also present in these rocks.

iv. *Undifferentiated volcanic or hypabyssal rocks.* Undifferentiated volcanic rocks form a small but distinct group of phenoclasts and fragments. They consist mainly of dark cryptocrystalline lava which often contains microlites or fine-grained laths of plagioclase, together with abundant aggregates of leucoxene. Similar fragments are often found, together with subordinate grains of quartz and plagioclase, in phenoclasts of volcanic sandstone. The matrix of these sandstones is rich in leucoxene. These phenoclasts usually have irregular angular or sub-angular outlines, in contrast to the characteristically rounded shapes of the rhyolites; it is probable that they are the products of volcanic activity which took place within or marginal to the geosyncline.

However, rhyolite fragments are so widespread throughout a great thickness of sediments that they must also, in part at least, represent volcanic activity in the source area during deposition in the geosynclinal basin.

v. *Quartzite and subarkose.* Sub-rounded to well-rounded quartz-rich sandstones and siltstones are probably even more abundant than rhyolites in the View Point conglomerates. The quartz, which has a range of about 70–90 per cent in these rocks, generally occurs as sub-rounded to rounded grains with secondary overgrowths, strongly undulose extinction and inclusions in the form of trains of vacuoles. In one specimen about 25 per cent of the quartz grains show strain lamellae of the type found in quartz of the Trinity Peninsula Series greywackes (Plate IXb). The other major constituent of these rocks is potash feldspar, which is conspicuous in thin section because of its strong relief and slight dustiness (Plate VIIIe). A few grains show microcline cross-hatching but microperthites are absent.

The heavy mineral suite appears to be limited to rounded tourmaline, sub-rounded zircon and sphene associated with scattered aggregates of leucoxene. A little haematite is generally also present. A recrystallized matrix with chlorite and sub-parallel sericite flakes occurs in varying proportions up to about 15 per cent.

These sandstones are mature compared with the Trinity Peninsula Series greywackes and were probably deposited under relatively stable conditions. They were also subjected to low-grade regional metamorphism prior to their erosion and re-deposition.

vi. *Schists.* Schist phenoclasts and fragments are scarce in the conglomerates and sandstones, and only one specimen has been examined in thin section. It consists of discontinuous, fine alternating bands of muscovite and a finely granular, grey-polarizing indeterminate mineral. It is possible that these schists represent the argillaceous parts of the metasedimentary succession to which the quartzites and subarkoses belong. Their comparative rarity may be due either to a rarity in the source area or to their low resistance to mechanical break-down during erosion and transport.

vii. *Other sedimentary rocks.* In this category are included a relatively small number of dark, very angular, argillaceous fragments, together with siltstones and greywackes. These rocks were probably derived from previously deposited Trinity Peninsula Series sediments, eroded within the geosyncline, because they have a close mineralogical similarity to these sediments and also a low degree of roundness. Dark shale fragments are a characteristic feature of graded greywackes of the Trinity Peninsula Series and of turbidites in general.

e. *Mode of deposition.* Before discussing the way in which these conglomerates might have been deposited, it is useful to summarize the facts concerning them.

i. The conglomerates form part of a very thick sequence of flysch-like deposits, consisting of well-bedded greywacke sandstones and siltstones, alternating with dark grey shales or phyllites.
ii. Many of the associated sandstone beds are graded.
iii. The conglomerates are partially graded.
iv. No unconformity or disconformity is associated with these deposits.
v. The phenoclasts are rounded or sub-rounded, poorly sorted and of widely differing rock types.
vi. The matrix consists of a sandstone which has a similar texture and composition to the local greywacke sandstones.
vii. The conglomerate contains very angular dark shale or phyllite fragments which commonly occur in the basal parts of local graded greywacke beds (Plate IXa).

This conglomerate, and those from stations D.3660 and 3881, 45 and 75 miles (72 and 121 km.) to the south-west respectively, are unique rock types in a very thick geosynclinal succession and they were undoubtedly formed under an unusual set of circumstances. The phenoclasts probably represent re-deposited sedimentary material, because they could only have reached their present degree of roundness by stream or beach transport and abrasion, and there is no evidence that any of the Trinity Peninsula Series rocks were deposited in such environments. The greywacke sandstones with which the conglomerates are associated show evidence that they were deposited by turbidity currents. In the author's opinion these currents are the only transporting medium with enough power to deposit the varied load of sediment represented by these conglomerates. However, there is no evidence to suggest why conglomerates should be restricted to only a small part of this very thick turbidite succession.

McBride (1962, p. 75) arrived at similar conclusions for the mode of deposition of conglomerates in flysch from the central Appalachians.

On a ridge flanking the western part of Shortcut Col (D.4302), conglomerate beds crop out with a total thickness of about 20 ft. (6·1 m.). These conglomerates contain no quartzite or igneous rocks but they consist of poorly sorted, sub-angular to angular phenoclasts similar in appearance to the metamorphosed sandstones and phyllites of the adjacent beds. The phenoclasts, which comprise about 90 per cent of sandstone and 10 per cent of phyllite, range from granule size to pebbles 30 cm. long. The elongated pebbles show a strong preferred orientation parallel to the bedding surface. The nature of the matrix is obscure owing to metamorphism. In thin section one of the pebbles has the mineralogical composition of a quartz-sericite-metagreywacke and it shows the grade of metamorphism generally present in this area.

The local derivation and angularity of the phenoclasts in this conglomerate suggest that it was formed by brecciation and re-deposition of the local beds before they became fully indurated.

2. *Pebbly mudstones*

a. *General description.* Mudstones are the predominant rock type on the ridges and outlying nunataks beneath the south-east scarp of Louis-Philippe Plateau. In seven localities (D.3639, 3801, 3802, 3808, 3809, 3811, 4276) the mudstones contain dispersed phenoclasts, and are called "pebbly mudstones" (Crowell, 1957, p. 1003).

i. *Field relations.* The nature of the bedding has been seen at only one locality (D.4276), where the pebbly mudstone is interbedded with thin beds of sandstone and siltstone which have been sheared into interlocking lenses by two sets of cleavage planes at a low angle to the bedding planes. The thickness of the beds ranges from 6 in. to 8 ft. (15 cm. to 2·4 m.) but thicknesses greater than this are probably common. At none of the localities where thick beds of pebbly mudstone occur were the underlying strata exposed. However, the overlying shale, thin sandstone and siltstone beds show occasional slight contortion, but no evidence of sub-aqueous slumping, sliding or mass flow was seen. Higher up the succession rhythmically bedded units of sandstone begin to appear (Table II). 2·5 miles (4 km.) east of the easternmost outcrop of pebbly mudstone and at approximately the same horizon there is evidence of slumping and sliding in laminated mudstone. The very finely laminated siliceous bands show broken bedding and small complex folds with disruption along discrete slip planes, suggesting mass gravitational movement in the semi-consolidated state.

It is also possible that the View Point conglomerates are at approximately the same stratigraphic level (Map 2) and that the two conglomeratic types may be genetically related.

ii. *Mudstone matrix.* The mudstone is grey to dark grey in colour, well indurated and possesses a somewhat irregular cleavage which has resulted in the fracturing and disruption of some phenoclasts (Plate IIIb). In thin section the mudstone consists mainly of tiny flakes of sericite and chlorite in a cryptocrystalline siliceous groundmass. Closely spaced shear planes are interlaced throughout the rock except in the more siliceous areas (Plate IIIc). These areas of more silicified mudstone are sometimes in the form of broken and contorted bands but they also occur adjacent to siliceous phenoclasts, illustrating the re-mobilization of silica that is commonly shown by many of the Trinity Peninsula Series sedimentary rocks. Concentrations of indeterminate black dusty material mark the network of cleavage planes. This mudstone, like most other specimens of argillaceous rock from this area, contains many silt-sized quartz and a few feldspar grains, forming the most abundant group of clasts in the rock.

iii. *Phenoclasts.* All size grades ranging from silt-sized grains to small cobbles are present. The largest phenoclast recorded is 20 cm. in diameter but the majority are granule or small pebble size. The shape of these phenoclasts is difficult to estimate, because they have usually been sheared and because the outlines of some of the argillaceous rocks of similar composition to the mudstone are barely distinguishable. If these effects are allowed for, it is probable that many of the phenoclasts were rounded before shearing and induration took place. It is not known if any of the phenoclasts are striated or faceted, since they cannot be separated from the mudstone, but several of the pebbles shown in Plate IIIb appear to have one or two flat faces.

Counts of phenoclasts of coarse sand size and over, in three thin sections from specimens taken from the same outcrop, are given in Table VI where they are compared with other rudaceous rocks from the Trinity Peninsula Series. The most abundant group (45·7 per cent) consists of volcanic rock types comprising mainly rhyolites and acid porphyries. This group is also the first or second in abundance in all other Trinity Peninsula Series rudaceous and psammitic rocks whose phenoclasts or rock fragments have been counted. Sedimentary and low-grade metamorphic rocks form 31·4 and 20·0 per cent, respectively, but the distinction between these two types is not precise, because the pebbly mudstone itself has suffered a very low grade of regional metamorphism. The metamorphic rocks have a quartz-muscovite-chlorite mineral assemblage and they are characterized by the parallel orientation of their flaky minerals, but some of the argillaceous rocks are barely distinguishable from the mudstone matrix. A few of these vaguely defined mudstone phenoclasts have a contorted and squeezed appearance which indicates that they may have been soft at the time of their incorporation into the mudstone matrix. A consideration of these factors suggests that the proportion of phenoclasts derived from older rocks belonging to the Trinity Peninsula Series may be considerably greater than that indicated in Table VI.

b. *Mode of deposition.* The thorough mixing of coarse gravel and mud represented by these pebbly mudstones could have resulted from direct deposition from glacier ice or from sub-aqueous turbidity flow. Although it is possible that the Trinity Peninsula Series was in part deposited during the widespread glaciation which affected all the southern continents during the Permo-Carboniferous, a glacial origin for these pebbly mudstones is considered unlikely, for three reasons. First, no ancient striated pavement is present in this area. Secondly, granules and pebbles occur only in the pebbly mudstone and not in the associated beds of siltstone, shale and sandstone (Pettijohn, 1957, p. 266). Thirdly, no pebbles over 20 cm. have been found. Cobbles and boulders are generally present in glacial till.

The alternative hypothesis of deposition by sub-aqueous turbidity flow is supported by the following facts:

- i. The pebbly mudstones occur in the middle of a sequence of eugeosynclinal deposits with a total thickness of about 45,000 ft. (13,715 m.).
- ii. Thick sequences of graded and non-graded greywackes occur above and below the pebbly mudstone sequence, suggesting a turbidite environment.
- iii. The beds of pebbly mudstone are well-defined, repetitive and often separated by apparently undisturbed thin beds of siltstones.

These and other criteria have been discussed by several authors, including Dott (1961), and Schermerhorn and Stanton (1963). A combination of glacio-marine deposition in some unknown shelf area, followed by turbidity-current transport to the present site, cannot be entirely ruled out, because it is not known whether the pebbles are glacially striated and faceted. The presence, at approximately the same stratigraphic level, of mudstones which have been subjected to sub-aqueous slumping and sliding, together with conglomerates, is also regarded by the author as favouring the turbidity-current hypothesis. The slumped mudstones indicate gravitational instability while the conglomerates provide another example of the transport of extra-basinal sand and gravel into a turbidite environment.

The pebbly mudstone at station D.3639 differs from the others in that it contains phenoclasts exclusively of greywacke sandstones and siltstones identical to those found locally. Though neither the top nor the bottom of this bed has been seen, it appears to be at least 100 ft. (30·5 m.) thick without any obvious bedding or lamination structure within it. The phenoclasts range in size and lithology from greywacke cobbles up to 4 ft. (1·2 m.) across to sand-sized grains of silty mudstone. Their shapes are somewhat flattened and oval, but they have clearly been modified by strong shearing of the surrounding mudstone (Plate IIId).

In thin section the dark grey mudstone contains vaguely defined contorted silty laminae and discrete phenoclasts. The phenoclasts are irregular in shape and show evidence of abrasion within the rock by relative movement of the surrounding mud which appears to have penetrated cracks in the phenoclasts and to have torn off sand and silt grains. There is no evidence that the phenoclasts were abraded by normal agents of subaerial erosion.

It was originally thought that this particular type of pebbly mudstone represented a very advanced stage of boudinage structure. However, the evidence from the thin section described above suggests an origin by sub-aqueous plastic mass flow of an unlithified mud containing thin beds and laminae of sand and silt.

B. Sandstones

Throughout north-east Graham Land most of the Trinity Peninsula Series rocks have been subjected to varying degrees of metamorphism (p. 40). The sedimentary features of those rocks least affected by metamorphism are described in the next three sections. Even in cases where the rocks have a low grade of metamorphism, sedimentary rock terms are used in order to emphasize the original lithology.

Sandstones and their more common siltstone equivalents (p. 36) comprise about half the total thickness of the Trinity Peninsula Series, though this proportion varies widely from one area to another. Mineralogical modal analyses of 23 specimens of sandstone from the area north-east of Russell East Glacier show variations in composition which coincide with the stratigraphical sub-divisions within this area (Fig. 3). Since these sandstones all have over 15 per cent of detrital matrix, they are classified

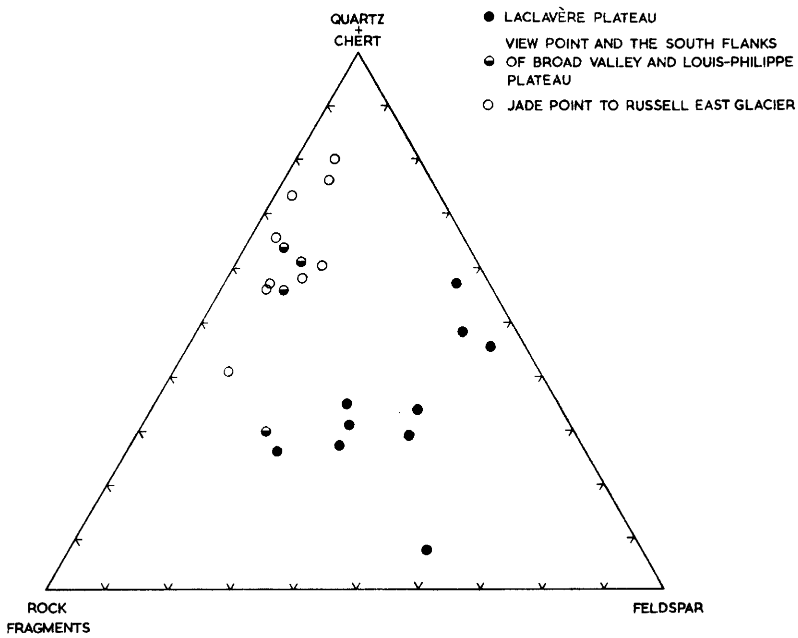

FIGURE 3

Estimated mineralogical compositions of 23 specimens of sandstone from the Trinity Peninsula Series.

as greywackes (Pettijohn, 1957, p. 291). The arbitrary upper size limit for the detrital matrix is taken as 0·03 mm. The modal analyses are set out in Table IX.

The greywackes are very poorly sorted sandstones when both the matrix and the sand-sized fraction are taken into account. The histograms in Fig. 4 give a visual picture rather than a quantitative measure of sorting but they show clearly that the size distribution is characteristically bimodal and that even in the sand-sized fraction the degree of sorting is only fair to poor.

1. *Regional characteristics*

The sandstones in the three main areas least affected by metamorphism (Fig. 1, areas I, II and III) are compared below.

a. *Laclavère Plateau.* Greywackes are the predominant rock type in this area and they usually occur as graded beds alternating with thin shales. The greywackes are generally grey in colour, weather to grey-brown and commonly contain conspicuous fragments of shale, especially near the base of graded beds.

In thin section the greywacke shows the characteristic moderate to poor sorting and a predominance of angular to very angular grains (Plate IXc). The average composition of 10 greywacke specimens from this area is that of a feldspathic greywacke with 21·5 per cent of quartz, 26·8 per cent of feldspar, 17·3 per cent of rock fragments and 31·3 per cent of detrital matrix. Six out of the 10 specimens are feldspathic greywackes (feldspar > rock fragments) and the rest are lithic greywackes (Pettijohn, 1957, p. 291). The relatively high feldspar and low quartz contents distinguish these greywackes from others which have been analysed from this area.

b. *View Point–Louis-Philippe Plateau area.* In this area greywackes and siltstones comprise about one-sixth of the total succession, with siltstones predominating. In contrast to those described above, the greywackes have a more siliceous appearance and they weather a light reddish brown colour.

TABLE IX

MODAL ANALYSES OF GREYWACKE SANDSTONES FROM THE TRINITY PENINSULA SERIES

Area	*Specimen Number*	*Rock Fragments*	*Quartz and Chert*	*Potash Feldspar*	*Plagioclase Feldspar*	*Detrital Matrix*	*Other Minerals*
	D.4417.1†	4·7	25·8	1·3	21·9	45·0	1·2
	D.4415.2	38·1	19·5	7·0	11·6	20·0	3·8
	D.4408.1†	3·8	31·0	1·7	31·9	29·7	1·9
	D.4405.1†	2·7	30·3	2·2	17·8	44·9	2·1
Laclavère	D.4401.1†	15·0	5·5	2·0	44·0	32·4	1·1
	D.3873.1	27·5	18·5	8·0	15·5	28·5	2·0
Plateau	D.3872.1	16·2	22·6	3·2	26·2	25·0	6·8
	D.3824.1	22·5	19·0	5·5	15·5	32·5	5·0
	D.3821.2	22·5	22·5	4·5	16·0	31·5	3·0
	D.3702.1	19·6	20·4	4·0	28·0	23·6	4·4
View Point and the	D.3877.3*	11·0	49·0	5·0	7·0	26·0	2·0
south flanks of	D.3811.1	19·0	40·0	2·2	4·8	33·2	0·8
Broad Valley and	D.3807.2	22·4	46·8	1·0	3·8	25·0	1·0
Louis-Philippe Plateau	D.3701.2	22·6	36·6	1·2	5·6	33·4	0·6
	D.3657.1	35·6	20·8	1·2	13·6	23·6	5·2
	D.3804.1	32·6	25·8	2·2	3·6	34·6	1·2
	D.3646.1	23·2	49·2	1·2	2·0	22·6	1·8
Jade Point	D.3645.1	9·9	55·9	1·4	3·1	29·4	0·3
	D.3644.1	18·6	56·1	1·7	1·6	21·6	0·4
to	D.3641.1	18·8	36·2	0·4	7·2	36·8	0·6
	D.3640.1	17·0	39·6	2·2	7·2	33·0	1·0
Russell East Glacier	D.3639.1	25·8	39·0	5·2	0·2	28·8	1·0
	D.3636.1	11·4	54·2	4·0	2·0	27·4	1·0
	D.3624.1	28·0	41·4	2·4	3·4	24·0	0·8

* Sandstone matrix from View Point conglomerate given for comparison.
† Analysis by D. H. Elliot.

Sorting is characteristically poor but there is a broader range of roundness in the quartz which includes a few sub-rounded grains. Modal analysis of 4 specimens of sandstone shows them to belong to the lithic greywacke class. The average composition is 36·1 per cent of quartz, 8·3 per cent of feldspar, 27·4 per cent of rock fragments and 28·8 per cent of detrital matrix. The relatively low total feldspar and high quartz contents clearly distinguish these lithic greywackes from those of the previous area. However, the predominance of plagioclase over potash feldspar is a common feature in both areas.

c. *Jade Point–Russell East Glacier area.* Over this area as a whole greywackes and siltstones average about one-third of the total thickness. These beds generally weather to a conspicuous light reddish brown colour (Plate VIb), while fresh surfaces have a light grey siliceous appearance.

In thin section quartz grains show an even greater range of roundness than in the previous areas, varying from rounded to very angular. Again, poor sorting is general with an average detrital matrix content of 28·6 per cent from 9 specimens. The average content of the other main constituents is 44·1 per cent of quartz, 5·8 per cent of feldspar and 20·6 per cent of rock fragments. The marked increase in the quartz content at the expense of all other constituents is reflected in the more siliceous appearance of the rock.

d. *Other areas.* In all other areas in which sandstones and siltstones occur (p. 40–42), metamorphic recrystallization of the matrix and the finer clastic grains, together with extensive shearing, precludes any direct mineralogical comparison with the rocks already described. All the sandstones which have been microscopically examined are recognizable as greywackes and they include both lithic and feldspathic varieties. However, regional variations are obscure and no mineralogical correlation has been attempted, though it is clear that, with the exception of the unusually chloritic metagreywackes associated with the greenschists in the Tower Peak area (p. 42), there are no important differences between these greywackes and those already described.

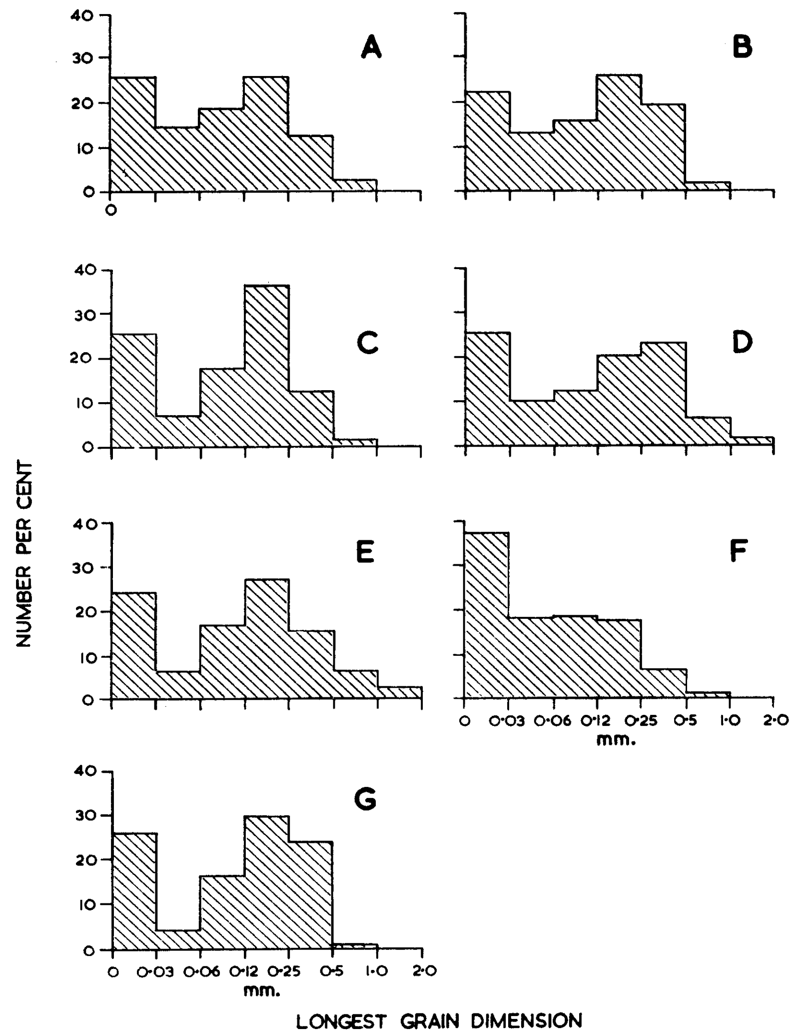

FIGURE 4

Histograms illustrating grain-size distribution in sandstones from the Trinity Peninsula Series. A. D.3872.1; B. D.3702.1; C. D.3807.2; D. D.3657.1; E. D.3646.1; F. D.3641.1; G. D.3877.3 (sandstone matrix of the View Point conglomerate).

2. *Petrography*

The general regional differences in the mineralogical composition of the sandstones are almost certainly paralleled by differences in the detailed mineralogy of individual mineral species. These detailed differences have not been fully worked out. Nonetheless, certain characteristic minerals and rock fragments are recognized throughout the succession and in many cases they can be directly related to the minerals constituting some of the main rock types in the View Point conglomerates (p. 23–26). These minerals and rock fragments are described more fully below.

a. *Mineral grains*. Quartz is the main mineral in the greywackes and siltstones, and its amount is rarely exceeded by any other constituent. The majority of quartz grains show slightly to strongly undulose extinction.* Grains showing semi-composite and straight extinction are occasionally present but grains with composite extinction are rare. Grains showing straight extinction are usually sub-rounded with few inclusions. They appear to be characteristic of the phenocrysts in the type of rhyolite found in the View Point conglomerate.

* The empirical classification of Folk (1959, p. 71) is used for describing the extinction characteristics of quartz; *straight extinction* is the equivalent of uniform extinction.

A distinctive type of quartz showing strain lamellae (Plate IXb) is present in a few grains in many of the greywackes. Most quartz grains contain moderate to large amounts of inclusions, which usually take the form of vacuoles either dispersed or arranged in a linear manner. Sometimes the inclusions are in the form of rutile needles (Plate IXd) but the source of these grains is uncertain. Quartz showing strain or deformation lamellae has been described by Fairbairn (1941) as having an "invariable habitat in non-recrystallized, highly deformed rocks". It is possible that these examples are post-depositional and have formed during regional deformation. However, the present rocks are not "highly deformed" and it is unlikely that only a small proportion of the quartz grains would be affected in such a way. Therefore, this type of quartz probably came from some highly deformed source rock.

Potash feldspar occurs in all the greywackes, the most common types being patch microperthite and vein microperthite. The orthoclase is often dusty with alteration products and the patches and veins of albite are fine and irregular, often comprising only a small part of any particular grain. In a few grains of perthite the albite shows varying degrees of alteration to the chequer-board form (Plate IXc), indicating a possible derivation from gneiss or granite-gneiss (p. 23). Microcline is commonly present but it is subordinate to microperthite and probably has been derived from several different source rocks. Clear untwinned orthoclase is rare in two thin sections stained with potassium cobaltinitrite, suggesting that the error due to misidentification in unstained sections is small.

Numerous varieties of plagioclase occur in the greywackes. However, they have one important common characteristic in that they appear to be invariably sodic. No compositions more calcic than oligoclase have been identified and grains showing zoning are absent. Four varieties of plagioclase are particularly distinctive:

i. Types showing fractured albite and polysynthetic twinning (Plate IXe).
ii. Untwinned or Carlsbad-twinned oligoclase or albite crowded with large inclusions of sericite and clay minerals.
iii. Albite or oligoclase with vaguely defined twin lamellae and dusty inclusions.
iv. Chequer-board albite (Plate IXc).

Features similar to those shown by the first of these plagioclase varieties have been described by Vance (1961, p. 1108) and they are thought to be due to glide twinning resulting from deformation. Again, the question arises as to whether these features are due to deformation in the present rocks or in the source rocks. The author favours the latter explanation for three reasons. First, most of the sandstones in which this variety occurs show no evidence of strong deformation. Secondly, most of the deforming stress would be taken up by the argillaceous rocks and the detrital matrix in the sandstones. Thirdly, deformed plagioclase is well developed in the granites and granite-gneisses of the View Point conglomerate (p. 24).

The third variety of plagioclase is often present as phenocrysts in the rhyolitic rock fragments and phenoclasts, which occur in the sandstones and conglomerates.

Chequer-board albite is a very distinctive mineral and it occurs in many of the greywackes either as discrete grains or as an intergrowth in microperthite. This type of albite has been recorded by many writers and it appears to form mainly by the metasomatic recrystallization of albite in keratophyres or by the alteration of perthite (Deer, Howie and Zussman, 1963, p. 75, 148). A derivation from microperthite is probable in most of the present examples (p. 24).

In the greywackes which have been affected by thermal metamorphism the feldspars are crowded with sericite and other alteration products, and they are distinguished from micaceous rock fragments only by the absence of strong orientation of the micas. The feldspar grains may also be partially replaced by calcite or much less commonly by prehnite.

The estimated percentages of accessory framework constituents are shown together under the heading "others" in Table IX and comprise 0·3–8·5 per cent of the greywackes. The results of counts of heavy minerals in six thin sections of sandstone are given in Table X.

The marked differences in the total amounts of these accessory constituents are directly related to the feldspar content. The estimated heavy mineral content is generally about 1·0 per cent and the other accessory minerals in the feldspathic greywackes are mainly biotite and chlorite. The biotite may be bleached but more commonly it is partially or completely altered to chlorite (pennine) and it occurs in flakes which have been bent and squeezed by contact with the adjacent clastic grains. In specimen

TABLE X

HEAVY MINERALS* IN THIN SECTIONS OF SANDSTONES FROM THE TRINITY PENINSULA SERIES

(Expressed as percentages of the total number of heavy mineral grains counted in each thin section)

	1	2	3	4	5	6	7
Allanite	—	—	3	3	1	1	—
Apatite	7	3	3	14	6	5	—
Epidote	15	30	49	9	1	5	2
Garnet	1	—	—	10	3	7	64
Iron ore	25	24	28	43	53	50	30
Rutile	5	4	2	2	6	8	—
Green spinel	—	—	—	1	—	—	—
Sphene	31	29	13	4	1	6	2
Tourmaline	—	—	—	2	3	6	2
Zircon	16	10	2	12	26	12	—

* Micas and chlorite are excluded from the heavy mineral category.

1. Feldspathic greywacke (D.3872.1), Laclavère Plateau.
2. Feldspathic greywacke (D.3702.1), Laclavère Plateau.
3. Lithic greywacke (D.3657.1), north-west side of Cugnot Ice Piedmont.
4. Quartz-rich lithic greywacke (D.3807.2), north-west side of Cugnot Ice Piedmont.
5. Quartz-rich lithic greywacke (D.3646.1), south-east side of Cugnot Ice Piedmont.
6. Quartz-rich lithic greywacke (D.3641.1), south-east side of Cugnot Ice Piedmont.
7. Sandstone matrix from View Point conglomerate (D.3877.3).

D.4401.1 calcite is an important constituent, forming about 7·0 per cent of the rock. It is uncertain whether this mineral is completely authigenic or partially detrital in origin. Calcite has been found in abundance in only one specimen of metagreywacke (p. 41) and in rare nodules (D.3644.2). No calcite has been recorded in the form of shell fragments or other organic detritus.

Leucoxene is generally the most abundant of the heavy minerals, occurring either as discrete grains or intergranular aggregates. Some leucoxene is associated with chloritized biotite. Pyrite is common in areas of thermal metamorphism but though it is often present in volcanic rock fragments it is rare as discrete detrital grains. The iron ores together with leucoxene are particularly predominant in the feldspar-poor greywackes, comprising about 50 per cent of the heavy mineral content.

The feldspar-rich greywackes also appear to differ from the others in that they are proportionately rich in epidote and sphene, and poor in garnet and tourmaline. The epidote occurs in sub-angular to very angular grains and it probably has a volcanic source judging by its presence in several volcanic rock fragments in the greywackes. The sphene often shows euhedral outlines and it is relatively coarse-grained compared with most of the other heavy minerals, which indicates a plutonic source. A few grains of sphene showing polysynthetic twinning have also been recorded.

Zircon, apatite and rutile are present in all thin sections of greywacke. Zircon occurs in small grains which are well-rounded to angular in shape, suggesting that they were derived from both sedimentary and plutonic source rocks. Apatite also has a varied source, since it has been observed in fragments of both volcanic and plutonic rocks in the greywackes. The rutile grains are mostly small and sub-rounded to well-rounded in shape, indicating a re-worked sedimentary source.

Three other heavy minerals which have been recorded, namely allanite, tourmaline and garnet, are apparently confined mainly to the quartz-rich feldspar-poor greywackes. The allanite is pleochroic from very pale brown to brown or yellowish brown and it occurs in sub-angular to rounded grains. This mineral has not been recorded from any rock fragments or phenoclasts in Trinity Peninsula Series sediments but it is a common accessory mineral in granite-gneisses of the Basement Complex of the Marguerite Bay area (Hoskins, 1963, p. 25). The tourmaline occurs in sub-rounded to well-rounded grains and it is generally bright yellow-brown though rare greenish grey or slate-blue grains have been recorded. The former variety is common in some phenoclasts of quartzite from the View Point conglomerate and this quartzite is probably the main source of the tourmaline. Garnet is the most problematical of all the greywacke constituents, because it has not been recorded from any rock fragment or phenoclast in a Trinity Peninsula Series sedimentary rock, though its most abundant occurrence is in the sandstone matrix of the View Point conglomerate (Table X). In thin section the garnets are up to 0·2 mm. in size, very pale pink in colour and show varying degrees of alteration to chlorite. Many of the least altered garnets are euhedral with only slight rounding of the corners, suggesting derivation from some easily weathered penecontemporaneous rock such as a lava.

b. *Rock fragments.* Rock fragments are generally an important constituent of the greywackes and they apparently increase in quantity with larger grain-size. The coarsest fractions at the bases of graded beds are particularly rich in rock fragments and they could often be described as granule conglomerates. The estimated proportions of the different rock fragments in some of the coarser greywackes are shown in Table XI. Vein quartz is not included as a rock fragment.

It is worth noting that igneous rock fragments comprise an estimated 60–90 per cent of the total rock

TABLE XI

ROCK FRAGMENTS FROM TRINITY PENINSULA SERIES GREYWACKES EXPRESSED AS PERCENTAGE ESTIMATES OF THE TOTAL ROCK FRAGMENT CONTENT

Specimen Number	*Granite and Gneiss*	*Metamorphic Rock Fragments*	*Rhyolitic Lavas and Pyroclastic Rocks*	*Unclassified Lavas and Pyroclastic Rocks*	*(?) Trinity Peninsula Series Rocks*	*Quartzite and Subarkose*
D.4405.1*	55·6	37·0	7·4	—	—	—
D.4408.1*	26·3	2·6	47·4	2·6	21·1	—
D.4415.1	41·5	3·9	10·4	15·6	26·0	2·6
D.4417.1*	40·4	8·5	46·8	4·3	—	—
D.3872.1	48·1	3·7	22·3	18·5	7·4	—
D.3821.1	30·6	11·1	40·2	4·8	2·2	11·1
D.3873.1	27·2	6·0	38·0	18·1	7·2	3·5
D.4401.1*	16·7	1·3	72·7	5·3	4·0	—
D.3824.1	26·7	4·4	35·6	20·0	11·1	2·2
D.3807.2	36·4	6·1	33·3	15·0	6·1	3·1
D.3657.2	14·8	17·0	48·9	4·9	7·1	7·1
D.3646.1	27·5	4·0	18·0	19·5	26·5	4·5
D.3648.1	6·5	6·8	9·7	3·3	66·1	7·6
D.3616.1	16·0	7·5	25·0	14·5	22·0	15·0
D.3624.1	10·5	18·5	14·5	10·5	37·5	8·5

* Analysis by D. H. Elliot.

fragment content in most of the greywackes from the areas north of Cugnot Ice Piedmont. Therefore, according to the widely accepted classification of Folk (1959), these sandstones are mainly arkoses or subarkoses, since his three end members are detrital quartz and chert, metamorphic rock fragments plus micas coarser than 0·03 mm., and feldspar plus igneous rock fragments. According to Folk, the high proportion of detrital matrix is an indication of textural immaturity, which should be separated from the composition name, i.e. immature subarkose. He has regarded metamorphic rock fragments as the main essential constituent of greywackes.

Fragments of granite or granite-gneiss generally consist of quartz intergrown with potash feldspar. No intermediate or basic plutonic rock fragments have been observed in these rocks. Metamorphic rock fragments consist mainly of quartz-muscovite-chlorite-phyllites and schists together with metasiltstones. Apart from gneiss, only low-grade metamorphic rock fragments have been recorded. Quartzite and subarkose fragments, though common in the conglomerates, generally form only a small proportion of these rocks. This is probably because they break down relatively easily into their constituent grains.

Rock fragments closely resembling types found in the Trinity Peninsula Series are common in some of the sandstones. In the granule conglomerate from the base of one graded greywacke bed (D.3648.1) they amount to 66·1 per cent. These penecontemporaneous fragments are mainly of argillaceous rocks. The fragments with a high proportion of dark clay or mud generally show flattening and shearing with the adjacent sand grains protruding into the argillaceous material (Plate IXa). An intra-basinal source is inferred for these fragments, because of their relative angularity and the absence of recrystallization and strong orientation in their micaceous constituents.

Acid lavas and associated tuffs form an important and abundant group of rock fragments. They generally consist of a very fine-grained intergrowth of quartz and feldspar. Phenocrysts of quartz and plagioclase are occasionally present in the larger fragments. The plagioclase, usually oligoclase, shows a characteristic cloudiness and vaguely defined twinning.

Among the undifferentiated lavas, fragments with irregular shapes are common. The predominant types of lava are either dark and cryptocrystalline or possess a distinctive trachytic texture (Plate IXe).

The only other type of rock fragment which has been distinguished in the greywackes is chert. It appears to be present in fairly small amounts but considerable difficulty has been experienced in distinguishing it from very fine-grained non-porphyritic rhyolite. The critical deciding factor is the presence or absence of feldspar. Where marked refractive index differences or vague twinning are present, the rock fragment has been classified as a rhyolite.

c. *Matrix*. The estimated proportion of detrital matrix in the sandstones varies from 20·0 to 47·6 per cent (Table IX). The matrix is somewhat siliceous and in the least altered specimens it appears to consist of cryptocrystalline greenish brown muddy material which is dark polarizing under crossed nicols. Where diagenetic recrystallization of the matrix has taken place to the extent of producing recognizable minerals, it can be seen that the matrix consists predominantly of chlorite, sericite and cryptocrystalline silica. Chlorite is generally the most abundant of these minerals, occurring in minute vermicular or flaky shreds. The matrix is highly chloritic in a few specimens which are rich in detrital chlorite or volcanic rock fragments. Sericite is the predominant matrix mineral in only two specimens, one of which contains more detrital muscovite than is usually present.

In nearly all the thin sections there is a slight to moderate degree of intergrowth between matrix constituents and adjacent quartz or feldspar grains, resulting in the grain boundaries becoming hazy or obscure. This diagenetic encroachment of the matrix is a common feature of indurated greywackes. In rare cases both the matrix and adjacent grains have been indiscriminately replaced by calcite (D.3644.2).

It is generally thought that the matrix constituents of greywackes represent the authigenic re-organization of an original detrital mud (Pettijohn, 1957, p. 306). Cummins (1962) has postulated that much of the fine-grained matrix in greywackes is produced by post-depositional processes involving the break-down of unstable grains and the partial transfer of the products by interstitial water. The only petrographic evidence from the present study which has a bearing on this problem is the presence (amounting to a few cases in each thin section) of unstable grains which have partially or completely disintegrated into muddy cryptocrystalline material that closely resembles the matrix (Plate IXf). However, it is difficult to believe that of the total volume of matrix, often amounting to one-third of the rock, anything but a small fraction could have resulted from these post-depositional processes.

C. Argillaceous and Non-clastic Rocks

Argillaceous rocks are abundant in the Trinity Peninsula Series and they are estimated to comprise one-half to two-thirds of the total succession. Non-clastic sedimentary rocks are represented only by very rare occurrences of chert. The rocks described here are mostly from areas north-east of Russell East Glacier which have been little affected by metamorphism, but there is no doubt that, with the exception of the greenschists, most of the rocks in the areas to the south-west originally had similar lithologies.

The argillaceous and non-clastic rocks have been classified into five distinctive but partially interrelated types which are described below.

1. *Siltstone*

The siltstones are the fine-grained equivalents of the greywacke sandstones and there is a continuous gradation between the two rock types which are often associated with each other within a cyclic sequence (p. 37). Examples of siltstone beds and laminae are shown in Plates Va, b, VIa, c and d. Distinct beds and laminae range in thickness from less than 1·0 cm. up to about 12·0 cm. Beds with a greater thickness than 12·0 cm. appear to be fine sandstones rather than siltstones. Many of the beds appear to be unlaminated but close inspection, particularly of polished sections, suggests that lamination and soft-sediment deformation structures are commonly present. The siltstones closely resemble the associated greywackes both in general appearance and mineralogy, except that they are better sorted and have a lighter colour reflecting their more siliceous composition. These rocks are even more widely distributed than the greywackes and they commonly occur in predominantly shaly sequences and in cyclic units, in which sandstones are thinly developed or entirely absent.

2. *Siliceous mudstone*

The most siliceous clastic rocks are the siliceous mudstones, which are common only in the area south of Cugnot Ice Piedmont. These mudstones are pale green to dark greenish grey in colour and they occur in groups of very thin flaggy beds or in fine laminae intercalated with shale. Individual laminae as thin as 0·3 mm. have been recorded, and separated from adjacent laminae either by a veneer of shale consisting mainly of sericite and chlorite or by a concentration of leucoxene and other heavy mineral grains (Plate Xb). The siliceous mudstone consists of fine silt-sized quartz grains in a siliceous cryptocrystalline matrix with dispersed flakes of sericite and chlorite. Current bedding and soft-sediment deformation are less common than in the siltstones but it is mainly on the soles of these beds that markings of organic origin have been found (Plate IVd). The siliceous mudstones are the fine-grained equivalents of the siltstones and there is probably a genetic relationship between the two rock types.

3. *Dark laminated mudstone*

Dark laminated mudstones occur throughout the succession of the Trinity Peninsula Series. In the field these rocks often have the appearance of dark, indurated, homogeneous blocky mudstones but close inspection of hand specimens and thin sections shows that they consist of two rock types in distinct sedimentation units. These comprise dispersed siltstone laminae within a dark heterogeneous silty mudstone or shale. Some of the mudstones are fissile but the fissility is imparted by weak strain-slip cleavages rather than by the orientation of micaceous constituents resulting from depositional processes. The differences in fissility or cleavage appear to be related to the ratio of silt to clay in the rock.

The clay part of the mudstone is dark polarizing and appears to consist mainly of chlorite and cryptocrystalline silica containing black dusty material. Sericite, in minute orientated flakes averaging about 0·005 mm. in length, is also an essential constituent. The colour of the mudstone ranges from darkish grey to almost black, depending on the amount of quartz and carbonaceous material in the rock. Some dark laminated mudstones are particularly rich in carbonaceous detritus but no spores or pollen grains have been found in a preparation made from specimen D.3821.1.

As in the siliceous mudstones, iron ore and heavy mineral grains tend to be concentrated at the base of siltstone laminae. Some of the iron ore, especially in specimen D.3702.2, occurs in minute spherical bodies up to 0·017 mm. in diameter, which show a nobbly surface in reflected light known as a framboidal texture (Rust, 1935, p. 407). Pyrite with this texture is syngenetic and has been attributed to colloidal deposition (Deer, Howie and Zussman, 1962*c*, p. 139). The associated heavy minerals in this particular concentrated band consist of epidote, sphene and zircon. The silt fraction also contains detrital micas, chlorite and carbonaceous fragments.

Soft-sediment deformation structures appear to be common in these rocks but they have not been studied in detail. The dispersed siltstone laminae are commonly sheared into isolated lenses; boudinage structures on a microscopic scale have also been recorded.

4. *Shale*

The shales are distinguished from the mudstones by being poorer in silt and by their occurrence in relatively thin sedimentation units between thicker laminae and beds of siltstone or greywacke sandstone. In one specimen (D.3627.1) silt appears to be absent altogether but it is not known how common this pure clay shale is.

In most areas the shales are dark grey in colour, unevenly cleaved and often veined with quartz or calcite. South of Cugnot Ice Piedmont, however, unusual green and red shales occur in close association and are interbedded with siliceous mudstones. The green shale (D.3635.1) is siliceous but it contains enough very fine mica and chlorite to give it fissility. The red shale (D.3635.2) is also composed mainly of cryptocrystalline silica but it contains some ferruginous pigment which gives it a pale blood-red colour in reflected light.

This red shale specimen is of particular interest, because it contains siliceous organic material which is distinctive but of unknown affinity. This material consists of spicules having three rays with a globular swelling on the tip of each ray (Plate Xc). These objects have a maximum length of only 0·05 mm. and each ray has a maximum shaft diameter of 0·007 mm. In shape they resemble megascleres (sponge spicules) but this identification is improbable because they are far too small and they lack the characteristic central canal. Some round and oval bodies with diameters of 0·024–0·046 mm. (Plate Xc) are also present. Similar objects have not been found in any other thin section.

5. *Chert*

The only outcrop of chert recorded in this area is at station D.3642 on a nunatak 3 miles (4·8 km.) north of Camp Hill. This chert occurs in very thin well-defined beds up to 2·5 cm. thick and is pale green in colour with small cubes of pyrite visible in the hand specimen. In thin section the rock appears dark polarizing under crossed nicols and it is composed of cryptocrystalline silica with dispersed orientated flakes of sericite up to 0·01 mm. in length in irregular bands together with a few flakes of chlorite.

D. Sedimentary Structures

1. *Bedding*

Many of the bedding features which are generally characteristic of flysch deposits are present in the Trinity Peninsula Series, but they have not been studied in great detail and are described only briefly below.

a. *Large-scale rhythmic bedding*. Large-scale rhythmic bedding, reflecting a form of cyclic sedimentation, is a characteristic feature of the Trinity Peninsula Series in many outcrops between View Point and Victory Glacier, and in the Mount Roberts area. The sandstone part of a cyclic unit forms the fold in Plate VIb. A typical unit is about 100 ft. (30·5 m.) thick and it comprises about 20–30 ft. (6·1–9·1 m.) of sandstone and siltstone and 70–80 ft. (21·3–24·4 m.) of laminated mudstone and shale (p. 50). As the sequence is followed upwards, laminated mudstone gives way rapidly to thin siltstones or sandstones with shale intercalations, followed by a group of thick sandstones. Shale intercalations between the thick sandstones are either very thin or absent altogether. The sandstones give way more gradually to thin siltstones or sandstones. Finally, laminated mudstones or shales are again encountered, marking the start of the next cycle. The sandstone beds generally show graded bedding. In some cycles the thick sandstones are absent and only thin sandstones and "laminites" are present.

According to Sujkowski (1957, p. 549), rhythmic deposition does not exist in flysch deposits and, if this is so, the present example is very unusual. It may be that the environment of deposition is more like that of the Mam Tor Sandstones which are cyclothemic "turbidites" derived from nearby deltaic deposits (Allen, 1960). However, no deltaic deposits have been found associated with the Trinity Peninsula Series.

b. *"Laminites"*. The term "laminites" has been used recently to describe the repeated alternation of thin beds of fine sandstone or siltstone and shale, commonly found in association with turbidites in flysch deposits (Lombard, 1963). Such beds are characteristic of the Trinity Peninsula Series where they are also associated with turbidites (Plates Va, VIa, c). Poorly developed graded and current bedding have been noticed by the author in "laminite" siltstones but it is not certain how common these structures are.

c. *Graded bedding*. Graded bedding is a common feature in the sandstones of this area. It is most noticeable in the greywackes containing granule or coarse sand-sized material which have shale intercalations. In the thicker beds the size range is often small and the beds have a massive appearance. Graded bedding has proved a very useful "way-up" criterion on which the interpretation of the major fold structures of the area is based.

While cyclic deposition is common over much of this area, the Louis-Philippe and Laclavère Plateaux areas are formed of thicker sequences of sandstones with shale intercalations. Graded bedding is also common in these areas.

d. *Current bedding*. Large-scale current bedding is absent from the Trinity Peninsula Series. Small-scale current bedding was not commonly observed, though it is suspected that this structure is far more widespread than it appears to be in the field. Usually, the tops of sandstone beds grade into fine "laminites" (Plate Vc). The few cases of current bedding that do occur are confined to the top 2 in. (5 cm.) of graded beds and they are associated with broken and convoluted fine lamination.

e. *Slump bedding*. Slump bedding is uncommon except in the mudstones near Stepup Col (p. 28).

2. *Sole markings*

a. *Flute casts and groove casts*. Few recognizable sole markings (Kuenen, 1957) have been found in the Trinity Peninsula Series, although they were searched for in vain on many bedding surfaces. Where they are present they are poorly defined, and only at three localities (the south-west face of Panhard Nunatak (D.4273), the coast south-west of Crystal Hill (D.3648) and the ridge 2 miles (3·2 km.) north of Theodolite Hill (D.3822)) did they give any indication of palaeocurrent direction. The best examples were recorded at the first locality on the soles of steeply dipping overturned beds of sandstone (Plates IVa, b, c). Palaeocurrents from a direction of 327° are indicated by flute and groove casts at this locality. At station D.3648 groove casts indicate a current from a direction of either 152° or 332°, while at station D.3822 flute casts have a poorly developed asymmetry which indicates a current flowing from a north-west direction. These palaeocurrent directions have not been corrected for the effects of folding because there is no precise information on the fold geometry.

b. *Sole markings of organic origin*. A few structures on the bedding planes of siliceous mudstones and other argillaceous rocks are thought to be casts of tracks and infilled burrows of bottom-dwelling organisms. The burrows are usually small (0·5–1·5 mm. in diameter) and sinuous, but one straight cylindrical cast with a diameter of 12 mm. was found. The tracks were found at station D.3651 on the coast 3 miles (4·8 km.) west of Crystal Hill. They are mostly vague markings with the exception of specimen D.3651.4, which is a zig-zagging ribbon-like trail about 16 mm. wide and resembling a shallow trough with regularly spaced bulges on either side (Plate IVd).

E. Provenance and Palaeogeography

The Trinity Peninsula Series consists of a great thickness of flysch-type sediments forming an apparently unbroken succession. However, fragments and phenoclasts consisting of greywacke-facies sediments are common as constituents of the conglomerates and sandstones, indicating that some of the earlier parts of the succession were lithified and exposed to erosion well before the final beds were deposited. Penecontemporaneous volcanic sediment has a sparse but widespread distribution in most of the rocks but it probably occurs in abundance in the metasediments associated with the greenschists of the Tower Peak area (p. 42). On the basis of this evidence, it is concluded that different parts of the geosynclinal trough subsided at differing rates. While sedimentation was continuing over the basin as a whole, certain periods were marked by an increase in tectonic activity, resulting in volcanism and localized uplift and erosion.

The sediments which were deposited in this trough are of two distinct types and they probably represent two distinct modes of deposition:

- i. Shales and mudstones deposited at a very slow rate in quiet waters. These argillaceous deposits represent the normal type of deposition for the environment.
- ii. Siltstones, sandstones, conglomerates and pebbly mudstones, representing sudden accidental influxes of coarser sediment mainly by the medium of sub-aqueous turbidity currents.

No widespread deposits have been found with structures indicative of estuarine, deltaic, near-shore or terrestial deposition. Features such as large-scale current bedding, wave-ripple marks, washouts, lenticular bedding and the predominance of one lithological type are rare or absent. However, regular graded beds with shale intercalations are common and it is these beds, together with the association of exotic pebbles with sand and mud, which are the most diagnostic criteria of turbidity-current deposition (Dott, 1963, p. 118).

In parts of the succession, normal grey shales and mudstones are rare and instead green shales, siliceous mudstones and cherts occur interbedded with normal graded sandstones and siltstones. The grey and green colour of these beds indicates a deep-water reducing environment in which no oxygenated waters were circulating. The presence of cherts may also be interpreted as an indication of deep quiet waters far from any shoreline (Pettijohn, 1957, p. 443). The presence of graded-bedded sandstones is not incompatible with this type of environment, since turbidity currents are known to carry their load for great distances down gentle slopes.

The composition of the sandstones, with over 5 per cent clay and micaceous minerals, indicates textural immaturity (Folk, 1959, p. 100). However, the degree of textural maturity of the present rock, based on clay content, gives no indication of the sediment which originally became incorporated into the turbidity current, since the clay and sand would be mixed together during transport. However, the following features of the sandstones do suggest immaturity in the (?) near-shore continental shelf deposits which probably provided sediment for the turbidity currents:

- i. The poorly sorted angular nature of the grains.
- ii. The presence of feldspathic greywackes with a variety of feldspars and heavy minerals.
- iii. In the feldspathic greywackes most of the feldspar grains show a moderate to high degree of alteration but a few are relatively unaltered. In general the feldspar grains appear to have an average size equal to or greater than that of the associated quartz grains.

These last observations may be interpreted as indicating a temperate humid climate in a source area of high relief (Folk, 1959, p. 114).

Some indication of the rocks of the source area is given in the petrographical descriptions on p. 23–26 and in the concluding section of this report (p. 59).

The greywackes from the area between Jade Point and Russell East Glacier are rich in quartz and poor in feldspar, indicating that they are either more mature sediments in themselves or that they were derived from mature sediments such as *ortho*quartzites. The quartz-rich greywackes from the McCalman Peak area are also associated with highly siliceous argillaceous rocks, suggesting that both these very different types of sediment were ultimately derived from the same quartzose source rocks.

The sediments comprising the Trinity Peninsula Series probably make up a thick wedge, or possibly a series of thick wedges, which now forms a large part of the elongated landmass of north-east Graham Land. Although no deposits have been found which might represent the margins of the geosyncline, it is assumed that the axis of the trough followed roughly the present trend of the peninsula arc. In this respect the findings of previous workers in the Hope Bay area are important. Identifiable plant remains, though very poorly preserved, are present in some of the argillaceous beds at Hope Bay (Croft, 1947), whereas farther to the south-west plant remains appear to be restricted to microscopic fragments in the greywackes and siltstones. Hooper (1955) found evidence of a change in sedimentary facies from south-east to north-west in Tabarin Peninsula and tentatively concluded that a shoreline lay to the north or north-west.

Information indicating where the source of the sediments was situated is very scanty. All that can be concluded from the author's observations is that there is a slightly greater possibility of a land source to the north-west than in any other direction. At least, the few indications of palaeocurrent direction are consistently from the north-west but no conclusions can be made which are statistically valid and derivation from the south-east is certainly not ruled out. No rocks definitely older than the Trinity Peninsula Series have been found on the islands either north-west or south-east of Trinity Peninsula. A source outside this adjacent area has not been considered by the present writer but Adie (1962, p. 32) has indicated that the greater part of this geosyncline "formed alongside the stable block of East Antarctica".

F. Metamorphism

In his study of the Trinity Peninsula Series, Adie (1957*b*) concluded that:

> "From the abundant evidence of highly contorted and sheared rocks in Tabarin Peninsula and Trinity Peninsula it is clear that the Trinity Peninsula Series has been subjected to severe cataclasis in pre-Jurassic times. As a result of the emplacement of the Early Tertiary Andean intrusives the sediments within the thermal aureoles have undergone superposed contact metamorphism."

The present study is based on the microscopic examination of 130 thin sections of representative specimens collected mainly from recently mapped areas. The new information broadly supports Adie's conclusions though the present author prefers to emphasize the regional rather than the purely cataclastic nature of the earlier metamorphism.

The grade of regional metamorphism is always low but not uniform and the almost unaltered sedimentary rocks in the north-east give way to phyllites, metagreywackes and greenschists in the south-west. Most of the rocks affected by the later thermal metamorphism show clear relict structures from the regional metamorphism. However, in a few cases plutonic intrusion was accompanied by considerable local deformation, resulting in the formation of true mica-schists (p. 45).

1. *Regional metamorphism*

Outside the thermal aureoles of the plutonic intrusions the metamorphic grade is never higher than that represented by the greenschist facies, as defined by Turner (Fyfe, Turner and Verhoogen, 1958, p. 217). If a zonal classification is used, then the rocks all fall into the chlorite zone with the exception of some of the amphibolitic greenschists. Metamorphic biotite has never been found, though it is a characteristic mineral within the thermal aureoles.

Over much of the area north-east of Russell East Glacier, alteration of the rocks is so slight that it is difficult to distinguish between metamorphic and diagenetic effects. The very low-grade mineral facies described by Coombs (1960) for rocks of the New Zealand Geosyncline cannot be used here, because the critical minerals (heulandite, laumontite, prehnite, pumpellyite and lawsonite) are either absent or present only in insignificant amounts.

Another method of subdividing these low-grade metamorphic rocks is by sub-zones based on the stage to which reconstitution has proceeded in either the greywacke or pelitic derivatives (Turner, 1935, p. 344–45). However, even the most advanced stage of reconstitution recorded is only equivalent to the first of Turner's four chlorite sub-zones in the Otago schists of New Zealand.

It is therefore concluded that, although a north-east to south-west increase in grade of regional metamorphism can be clearly demonstrated, there is no sensible basis for erecting arbitrary zonal sub-divisions.

a. *Metagreywackes, phyllites and schists.* The mineralogy of the least-altered greywacke and pelitic rocks in this area is described on p. 28–37. The greywackes consist mainly of sand-sized clastic grains of quartz and various types of alkali-feldspar, together with rock fragments. The matrix between these grains appears as greenish brown to dark brown muddy material, whose constituents cannot be resolved even with a high-power objective. In the siltstones and mudstones the mineral composition is similar, but with a decrease in size of the clastic grains and an increase in proportion of matrix material and clastic micas. Unaltered sedimentary rocks of these types occur only in the View Point and Laclavère Plateau areas.

The first signs of regional metamorphism are represented by a slaty cleavage in the finest-grained argillaceous rocks and the growth of minute flakes of chlorite and sericite in the matrices of the siltstones and greywackes (Plate IXb). These minute flakes commonly show a preferred orientation similar to the slaty cleavage in the slates. However, the slaty cleavage is never strongly developed, because of the later superposition of fracture and strain-slip cleavage (p. 51). Fracture cleavage is common even in the unmetamorphosed rocks, though it is confined mainly to the argillaceous types.

The very gradual increase in grade of metamorphism towards the south-west is marked by an increase in size of the chlorite and sericite flakes and the recrystallization of quartz to give a fine mosaic. In the Russell East Glacier area the purer pelitic sediments have been converted into true phyllites (D.3612.1), while the rare quartzites and cherts show almost complete recrystallization with small flakes of chlorite and sericite dispersed within the quartz mosaic (D.3613.1).

Of all the sedimentary rocks, the greywackes retain most of their original identity, and for this reason the term "metagreywacke" is used as a name for their regional metamorphic equivalents. In the Russell East Glacier area they invariably occur in steeply dipping beds and metamorphic crystallization has been markedly affected by contemporaneous stretching and concentric shearing resulting from the very large-scale folding which has affected the whole area (p. 51). Even so, alteration has been mainly confined to the matrix and the smallest clastic grains. The simple sand-sized grains of quartz and feldspar have retained their identity but their shapes have been somewhat modified by shearing, marginal recrystallization and reaction with the matrix. However, the characteristic wide range of roundness is still apparent (Plate XIb). Few grains have broken, because the shear planes tend to follow the intergranular matrix which has less resistance to shear. Mud fragments in the greywackes have been converted to phyllites and show strain-slip cleavage. Most of the other larger rock fragments, such as rhyolites, granites and psammitic sedimentary rocks, are still easily identifiable, because they are mainly composed of quartz, feldspar and mica. The effect of metamorphism has been recrystallization of these constituents to give a coarser grain-size. Finer silt-sized clasts have merged with the matrix. Metamorphic crystallization of the matrix has reached the stage where sericite and chlorite flakes are mostly between 0·015 and 0·03 mm. in length, showing strong orientation parallel to the principal shear direction which makes an acute angle with the bedding.

South-west of Russell East Glacier the character of the folding changes and strain-slip cleavage is prominent even in the greywackes, where it displaces the earlier shear planes (p. 53; Plate XIIe). In the Mount Roberts area the degree of alteration is slightly greater than in the Russell East Glacier area, but even in the phyllites clastic quartz grains still survive. Epidote and calcite occur in small amounts in many of the metagreywackes, particularly those richer in feldspar and rock fragments at the expense of quartz.

However, in rare cases such as specimen D.3998.1, calcite is very abundant, comprising 40 or 50 per cent of the rock which is otherwise a somewhat quartz-rich metasiltstone with contorted bands rich in sericite, finely divided (?) graphite, leucoxene and pyrite partially altered to haematite. Whilst this calcite is clearly not in an original sedimentary state, it may nevertheless represent a re-mobilized form within an originally calcareous greywacke. Alternatively, a hydrothermal origin is considered more likely, because the calcite has replaced both granular quartz and quartz forming the pressure fringes of pyrite crystals, indicating that it is post-deformational.

The phyllites which show the most advanced alteration occur in the area around the head of Larsen Inlet but they still have a quartz-muscovite-chlorite assemblage. In specimen D.4259.1 the minerals show a tendency to be segregated into thin micaceous and quartzitic bands but the grain-size is still too fine (mica flakes average about 0·03 mm. in length) for the term "schist" to be used for the rock. The quartz, in a characteristic mosaic form, is only slightly strained and unsheared, suggesting that crystallization was caused by heat without the influence of shearing stress. However, there is no sign of reaction between the muscovite and chlorite to produce biotite, which is characteristic of the hornfelses and schists in the nearby thermal aureole (p. 45).

The remaining area where regionally metamorphosed Trinity Peninsula Series rocks have been recorded is between Mount Wild and Longing Gap. The lithology here is more variable than in any of the areas previously described, while the regional structure appears complex and obscure on the basis of present knowledge (p. 53).

Two main groups of rocks occur here, namely, the greenschists and a group comprising metagreywackes, phyllites and metamorphosed pebbly mudstones. The predominance of chlorite over sericite in the recrystallized matrix of these rocks is their main distinguishing feature. The chlorite forms very small flakes about 0·015 mm. long. In several specimens, notably D.3935.1 and D.3883.1, a much coarser secondary pennine occurs. Specimen D.3935.1 is a feldspathic greywacke in which the pennine envelops and partially replaces clear unstrained quartz grains (Plate XId). The second rock type is a phyllite containing numerous lenses of unstrained mosaic quartz and compound flakes of pennine. Both the quartz lenses and the chlorite flakes are orientated parallel to the foliation but the lack of strain textures and the relative coarseness of the grain suggest that these structures post-date the main regional metamorphism and may be of hydrothermal origin (p. 48). In some of the rocks a little epidote and calcite have developed both in the matrices and in certain rock fragments. Quartz veins containing these two minerals are also common. An increase in the chlorite content of these rocks is accompanied by an increase in leucoxene, and this association suggests basic volcanic material was being contributed to the sediments in this area. These quartz-chlorite-sericite rocks occur below the thrust plane on Mount Wild and in the outcrops flanking the Sjögren Glacier tongue between Downham Peak and Longing Gap. The bulk of Mount Wild above the thrust plane and many of the ridges between Tower Peak and Shortcut Col are composed of greenschists.

b. *Greenschists.* The term "greenschist" is used in this report for low-grade metamorphic rocks which have a conspicuous green colour in the hand specimen due to the presence of a chlorite-amphibole-epidote assemblage. However, like most of the rocks which have suffered only regional metamorphism, the schistosity is not very well developed.

A thin-section examination of 8 greenschist specimens reveals that this group may be divided into three distinct types:

i. Volcanic metagreywackes and phyllites mainly composed of completely sericitized feldspar grains in a muddy-looking matrix rich in leucoxene and chlorite, but also with a few dispersed clastic quartz grains.
ii. A rock with large conspicuous grains of pyroxene and ilmenite in a banded, fine-grained groundmass of quartz, sericite and chlorite.
iii. Fine-grained rocks with a chlorite-amphibole-leucoxene-quartz-epidote-calcite mineral assemblage but with no relict clastic grains.

The mineralogy of types (i) and (ii) suggests a close association with the very distinctive albite-augite-ilmenite dykes described on p. 11. Type (i) rocks are comparable with the chlorite-rich metagreywackes described on p. 41, but they are richer in chlorite and leucoxene, and more thoroughly altered (Plate XIe). The greenschists of Mount Wild are of this type. In one thin section of a specimen from near Mount Brading (D.3924.1), ilmenite showing partial alteration to leucoxene is abundant and a few rock fragments composed of chlorite or epidote are also present. Among the minor constituents are tremolitic amphibole, calcite and stilpnomelane. The last-named mineral has developed in association with quartz veins and it is identical to that which occurs abundantly in one of the albite-augite-ilmenite dykes (D.4268.3) exposed on the north side of Victory Glacier. The stilpnomelane shows parallel extinction and occurs either as single, small bladed crystals or in sheaf-like aggregates. It is distinguished from biotite by its pleochroism (α' = golden brown, $\beta' = \gamma'$ = very dark brown to nearly black) and the absence of the wavy mottled appearance characteristic of biotite. Stilpnomelane has not been previously recorded in the Trinity Peninsula Series, though it is common in regionally metamorphosed greywacke sequences in New Zealand (Turner and Verhoogen, 1951, p. 471).

The pyroxene-ilmenite-greenschist (D.3923.1) exposed 2 miles (3·2 km.) east-north-east of Mount Tucker is an unusual rock type and most closely resembles the albite-augite-ilmenite dyke rocks. Its occurrence is probably more restricted than the other members of the greenschist sequence. The pyroxene is an augite ($2V\alpha \simeq 59°$; $\gamma{:}c = 45°$) forming abundant partially granulated grains (up to 1·8 mm. across), some of which are twinned (Plate XIf). Leucoxene is also abundant either as thin wavy streaks or as larger grains, some of which enclose skeletal ilmenite. It is probable that much of the leucoxene in the greenschists as a whole is derived from the break-down of primary ilmenite. These relatively coarse-grained minerals are dispersed throughout a fine-grained groundmass containing irregular lenses and wavy bands of muscovite and chlorite intermingled with fine quartz grains. Feldspar is absent but these lenses and wavy bands may represent the degradation products of original plagioclase. The origin of this rock is difficult to determine, because its field relations are unknown and its original texture has been lost during regional metamorphism. The lack of evidence for the former presence of feldspar phenocrysts suggests the rock might have been a lava containing tiny laths of plagioclase rather than a sill with the type of granular texture present in the albite-augite-ilmenite dyke rocks.

Greenschists of type (ii) are uniformly fine-grained and quartz is generally rare or absent except in veins. The bulk of these rocks is composed of a dense, very fine-grained aggregate of amphibole, chlorite, epidote and leucoxene. Amphibole is the most abundant of these minerals. It forms tiny acicular crystals occurring either singly or in clusters, is either colourless or slightly pleochroic to a very pale green ($\gamma{:}c = 16\text{–}18°$) and probably belongs to the tremolite-actinolite series. Epidote is generally in the form of minute irregular grains. Except in specimen D.4323.1, muddy dark brown leucoxene is very abundant, either dispersed in irregular clots or segregated into streaks and lenses. Interstitial chlorite occurs in varying amounts but this mineral is mainly segregated in irregular and impersistent veins and lenses, which are often abundant and have formed during regional metamorphism. These bodies also contain segregations of quartz, epidote and pyrite. A little albite is also present in some specimens but, in general, plagioclase is restricted to a few vague, highly altered relicts in the host rock. Calcite is abundant in later less-deformed veins but it also occurs occasionally in minute irregular patches dispersed throughout the rock.

The amphibole-chlorite-epidote assemblage described above is a characteristic product of the low-grade regional metamorphism of basic to intermediate igneous rocks. The marked paucity of feldspar in the assemblage is difficult to explain but it may be only apparent as the rocks are very fine-grained, a feature which is almost certainly characteristic of the original rock. The textures of these rocks are variable; some are uniformly fine-grained while others contain highly contorted discontinuous veins of quartz and chlorite which may be deformed vesicles.

2. *Thermal metamorphism*

Thermal or contact metamorphism superimposed on deformed rocks of the Trinity Peninsula Series was reported by Adie (1957*b*) from the Hope Bay and Tabarin Peninsula areas (Map 1) as well as other localities outside north-east Graham Land. These rocks include low-grade biotite-cordierite-hornfelses, hornblende-hornfelses and medium-grade pyroxene-quartz-plagioclase-hornfelses. They occur in the aureoles surrounding intrusions of diorite, quartz-diorite and granodiorite of the Andean Intrusive Suite.

The extension of field mapping as far south as Larsen Inlet has subsequently revealed several more plutons with aureoles of thermally metamorphosed rocks similar to those described by Adie. The distribution and approximate extent of these aureoles are shown in Maps 2 and 3. Where a steep contact between pluton and country rock is exposed, it is found that the aureole is generally about 1–2 miles (1·6–3·2 km.) wide.

Turner (Fyfe, Turner and Verhoogen, 1958, p. 200) has divided metamorphic rocks into five broad chemical classes, only three of which have been recorded in this area. These are:

i. Quartzo-feldspathic; derivatives of greywackes.
ii. Pelitic; derivatives of argillaceous rocks rich in alumina.
iii. Basic; derivatives of basic or intermediate hypabyssal and volcanic rocks and some volcanic sedimentary rocks.

These three classes grade into each other but nevertheless there are distinctive mineral assemblages which correspond to each class. Calcareous rocks are rare, though secondary and vein calcite are abundant in some greywackes.

The effects of thermal metamorphism are now considered in relation to the four main intrusive complexes which are situated north of Russell West Glacier, between Victory and Aitkenhead Glaciers, at the head of Sjögren Glacier and north-east of Mount Tucker.

a. *Aureole of the Russell West Glacier–Marescot Ridge intrusive complex.* Apart from Marescot Ridge itself, the outcrops in this area are widely scattered and apparently disconnected. All the sedimentary rocks show some degree of thermal metamorphism indicating an extensive aureole, and it is probable that the plutonic rocks are part of a large intrusive complex (p. 17). This hypothesis is supported by geophysical evidence (personal communication from A. Allen).

On the eastern margin of the aureole, only two exposures (D.3837, 3842) show the alternation of steeply dipping greywacke and argillaceous beds so characteristic of the adjacent area. In thin section, single specimens of greywacke from both stations exhibit strong intergranular shear. Thermal metamorphism is indicated by the slightly more advanced degree of matrix recrystallization and alteration of feldspars and rock fragments. In specimen D.3937.1 the sericite and chlorite are partially converted to biotite with pleochroism from very pale straw to yellow-brown.

The rocks of Marescot Ridge are mainly dark mudstones containing varying amounts of sand and silt, which have been indurated and altered to low-grade hornfelses. Two specimens (D.3845.1, 3846.1) with microcrystalline spots up to 0·2 mm. in diameter illustrate the early stages in the formation of a mineral which is probably cordierite. The spots in the first rock consist of green chlorite and iron ore, while in the second rock a later stage has been reached with the production of a dark polarizing, biaxial mineral containing minute inclusions of biotite and iron ore or graphite. Orientated shreds of sericite and chlorite have been partially replaced by small flakes of biotite in the second specimen, but both rocks still contain clastic quartz grains of silt size. No rocks of higher grade were observed in this part of the aureole.

At the foot of the north face of Corner Peak there are gently dipping greenschists which contain fine lenses and thin laminae of calcite. In thin section this fine-grained rock (D.3840.1; Plate XIc) consists of sub-parallel fibres of actinolitic amphibole (α' = pale yellow-green, γ' = dull olive-green; $\gamma{:}c = 15°$) interspersed with irregular epidote grains which are either clear and pleochroic from pale green to yellowish green or are partially or completely obscured by included cryptocrystalline muddy brown material. Calcite is a fairly abundant interstitial mineral but it is very abundant in lenses and must form at least 25 per cent of the total mineral content of the rock. Some of these lenses are also rich in albite. The only other mineral present is a little iron ore; quartz is absent.

The mineral assemblage of this rock (actinolitic amphibole-epidote-calcite-albite) is characteristic of greenschists formed under conditions of low-grade regional metamorphism. The formation of epidote is favoured by shearing stress and low temperature (Deer, Howie and Zussman, 1962*a*, p. 208), and its presence in dispersed muddy grains suggests it was formed by the metamorphic alteration of pyroxene in a basic igneous rock. The actinolitic amphibole was probably also formed during this phase. The presence of fresh epidote and abundant calcite suggests that here plutonic intrusion has mainly resulted in carbon dioxide and calcium metasomatism rather than straight-forward thermal metamorphism of an originally calcareous rock

The most advanced grade of thermal metamorphism in this aureole is shown by the well-bedded hornfelses exposed 2 miles (3·2 km.) east-north-east of the granite outcrops of Wimple Dome. These rocks are indurated, fine-grained and mainly quartzo-feldspathic but thin pelitic bands are also present. In thin section these rocks (D.3853.1, 2) exhibit strong shearing in the pelitic bands together with stretching and elongation of feldspar and quartz grains sub-parallel to the bedding. This deformation may be due either to local faulting (for which there is no direct evidence) or to a regional deformation connected with plutonic intrusion.

Like the greenschist described above, this rock also has a peculiar mineral assemblage, with the pelitic bands consisting of chlorite, sericite, epidote, sphene and iron ore, while the remainder of the rock is composed of quartz and feldspar with some iron ore and segregations of calcite and diopsidic pyroxene ($2V\gamma \simeq 59°$; $\gamma{:}c = 41°$). The plagioclase has a refractive index slightly less than Canada balsam and is therefore albitic, making the assemblage a normal one for low-grade regional metamorphism, if the pyroxene is disregarded. The calcite has partially replaced the pyroxene and the quartzo-feldspathic host rock, and it has clearly formed as a result of late metasomatic or hydrothermal activity. The pyroxene itself may be metasomatic, since it is also associated with calcite. An alternative explanation is that the rock was a pyroxene-hornfels, and late deformation accompanied by metasomatism caused differing degrees of retrograde metamorphism in adjacent bands. A third possibility is that the pyroxene together with the albitic plagioclase and leucoxene are original detrital minerals derived from albite-augite-ilmenite volcanic rocks associated with the dykes described on p. 11.

b. *Aureole of the Victory Glacier—Aitkenhead Glacier intrusions.* The intrusions of Mount Reece and the Tufft Nunatak area are linked by a small composite intrusion 1 mile (1·6 km.) north-west of Mount Bradley. The surrounding aureole is therefore considered as one unit (Maps 2 and 3). The widths of the south-western and south-eastern parts of this aureole are small as neither specimen D.4256.1 from the west side of Aitkenhead Glacier nor D.3660.1 from the south-east ridge of Mount Bradley show much more recrystallization than that resulting from local regional metamorphism. Both these localities are within 1 mile (1·6 km.) of granite outcrops. The aureole is probably much more extensive on the north-west side, because a specimen of quartz-sericite-chlorite-phyllite from the north side of the

Victory Glacier amphitheatre (D.3671) also contains thin contorted veins of quartz and oligoclase with a conversion of sericite and chlorite into biotite adjacent to the veins.

Most of the metasedimentary rocks in the area between the two major plutons belong to the banded hornfels group described on p. 48–49.

c. *Aureole of the Sjögren Glacier igneous complex*. The thermally metamorphosed rocks in the aureole of the Sjögren Glacier igneous complex (p. 17) all possess relict structures of the earlier period of regional metamorphism. With one exception (p. 46), these rocks show by their mineralogy that they are the equivalents of the metagreywackes and phyllites described in the section on regional metamorphism.

This aureole also differs from the others in having definite representatives of Turner's hornblende-hornfels facies, in which the most diagnostic mineral is oligoclase or andesine in preference to albite, which is diagnostic of the lower-grade albite-epidote-hornfels facies. The main ferromagnesian mineral is biotite rather than hornblende or other amphibole. However, in several instances it is uncertain to which of these two facies the rocks belong, because of the difficulty in identifying the plagioclase which is generally untwinned and forms a fine-grained granular mosaic with quartz (p. 49).

In the pelitic rocks the lowest grade of thermal metamorphism is marked by the growth of biotite flakes, which often have a discordant orientation in relation to the pre-existing cleavage. In a specimen from the east side of Polaris Glacier (D.4296.1), biotite of this type has a pleochroism scheme α' = pale straw, $\beta' = \gamma'$ = reddish brown and contains dusty inclusions aligned parallel to the strongly orientated sericite which marks the slaty cleavage impressed on the rock during regional deformation (Plate XIIc).

In some of the quartzo-feldspathic rocks clastic quartz grains are still recognizable, even when adjacent pelitic beds have been completely converted to quartz-mica-schists containing cordierite and andalusite. A specimen of biotite-cordierite-schist from the north-east side of Sjögren Glacier 6 miles (9·6 km.) east of Mount Hornsby (D.3987.1) and a specimen taken from a bed of metagreywacke immediately adjacent to it (D.3987.3), illustrate this contrast well (Plates XIIa, b). The quartzo-feldspathic rock is still recognizable as a metagreywacke which is hard, grey and without cleavage or schistosity, while the schist has a strong micaceous foliation with visible dark porphyroblasts of cordierite up to 7·0 mm. long and thin highly contorted lenses and veins of quartz and feldspar. In thin section this metagreywacke consists of dispersed relict grains of quartz and feldspar up to 0·32 mm. across set in a fine-grained groundmass of biotite, chlorite, quartz and feldspar. A few relict heavy minerals, such as sphene and garnet, are also present. The relict structures in the schist consist of thin bands of iron ore and (?) graphitic material which have been folded and deformed by strain-slip cleavage, and which pass unbroken through both the large cordierite porphyroblasts and the included biotite. The relative distortion of the bands clearly demonstrates that this rock has been subjected to at least two periods of compressive shear (Plate XIIa). The first of these probably represents the earlier regional metamorphism, while the second represents deformation operating during thermal metamorphism. The bands themselves may represent an original sedimentary structure such as that described on p. 36, but they are considered more likely to be early shear planes in which very fine black material (? iron ore and graphite) has become concentrated by dilatancy (Hills, 1963, p. 121). The cordierite also contains inclusions of quartz and possesses a crude sector twinning. The general foliation surfaces comprise bands rich in muscovite and they also contain a few small andalusite crystals.

In another specimen of this type (D.3972.1), andalusite is abundant but in subidioblastic crystals up to 1·6 mm. in size, which have straight faces adjacent to biotite and ragged irregular margins adjacent to the fine-grained quartzo-feldspathic mosaic. Dark, dusty inclusions in dense wavy bands are abundant in most of the andalusite porphyroblasts together with rounded blebs of biotite and quartz. The biotite has the pale straw to bright reddish brown pleochroism characteristic of well-crystallized hornfelses. A third mica is present in addition to biotite and muscovite; this has a markedly different habit, occurring in broad ragged porphyroblasts up to 1·28 mm. long which enclose wavy trains of black dusty inclusions, numerous long flakes of muscovite and lesser amounts of biotite (Plate XIId). This mica has a pleochroism scheme α' = very pale straw, $\beta' = \gamma'$ = pale greenish brown and $2V\alpha \simeq 10°$. The magnesium-rich mica, phlogopite, is the most likely mineral fitting this description. According to Deer, Howie and Zussman (1962*b*, p. 50), phlogopite usually occurs either in regionally metamorphosed impure dolomitic limestones or in rocks which have been subjected to fluorine metasomatism. However, in this instance, the associated mineral assemblage includes no calc-silicates, carbonates or fluorine minerals and this unusual occurrence is difficult to explain. Evidently, magnesia, which is normally taken up in the formation of cordierite, has gone into phlogopite instead. The textural evidence shows that the phlogopite was formed during an early phase of thermal metamorphism, and this may be linked with the fact that the aureole surrounds an intrusive complex in which there have been several different intrusions, possibly spanning a considerable period of time.

The cherts and siliceous mudstones are the most quartz-rich members of the Trinity Peninsula Series, and a specimen from the north side of Shortcut Col (D.3958.1) represents the thermally metamorphosed equivalent of the second of these rock types. This specimen is hard and has a grey appearance with visible dark shear planes which are prominent in thin section as contorted dark bands, containing black very finely granular material, in contrast to the fine-grained quartz mosaic forming the rest of the section. Most of the small amount of biotite in the rock is associated with the dark bands.

The only rocks in which amphibole is an important thermal metamorphic mineral were found 1 mile (1·6 km.) south of Mount Hornsby (D.3959). They are exemplified by specimen D.3959.1, which is a fine-grained grey hornfels with very fine laminae alternately rich in quartz (with indeterminate plagioclase) and a green amphibole, probably belonging to the actinolite-hornblende series, with a pleochroism α' = pale greenish brown, β' = brownish green and γ' = olive-green, and $\gamma{:}c \simeq 18°$. There are also a few laminae and lenses rich in calcite.

Garnets have a sparse but widespread distribution in many of the thermally metamorphosed rocks from Trinity Peninsula. They are regarded by the author as an important metamorphic mineral in only one rock (D.4291.1) from this area, though Adie (1957*b*, p. 15) has described their occurrence in a specimen of argillaceous greywacke from elsewhere in Graham Land. Generally, they are very small, pale pink and free from inclusions, and are sometimes difficult to distinguish from apatite. Most of them are probably relicts of clastic garnets.

Specimen D.4291.1 from a ridge on the east side of Eliason Glacier is a biotite-cordierite-hornfels with a quartz-biotite-cordierite-garnet-spinel assemblage. The garnets, forming idioblastic crystals up to 1·2 mm. in diameter, are dispersed throughout the rock and range in colour from pale purplish red to almost black. The cordierite is visible as dark oval markings up to 5 mm. across, but in general the rock is very fine-grained.

In thin section the garnets contain inclusions of magnetite in varying amounts (which cause the variation in colour) together with small blebs of quartz and biotite (Plate XIIf). The refractive index of the garnet, $1 \cdot 804 \pm 0 \cdot 003$, suggests an almandine-spessartine composition. The cordierite also contains abundant inclusions of quartz, biotite and magnetite, and some of the porphyroblasts possess irregular sector twinning. The dominant structure in the rock consists of very fine, closely spaced bands alternately rich in biotite (with iron ore) and quartz, which persist within the cordierite porphyroblasts. In addition, the biotite flakes show strong preferred orientation at an angle between 40° and 60° to the banding. This specimen contains two other unusual minerals, the first of which consists of conspicuous radial aggregates of chlorite growing outwards from an indeterminate central core and completely enveloped by cordierite (Plate XIIf). Trains of magnetite continue through these aggregates which suggests they are altered cordierite. The second mineral consists of clusters of very small rounded blebs of olive-green spinel included in cordierite.

The most advanced stage of metamorphism is present in xenoliths in the granite, and is indicated by a relative coarseness of grain rather than any higher-grade mineral assemblage. In a xenolith specimen (D.4288.2) the assemblage is quartz-oligoclase-biotite-muscovite-cordierite, the cordierite being partially altered to pale yellowish green pinite, while the biotite is partially chloritized.

The last mineralogical variation noted in the rocks of this aureole can be attributed to potash metasomatism rather than to a variation in original sedimentary composition, particularly as the rock in question (D.3982.1), from a knoll 5 miles (8 km.) north-east of Mount Hornsby, is near a potassic granite containing 63·3 per cent modal orthoclase (p. 18). The mineral assemblage of this rock is quartz-biotite-cordierite-andalusite-spinel-muscovite-microperthite. While white mica is common in this aureole, in this rock it occurs as broad flakes of muscovite up to 0·64 mm. long, which clearly post-date the development of most of the other minerals. The microperthite, which occurs mainly in the abundant quartz lenses and segregations in the rocks, contains very fine straight lamellae of albite and forms anhedral crystals up to 0·2 mm. across.

Table XII shows clearly that, although each specimen collected from this aureole has a slightly different

TABLE XII

SUMMARY OF THE MINERAL ASSEMBLAGES OF METASEDIMENTS FROM THE THERMAL AUREOLE OF THE SJÖGREN GLACIER IGNEOUS COMPLEX

	D.3958.1	D.3959.1	D.3970.1	D.3972.1	D.3973.1	D.3982.1	D.3987.1	D.3987.2	D.4288.2	D.4291.1	D.4292.1	D.4296.1
Quartz	x	x	x	x	x	x	x	x	x	x	x	x
Albite	x	?						?				?
Plagioclase		?	x					?	x			?
Microperthite						x						
Cordierite			x			x	x		x	x		
Andalusite				x		x	x					
Chlorite	x							x		x	x	
Biotite	x		x	x	x	x	x	x	x	x	x	x
Muscovite	x					x	x		x		x	
Phlogopite				x								
Hornblende		x										
Garnet										x		
Calcite	x	x										
Iron ore	x	x	x	x	x	x	x	x	x	x	x	x
Spinel (green)										x		

mineral content, the assemblages in general reflect a gradation from the quartzo-feldspathic composition of the original greywackes to the aluminous composition of the original pelitic sediments.

Taken as a whole, the petrographical evidence indicates at least three stages in the thermal metamorphism of these rocks:

i. The growth of new minerals, such as biotite and cordierite, under conditions of rising temperature relatively unaffected by shearing stress.
ii. The continued growth of new minerals under conditions of both high temperature and shearing stress.
iii. The growth of a different set of minerals and the alteration of existing minerals by one or possibly several phases of localized metasomatism.

While these events could occur during one phase of plutonic intrusion, the field evidence indicates that the intrusive complex comprises several intrusions of different composition emplaced at different times, and it is probable that the metamorphic stages are related to this complex plutonism.

d. *Aureole of the granite intrusion north-east of Mount Tucker.* The aureole of the biotite-granite intrusion centred 4 miles (6·4 km.) north-east of Mount Tucker appears to have a small extent, corresponding to the size of the intrusion (Map 3). Several specimens were collected from the area adjacent to the intrusion but only one of them (D.3953.1), taken approximately 400 yd. (366 m.) from the contact, shows any evidence of thermal metamorphism. This specimen is a greenschist which still retains a characteristic very fine-grained muddy appearance in thin section, together with a fine irregular alternation of quartz-rich and muddy bands. The mineral assemblage includes quartz, epidote and actinolite, together with muddy material which is probably leucoxene with sphene or rutile. There are also small segregations of muscovite and albite. Epidote is dispersed as minute grains throughout the rock and also forms conspicuous granular mosaics pseudomorphing pyrite. The actinolitic amphibole is mostly segregated in lenses and veins, and includes both a fibrous variety and one in which the maximum absorption colour is turquoise-green, indicating a soda-rich composition. Both the mineral assemblage and the fineness of grain show that this rock belongs to the lowest-grade albite-epidote-hornfels facies of thermal metamorphism.

3. *Hydrothermal and pneumatolytic mineralization*

Narrow veins and lenses containing a variety of minerals such as quartz, calcite, albite, epidote, chlorite, actinolite and pyrite occur in the Trinity Peninsula Series in this area. Quartz veins are particularly abundant throughout the whole area but calcite veins are also common. Nearly all the veins exhibit some degree of deformation, ranging from strong contortion and shearing to slightly undulose extinction of the quartz grains. Another common feature is that the veins reflect the mineralogy of the groups of rocks in which they have formed, suggesting that the mineralizing solutions, from which the vein minerals were precipitated, were of local rather than extraneous origin.

Unusually rich concentrations of certain minerals in small lenses within thermally metamorphosed rocks have already been described and attributed to mineralization by liquids or gases emanating from adjacent plutonic intrusions. However, the only veins recorded which are directly associated with plutonic intrusion are those near the north-east margin of the Mount Reece granite (D.3673, 3674). Though a little green copper staining was observed in the field, specimens from the veins consist only of quartz and vermicular chlorite. Tourmaline-bearing veins or rocks similar to those described by Adie (1957*b*, p. 11) have not been found outside the original locality.

4. *Stratigraphic implications of metamorphism*

The small but well-marked increase in grade of regional metamorphism from north-east to south-west described on p. 40–42 may mean that deeper crustal and stratigraphical levels are exposed towards the south-west. This direction also coincides with that of the regional strike, suggesting that there is a gentle plunge of the major folds towards the north-east, exposing more deeply buried strata in the south-west. However, there is no conclusive structural evidence to support this explanation, because the few minor fold axes which have been measured show no consistent plunge direction.

While there appear to be no major lithological variations in a general section between Aitkenhead and Polaris Glaciers, important changes take place to the south-east, between Shortcut Col and Longing Gap, where there is a thick group of volcanic rocks represented by greenschists. The fact that these greenschists have the same grade of regional metamorphism as rocks in adjacent areas suggests that they represent a lateral facies change rather than a markedly different stratigraphical level. The probable association with albite-augite-ilmenite dykes of the type intruded into the normal quartzo-feldspathic and pelitic metasediments to the north-west implies that they are in a younger part of the Trinity Peninsula Series succession. Unfortunately, there is not enough evidence at present to indicate the mode of eruption and deposition of these volcanic rocks.

IV. BANDED HORNFELSES

1. *Field relations*

A group of banded hornfelses (p. 11) is exposed north-west of Mount Bradley and around the southern side of the upper amphitheatre of Victory Glacier (Map 2). The plutons of Mount Reece and Tufft Nunatak display sharp intrusive contacts against these rocks and form respectively the north-east and south-west boundaries of the outcrop. To the north-west the outcrop probably extends beneath the ice to the far side of Detroit Plateau (p. 11), while somewhere beneath the south-east face of Mount Bradley there is a boundary with the Trinity Peninsula Series represented here by regionally metamorphosed conglomerates (p. 20). This boundary has not been observed directly.

The banded hornfelses consist of thermally metamorphosed, light grey quartzo-feldspathic siltstones intercalated with dark grey pelites in thin beds and laminae. The thickest bed recorded is only 2 cm. and some of the laminae have the appearance of fine varves but there is no indication whether deposition was of a seasonal, annual or more complex cyclical nature. Sandstones, conglomerates and pebbly mudstones appear to be absent from this group. The beds dip evenly, without marked flexuring, at angles of 25–55° in directions trending outwards from the Mount Reece granite (Plate Ic). In contrast, dip values in the Trinity Peninsula Series are generally between 60° and 90° with strong folding and contortion in places.

2. *Metamorphism*

Unlike the metamorphic rocks of the Trinity Peninsula Series, the banded hornfelses show no evidence of regional metamorphism except for one specimen of doubtful affinity (D.3661.1). The mineral assemblages resulting from thermal metamorphism are those of the low-grade albite-epidote-hornfels facies which are to be expected from pelitic and quartzo-feldspathic rocks. Higher-grade assemblages have not been recorded from these rocks even within a few feet of intrusive contacts, but the distinction between the lower metamorphic grades is not always clear, because of the difficulties in identifying the type of plagioclase present (p. 45).

The earliest stage in this metamorphism is represented by a spotted silty mudstone from the ridge 3 miles (4·8 km.) north-west of Mount Bradley (D.3665.1). The spots weather out as dark oval markings averaging about 9 mm. in length and 3 mm. in breadth on the plane of lamination. In thin section they consist of very fine-grained flakes of chlorite and muscovite, scattered aggregates of cryptocrystalline rutile or sphene and relict clastic quartz grains. The dark pelitic bands in which the spots occur consist of flakes of chlorite with associated cryptocrystalline rutile or sphene, together with grains of quartz and feldspar enclosing an abundance of finely divided (?) graphitic dust. The irregular margins of the spots appear to have spread and consumed the surrounding minerals (Plate Xf) and it is probable that these spots are cordierite porphyroblasts which have been altered to pinite during the final retrogressive phase of metamorphism. Probably much of the chlorite was also formed at this stage as a result of alteration from biotite, because the cleavage cracks are occupied by cryptocrystalline rutile or sphene. Partially altered biotite of this type is very common in other specimens from this area.

Even in a specimen taken 3 ft. (0·9 m.) from the contact with the Mount Reece granite the mineral assemblage is still quartz-albite-biotite with sericitized cordierite spots (Plate Xe). The biotite here is mainly unaltered and pleochroic from pale straw to reddish brown but in the quartzo-feldspathic bands the small amount of biotite present is completely chloritized.

The specimen of doubtful affinity (D.3661.1) comes from an exposure on Mount Bradley, where the rocks appear to belong to the banded hornfels group, but this rock shows a microcrystalline augen structure in which composite quartz and potash feldspar grains are outlined by mimetic flakes of biotite (Plate Xd). The regular even banding of this rock is characteristic of the banded hornfelses but in thin section it has the appearance of a thermally metamorphosed deformed greywacke.

V. TECTONIC STRUCTURES

A. Folding in the Trinity Peninsula Series

The mainland of north-east Graham Land has already been subdivided, for the purposes of stratigraphic description, into areas of distinctive rock types. The characteristic folding and small-scale tectonic structures are now described but no detailed geometrical description of the structures has been attempted, because this was incompatible with the reconnaissance nature of the field mapping. However, a gradual regional change in the form of folds and associated micro-structures has been observed and some idea of the overall structure of the area has been obtained.

1. *North of Russell East Glacier*

a. *South-east limb of the anticlinorium.* Over most of this area, which includes the south-east escarpment of Louis-Philippe Plateau and the nunataks and coastal rock outcrops south-east of Cugnot Ice Piedmont

(Map 2; Fig. 1, areas II and III), the beds show a general "younging" towards a direction varying between south-east and south-south-west. Graded bedding, and to a lesser extent sole markings and the orientation of minor folding and cleavage, are the criteria from which "younging" directions have been deduced.

110 strike directions measured in this area (Fig. 5) show a predominant value varying between 050° and 110°, suggesting a certain amount of folding about axial planes approximately perpendicular to the 080° strike direction. Steep dips to the north-west or north predominate over much of this area and in many instances inversion of the beds has been proved. Where the direction of "younging" is to the north or north-west, there is generally some indication that the beds are involved in disharmonic folding.

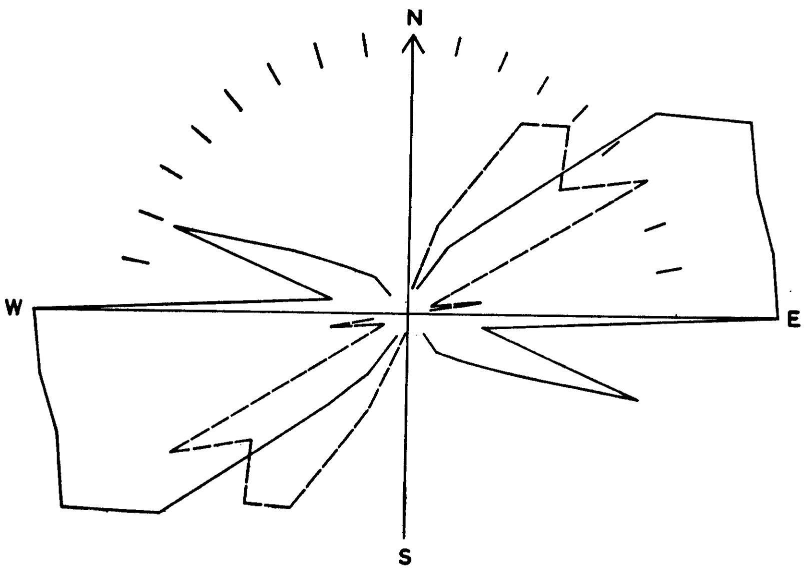

FIGURE 5

Strike frequency diagrams of bedding planes in the area bounded by Duse Bay, Louis-Philippe Plateau and Victory Glacier (solid line), and fold axes in the area between Aitkenhead and Sjögren Glaciers (dashed line).

Isolated disharmonic folds are characteristic of the area south-east of Cugnot Ice Piedmont and the nunataks flanking the lower part of Russell East Glacier. They appear to become increasingly rare away from this area. The best and most spectacular example occurs on the south-west face of Panhard Nunatak (Plate VIb). This fold has the following characteristics:

i. It involves about 10 separate beds of sandstone which together comprise a 30 ft. (9·1 m.) competent unit between two incompetent shale units (p. 37).
ii. It consists of a syncline and an anticline forming one unit with a short-limb height of 70 ft. (21·3 m.) and an axial-plane separation (short limb) of 45 ft. (13·7 m.) (Matthews, 1958).
iii. The adjacent beds of sandstone with shale intercalations are relatively undisturbed and dip north-westwards at angles varying between 68° and 87°. The general direction of "younging" is between south and south-east.
iv. The beds are thicker at the hinges of the folds than on the limbs.
v. The incompetent argillaceous rocks involved in the fold show well-marked cleavage which has a strike varying between 020° and 050° and which converges towards the fold axes.
vi. The anticlinal axis plunges south-westwards at 25°.

Most of the other folds of this type are somewhat smaller and more broken, but none demonstrate the relationship between competent and incompetent beds as clearly as the example described above.

In several of the smaller disharmonic folds, parts of the fold have become sheared and detached, leaving broken sandstone beds surrounded by phyllite (Plate Vd). In some cases, these broken beds are apparently unconnected with any fold structure. The disharmonic nature of the folds is further demonstrated by the plunge of their axes, which varies from 70° towards the north-north-east to 70° towards the south-south-west.

Two specimens (D.3638.1, 3649.1) show small-scale isolated disharmonic folds occurring in laminated siliceous mudstones with shale intercalations. Thin-section examination of these and several other rocks from folded Trinity Peninsula Series strata shows the following features:

i. The shales are strongly cleaved and the cleavage tends to converge towards the fold hinges. The cleavage does not generally cross the bedding surfaces except where the adjacent beds are also shaly. However, a few irregular fractures may pass from one bed to another in tight folds (Plate Xa).
ii. The beds involved in the folds show a slight to well-marked degree of thickening at the fold hinges and thinning in the limbs, implying flow of material within individual beds.
iii. Other evidence of flow in the relatively less ductile sandstones and siltstones includes dispersed intergranular shear planes, bending and distortion of micas and shale inclusions, stretching and fracturing of carbonaceous fragments and the presence of pressure fringes round pyrite crystals (Plate XIa; Hills, 1963, p. 129).
iv. Where mudstones containing thin beds of siltstone are involved in folding, boudinage structures are common and again indicate flow.

Features such as those listed above are cited as evidence of "flexural-flow folding" by Donath and Parker (1964). The fold mechanism, suggested by these authors, of bending by flow within layers is not new but it is particularly applicable to the folds of this area. However, in some isolated folds that occur in sequences of sandstones or siltstones, in which shale intercalations are either very thin or absent, thickening of the beds is not noticeable, and the fold mechanism appears to be mainly flexural slip producing folds of a more concentric form. There are cases where flexural-slip and flexural-flow features are present in different parts of the same fold (Plate Xa). It is probable that most of the folds were initiated as flexural-slip folds at an early stage of induration when the "ductility contrast" between shales and sandstones was at its greatest.

Another type of minor fold which is common in this area occurs in sequences of thin-bedded siltstones with shale intercalations. These folds generally consist of an anticline and a syncline forming one unit on the scale shown in Plate VIc. Small-scale disharmonic folds are present on the flanks of the parent fold, and crumpling and disruption of the competent siltstone beds is also common. These folds do not persist into adjacent argillaceous or sandstone sequences, so in the broad sense they are disharmonic and resemble the "quasi-flexural folds" of Donath and Parker (1964).

The argillaceous rocks generally lack a strong cleavage with a constant orientation independent of bedding attitudes. The type of cleavage commonly present (Plate IIId) causes the rocks to break up into irregular elongated chips which de Sitter (1956, p. 99) cites as occurring "in thick shale beds which have been rotated by the bending of underlying or overlying competent beds, during the development of shear planes". Regular parallel strain-slip cleavage (Turner and Weiss, 1963, p. 98) is found only in the purest shales, containing little or no silt such as in specimen D.3627.1. Slaty cleavage is generally poorly developed and crossed by strain-slip cleavages. In most of the steeply dipping argillaceous rocks of this area the cleavages are sub-parallel to the bedding and it is only in folds that the relations between the different cleavages can be easily seen, but these are too variable for any definite cleavage notation to be used at this stage.

While the mechanism of individual folds seems explicable, the isolation of these folds in a thick, steeply dipping sequence which is not severely folded, is difficult to account for. The general attitude and direction of "younging" of the beds in this area suggests that they form part of the south-east limb of an enormous anticlinal structure, whose axis presumably trends east-north-east to west-south-west, parallel to the regional strike (p. 50). During the compression of this huge fold, differential stretching between the competent and incompetent bedded units must have been very extensive, particularly on the outer limbs, remote from the fold core. It is possible that the folding began before the sediments were fully indurated. The general shearing component resulting from the formation of such a huge fold might have initiated the subsidiary folds, in which case they would be termed "drag folds" (Hills, 1963, p. 285). However, this general shearing component would have been operating on a succession of varying lithology and particular groups of beds would be more likely to react to the general stress by folding, because of their individual physical properties. It is perhaps in these particular groups of beds that the isolated disharmonic folds are now to be found.

b. *Axial zone*. Outcrops are widely scattered north of Broad Valley and Duse Bay. Although well-bedded sandstones and shales are usually present and the direction of "younging" is often determinable, the fold pattern in this area is confused and obscure. Strike directions vary from north–south to east–west and beds in both normal and inverted attitudes are common. It is possible that the wide variation in dip directions and apparent lack of recognizable fold structures is due to the disruptive effects of faulting, but no faults have been observed in the scattered exposures of this area. The only complete fold recorded is exposed on the west face of Mount Cardinall, though fold axes have been mapped by previous workers in the Tabarin Peninsula and Hope Bay areas.

It has already been suggested that the strata south of this area "young" predominantly to the south or south-east. Therefore, it seems likely that the axial part of the huge anticline or anticlinorium is present in this area.

c. *North-west limb of the anticlinorium*. The great thickness and extent of the sequence on the south-east limb of the anticlinorium flanking and south-east of Louis-Philippe Plateau (p. 9) suggests that the corresponding north-west limb extends to the north-west of the plateau. However, the few scattered exposures that occur in this area show no consistent structural trend, probably owing to the disruptive effects of multiple plutonic intrusion (p. 16). In the adjacent area, north-east of Marescot Ridge, Elliot (1965, p. 22) has reported thick greywacke-shale sequences with a steep regional dip to the north-west. In addition, the present author observed well-bedded metagreywackes generally dipping to the north-north-west at about 40° on Blake Island. In both these areas, the beds evidently represent the north-west limb of the anticlinorium.

2. *South-west of Russell East Glacier*

The clear similarity between the two diagrams in Fig. 5 illustrates the structural unity of Trinity Peninsula but they also reflect the way the strike directions follow the axial trend of the peninsula as it swings from a general south-west–north-east direction to a west-south-west–east-north-east one. The Russell East Glacier–Victory Glacier area appears to act as a hinge for this change in direction. In addition, a change in the form of folding takes place south-west of this area. The change is gradual except in the area flanking the lower part of Russell East Glacier, where there is a more marked contrast between the folding on Panhard Nunatak and on Azimuth Hill. The laminated siltstones and shales at the latter locality (Plate Vb) show "passive folding" in which the alternating siltstone and shale bands have not actively controlled the development of folding but simply indicate that the deformation has occurred (Donath and Parker, 1964). This type of folding has not been recorded north of this area but it becomes the commonest type towards the south-west.

Another important structural change is that, while the regional dip and "younging" of the beds to the south-east continues, folding of the rocks is general. Unfolded strata are rare on Mount Wild. The values of dip and strike measurements are very variable but inverted beds rarely occur. However, many fold axes are accessible for measurement, and 48 axial-plane strike directions show a predominant value between 030° and 060° (Fig. 5). Most of the pelitic rocks possess strain-slip cleavage generally dipping at 60–80° to the north-west and parallel to the axial planes of the folds.

The folds appear to have several distinct orders of size, the lower orders of fold forming subsidiary folds on the limbs of the higher orders. For instance, in a section along the north side of Diplock Glacier three orders of fold* are present with the following characteristic dimensions:

	1st order		*2nd order*		*3rd order*	
	(ft.)	(m.)	(in.)	(cm.)	(in.)	(cm.)
Short limb height	150	45·7	12	30·5	0·75	1·9
Long limb height	400	122	18	45·7	2·00	5·0
Axial-plane separation (long limb)	400	122	8	20·3	0·50	1·3
Axial-plane separation (short limb)	250	76	6	15·2	0·33	0·8

* The descriptive terms used are those of Matthews (1958, p. 511–13).

These three sets of dimensions are only intended to show the approximate relative sizes of the folds. Examples of 2nd and 3rd order folds are shown in Plate VId. Again, the size and form of the folds has been largely influenced by the size of the alternating competent and incompetent beds or groups of beds, indicating that in the early stages folding was of the flexural-slip or flexural-flow type. As orogenesis proceeded, these folds were modified to a more similar style, though some of the early fold forms are still preserved (Plate VId). The nature of this modification is demonstrated by a thin section across the junction between a phyllite and the overlying bed of metagreywacke (Plate XIIe), in which strong strain-slip cleavage in the phyllite has penetrated the metagreywacke. The slip along these cleavage planes has caused the bedding surfaces to fold. Three other structural elements which are sub-parallel to the bedding surfaces have also been affected by this folding and are therefore older than the strain-slip cleavage. These structural elements are:

i. Quartz veins which are partially within the silty laminae in the phyllite.
ii. Foliation due to the growth of metamorphic micas and the rodding of quartz grains in the direction of the *b* fabric axis.
iii. Intergranular shear planes in the metagreywacke.

The presence of this strain-slip cleavage indicates that the fold mechanism was primarily that of "passive flow", because the cleavage penetrates through the rock as a whole, causing flexing of nearly all the bands regardless of their lithology. However, an exceptionally homogeneous band (a prominent quartz vein in siltstone) does not appear to have been penetrated by the cleavage and therefore the passive-flow mechanism can only have been partially operative here.

The form of the folds and the directions of linear elements in this area suggest that folding took place during a period of strong compression acting either from a north-westerly or south-easterly direction. In the Mount Roberts area, where the longest exposed sections occur, the general dip of the cleavage and the asymmetry of the folds suggest that these beds are on the south-east limb of an anticlinorium, whose axis trends north-east to south-west. On Alectoria Island the asymmetry of the minor folds is in the opposite direction to that on the nearby mainland, and it is probable that the beds here are on the north-west limb of an anticline. If this is so, there must be a major synclinal axis between Alectoria Island and Mount Roberts. This large synclinal structure appears to be present in the ridges north-west of Mount Wild, but farther south-west the structure becomes confused and obscure owing to the effects of the igneous complex in the Sjögren Glacier area. The structural complexity near plutons is also exemplified by the rocks at Pitt Point, where there are small complex folds with axes striking nearly north–south and with frequent inversion of the strata as proved by graded bedding.

The type of variation in the regional strike which occurs north-east of Russell East Glacier (p. 50) is also present in this area (Fig. 5). The folding represented by these variations is shown on a small scale by irregular folds which are to be seen on rock faces showing strike sections (Plates Va, VIIa, b, c). These photographs also illustrate that the intensity of this folding increases towards the south-west of this area, reaching its greatest complexity below the thrust plane at the north end of Mount Wild (Fig. 2). A specimen of phyllite from this locality (D.3936.1) has a distinct but weak lineation defined by micro-crenulations crossing the folded foliation (= bedding) surfaces at nearly 90°. It is probable that kink folds (Turner and Weiss, 1963, p. 114) on a microscopic scale in chloritic phyllites on the south side of Sjögren Glacier also belong to this fold phase (Plate VIId). From the evidence outlined above it is clear that the Trinity Peninsula Series has suffered a second period of minor folding which is subordinate to the first period (p. 55).

Above the thrust plane on Mount Wild the greenschists (p. 42) have a much simpler and more uniform structure dipping fairly evenly to the south-east at 40–50°, sub-parallel to the underlying thrust plane. Exceptions to this general dip appear to be due to drag effects adjacent to normal faults (Fig. 2).

B. FAULTING

North-east Graham Land is an area which has suffered orogenic deformation and includes rocks formed under many different tectonic environments. However, the number of faults actually exposed, or whose existence may be inferred, is very few. This can be explained by the scattered nature of the exposures, the extensive ice cover and the absence of marker horizons in the lithologically monotonous Trinity

Peninsula Series. In general, fault zones are relatively less resistant to erosion and are therefore liable to be hidden beneath the ice cover. Even when faults are suspected from linear topographical features, their form is difficult to determine because the relative stratigraphic position of the rocks on either side of the fault line is generally unknown.

The most important exposed fault in this area is the thrust fault on Mount Wild (Map 3; Fig. 2). The thrust plane dips at an angle of about 45° towards the east-south-east and consists of a zone of shearing and brecciation varying in thickness from 9 in. (23 cm.) to 2 ft. (0·6 m.). The thrust plane is displaced by a later series of normal faults with downthrows to the east of up to 150 ft. (45·7 m.). These faults are marked by gullies, and it is probable that similar gullies diagonally crossing the many east–west trending ridges in this area may also mark fault lines. Steeply dipping dykes also form gullies. These have a general directional trend between 000° and 045°, and this is interpreted as being an important direction of tension fracture.

Two other important faults have been inferred by previous workers in this area. The first trends north-east across Longing Gap (Map 3). On the south-east side of the inferred fault zone are almost horizontal beds of fossiliferous Jurassic and Cretaceous siltstones at least 300 ft. (91 m.) thick but on the north-west side are rocks of the Trinity Peninsula Series. These are unconformably overlain by Jurassic strata to the north and west. 9 miles (14·5 km.) north of Longing Gap, Jurassic beds rest on the Trinity Peninsula Series which is heavily veined and often brecciated, suggesting the close proximity of a fault of pre-Jurassic age. The Jurassic beds dip east-south-eastwards at 24° but they are otherwise undisturbed. They do, however, contain pebbles which are mainly of vein quartz, probably of local derivation. The position of strata of different ages on either side of Longing Gap suggests either a throw of several hundred feet to the south-east, or a transcurrent fault of unknown displacement.

The second important fault has been inferred by Bibby (in press) to extend from Bald Head to Church Point (Map 2). He has considered that "this fault has moved more than once, and in different directions, since it was first formed" and that its downthrow at Bald Head is approximately 770 ft. (235 m.) to the north. He has also regarded this as one of several faults affecting the Prince Gustav Channel area.

The outcrops of only ten other minor faults were seen, mostly on inaccessible cliff faces. Of these, four are normal faults of unknown throw sub-parallel to the strike of the bedding, while three are small thrusts with a displacement of only a few feet. The remaining three faults trend in a direction making an angle of 60–80° with the eastward bearing of the regional strike. The best exposed of these is on the western slope of Chapel Hill, where the fault has caused the strike of the beds to bend, thus proving that it is a transcurrent fault with a sinistral displacement (Map 2).

Indirect evidence of faulting is the presence of several large valleys trending obliquely to the axis of the peninsula, and in the linearity of some of the plateau scarps. Russell East and Russell West Glaciers are the most obvious examples of the former trend (Map 2). There are four examples of a distinct linearity of plateau scarps: the north-western and southern scarps of Laclavère Plateau, the foot of the scarps overlooking Cugnot Ice Piedmont and the ice piedmont between Diplock Glacier and Mount Wild. If these are lines of fracture, there is no geological evidence of the amount of displacement.

C. General Tectonic History

No rocks older than (?) Carboniferous have been recorded in north-east Graham Land, except for phenoclasts and rock fragments in the conglomerates and sandstones of the Trinity Peninsula Series. A significant proportion of these inclusions consists of rocks belonging to the greywacke facies and having either the same or only a slightly higher grade of regional metamorphism than the enclosing sediment. This observation suggests that the inclusions were probably derived from older members of the Trinity Peninsula Series rather than from a much earlier geosynclinal succession (p. 35). Moreover, the other phenoclasts consist mainly of Basement Complex granites and gneisses, acid volcanic rocks and sedimentary quartzites. Therefore, it seems likely on the present evidence from this area that the deposition of the Trinity Peninsula Series marked the first phase in the history of an orogenic belt which has remained periodically active through to the present day.

After the deposition of a great thickness of sediment, the rocks were probably tilted south-eastwards and compressed with the consequent development of huge asymmetrical anticlinoria with various forms of subsidiary folds developing on the steep south-east limb. The later stages of folding were accompanied by low-grade regional metamorphism. Folding on this gigantic scale, involving geosynclinal sediments of approximately the same age, is also present in other parts of the circum-Pacific orogenic belt. For instance, in the South Island of New Zealand the very thick Upper Palaeozoic—Triassic sequence is folded into a synclinorium with a steeply dipping north-east limb, over 25 miles (40 km.) across (Mutch, 1957).

An extension of the hypothesis of Hawkes (1962) on the structure of the Scotia arc provides the basis for a possible explanation of the second period of folding which has affected the Trinity Peninsula Series (p. 53). Hawkes has suggested that the Antarctic Peninsula and the islands of the Scotia arc were linked directly to South America at the end of the Palaeozoic and that an eastward advance of the Pacific crust disrupted this "continental strip". One obvious effect of this was to cause the Antarctic Peninsula to bend into an arcuate form with the steeply dipping beds of the newly folded Trinity Peninsula Series succession on the concave side of the arc. In this situation these beds would be subjected to compression acting parallel to the curvature of the peninsula during the process of bending.

Three other lines of evidence throw some light on the time factor involved in the deposition of the Trinity Peninsula Series and the age of the folding and deformation that followed.

i. The total maximum thickness of these deposits is at least 45,000 ft. (13,715 m.) of which roughly one-sixth is shale and mudstone. In estimating the time taken for the deposition of the Carpathian flysch, Sujkowski (1957) assumed that the shales were deposited by slow accumulation in quiet waters at a rate of the order of 1 in. (2·5 cm.)/1,000 yr. If these same assumptions are applied to the Trinity Peninsula Series, then an estimated period of about 90 m. yr. would be required for their deposition. In making this estimate it is also assumed that the deposition of the sandstones and siltstones was mainly by turbidity currents and the time taken for deposition was negligible compared with that of the argillaceous rocks. However, without a very detailed section through the whole succession, the estimate of the total shale thickness can only be very approximate.

ii. The Trinity Peninsula Series has been tentatively correlated with the Greywacke-Shale Series of the South Orkney Islands, which form part of the same orogenic belt and have also been subjected to intense folding (Adie, 1957*b*, p. 21). An Upper Triassic age, determined by the potassium-argon method, has been postulated for the last major metamorphism of the schists underlying the Greywacke-Shale Series (Miller, 1960). Miller has further postulated that this radiogenic age is also that of the orogeny which caused the folding of the Greywacke-Shale Series. It is probable that the folding and deformation of the Trinity Peninsula Series took place during the same orogeny.

iii. The Trinity Peninsula Series is unconformably overlain by gently folded, Middle Jurassic plant-bearing strata and both the first and second periods of folding must therefore be older than Middle Jurassic.

Some tectonic activity during the Middle and Upper Jurassic is suggested by the local deposition of coarse conglomerates, and it was accompanied by crustal tension resulting in widespread vulcanism and minor intrusion.

There is little evidence to show what geological events took place between the Upper Jurassic and the upper part of the Cretaceous. Radiogenic dates for the intrusion of plutonic rocks in the Cape Legoupil area (Halpern, 1962) indicate a possible commencement of plutonic activity in the middle or even lower part of the Cretaceous (p. 16). If this was so, then a certain amount of tectonic activity and metamorphism would be expected to have accompanied this plutonism. The gentle folding of the Jurassic rocks may have taken place during this period. Certainly, there was uplift and erosion towards the end of the Cretaceous, which resulted in the deposition of the Cretaceous beds of the Cape Legoupil area and the James Ross Island group. The Cape Legoupil beds probably represent the latest geosynclinal phase of deposition in the north-east Graham Land part of the orogenic belt (Halpern, 1964). Unlike the earlier Trinity Peninsula Series phase, this deposition and subsequent uplift was associated with major plutonic activity, which resulted in the emplacement of rocks of the Andean Intrusive Suite, in plutons of batholithic proportions. The intrusions resulted in the contact metamorphism and further compression of the adjacent rocks of the Trinity Peninsula Series and was probably associated with large-scale faulting.

VI. COMPARISON WITH OTHER AREAS OF GRAHAM LAND AND THE SCOTIA ARC

THE fact that the area described in this report forms only a small part of the Graham Land mountain chain invites comparison with other parts of this same orogenic belt both in Graham Land and in the Scotia arc. Several authors, notably Adie (1957*b*) and Matthews (1959), have drawn attention to the similarities between the folded geosynclinal sediments comprising the Sandebugten Series of South Georgia, the Greywacke-Shale Series of the South Orkney Islands and the Trinity Peninsula Series of Graham Land. Hobbs (1962) has suggested that the Miers Point Series of Livingston Island can also be tentatively correlated with the Trinity Peninsula Series. Some of the significant characteristic features common to these successions are set out in Table XIII. The information on the South Orkney Islands is based on the work of Tilley (1935) and Matthews (1959), whereas that on South Georgia is from the papers by Trendall (1953, 1959).

Recent work by D. H. Elliot (personal communication) in the area south-west of Cape Longing has confirmed the presence (Adie, 1957*b*) of an extensive outcrop of Trinity Peninsula Series metasediments forming a continuation of the orogenic belt 50 miles (80 km.) south-west of the area described here as far as Drygalski Glacier. Plutonic intrusion, regional and thermal metamorphism, and large-scale folding of the thick sedimentary succession continue as important features of the geology, but the metamorphic grade decreases to the north-west and the axial part of the anticlinorium is thought to be south-east of the mainland area.

The geology of Joinville Island, which is off the north-east coast of Graham Land, has close similarities to that of the mainland, with the occurrence of similar lithologies and structures in the Trinity Peninsula Series sediments, which are also intruded by granitic rocks of the Andean Intrusive Suite. Here, too, there is a marked unconformity between the folded Trinity Peninsula Series and the overlying Mesozoic rocks.

The South Shetland Islands form an arcuate island group trending parallel to the axis of Graham Land. Investigations on Livingston Island (Hobbs, 1962), one of the largest in the group about 75 miles (121 km.) north-west of Trinity Peninsula, have shown the presence of a eugeosynclinal sequence of feldspathic greywackes (the Miers Point Series) closely comparable with the Trinity Peninsula Series. This sequence has a thickness of 10,000 ft. (3,050 m.) and consists mainly of shales, siltstones and feldspathic greywackes with subordinate interbedded conglomerates, pebbly mudstones and volcanic (or hypabyssal) rocks of intermediate composition. There appears to be a particularly close similarity in the types of phenoclasts and rock fragments in the conglomerates and greywackes of the two sequences and in the environmental conditions in which the sediments are thought to have been deposited. Another similarity is that the rocks of the Miers Point Series are intruded and thermally metamorphosed by large quartz-diorite plutons. There is also a group of rocks on Livingston Island called the False Bay schists, but these are of limited extent and their relation to the other rocks on the island is not fully understood.

Tilley (1935) has described representative specimens from the Greywacke-Shale Series of the South Orkney Islands which are situated 450 miles (724 km.) north-east of Graham Land. From these descriptions the greywackes appear to have much in common with those of the Trinity Peninsula Series. In particular, they contain an abundance of "angular sericitized and twinned albite" and acid igneous rock fragments which led Tilley to conclude that sodic igneous rocks formed the main source of these sediments. According to Tilley, sediments derived from the older metamorphic rocks that occur elsewhere in these islands form only a minor constituent of the greywackes. Structurally, the Greywacke-Shale Series is folded about axes trending in a general north—south direction, which is contrary to the apparent east–west trend of the Scotia arc in this region.

The isolated island of South Georgia comprises the northernmost and easternmost development of thick eugeosynclinal sedimentary sequences in this part of the orogenic belt (Trendall, 1953, 1959). There are two such sequences: namely, the Sandebugten Series, and the Cumberland Bay Series, which is predominantly tuffaceous and contains a Cretaceous marine fauna in its uppermost part. The latter sequence is probably unconformable on the former and both are strongly folded about axes trending sub-parallel to the north-east to south-west axis of the island itself. The quartzose greywackes of the Sandebugten Series have only been briefly investigated and, although they have a similar appearance to those of the Trinity Peninsula Series, insufficient information is at present available for a valid comparison

Table XIII

COMPARISON OF THE CHARACTERISTICS OF GEOSYNCLINAL SEQUENCES IN THE SCOTIA ARC AND GRAHAM LAND

	Sandstone Composition	*Associated Fossils*	*Trend of Major Fold Axes*	*Provenance of Sand Grains*	*Composition of Phenoclasts and Rock Fragments*			
					Granitic	*Rhyolitic*	*Andesitic*	*Metamorphic*
Trinity Peninsula Series of north-east Graham Land	Lithic and feldspathic greywacke	Very rare poorly preserved plants of (?) Carboniferous age. Few trace fossils	North-east to south-west in south; east-north-east to west-south-west in north	Derived from granite-gneisses, rhyolites and quartzose metasediments	Commonly present	Abundant	Scarce but present in most parts of the succession	Low-grade metasediments common in some parts of the succession
Miers Point Series of Livingston Island, South Shetland Islands (Hobbs, 1962)	Feldspathic greywacke	Rare, poorly preserved plant remains. Few trace fossils	North-east to south-west	Derived from (?) granite-gneisses, rhyolites and calcareous and (?) quartzose metasediments	Subordinate	Abundant	Present in some parts of the succession	Fairly common at some horizons
"Younger Greywacke-Shale Series" of the South Orkney Islands (Tilley, 1935; Matthews, 1959)	Feldspathic greywacke	Rare, poorly preserved plant remains of (?) Carboniferous age	North-north-west to south-south-east	Derived mainly from rhyolites with lesser amounts of granitic and metamorphic material	Subordinate	Abundant	Present in some parts of the succession	Fairly common at some horizons
Sandebugten Series of South Georgia (Trendall, 1953, 1959)	Quartzose greywacke	Rare trace fossils	North-west to south-east	?	?	?	Present in small amounts	?

to be made. In common with other regions of this orogenic belt, these thick sedimentary sequences are intruded in the south-east part of South Georgia by a plutonic igneous complex.

VII. CONCLUSIONS

ROCKS belonging to five major stratigraphic units crop out in the Duse Bay–Larsen Inlet area of north-east Graham Land. Because there is less ice cover south-east of the partially dissected plateau forming the backbone of the peninsula, most of the rock exposures occur in this area.

The Trinity Peninsula Series of (?) Carboniferous age is the oldest and most widespread group of rocks in this area. The rocks of this series include conglomerates and pebbly mudstones, feldspathic and lithic greywacke-sandstones and siltstones, green cherts and siliceous mudstones, dark grey, green and red shales, and dark grey laminated mudstones. Thick sequences of greenschists occur in the southern part of the area in association with metagreywackes and phyllites rich in chlorite, leucoxene and highly altered clastic feldspar. These rocks represent intermediate or basic hypabyssal and volcanic rocks, and their clastic derivatives, but the nature of the original volcanism has yet to be proved.

These sedimentary and volcanic rocks, and their metamorphic equivalents, form flysch-type sequences with a total thickness of the order of 45,000 ft. (13,715 m.), though neither the base nor the top of the succession has been seen. No detailed correlation within the Trinity Peninsula Series has been attempted owing to the complete absence of stratigraphically useful fossils, the repetitive nature of the lithology and the lateral changes in metamorphic grade. However, certain parts of the succession possess general lithological distinctions, such as the following (Map 1):

i. In the Laclavère Plateau area there is a predominance of greywackes richer in feldspar than in quartz. The proportion of plagioclase generally exceeds that of potash feldspar. Of the heavy minerals, epidote and sphene are abundant.
ii. Conglomerates and pebbly mudstones are confined mainly to a zone trending westwards from View Point to the Benz Pass area.
iii. The greywackes in the zone extending from Jade Point to Russell East Glacier are relatively rich in quartz but poor in feldspar. The heavy mineral suite is distinguished by moderate amounts of tourmaline, garnet and allanite, and it is proportionately richer in iron ore and leucoxene.
iv. Beds of chert associated with green and red shales, and siliceous mudstones, occur only in the nunataks north of Camp Hill.
v. Greenschists, which probably originated as lavas and tuffs, form thick sequences interbedded with chloritic metasediments in the Tower Peak and Mount Wild areas. Some of these greenschists are probably associated with penecontemporaneous minor igneous intrusions represented by albite-augite-ilmenite dykes.

The sandstones in the first three sequences also have several other differences in detail.

The following structural, textural and compositional features of these sediments indicate that they were deposited in a geosyncline in which slow accumulation of pelagic mud was periodically interrupted by influxes of coarser sediment transported by turbidity currents:

i. The predominant lithology for many thousands of feet of sediment comprises greywackes and siltstones alternating with shales or mudstones.
ii. The greywackes are poorly sorted sandstones, often occurring in regular graded beds.
iii. Angular shale fragments are common in the greywackes.
iv. Rudaceous rocks in the form of conglomerates and pebbly mudstones occur in some parts of the succession interbedded with the normal greywackes and shales. They contain phenoclasts from both intra-basinal and extra-basinal sources but they show no positive evidence of a glacial origin.

Although identifiable fossils are absent, trace fossils on the soles of siltstone beds and the widespread occurrence of carbonaceous material indicate that there was some organic life both in the depositional environment and in the source area.

The source area was a continental landmass largely formed of granite and granite-gneiss, quartzites and subarkoses with a low grade of metamorphism, and rhyolites with associated pyroclastic rocks. The Trinity Peninsula Series sediments also include fragments of sedimentary rocks deposited earlier in the history of the geosyncline. The granitic rocks forming phenoclasts in the Trinity Peninsula Series conglomerates have several features in common with similar rocks described from the Basement Complex of south-west Graham Land.

The shape of the basin of deposition is uncertain, but it is assumed to have been aligned sub-parallel to the north-eastern part of the present Antarctic Peninsula. The little evidence of palaeocurrent directions that has been obtained suggests the source area was situated to the north or north-west but this is far from conclusive and the possibility of a derivation from a continental landmass to the south-east cannot be eliminated.

Varying thicknesses of coarser sediment with cyclic sequences in some areas probably reflect periods of uplift in the source area. The greywackes of Laclavère Plateau contain an abundance of both altered and fresh feldspar grains which appear to have an average size equal to or larger than the associated quartz grains. This evidence suggests that a high relief and a temperate to warm humid climate prevailed in the source area, at least during the early part of the depositional period. These changes in relief, the frequency and abundance of turbidity currents, and the penecontemporaneous volcanism, all indicate that there was considerable tectonic activity at that time.

This tectonic activity culminated in the compression and folding of the geosynclinal sediments prior to the deposition of the Middle Jurassic beds. The folding occurred in two phases and the effect of the first and main phase was to form an anticlinorium with its axis trending sub-parallel to the length of Trinity Peninsula. North-east of Russell East Glacier, the south-east limb of the anticlinorium is formed of steeply dipping or overturned beds with isolated disharmonic folds but farther to the south-west folding is more intense and complex in association with a slight increase in grade of regional metamorphism. The second, or subordinate, fold phase resulted from compression along the length of the peninsula, producing large-scale variations in strike of the steeply dipping beds with strong puckering in the strata more intensely deformed by the first fold phase.

Although the grade of regional metamorphism is always low, it is not uniform and the almost unaltered sediments of north-east Trinity Peninsula give way to phyllites, metagreywackes and greenschists in the south-west. Only in the case of the greenschists is the original nature of the rock uncertain. The mineral assemblages resulting from regional metamorphism generally fall within the lower sub-facies of the greenschist facies as defined by Turner (Fyfe, Turner and Verhoogen, 1958).

Higher grades of thermal metamorphism are confined to the aureoles of several plutonic intrusions and intrusive complexes of the Andean Intrusive Suite which occur between Marescot Ridge and Larsen Inlet. This metamorphism has transformed the metagreywackes into quartz-biotite-albite-hornfelses and the phyllites into quartz-mica-cordierite-schists. Higher-grade assemblages of the hornblende-hornfels and pyroxene-hornfels facies are rarely developed. Relict structures from the earlier regional deformation are preserved in both the hornfelses and schists and there is also evidence that in its later phases thermal metamorphism was accompanied by considerable shearing stress. Metasomatism does not appear to have had any great effect on the mineral content of the metamorphic rocks except in a few isolated cases.

Although no detailed comparisons have yet been made, the present petrographic and structural study supports the conclusions of other workers that there is a close affinity between the Trinity Peninsula Series and other geosynclinal sequences in the Scotia arc.

One group of metasedimentary rocks, the banded hornfelses in the thermal aureole of the Mount Reece granite, shows neither evidence of the intense deformation nor does it include the metagreywackes which characterize the Trinity Peninsula Series succession. These sediments are therefore regarded as a distinct stratigraphic unit which is in all probability younger than the (?) Upper Triassic orogeny that resulted in the folding and regional metamorphism of the Trinity Peninsula Series but older than the late Cretaceous to early Tertiary Andean Intrusive Suite.

In the Sjögren Glacier–Larsen Inlet area Middle Jurassic plant-bearing mudstones, together with sandstones and conglomerates, are conformably overlain by Upper Jurassic volcanic rocks of intermediate to acid composition. In general, the various sequences together form a succession similar to those already described by previous authors from the Trinity Peninsula area, with lavas and pyroclastic rocks ranging from andesites to rhyolites and with the acid types predominating in the upper part of the succession.

However, in two of the sequences where sedimentary rocks with identifiable fossil plants are absent, the basal conglomerates and sandstones contain penecontemporaneous volcanic material, indicating that the volcanic rocks are to some extent diachronous. The youngest rocks in this succession are described in this report as crystal tuffs and "quartz-plagioclase-porphyries" but their classification is only tentative, because of devitrification and the absence of tuffaceous textures. The crystal tuffs have a pseudo-stratification which probably represents different degrees of welding and contrasts with the massive appearance of the more acid "quartz-plagioclase-porphyries".

Dykes having a close petrographic affinity to the andesitic and rhyodacitic Upper Jurassic volcanic rocks are scattered throughout this area and they include pyroxene- and hornblende-microdiorites, felsites and "plagioclase- and quartz-plagioclase-porphyries". An exceptionally dense swarm of "quartz-plagioclase-porphyry" dykes, cut by the Mount Reece granite, occurs in Trinity Peninsula Series meta-sediments near Pitt Point, but its presence at this particular locality has not yet been explained.

Although Cretaceous sedimentary rocks occur in the coastal areas of north-west and south-east Trinity Peninsula, they are absent from the area described in this report, and rocks of this age are confined to members of the Andean Intrusive Suite which are second only to the Trinity Peninsula Series in the extent of their outcrop. Major intrusions of this suite occur either singly or in complexes in the Marescot Ridge–Russell West Glacier, Victory Glacier–Aitkenhead Glacier and Sjögren Glacier areas. Within each of these areas there are several intrusions of different composition, ranging from quartz-gabbro and tonalite to alkali-granite. Intrusive contacts at three localities indicate that the granitic rocks are younger than those of a more basic composition. In general, the larger plutons have a more regular oval-shaped plan and consist of granodiorites, adamellites and granites with a homogeneous appearance, sharp intrusive contacts and few xenoliths, though large rafts of country rock occur in some intrusions. In contrast, the intermediate rocks form relatively small irregular intrusions marginal to the granitic plutons, contain abundant xenoliths and have more gradational contacts with the country rock. However, the Sjögren Glacier igneous complex also includes a large granitic intrusion of variable appearance containing irregular rafts of amphibolite and country rock, and it is thought that the composition of this and most of the intermediate rocks have been modified by assimilation.

Two of the dykes in the Sjögren Glacier area may also be associated with the Andean Intrusive Suite. They consist of alkali-granite and quartz-microdiorite. The first rock, which contains both riebeckite and aegirine, is unique in northern Graham Land.

No new direct evidence has come to light concerning the age of the Andean Intrusive Suite but it is hoped that radiogenic age determinations at present being carried out, will help to resolve this problem.

Apart from a problematical exposure of conglomerate at View Point, the only Tertiary deposits in this area are the palagonite-tuffs and breccias forming two outliers of the James Ross Island Volcanic Group on the south side of Broad Valley. Nevertheless, olivine-dolerite dykes of the same age are fairly common in this part of north-east Graham Land.

VIII. ACKNOWLEDGEMENTS

THE field work was carried out from the British Antarctic Survey station at Hope Bay during the period 1960–62, and invaluable field assistance was given by colleagues at this station. I am also grateful to D. H. Elliot and M. Fleet for making available their specimens and field notes relevant to the area described in this report. The laboratory work was done in the Department of Geology, University of Birmingham, by kind permission of Professor F. W. Shotton. I wish to thank Dr. R. J. Adie for his guidance on many aspects of the work and his help and encouragement in the preparation of the manuscript. Stimulating discussion and criticism by members of the British Antarctic Survey research group and the Department of Geology, University of Birmingham, has been much appreciated.

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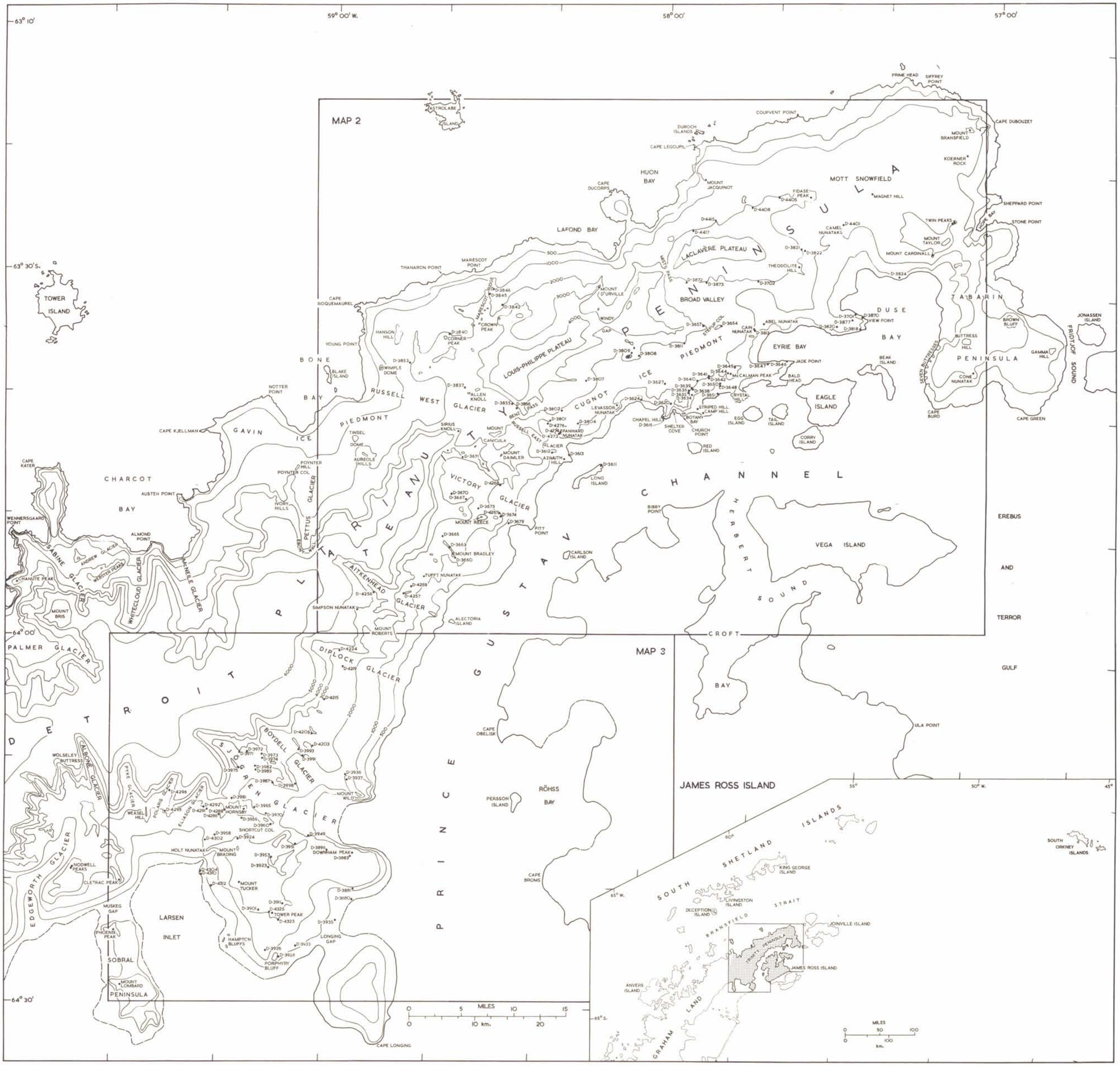
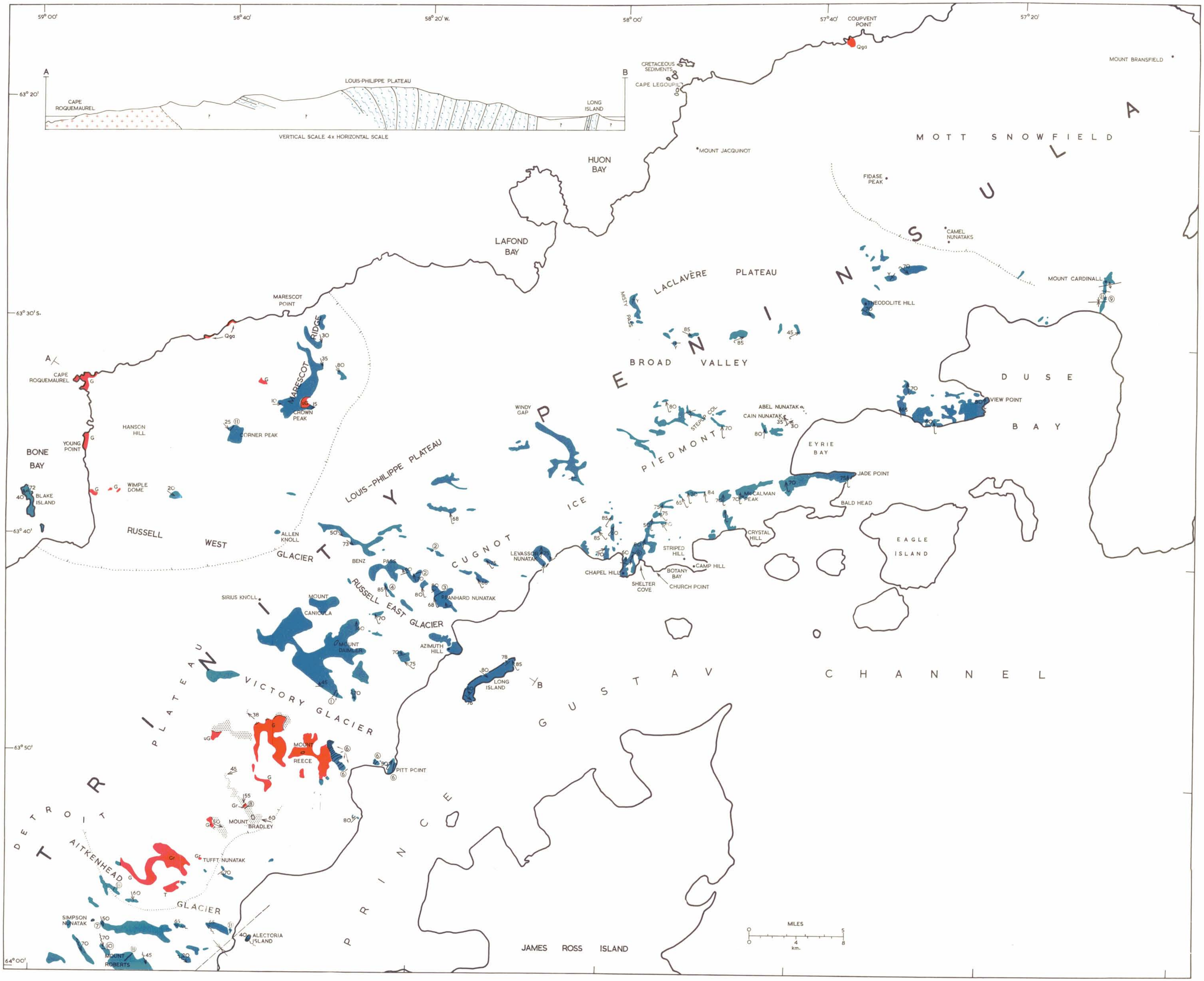
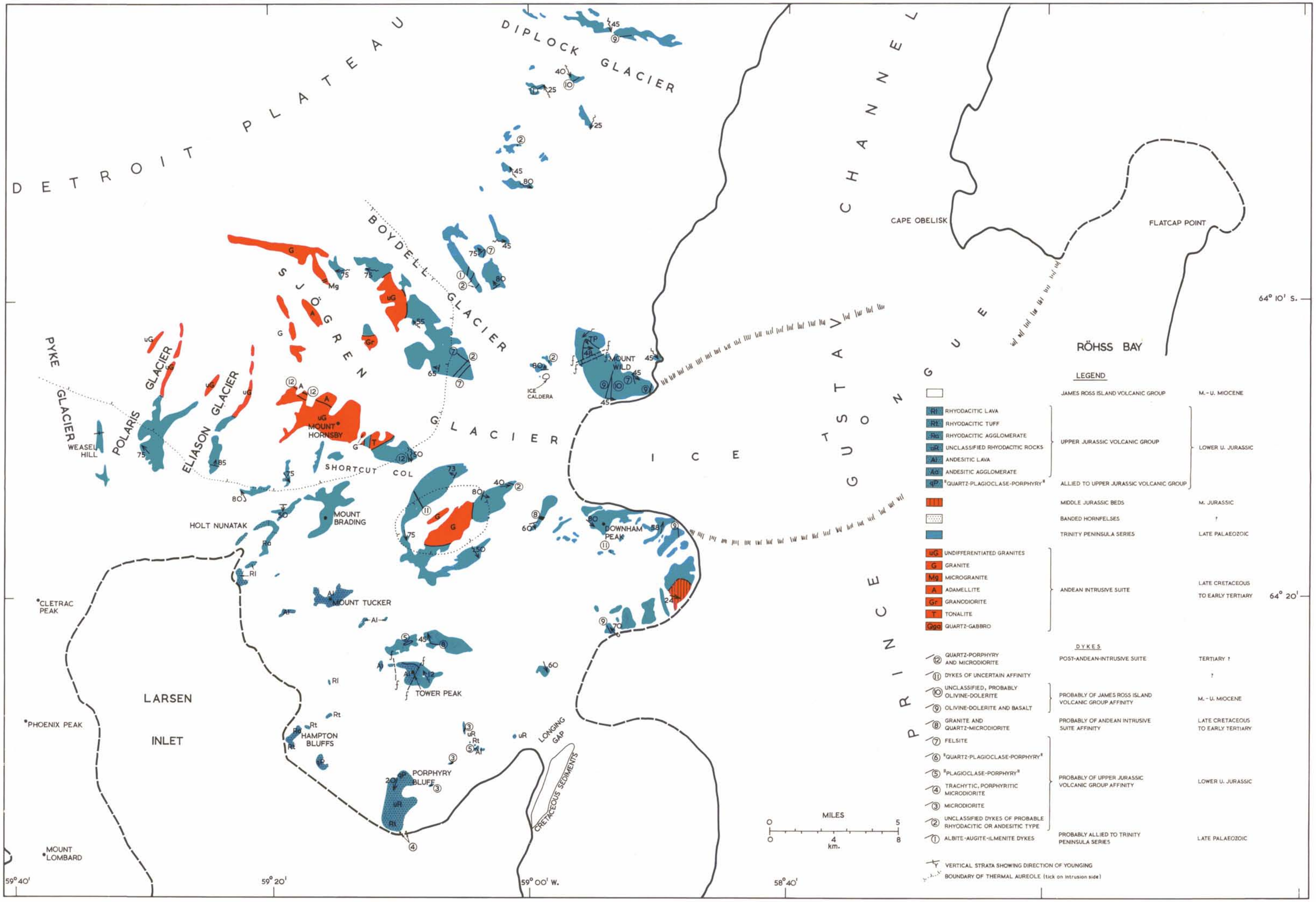


Map 1
Map of north-east Graham Land showing the topography, place-names and station numbers.
The inset shows the position of the area in its regional setting.



MAP 2
Geological map of Trinity Peninsula (Duse Bay to Aitkenhead Glacier).



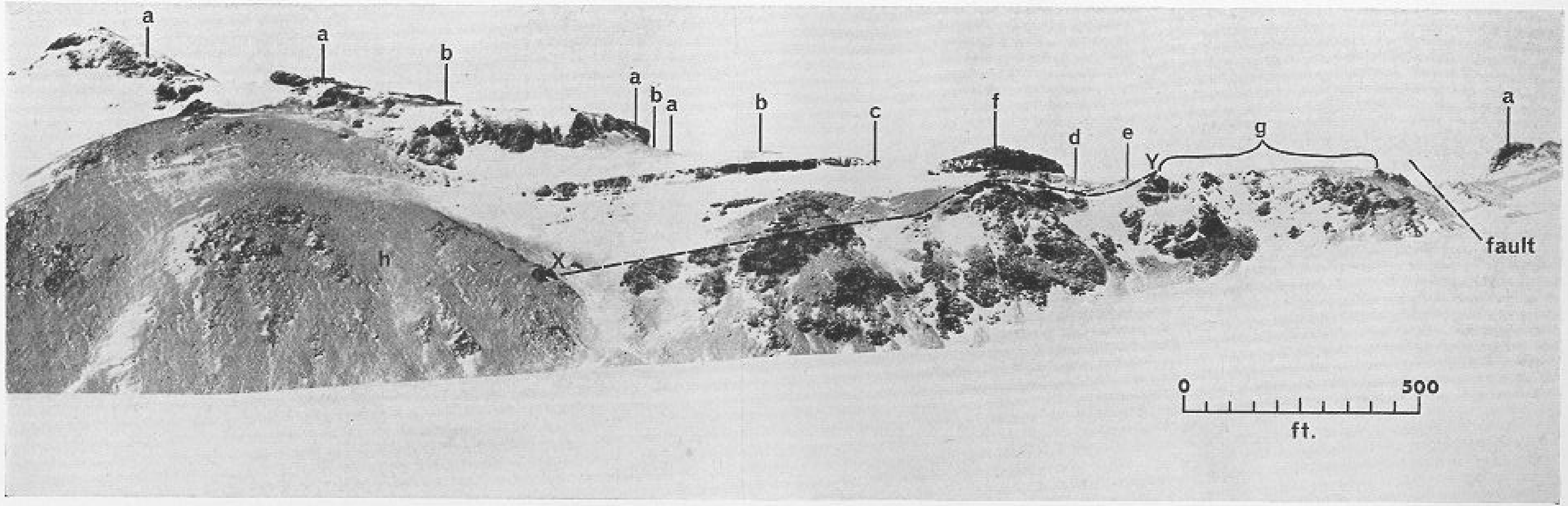
MAP 3
Geological map of Trinity Peninsula (Diplock Glacier to Larsen Inlet).

PLATE I

a. The west ridge of Tower Peak, viewed from the north, showing gently dipping strata comprising Jurassic sedimentary and volcanic rocks (a–e) intruded by a laccolith of porphyritic microdiorite (f), lying with strong unconformity (X–Y) on Trinity Peninsula Series metasediments (p. 13–15). The scale is approximate.
a. Blocky andesitic lavas and agglomerates; b. Conglomerate; c. Garnetiferous conglomerate; d. Fissile sandstone with plant remains; e. Basal conglomerate; f. Porphyritic microdiorite; g. Trinity Peninsula Series metasediments.

b. The peaks on the north-east side of Russell East Glacier viewed from Azimuth Hill. Panhard Nunatak, with its cirque glacier, is on the right of the photograph.

c. Looking south from the small nunatak (D.3670) in the upper amphitheatre of Victory Glacier to the north-west face of the Mount Reece massif, showing banded hornfelses dipping uniformly away from the granite intrusion at about 30° to the west-north-west (p. 48).



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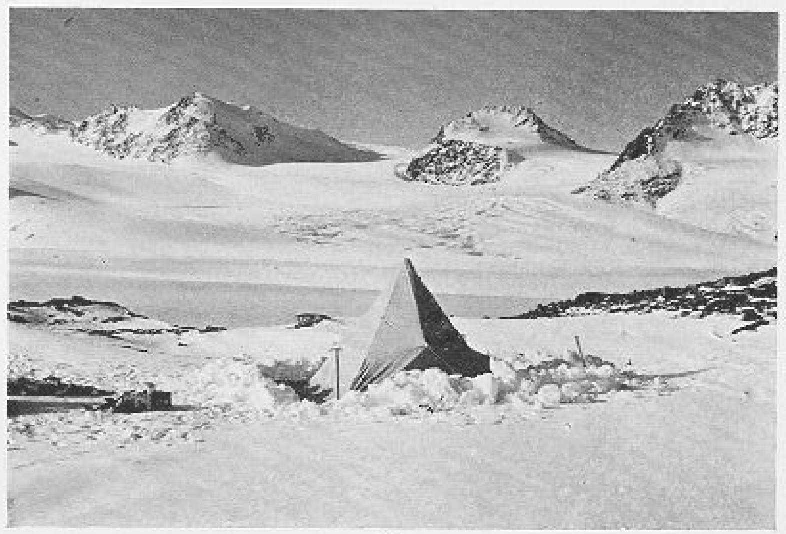

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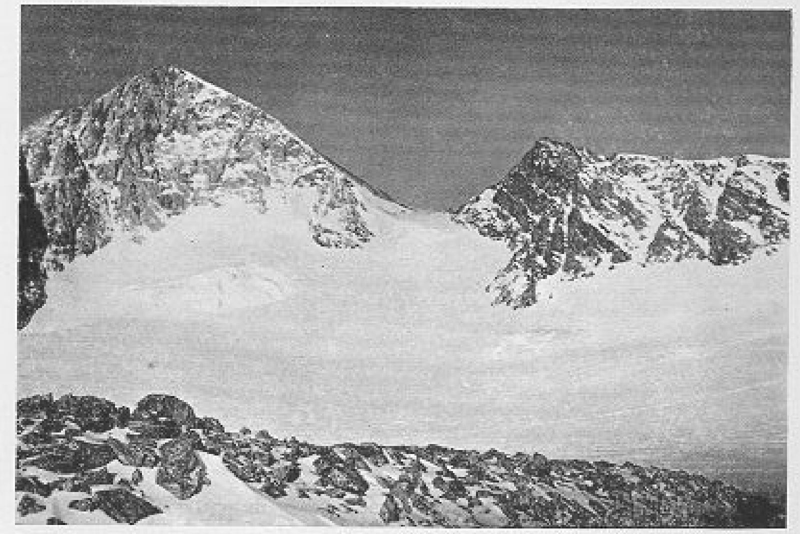

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PLATE I

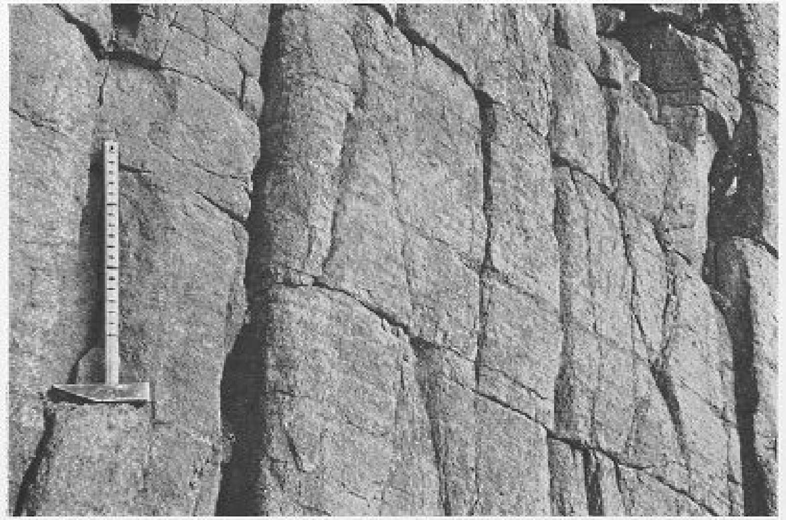
PLATE II

a. A vertical cliff facing north-west on the western outcrop of Hampton Bluffs (D.4317), showing lamination in rocks tentatively classified as crystal tuffs (p. 14). The scale is in inches.

b. A north-facing cliff (D.4267) overlooking Victory Glacier 1 mile (1·6 km.) north-east of the summit of Mount Reece, showing a multiple swarm of very closely spaced light-coloured dykes of "quartz-plagioclase-porphyry" intruded into dark phyllites of the Trinity Peninsula Series (p. 15) and forming narrow wedges between the dykes. The scale is given by the figure on the snow at the bottom left.

c. Cliffs about 1,500 ft. (457 m.) high forming the head wall of a north-facing cirque of Mount Hornsby overlooking the upper amphitheatre of Sjögren Glacier. The cliffs are composed of undifferentiated granite of the Andean Intrusive Suite containing huge rafts of dark metasedimentary and amphibolitic rock (p. 18). The prominent dykes are probably microdiorite (dark) and aplite (light).

d. Looking due east at the 250 ft. (76 m.) high south-west face of Cain Nunatak (D.3813), showing bedded tuffs and volcanic breccias of the James Ross Island Volcanic Group (p. 19).



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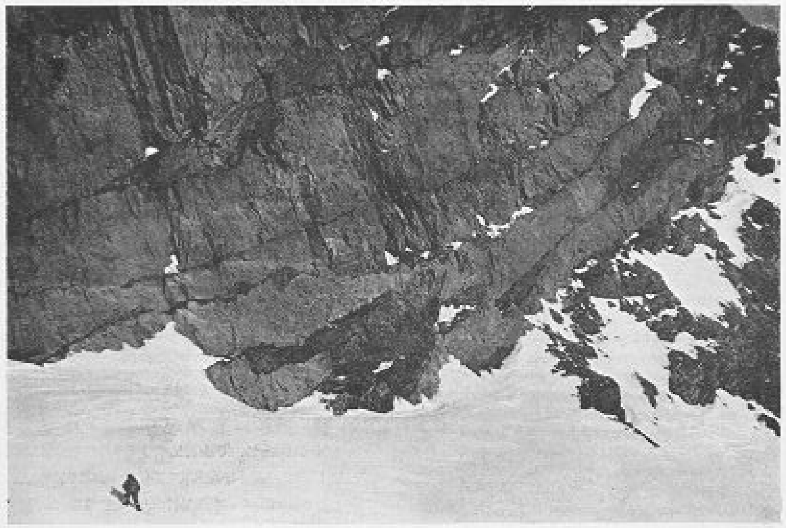

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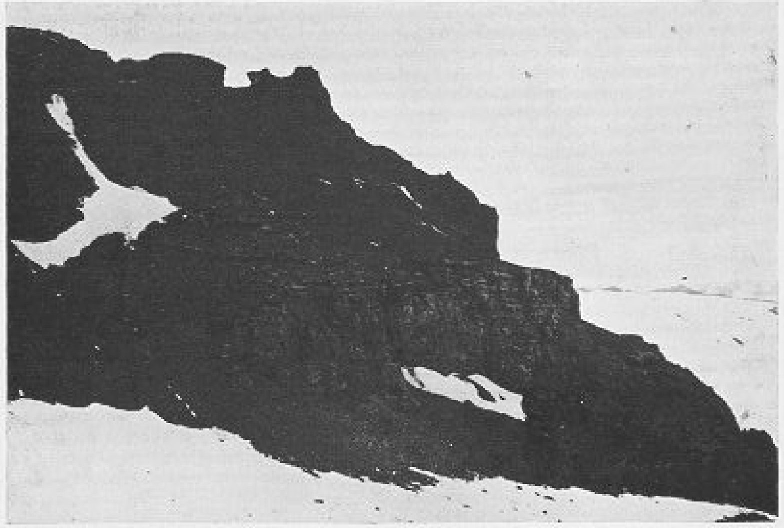

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PLATE II

PLATE III

a. A specimen of Trinity Peninsula Series conglomerate (D.3820.4) from View Point, showing a weathered surface (p. 21).

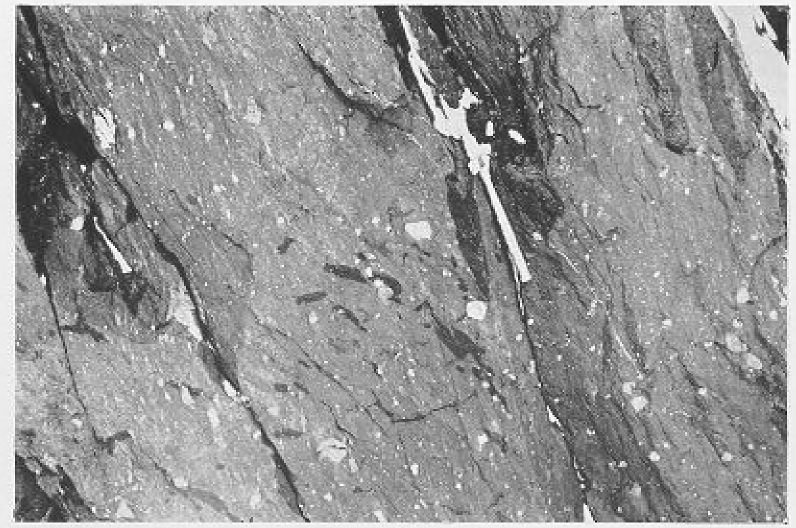
b. Cleaved pebbly mudstones forming a north-east-facing cliff 2 miles (3·2 km.) east-south-east of Benz Pass (D.3801). The hammer is 23 in. (58 cm.) long.

c. Pebbly mudstone showing shear planes and a variety of rock fragments and mineral grains (D.4276.1; unpolarized transmitted light; ×4·9).

d. Part of a steep cliff forming the north-west face of a nunatak 2·5 miles (4 km.) north of Camp Hill, showing sheared mudstone containing "phenoclasts" which are probably the squeezed and sheared remains of greywacke and siltstone laminae (p. 28). The cleavage is sub-parallel to the bedding which is overturned and steeply dipping to the north-west.

PLATE III

a



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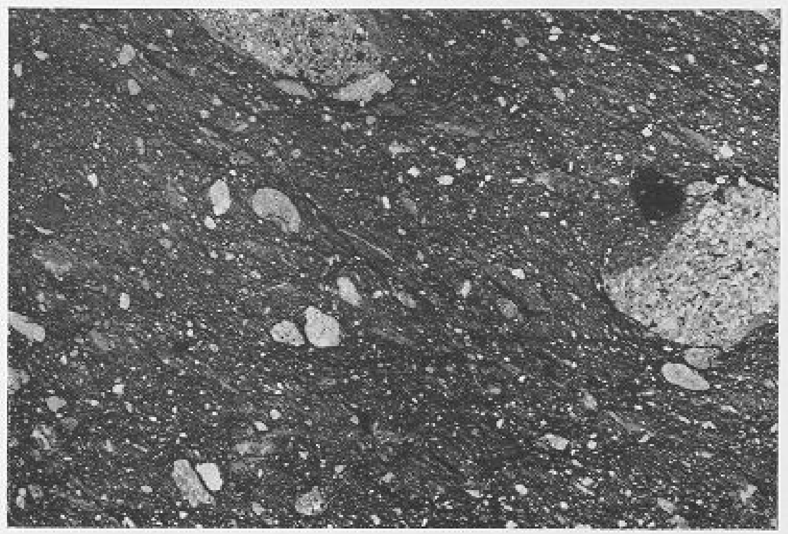

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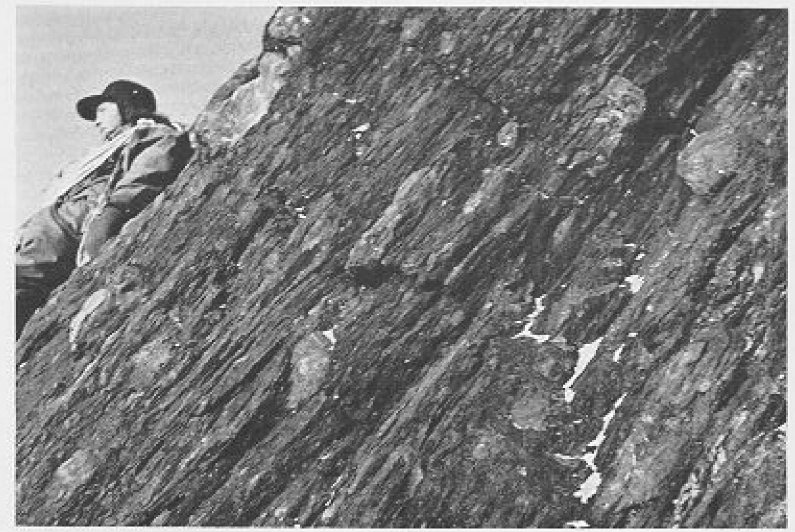

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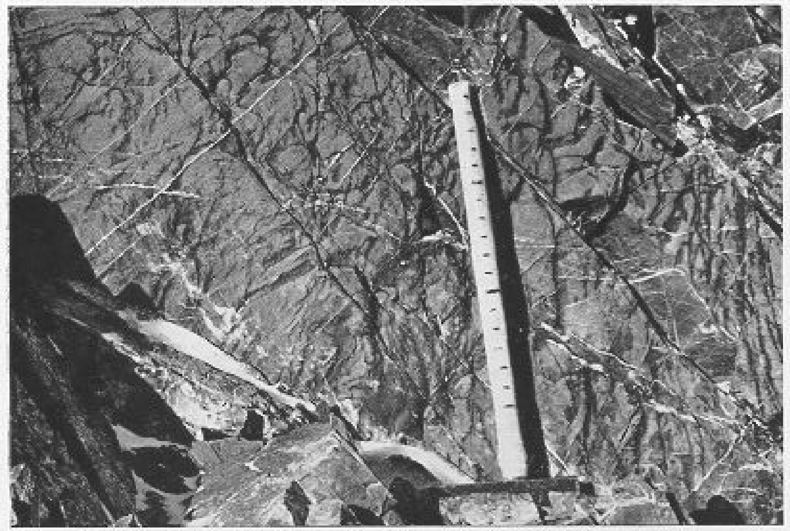
PLATE IV

a. Flute casts on the sole of an overturned bed of greywacke, dipping at 80° in a direction 323° and situated at the foot of the south-west ridge of Panhard Nunatak (D.4273; Plate Ib; p. 38). The scale is in inches.

b. Flute casts at the same locality as those in Plate IVa. The scale is in inches.

c. Groove casts at the same locality as the flute casts shown in Plates IVa and b. The scale is in inches.

d. The sole of a very thin bed of siliceous mudstone collected from station D.3651 2 miles (3·2 km.) west of Crystal Hill, showing a cast of the meandering track of some bottom-dwelling organism.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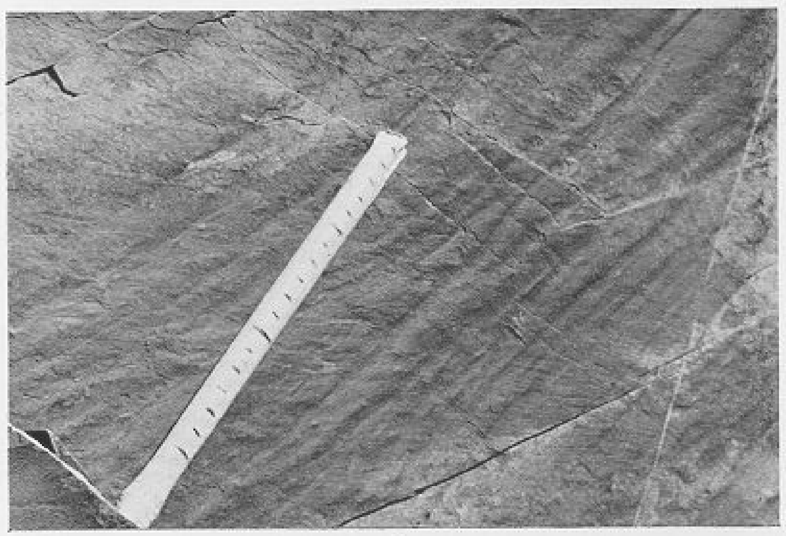
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PLATE IV

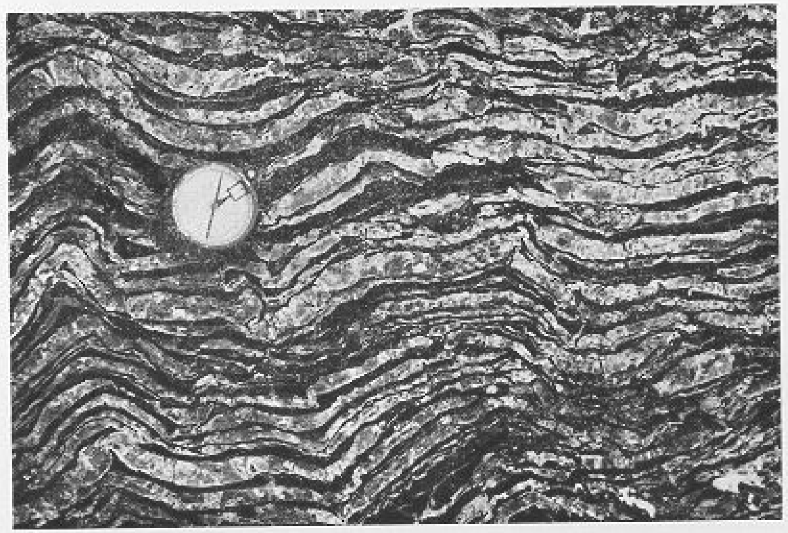
PLATE V

a. Looking vertically down on a horizontal slab of interbedded siliceous siltstones and shales at station D.3654 near Stepup Col (p. 36). The dip is vertical with a strike direction of 053°.

b. "Passive folding" (p. 52) in laminated phyllites and metasiltstones forming a south-west-facing inclined slab at Azimuth Hill (D.3612). The hammer is 23 in. (58 cm.) long.

c. Part of the south-west-facing cliff 2 miles (3·2 km.) north-west of Benz Pass (D.3855), forming the south-west escarpment of Louis-Philippe Plateau, showing part of a bed of heavily veined and sheared metagreywacke dipping from the top left to the bottom right of the photograph at 50° to the south-east (Table II). The ice axe is about 3 ft. (0·9 m.) long.

d. Minor fold in metagreywackes and phyllites forming the south-west face of a knoll at Azimuth Hill (D.3612). The hammer is 23 in. (58 cm.) long.



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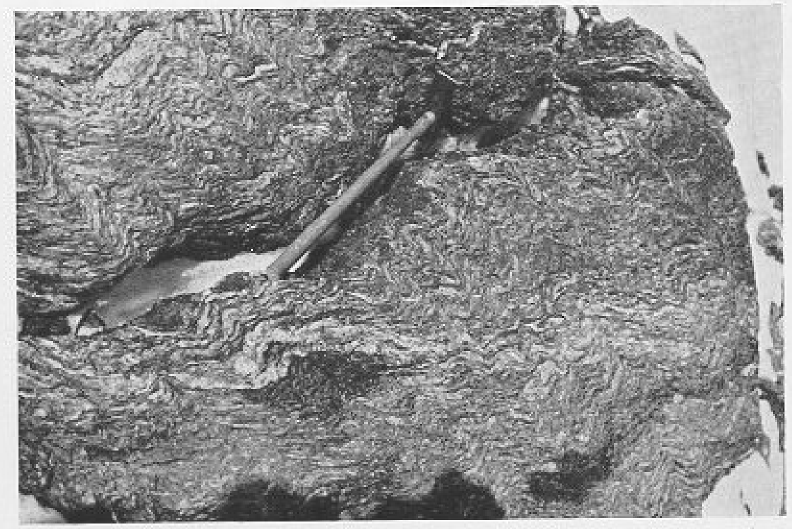

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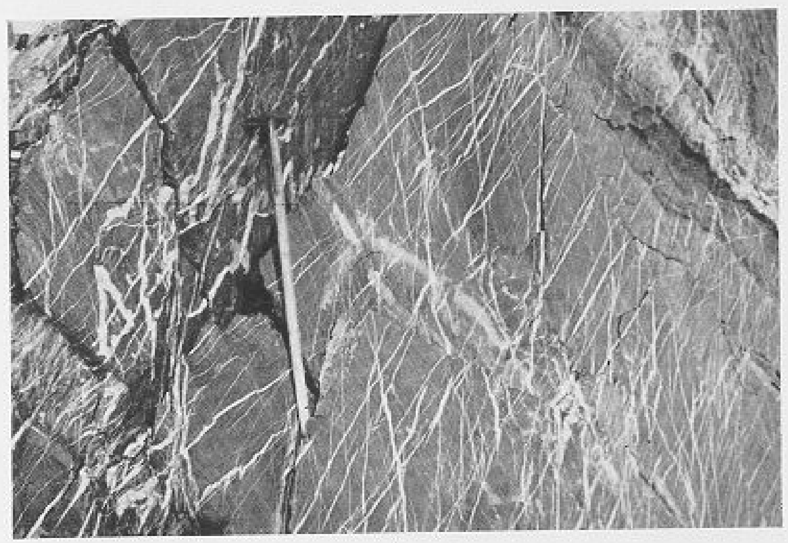

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PLATE V

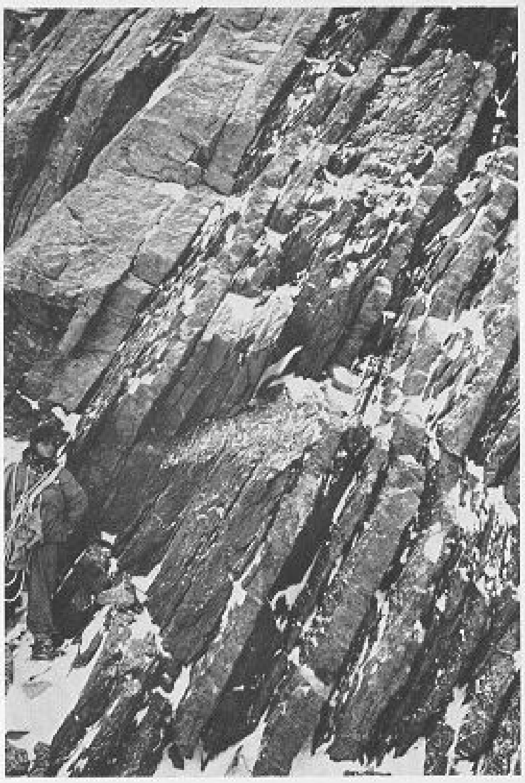
PLATE VI

a. A cliff forming the west side of the ridge trending north-north-west from Chapel Hill, showing inverted beds of greywacke, siltstone and shale dipping at 80° to the north-north-east.

b. Isolated disharmonic fold on the west face of Panhard Nunatak (D.4274), involving one cyclic unit comprising a group of sandstone beds and adjacent shales (p. 37, 50). The scale of the fold is shown by the figure on the snow marked with a circle.

c. Part of a north-facing coastal cliff at View Point (D.3870), showing an isolated fold in siltstones with shale intercalations, which have a general inverted dip of 70° to the north. The hammer shaft is 15 in. (38 cm.) long.

d. Metasiltstones and intercalated phyllites at station D.4206, 5 miles (8 km.) north-west of Mount Wild, showing similar style folds with small "drag folds" in the limbs (p. 53). The scale is in inches.



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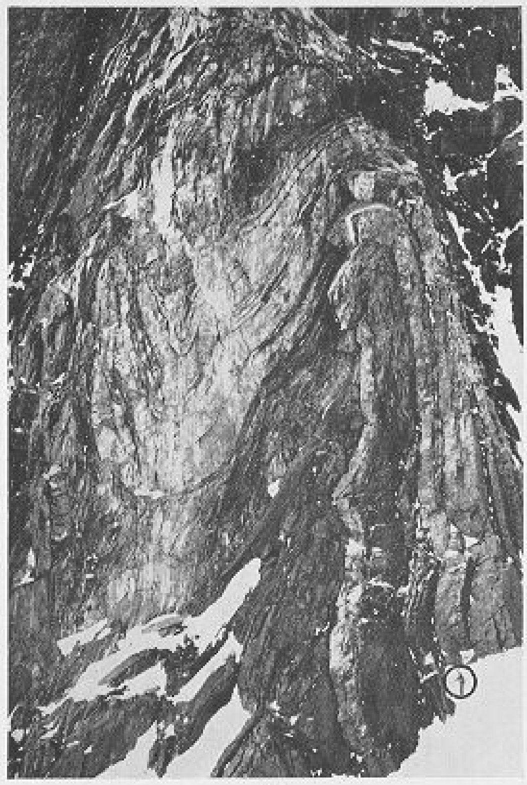

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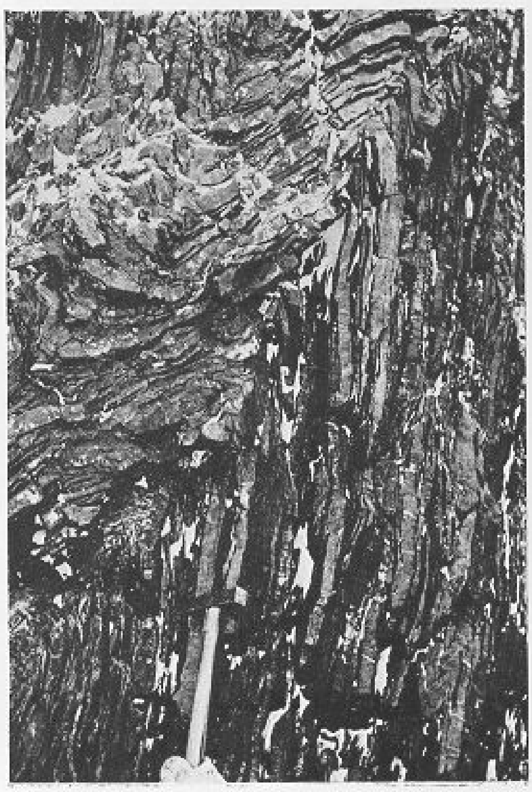

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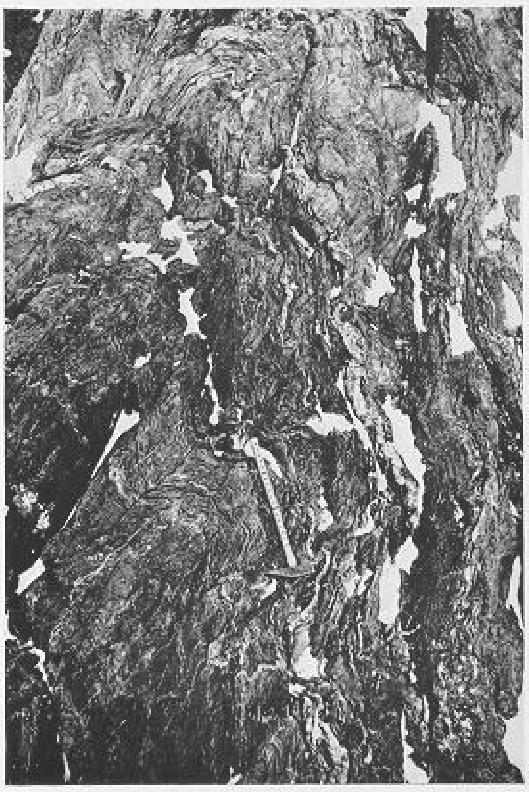
PLATE VII

a. The south-west-facing part of a cliff at station D.4219, 5 miles (8 km.) south-west of Mount Roberts, showing a dip section in finely laminated metasiltstones typical of the Mount Roberts area. The scale is in inches.

b. A strike section of the same beds of metasiltstone shown in Plate VIIa, showing second-phase folding (p. 52) with axes approximately perpendicular to the regional strike.

c. A south-east-facing cliff at station D.3936 at the north end of Mount Wild, showing complexly folded metasediments (Fig. 2; p. 53). The scale is in inches.

d. Kink folding in chloritic phyllite from the south side of Sjögren Glacier, 6 miles (9·7 km.) south-west of Mount Wild (D.3949.1; unpolarized transmitted light; ×5·2).



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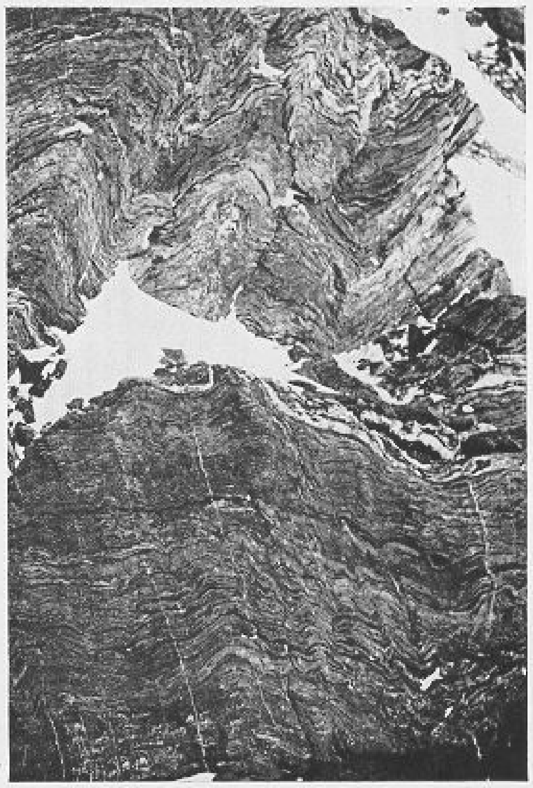

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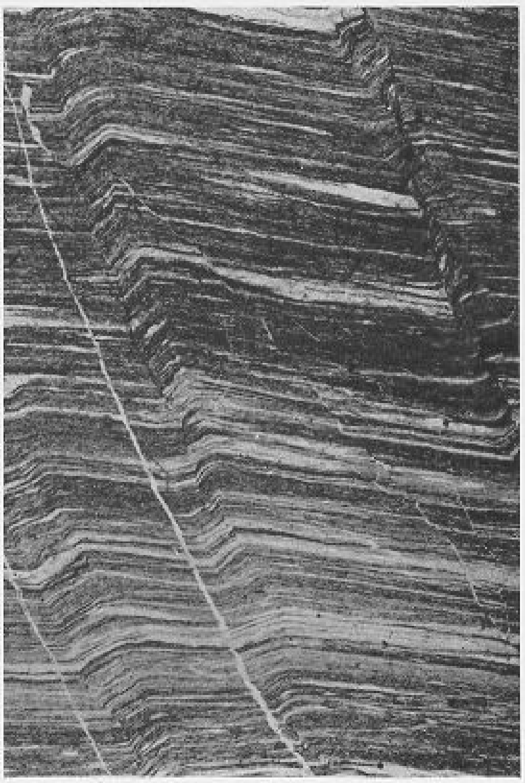

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PLATE VIII

a. A peculiar dyke rock showing a bent plagioclase crystal (An_{9-12}) penetrating partially granulated and altered augite and flanked by skeletal ilmenite (black) which has partially altered to leucoxene (D.3993.3; ordinary light; ×54).

b. Porphyritic microdiorite dyke rock, showing an aggregate of calcic andesine crystals near a complexly altered orthopyroxene phenocryst; both are set in a pilotaxitic groundmass (D.4215.1; ordinary light; ×52).

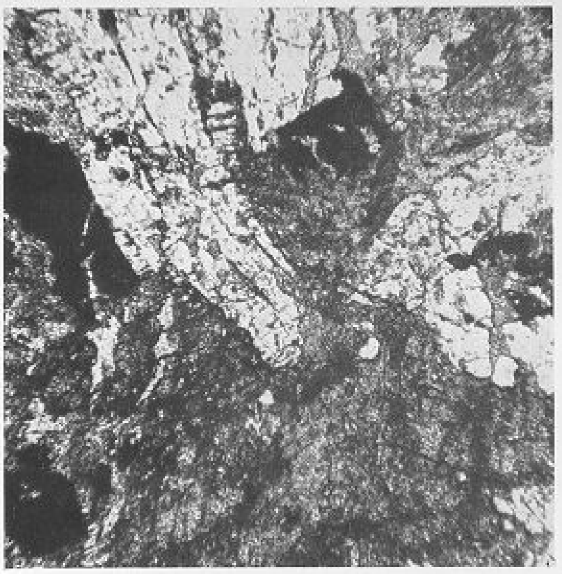
c. Olivine-basalt dyke rock, showing orientated labradorite laths and pseudomorphs after olivine set in a brownish coloured cryptocrystalline groundmass. The largest feldspar crystal is probably a xenocryst. The irregular light-coloured patches are amygdales containing calcite and chlorite (D.3880.2; ordinary light; ×52).

d. Granite-gneiss from the View Point conglomerate, showing vermicular and lobate quartz replacing sericitized and partially twinned albite. The quartz contains abundant trains of vacuoles (D.3821.1b; X-nicols; ×47).

e. Quartzite from the View Point conglomerate, showing sub-angular to rounded grains of quartz and twinned potash feldspar. Some of the quartz shows strain lamellae (D.3620.2; X-nicols; ×47).

f. Porphyritic alkali-rhyolite from the View Point conglomerate, showing phenocrysts of quartz and albite in a very fine-grained quartzo-feldspathic groundmass (D.3877.5; X-nicols; ×47).

PLATE VIII



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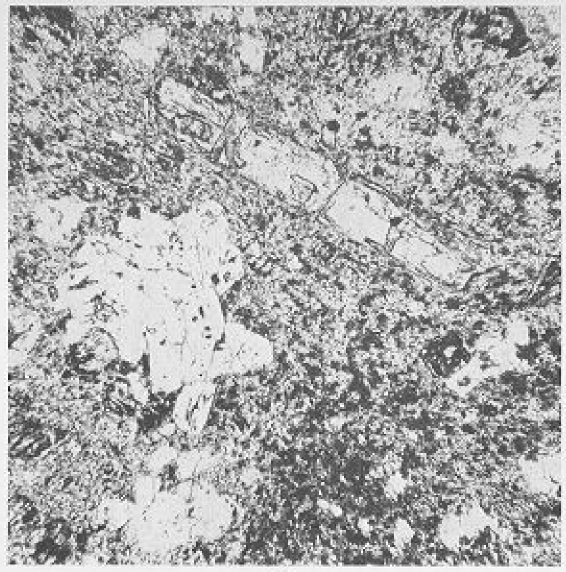

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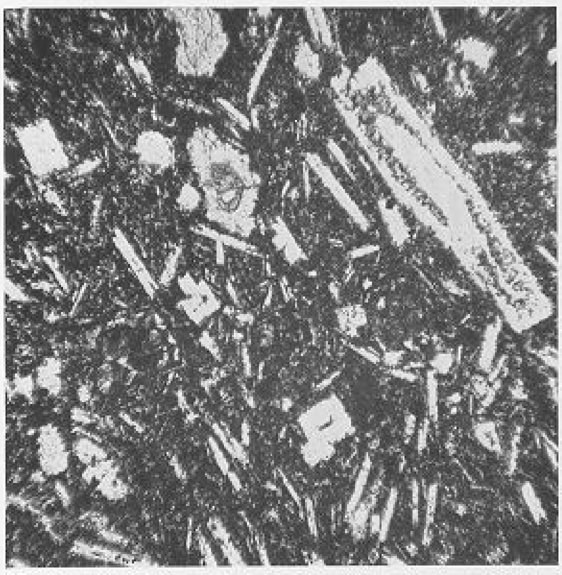

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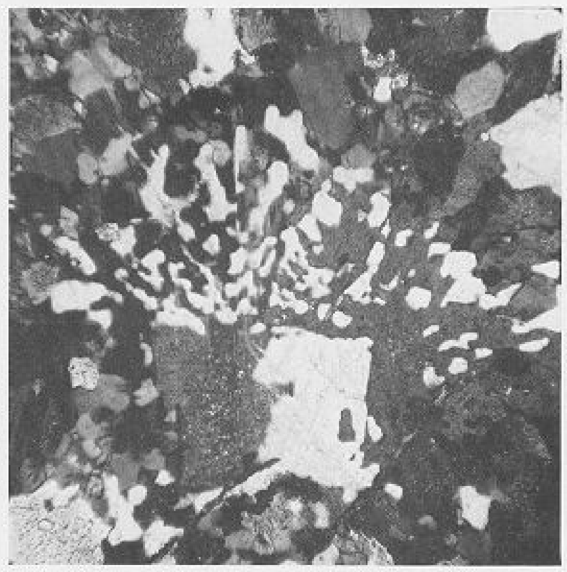

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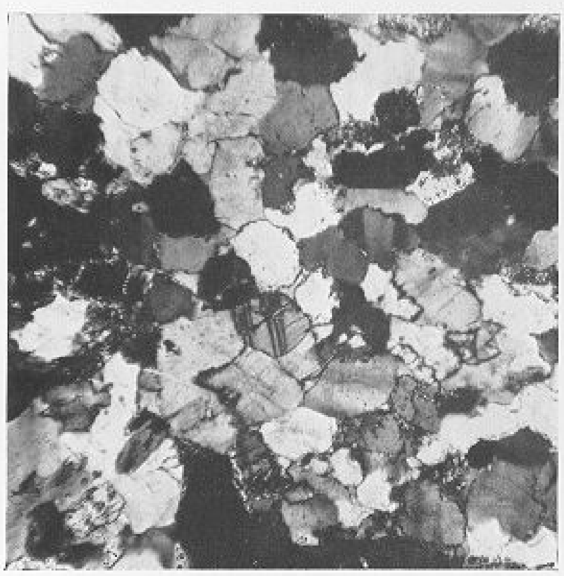

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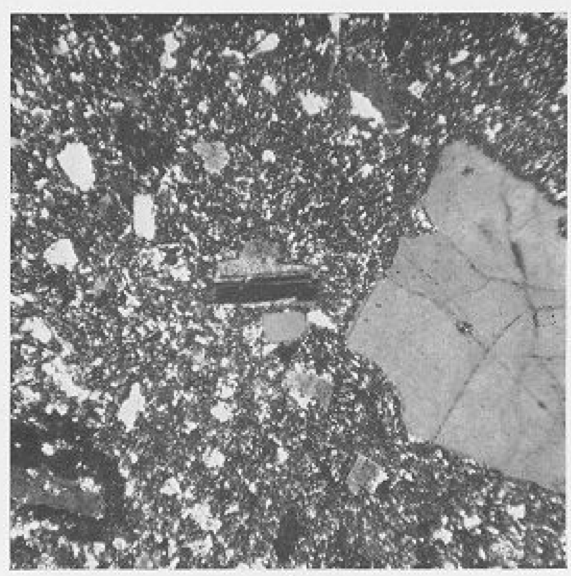

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PLATE IX

a. Shale fragment in a lithic greywacke from the coast west of Chapel Hill (D.3624.1; ordinary light; ×47).

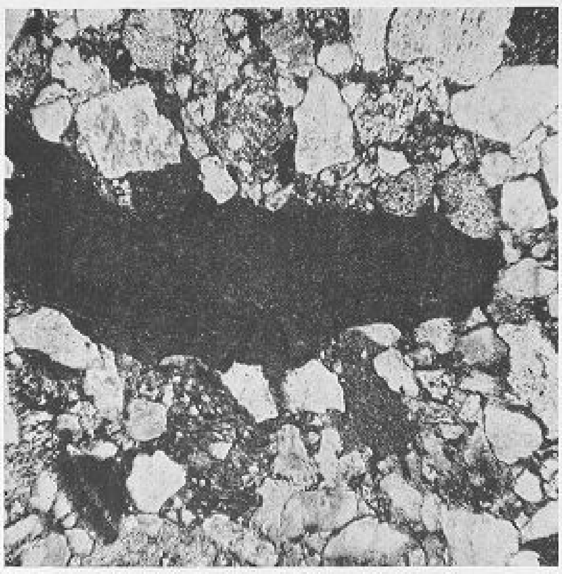
b. Greywacke from the north side of Laclavère Plateau, showing a quartz grain with strain lamellae and the characteristic intergrowth between clastic grains and the chloritic matrix (p. 32, 35; D.4417.1; ordinary light; ×208).

c. Chequer-board albite in a feldspathic greywacke from Camel Nunataks (D.4401.1; X-nicols; ×57).

d. A quartz grain with rutile needles in a greywacke from the north-west side of Cugnot Ice Piedmont (p. 32; D.3811.1; X-nicols; ×224).

e. Greywacke from a nunatak north of Camp Hill, showing a grain of plagioclase with fractured and bent albite twinning and a grain of trachytic lava or dyke rock (p. 32; D.3640.1; X-nicols; ×39).

f. Quartz-rich lithic greywacke from the coast north-east of Levassor Nunatak, showing interstices between quartz grains occupied by detrital matrix or partially disintegrated rock fragments resembling detrital matrix (p. 35; D.3624.1; ordinary light; ×47).



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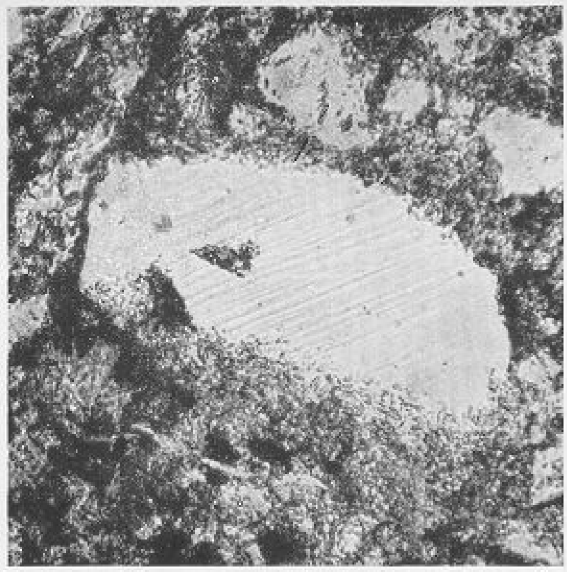

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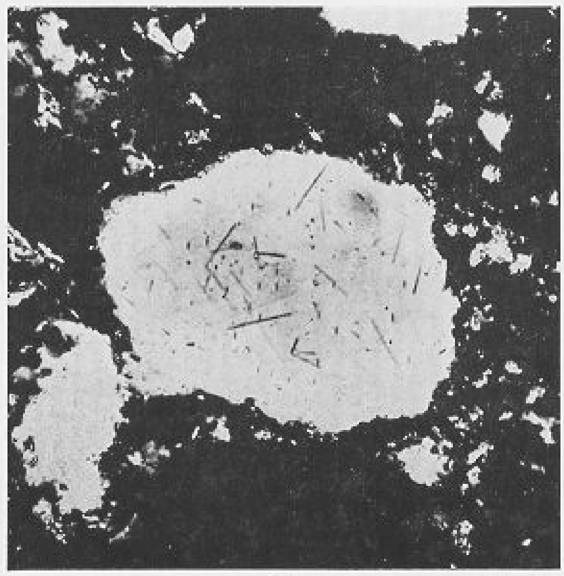

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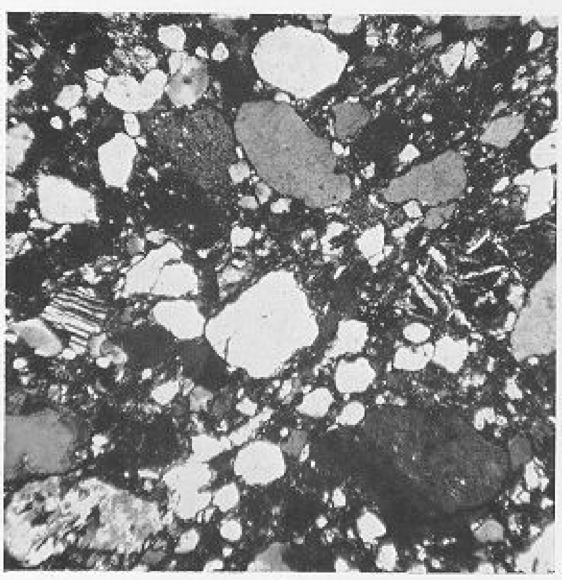

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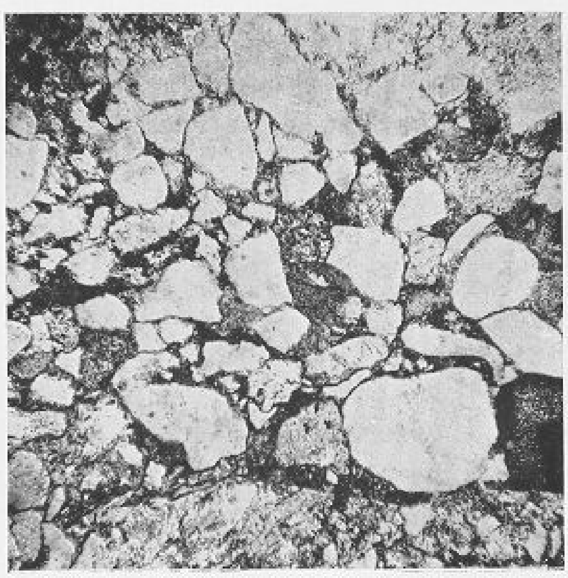

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PLATE X

a. Micro-fold in very finely laminated, green siliceous mudstone (p. 36; D.3638.1; ×4; unpolarized transmitted light). Details of the inset area are shown in Plate Xb. Note the fracture and strain-slip cleavage in the argillaceous laminae (bottom centre) and the shearing on the lamination planes between the siliceous laminae, suggesting both flexural slip and flexural flow within the same fold (p. 51).

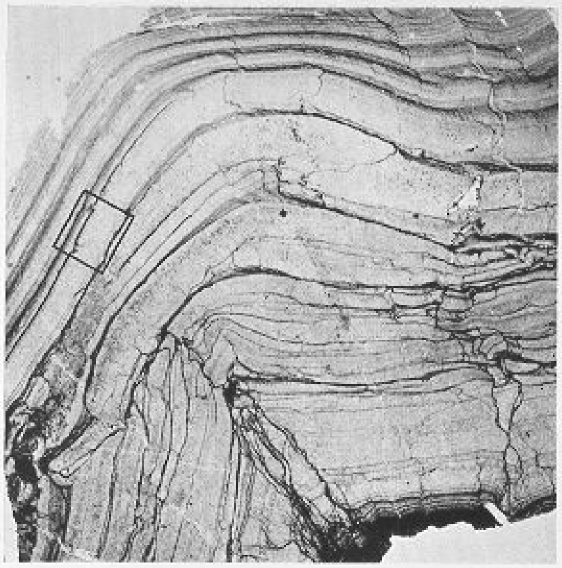
b. Green siliceous mudstone showing details of extremely fine lamination (see Plate Xa). The laminae are marked by concentrations of heavy minerals (mainly leucoxene) and micaceous bands. The disruption is probably caused by movement of some mud-dwelling organism (p. 36; D.3638.1; ordinary light; ×46).

c. Siliceous objects, resembling minute sponge spicules, in red shale from near Crystal Hill (p. 37; D.3635.2; ordinary light; ×785).

d. Quartz-biotite-microperthite-hornfels from Mount Bradley, showing small-scale augen structure probably representing relict flaser structure. The largest lenticular grain is composite quartz and the smaller grains are composed of quartz and microperthite. The dark mineral is biotite (p. 49; D.3661.1; ordinary light; ×43).

e. Banded hornfels from near the contact with the Mount Reece granite (p. 49; D.3667.2; unpolarized transmitted light; ×4·5).
Q. Quartzo-feldspathic bands consisting of granular quartz and albite; C. Chloritic bands within the quartzo-feldspathic band; P. Pelitic bands mainly composed of biotite with sericitized cordierite spots; these bands also contain distinct cross-laminae which are probably relict current-bedding structures; W. (?) Washout structure.

f. A pelitic band in a banded hornfels with prominent dark oval spots; from the ridge trending north-west from Mount Bradley. The left half of the photograph shows a cordierite porphyroblast apparently in the process of spreading and consuming the surrounding rock. The cordierite is altered to pinite, while the groundmass contains dark chlorite and relict sedimentary quartz grains (p. 49; D.3665.1; X-nicols; ×40).



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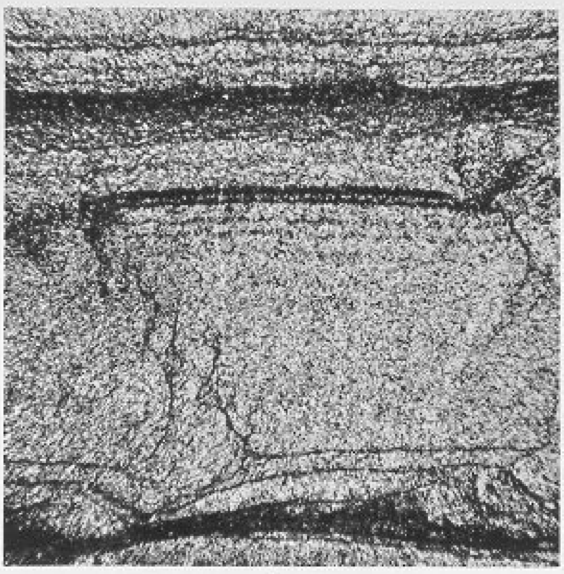

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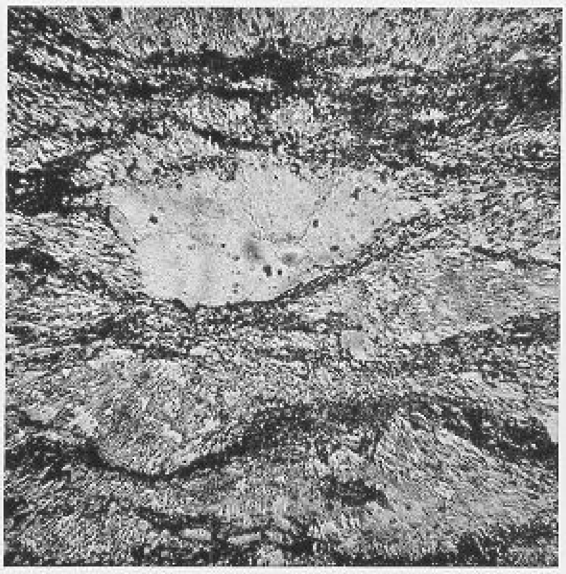

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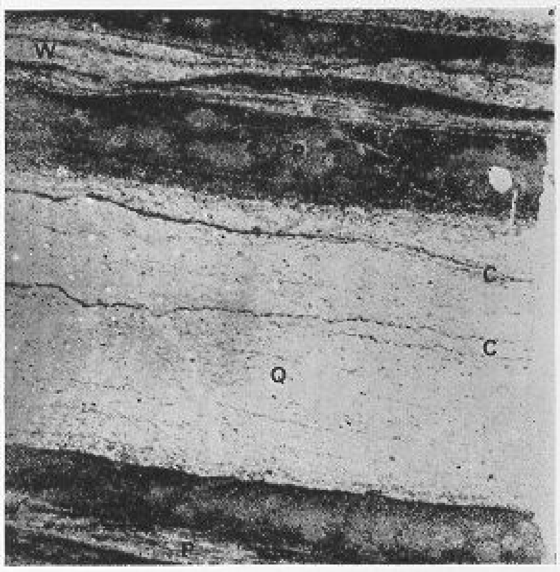

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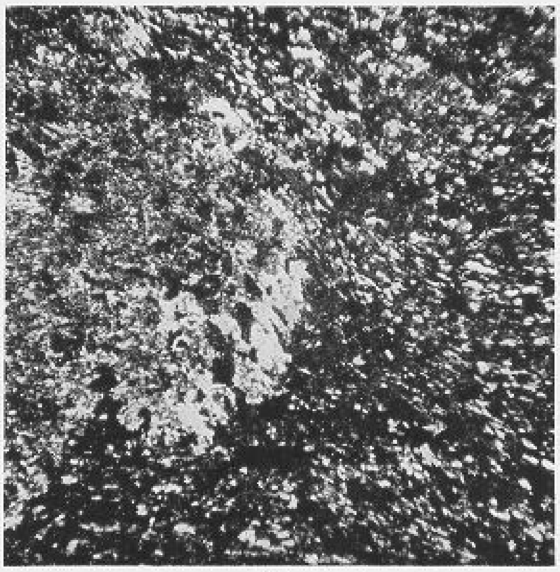

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PLATE XI

a. Pressure fringe of quartz and chlorite round a pyrite crystal, demonstrating the stretching of the surrounding siliceous mudstone (p. 51; D.3638.1; ordinary light; ×44).

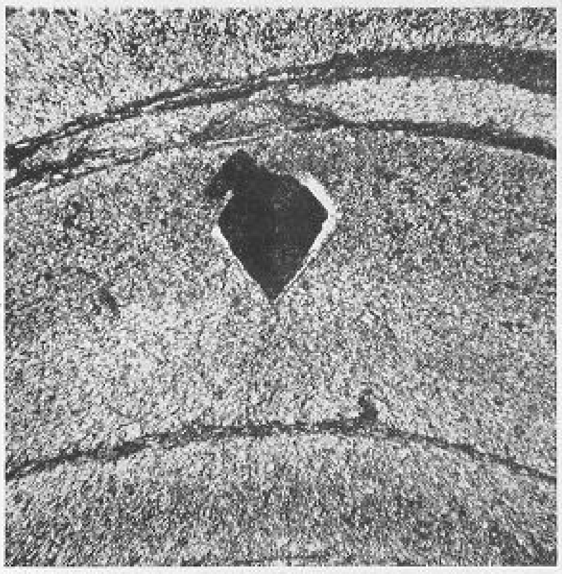
b. Metagreywacke from the south-west scarp of Louis-Philippe Plateau, showing a wide range of roundness in the quartz grains (p. 41; D.3856.1; ordinary light; ×37).

c. Epidote-actinolite-calcite-greenschist from Corner Peak. The epidote is full of dark inclusions and calcite is the light mineral. Orientated flakes of actinolite from the groundmass (p. 44; D.3840.1; ordinary light; ×40).

d. Feldspathic metagreywacke from a nunatak north of Longing Gap, showing clear quartz grains enveloped in chlorite and highly altered feldspar set in a dark chloritic matrix (p. 41; D.3935.1; ordinary light; ×32).

e. Green metagreywacke from near Mount Brading, showing grains of highly altered feldspar, ilmenite and clear quartz in a dark matrix rich in chlorite and leucoxene (p. 42; D.3924.1; ordinary light; ×38).

f. Pyroxene-ilmenite-greenschist from station D.3923, 2 miles (3·2 km.) north-east of Mount Tucker, showing a twinned augite grain and dark grains of leucoxene, probably after ilmenite, in a matrix composed mainly of muscovite, chlorite and very fine granular quartz (p. 42; D.3923.1; X-nicols; ×50).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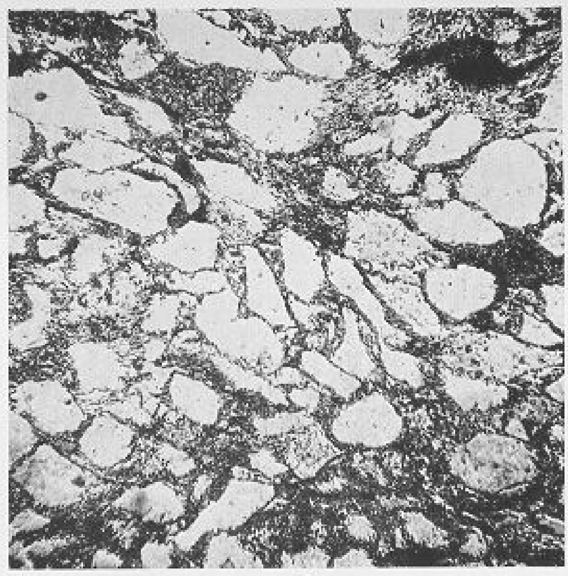
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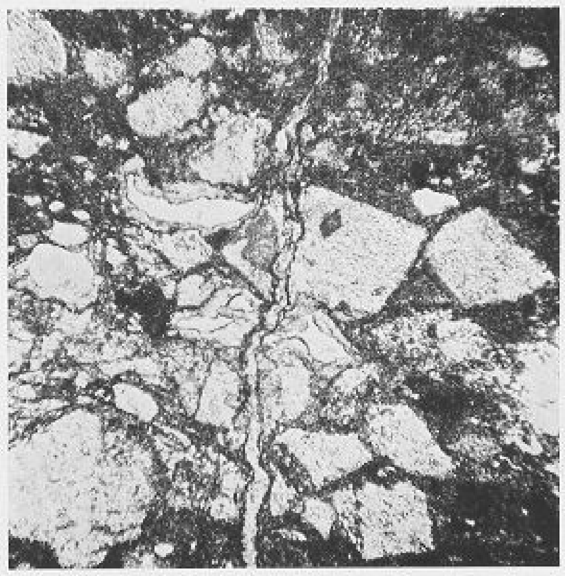
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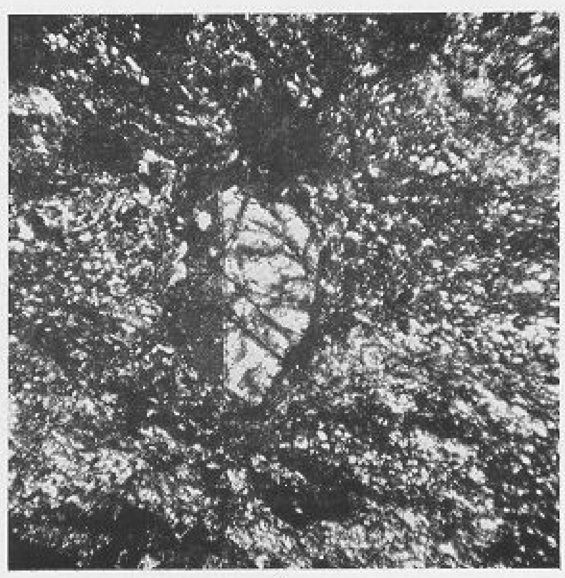
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PLATE XII

a. Trains of inclusions in a cordierite porphyroblast, representing contorted banding from the earlier period of regional metamorphism (p. 45; D.3987.1; ordinary light; ×33).

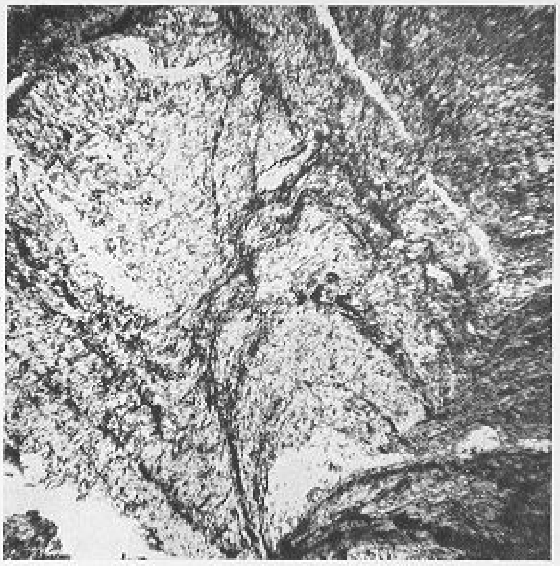
b. Thermally metamorphosed metagreywacke from the north-east flank of Sjögren Glacier showing relict sedimentary quartz grains (p. 45; D.3987.3; ordinary light; ×56).

c. Phyllite from the east flank of Polaris Glacier, showing biotite flakes resulting from thermal metamorphism lying discordantly across the foliation, which probably represents the earlier regional metamorphism (p. 45; D.4296.1; ordinary light; ×138).

d. Phlogopite with strong cleavage (centre) with poekiloblastic flakes of muscovite and biotite in an andalusite-mica-schist from the upper part of Sjögren Glacier. Andalusite forms the larger porphyroblasts of the top right (p. 45; D.3972.1; ordinary light; ×47).

e. Strain-slip cleavage in laminated phyllite penetrating the overlying bed of metagreywacke (p. 53; D.4224.1; unpolarized transmitted light; ×6).

f. Garnetiferous quartz-biotite-cordierite-hornfels from the Eliason Glacier area, showing a garnet porphyroblast with magnetite inclusions adjacent to an aggregate of radial chlorite enveloped by cordierite (p. 46; D.4291.1; ordinary light; ×28).



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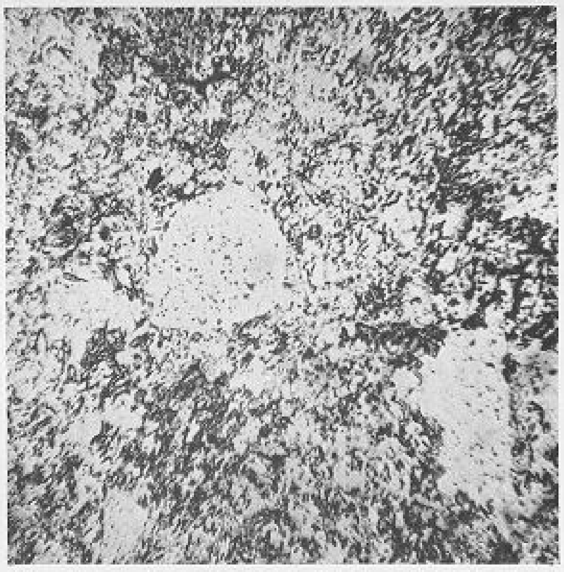

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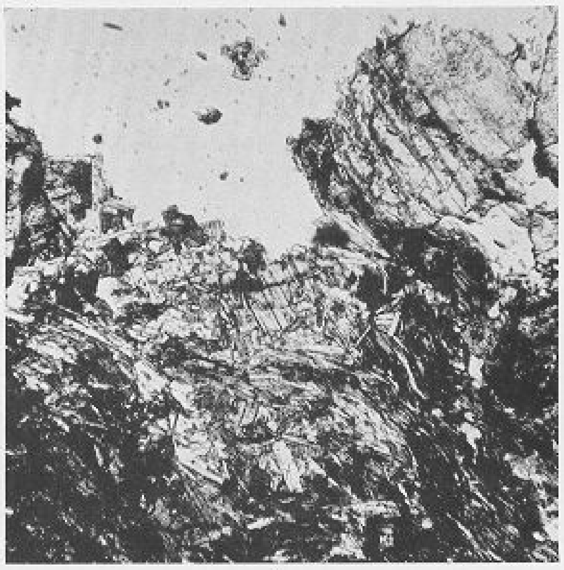

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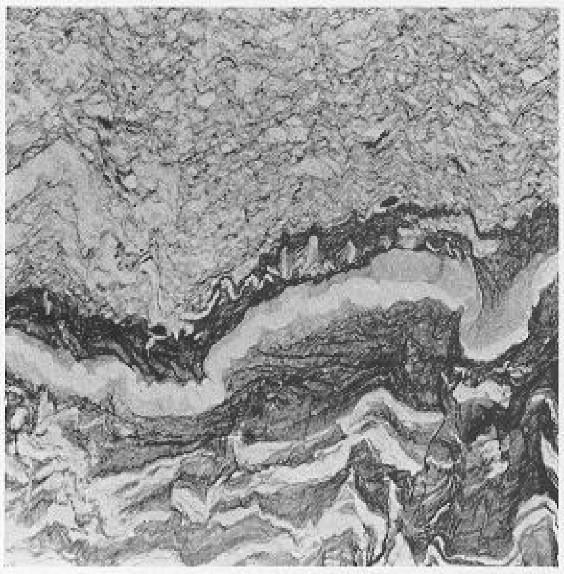

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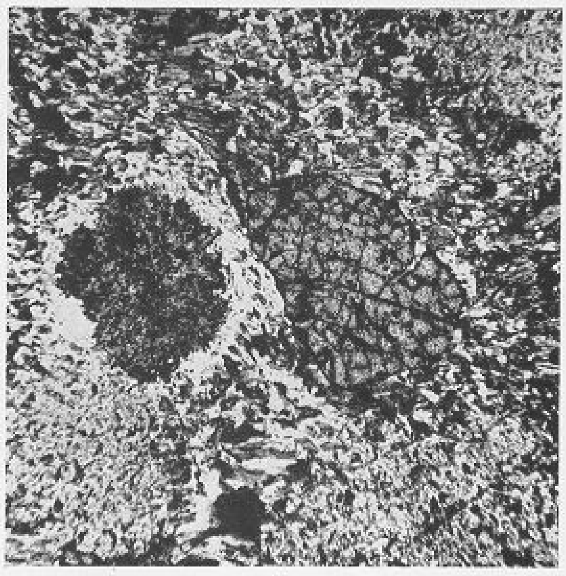

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