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## ABSTRACT

THE geology of the Oscar II Coast and the Seal Nunataks, which was mapped in the field on a scale of 1 : 100,000, is described. The oldest stratigraphic unit discovered in this area is the Trinity Peninsula Series, consisting of a great thickness of geosynclinal sediments which have been regionally metamorphosed and isoclinally folded about west-south-west to east-north-east axes. Jurassic sedimentary beds were deposited in hollows on an erosion surface cut across the highly folded Trinity Peninsula Series sediments. There is a gradual transition upwards from the Jurassic sedimentary beds into several thousand feet of *nuées ardentes* deposits of acid crystal tuffs and subordinate acid lavas, agglomerates and rare andesitic volcanic rocks, all of which comprise the Upper Jurassic Volcanic Group. A suite of quartz-perthite-porphyry dykes and plutons of "white granite" have intruded the volcanic rocks. Specimens of these volcanic, hypabyssal and plutonic rocks have been chemically analysed and their relationship to one another is discussed. The Andean Intrusive Suite comprises basic, intermediate and acid intrusive rocks which were probably injected into the core of the Antarctic Peninsula during late Cretaceous to early Tertiary times, and thermally metamorphosed the older rocks.

Apparently resting unconformably on the flat-lying Upper Cretaceous sediments of Cape Marsh, Robertson Island, are the mid-Tertiary James Ross Island Volcanic Group olivine-basalt lavas and agglomerates (containing olivine-enstatite-diopside-picotite nodules), which form the Seal Nunataks. These volcanic islands, which project through the Larsen Ice Shelf, are elongated in north-west to south-east or west-south-west to east-north-east directions, i.e. parallel to the strikes of the fissures through which the lavas were erupted. The final intrusive phase in the Oscar II Coast area was a suite of doleritic dykes which were closely related to the eruptive rocks of the Seal Nunataks.

Crane Glacier is believed to be the site of a major dislocation which has down-faulted the rocks in the south. It is also believed that there is a series of step faults, which trend west-south-west to east-north-east in the area between Crane and Stubb Glaciers, and that the presence of these faults was responsible for the regularity of the glacier system south of Crane Glacier.

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# I. INTRODUCTION

THE area described in this report is part of the coast and hinterland of the east coast of the Antarctic Peninsula. It is approximately 70 miles (113 km.) long and 15 miles (24 km.) wide, and extends from Cape Fairweather (lat. 65°00′S., long. 61°05′W.) to Stubb Glacier (lat. 65°40′S., long. 62°20′W.), including the Seal Nunataks (Figs. 1 and 2).

The Antarctic Peninsula forms part of the circum-Pacific orogenic belt, which extends southwards across the western part of Antarctica from the Antarctic Peninsula, but to the north it is connected to the South American Andes through the chain of scattered islands and submarine ridges forming the Scotia Ridge.

## 1. *Previous research*

The first expedition to attempt a visit to this area was the Swedish South Polar Expedition, 1901–03, led by Otto Nordenskjöld (Nordenskjöld and Andersson, 1905). A comprehensive summary of this and other geological expeditions in British Antarctic Territory has been given by Adie (1957*b*, p. 507–08; 1958, p. 6–10). From his base on Snow Hill Island, Nordenskjöld sledged southwards in 1902 to Christensen Nunatak and visited the easternmost of the Seal Nunataks which he established as consisting of basaltic rocks. He then continued southwards to Borchgrevink Nunatak and collected specimens of a "quartz-porphyry" (Andersson, 1906, p. 30). This was his only contact with the mainland in this latitude; an attempt to visit Cape Disappointment was thwarted by a ". . . canal-like crevasse, some 20 m. [65 ft.] broad and almost as deep, which seemed to run in towards the land as far as the eye could reach".

Although Nordenskjöld was only able to reach the coast of Graham Land at Borchgrevink Nunatak, he had more success in the north. His expedition published the first detailed accounts of the Middle Jurassic flora of Hope Bay and of the abundant Upper Cretaceous and Tertiary faunas of Seymour, Cockburn, Snow Hill and James Ross Islands.

In 1947, R. J. Adie, who had carried out detailed work in north-east Graham Land, was able to visit Cape Disappointment. Here he found "variegated green, pink and bright red, pyjama-striped rhyolitic tuffs, showing remarkable micro-structures and containing beds of carbonized woods" (Adie, 1958, p. 8). As a result of this and subsequent work from Stonington Island, he established a stratigraphic succession for Graham Land (Adie, 1953). Further visits to the Seal Nunataks were made by R. Stoneley in 1952 and by A. J. Standring in 1953. Standring continued southwards as far as Jason Peninsula which he found to consist mainly of acid volcanic rocks, probably contemporaneous with those of the Hope Bay area, and basalts of a similar type to those of the Seal Nunataks.

The northern part of Graham Land was photographed from the air in 1957 and the photographs cover as far south as Mapple Glacier on the east coast. They have been of considerable assistance in mapping and route-finding in the Oscar II Coast area.

The west coast is separated from the east coast by a high plateau which forms the back-bone of Graham Land. This has prevented traverses from one coast to the other in this area, although the two coasts are only a few miles apart. Thus the geological reports by any individual are usually limited to either one coast or the other.

Because the west coast is more accessible from the sea than the east coast, the establishment of a scientific station there is relatively easier. However, sledging from the west coast stations is more difficult because of the nature of the terrain.

In 1935, the British Graham Land Expedition, 1934–37, established a station at the Argentine Islands. In this area they found Upper Jurassic volcanic rocks consisting of andesitic agglomerates, lavas and tuffs intruded by Andean diorites. More recent work by members of the British Antarctic Survey shows that this is the general pattern of the geology in this area.

In 1955 and 1956, P. R. Hooper investigated the geology of Anvers Island and adjacent islands. He described an older sequence of volcanic lavas, tuffs and breccias, in places thermally metamorphosed by later Andean intrusions, which consist mainly of quartz-diorites. A series of lavas younger than the Andean Intrusive Suite was also found. No unmetamorphosed sediments are exposed on Anvers Island. M. B. Bayly worked from Danco Island in 1956, visiting north Wilhelmina Bay and Charlotte Bay, where he mapped acid and basic volcanic rocks intruded by Andean diorites and gabbros. G. J. Hobbs worked from the same station during the following year and investigated Paradise Harbour and Andvord Bay where there are volcanic rocks intruded by gabbros and quartz-diorites.

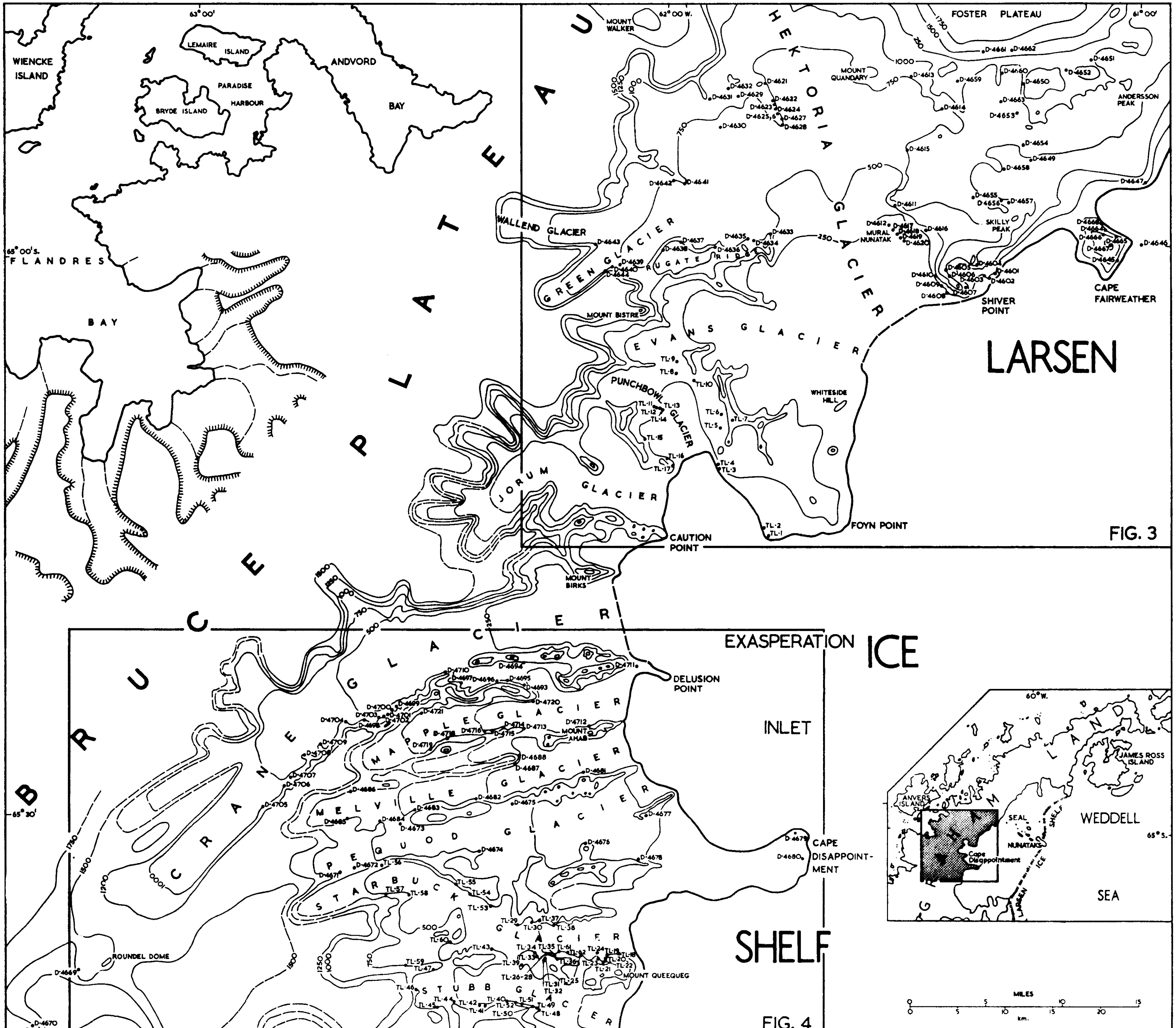
63° 00'
62° 00 W.
61° 00'
65° 00'S.
65° 30'
WIENCKE ISLAND
LEMAIRE ISLAND
PARADISE HARBOUR
BRYDE ISLAND
ANDVORD BAY
FLANDRES BAY
BRUCE PLATEAU
MOUNT WALKER
HEKTORIA GLACIER
FOSTER PLATEAU
MOUNT QUANDARY
ANDERSSON PEAK
WALLEND GLACIER
GREEN GLACIER
RUGATE RIDGE
MURAL NUNATAK
SKILLY PEAK
SHIVER POINT
CAPE FAIRWEATHER
MOUNT BISTRE
EVANS GLACIER
PUNCHBOWL GLACIER
WHITESIDE HILL
JORUM GLACIER
CAUTION POINT
FOYN POINT
LARSEN
MOUNT BIRKS
CRANE GLACIER
EXASPERATION INLET
ICE
DELUSION POINT
MAPPLE GLACIER
MOUNT AHAB
MELVILLE GLACIER
PEQUOD GLACIER
STARBUCK GLACIER
CAPE DISAPPOINTMENT
SHELF
ROUNDEL DOME
MOUNT QUEEQUEG
STUBB GLACIER
60° W.
GRAHAM LAND
JAMES ROSS ISLAND
ANVERS ISLAND
SEAL NUNATAKS
LARSEN ICE SHELF
WEDDELL SEA
Cape Disappointment
65° S.
MILES
km.

FIG. 3

FIG. 4

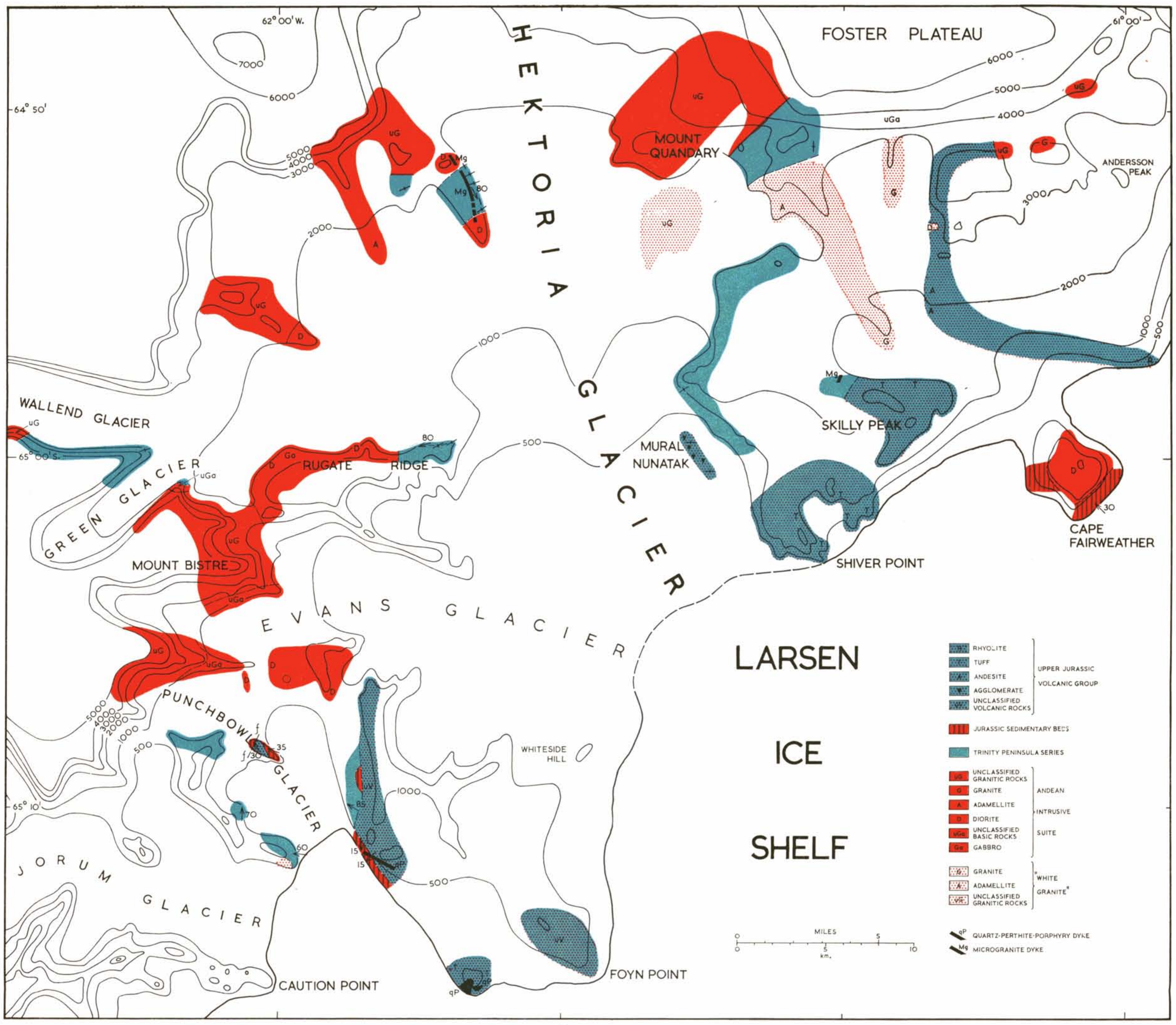


FIGURE 3

Geological sketch map of the Hektoria Glacier area, Oscar II Coast. The contours are at 500 ft. (152 m.), 1,000 ft. (305 m.), and at intervals of 1,000 ft. (305 m.) thereafter.


FIGURE 4

Geological sketch map of the area between Crane and Stubb Glaciers, Oscar II Coast. The contours are at 500 ft. (152 m.), 1,000 ft. (305 m.), and at intervals of 1,000 ft. (305 m.) thereafter.

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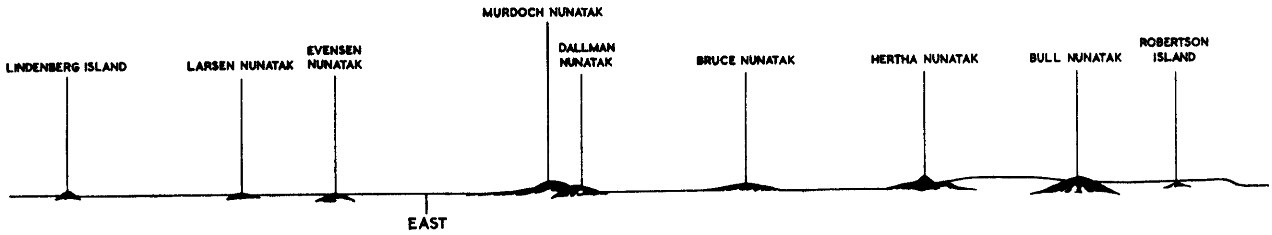


FIGURE 2

A panoramic sketch from the summit of Cape Fairweather looking east towards the Seal Nunataks. The distance between Lindenberg Island and the southern tip of Robertson Island is approximately 27 miles (43 km.).

2. *Scope of the present study*

The field work described here was undertaken during the period December 1961 to March 1964, while the author was employed by the British Antarctic Survey and stationed at Hope Bay (lat. 63°24′S., long. 57°00′W.) during the 1962 winter and at Stonington Island (lat. 68°11′S., long. 67°00′W.) during the 1963 winter. The purpose of the work was to continue the systematic geological survey of Graham Land southwards and to prepare a geological map of the Oscar II Coast area on a scale of 1 : 100,000.

The Oscar II Coast was first visited during a 4-month sledge journey which lasted from mid-June until mid-October 1962. In this period, the Hektoria Glacier area, Crane, Mapple, Melville and Pequod Glaciers, and some of the Seal Nunataks were visited (Figs. 3 and 4). A second 4-month sledge journey to the same area was made in late 1963 from Stonington Island. During this period, the Punchbowl, Starbuck and Stubb Glaciers area was visited.

Most of the geological units encountered in the Antarctic Peninsula, with the important exception of the Basement Complex, are represented in the Oscar II Coast area. By far the most abundant stratigraphic unit is the Upper Jurassic Volcanic Group, which is intruded by quartz-perthite-porphyry dykes and granites of two distinct ages. It is therefore natural that most interest should have been focused on these important units. Although the Trinity Peninsula Series is widespread in the Hektoria Glacier area, it appears to have been buried by the thick Upper Jurassic Volcanic Group in the southern part of the area. The Seal Nunataks are geographically and geologically distinct from the mainland. They consist of volcanic rocks of the James Ross Island Volcanic Group and in only one locality (Cape Marsh, Robertson Island) are Upper Cretaceous sediments present.

3. *Physiography and glaciology*

a. *Plateau.* The Bruce Plateau is one of several plateaux forming the mountainous back-bone of Graham Land which is occasionally broken by high snow-covered cols, but in this area the plateau is not dissected. The width of the plateau varies from about 5 to 20 miles (8 to 32 km.). Its surface is gently undulating and it is completely ice-covered. The ice cover is probably 200–300 ft. (61–91 m.) thick and it reflects the form of the rock surface beneath it (Linton, 1964, p. 96). A few ice-covered peaks on the plateau rise to over 6,000 ft. (1,830 m.) a.s.l., e.g. Mount Johnston.

The edge of the plateau is invariably formed by a 2,000 ft. (610 m.) escarpment (Plate Ia) which is the most noticeable topographical feature of Graham Land. It is well developed in the northern half of this area where the escarpment has little ice cover, although ice falls occur on its less steep parts. In the southern half of the area the escarpment is subdued and is covered mainly by ice falls and short steep glaciers descending from the plateau to the glacier systems below. In several places it is possible to sledge from the Larsen Ice Shelf to the plateau in this area, e.g. the head of Pequod Glacier provided a good route (Plate Ib).

b. *Inter-glacier ridges.* The plateau is being actively eroded by ice and remnants of a formerly much more extensive plateau are represented by the numerous inter-glacier ridges which extend from the present escarpment. This feature is very well illustrated by Linton (1964, p. 95, fig. 8). The ridges in this photograph, which are also viewed from the level of the Larsen Ice Shelf in Plate IIa, all have summits below the level of the plateau surface. The summits of some of the nunataks on the ridge between Crane and Mapple Glaciers are topped by flat ice-covered surfaces which are remnants of a formerly more widespread plateau. There is another completely isolated remnant in Starbuck Glacier (Plate Ic), the two arms of which re-join west of the granite bluff without any marked increase in altitude. This is clearly caused by the differential erosion of sediments and granites, both of which are exposed in Starbuck Glacier.

c. *Glaciers*. In this area the glaciers range in size from the smallest ice fall to the large broad Hektoria Glacier and the long narrow valley glaciers, of which Crane Glacier is an example. Hektoria Glacier has several major tributaries: Evans, Wallend and Green Glaciers, which coalesce to form a single glacier that flows into the Larsen Ice Shelf between Shiver Point and Foyn Point.

In the south, the glaciers are very regular; Mapple, Melville and Pequod Glaciers in particular are of similar length and parallel to one another. They are separated by sharp-crested, inter-glacier ridges which are almost unbroken from the plateau to the coast. However, south of Pequod Glacier the ridges are more eroded and there are cols connecting Starbuck and Stubb Glaciers. The tributaries to these glaciers are small but two are worthy of mention: the divide of the one glacier connecting Crane and Mapple Glaciers is about 1 mile (1·6 km.) from Crane Glacier and about 4 miles (6·4 km.) from Mapple Glacier; the other follows the local glacier pattern but it has been captured by Melville Glacier and flows for about 5 miles (8 km.) in the ridge between Mapple and Melville Glaciers before turning south into Melville Glacier.

It is interesting to compare the glacierization of the Oscar II Coast with the geology. There are two significant features in the southern part of this area which could explain the very regular glacier system: the first is that the rocks of Jurassic age extend into the plateau south of Crane Glacier, whereas in the north metamorphic rocks of the Trinity Peninsula Series are exposed in the upper parts of the glacier; the second is the distinct off-setting of the granite exposures in Melville and Mapple Glaciers (Fig. 4), which implies that the southern glaciers occupy a series of fault lines.

In the north, the fault system is probably more complicated because two periods of faulting may be expected: one associated with pre-Jurassic regional metamorphism and the other of post-Andean age. Thus, if the northern glaciers follow fault lines, the pattern emerging is unlikely to be regular.

d. *Larsen Ice Shelf*. All glaciers in this area eventually flow into the Larsen Ice Shelf, which is a broad expanse of floating ice that is thickened each year by snow accumulation and the addition of ice from the glaciers. Its width at this latitude is about 60 miles (96 km.) and its thickness, although no direct measurements have been made, is probably about 330 ft. (100 m.) (Fleet, 1965*a*, p. 66). The ice shelf slowly flows eastwards where large tabular icebergs break off into the Weddell Sea (Plate IIb). The fact that a flow of this nature occurs is shown in the Seal Nunataks where areas of pressured ice are developed by the shearing action of the ice shelf moving against the landmass (Plate IIc). Large rifts are also formed in the ice shelf and they are especially well developed near Cape Disappointment (Fleet, 1965*a*, p. 63).

Pressure occurs where the glaciers flow into the ice shelf and the severity of this depends on the size and flow velocity of the glacier. Where pressure is most severe, the ice shelf is ruptured into a chaos of broken ice blocks. Lenticular holes, crevassing and undulating ice-shelf surfaces occur in areas of weaker pressure. The coastline in this area is never exposed as a true coast, because of the semi-permanent nature of the Larsen Ice Shelf fringing it. Thus, the transition from land ice to a grounded or floating ice shelf is only apparent in a change of slope and by a series of hinge cracks which are kept open by the tidal movement of the ice shelf.

e. *Seal Nunataks*. This isolated group of nunataks is essentially a series of volcanic islands projecting through the Larsen Ice Shelf (Fig. 2). Most of the nunataks are free of a permanent ice cover and each nunatak is usually elongated along the line of the fissure through which the volcanic rocks were erupted. An exception to this is Robertson Island, the largest of the Seal Nunataks. It is almost completely covered by permanent ice and is the only one in which rocks other than the James Ross Island Volcanic Group have been discovered. These are Upper Cretaceous sediments, which are exposed at Cape Marsh at the eastern end of Robertson Island.

### 4. *Stratigraphy*

The stratigraphy of the Oscar II Coast is given in Table I where it is compared with the general stratigraphy of Graham Land (Adie, 1964*a*, p. 141, table 4). Fig. 5, a sketch geological section from the central Graham Land plateau to the Larsen Ice Shelf, also illustrates the stratigraphy of this area.

A Basement Complex (Adie, 1954) was not found *in situ* on the Oscar II Coast, although its possible presence at depth is indicated by two small fragments of hornblende-gneiss in an Upper Jurassic

TABLE I

A COMPARISON BETWEEN THE STRATIGRAPHY OF GRAHAM LAND (after Adie, 1964, p. 141, table 4) AND THE OSCAR II COAST AND THE SEAL NUNATAKS

| | *Graham Land* | *Oscar II Coast and Seal Nunataks* |
|---|---|---|
| M. Miocene | Osterrieth Range volcanic rocks and associated dykes<br>James Ross Island Volcanic Group | James Ross Island Volcanic Group |
| L. Miocene | Seymour Island Series | |
| Late Cretaceous to early Tertiary | Andean Intrusive Suite | Andean Intrusive Suite |
| L.-M. Campanian | Snow Hill Island Series<br>Cape Longing Series | Snow Hill Island Series |
| Aptian | | White granites<br>Quartz-perthite-porphyries |
| U. Jurassic | Andesite-rhyolite volcanic group | Upper Jurassic Volcanic Group |
| M. Jurassic | Mount Flora plant beds<br>Church Point plant beds<br>Basal conglomerate | Jurassic sedimentary beds |
| Carboniferous (?) | Trinity Peninsula Series | Trinity Peninsula Series |

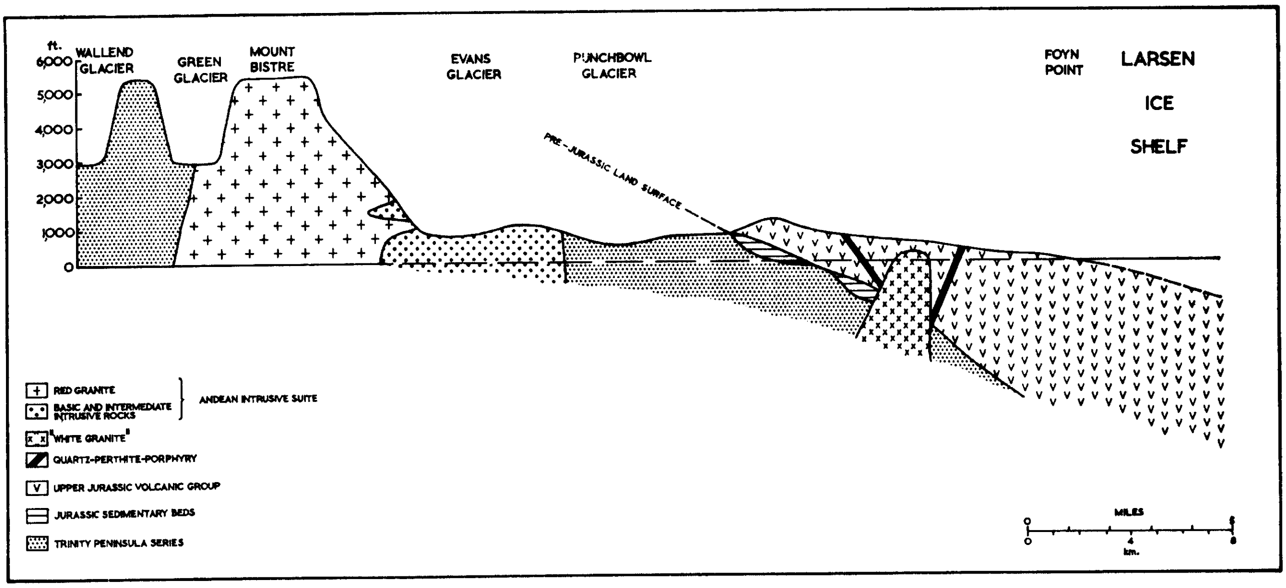


FIGURE 5

A sketch geological section from the central Graham Land plateau to the Larsen Ice Shelf to illustrate the stratigraphic relations on the Oscar II Coast.

agglomerate near Stubb Glacier. Also, allanite, which is a common mineral in both the Upper Jurassic Volcanic Group and the Andean Intrusive Suite, occurs frequently in the Basement Complex of Marguerite Bay (Hoskins, 1963, p. 27; Fraser, 1965, p. 8, 9); thus the allanite in the younger rocks may have been derived from underlying Basement Complex rocks.

The oldest rocks exposed on the Oscar II Coast are a series of isoclinally folded sediments which are correlated with the Trinity Peninsula Series of Carboniferous age (Adie, 1957*a*). Gently folded sediments which rest on the Trinity Peninsula Series and which are overlain conformably by crystal tuffs, agglomerates and lavas, are correlated with similar sediments which grade upwards into volcanic rocks at Hope Bay, where plant remains indicate a Middle Jurassic age for the sediments; the volcanic rocks are considered to be of Upper Jurassic age. On the Oscar II Coast, quartz-perthite-porphyry dykes and "white granite" plutons intrude the Upper Jurassic volcanic rocks. The sediments at Cape Marsh, Robertson Island, contain the Upper Cretaceous serpulid *Rotularia callosa* Ball (Fleet, 1966). The relationship between the "white granite" and members of an apparently later intrusive suite, the Andean Intrusive Suite (Adie, 1955), is not demonstrated on the Oscar II Coast, but the latter was probably intruded during the late Cretaceous—early Tertiary. A second phase of volcanicity, correlated with the Miocene James Ross Island Volcanic Group, resulted in the formation of the Seal Nunataks; the numerous doleritic dykes cutting the rocks of Graham Land were probably emplaced at about the same time.

## II. TRINITY PENINSULA SERIES

THE Trinity Peninsula Series has previously been described in detail from other areas of the Antarctic Peninsula by Adie (1957*a*), Aitkenhead (1965) and Elliot (1965, 1966), and the pre-Jurassic metamorphosed sedimentary rocks in the Oscar II Coast area have been assigned to this stratigraphic position for the following reasons:

i. Lithology; the succession consists of a great thickness of sandstone-shale alternations, in which the individual units vary in thickness from fractions of an inch to hundreds of feet.
ii. Metamorphic history; low-grade regional metamorphism followed by thermal metamorphism.
iii. Stratigraphic position; pre-Upper Jurassic in age.

The rocks assigned to the Trinity Peninsula Series are exposed in the upper parts of the Hektoria—Punchbowl Glaciers area in a broad belt which is parallel to the axis of Graham Land. Although the area between Jorum and Crane Glaciers has not been visited, it is probable that beds of the Trinity Peninsula Series are exposed in the greater part of this area. Crane Glacier appears to be the site of a major dislocation which has faulted down the Jurassic rocks to the south, thus burying the Trinity Peninsula Series in the Crane—Stubb Glaciers area. The Trinity Peninsula Series is again exposed at Roundel Dome on the Bruce Plateau at an altitude of 5,000–6,000 ft. (1,525–1,830 m.).

The bedding of these meta-sediments is either vertical or steeply dipping. In the Hektoria Glacier area their strike direction is constant at approximately west-south-west to east-north-east; in the Punchbowl Glacier area the strike direction is variable but the mean strike direction is similar to that in the Hektoria Glacier area. Dips of 50° and a strike direction of south-south-west to north-north-east were recorded on the south side of Crane Glacier.

The younging direction of these sediments was obtained where possible from a study of their graded- and current-bedding. Although metamorphism has obscured the fine details of the bedding, for instance the recrystallization of quartz, sufficient evidence was obtained to give a fairly reliable indication of the younging directions. Since the younging directions were found to differ in direction while the strike remained substantially the same, it was concluded that the beds are isoclinally folded, although no fold closures were actually observed in the field.

At Roundel Dome (D.4669) the sediments are predominantly arenaceous. The thin section of specimen D.4669.1 shows that the arenaceous layers are bi-modal and contain angular fragments of quartz and rare, heavily altered plagioclase about 0·2 mm. across which are set in a fine-grained matrix of the same minerals. The shale beds have been thermally metamorphosed to felts of small biotite crystals ($\alpha$ = very pale brown, $\beta = \gamma$ = deep red-brown). Iron pyrites is common in the argillaceous layers both as individual cubes and as minute crystals. It is associated with a vein which is deflected by a slip plane. Thus, the introduction of the iron pyrites pre-dates the regional metamorphism of these rocks and it may therefore have been the result of diagenesis. This might suggest that organic compounds containing sulphur were present in the original sediments.

Alternations of sandstones and shales near Mural Nunatak (D.4616) have been thermally metamorphosed to phyllitic hornfelses by a quartz-perthite-porphyry dyke. The shale beds consist of biotite ($\alpha$ = neutral, $\beta = \gamma$ = pale brown), muscovite, cordierite and abundant granules of iron ore. In the sandstone beds there are angular grains of unstrained quartz and less common oligoclase and potash feldspar; the latter is untwinned but it can be distinguished from quartz by the presence of grey dusty alteration products. Some quartz has recrystallized along the bedding planes in the sandy beds but the quartz grains in the shales have not been affected. Crystals of iron ore are much larger in the arenaceous beds than in the shales.

Small grains of tourmaline ($\omega$ = blue, $\epsilon$ = yellow) in specimen D.4643.1 (from the confluence of Green and Wallend Glaciers) indicate that the source of these sediments was a terrain composed of plutonic rocks. The bedding in these sediments is well developed, although thermal metamorphism has probably destroyed many of the original features. Quartz is abundant and it has recrystallized along the bedding planes.

The small-scale folding in specimen D.4611.1 (Plate VIa) from near Mural Nunatak is considered to be a slump structure. The complexity of the small-scale folding and dislocation in this rock could not have occurred after the rock had consolidated, unless high-grade regional metamorphism was involved and, since there is no evidence of this, it is more likely that these are slump structures. These small-scale folds are disharmonic, which is shown by the variation of their axial planes. Both the amplitude and wave-length are about 1 cm., although it is impossible to give precise measurements because of the complexity of the folding. In thin section the predominantly argillaceous nature of this rock is quite clear. The argillaceous beds have recrystallized to an aggregate of sericite, biotite ($\alpha$ = pale straw, $\beta = \gamma$ = red-brown), cordierite and andalusite. The sericite is aligned parallel to the microscopic puckering, which is common throughout the argillaceous beds, but the biotite flakes are not orientated. The sequence of events was probably:

i. Folding and puckering during slumping.
ii. Growth of sericite along the puckered bedding planes during low-grade regional metamorphism.
iii. Crystallization of biotite, cordierite and andalusite during thermal metamorphism.

Slip planes are common throughout the rock. The finer-grained arenaceous beds consist entirely of unsorted angular quartz fragments up to about 0·1 mm. across.

Near the north-east end of Rugate Ridge there is an isolated exposure of conglomerate, which is also believed to be a member of the Trinity Peninsula Series, because in this area there are other exposures of this succession whose dip and strike directions are conformable with the conglomerate. It consists mainly of vein quartz pebbles up to 9 cm. in diameter but it also contains a few shale fragments. The matrix is very hard, the rock has been sheared and well-bedded sand lenses in it have a vertical dip.

An unusual feature is the occurrence of a metamorphic limestone in the Trinity Peninsula Series near Hektoria Glacier (D.4626) (Fleet, 1965*b*).

The sediments described here belong to the greywacke facies. The succession consists of at least several thousands of feet of regularly alternating sandstones and shales, in which conglomerates and limestones are rare. The sediments are poorly sorted, no fossils were found but some slump structures were observed. The succession was subsequently subjected to compression from the north-north-west and south-south-east, resulting in isoclinal folding. Hence field observations in this area support the views of other workers (Adie, 1957*a*; Aitkenhead, 1965; Elliot, 1966) that the Trinity Peninsula Series was deposited in a geosynclinal environment.

The Trinity Peninsula Series has undergone two phases of metamorphism: an early low-grade regional metamorphism followed by thermal metamorphism, the latter being restricted to the metamorphic aureoles of the Andean Intrusive Suite rocks and the "white granites". Although metamorphism may have destroyed any earlier textural or mineralogical features, physical characteristics such as folding have remained.

### 1. *Regional metamorphism*

The low-grade regional metamorphism to which the succession has been subjected is shown by the small-scale folding in the rocks and by partial recrystallization in the argillaceous bands. Some recrystallization of quartz has also occurred.

The bedding of the meta-sediments at Roundel Dome is vertical. The specimen collected from this locality (D.4669.1) shows open cylindrical folds (Plate VIb), whose wave-length and amplitude are approximately 6 and 2·5 cm., respectively. (The terminology used here is that of Fleuty (1964).) The folding probably occurred while the rock was being subjected to a high confining pressure acting parallel to its original bedding, since the rock has not been fractured and there are no mineralogical indications of very high temperatures. It appears that the argillaceous bands acted as slip planes, over which the more competent arenaceous beds moved during folding. Some quartz lenses have crystallized with their axes parallel to the bedding of the rocks. In the vicinity of these lenses, small biotites ($\alpha$ = very pale brown, $\beta = \gamma$ = deep red-brown) are associated with larger chlorite flakes, which probably indicates that mobilization of silica occurred after the crystallization of the biotite.

A mudstone from near Punchbowl Glacier (TL.7) is contorted and brecciated, probably indicating low-temperature dynamic metamorphism. The thin section (TL.7.1) shows that no mineralogical reconstitution has occurred in the mudstone but, where the rock is arenaceous, quartz appears to have recrystallized into coarse crystals up to 2 mm. long. Lenses of indeterminate opaque material, presumably following the bedding, are included in the quartz crystals (Plate IXa, b).

A similar situation has been observed on the south side of the upper part of Crane Glacier, where a succession of alternating sandstones and shales is exposed. Paper shales crop out in the west, the succession becoming more arenaceous eastwards (or down-glacier) until at station D.4709 the content of arenaceous material forms 75 per cent of the exposures. These sediments dip at 50° in a direction 270° mag. and they are fractured, contorted and veined by quartz.

The lowest grade of regional metamorphism recorded is at station D.4616 close to Mural Nunatak, near the snout of Hektoria Glacier. The strike direction here is the same as at other exposures of the Trinity Peninsula Series sediments in the Oscar II Coast area, i.e. south-south-west to north-north-east. These rocks are vertical phyllites, in which the only effect of regional metamorphism appears to be the recrystallization of quartz lenses along the bedding planes (Plate VIc).

2. *Thermal metamorphism*

The emplacement of Andean intrusions in the Trinity Peninsula Series was the main cause of thermal metamorphism in this area. An earlier stage of thermal metamorphism was probably caused by the intrusion of the quartz-perthite-porphyry dykes and the plutons of "white granite".

The highest grade of thermal metamorphism recorded in the specimens collected occurs in a schistose muscovite-biotite-cordierite-hornfels (D.4643.1) from the confluence of Green and Wallend Glaciers. The relatively large muscovite flakes contain finely divided inclusions of iron ore. Small biotites ($\alpha$ = pale straw, $\beta = \gamma$ = deep red-brown) are abundant in the argillaceous bands but they have no preferred orientation. Non-pleochroic cordierite, which varies from colourless to yellow, is common. Lenses of recrystallized quartz are abundant throughout the rock.

Cordierite is also present in specimen D.4611.1 from near Hektoria Glacier. Slip planes associated with the earlier regional metamorphism pass through the mineral, thus demonstrating that regional metamorphism preceded thermal metamorphism. Small biotites ($\alpha$ = pale straw, $\beta = \gamma$ = red-brown) are common and muscovite occurs not only as larger flakes but also as elongated forms probably resulting from a second phase of thermal metamorphism. In this thin section there is a single euhedral crystal of andalusite, showing the aluminous composition of the sediments.

The contact between the Trinity Peninsula Series and a granite of the Andean Intrusive Suite is represented by specimen D.4613.2 from near Hektoria Glacier. In this case the plagioclase in the sediments is heavily altered and the metamorphic biotite has reverted to chlorite. It is interesting to note that the biotite in the granite is also frequently altered to chlorite, probably during a late stage in the crystallization of the granite.

## III. JURASSIC SEDIMENTARY BEDS

IN the upper reaches of Starbuck and Stubb Glaciers there are sedimentary beds at least 2,000 ft. (610 m.) thick. Since the dip of these beds appears to be conformable with the overlying Upper Jurassic Volcanic Group, they are also believed to be Jurassic in age. The Jurassic sedimentary beds grade upwards through a sequence of transitional beds into the Upper Jurassic Volcanic Group. These transitional beds show affinities to the Jurassic sedimentary beds yet they also contain evidence of contemporaneous volcanic activity, e.g. near Punchbowl Glacier (TL.13) there is a sandstone which is composed mainly of angular volcanic fragments (Plate VId). Because of features such as these, it is difficult to distinguish between the Jurassic sedimentary beds and the interbedded sediments of the Upper Jurassic Volcanic Group.

Similar sediments underlying the Upper Jurassic Volcanic Group have been recorded at several localities in Graham Land. The best known are the Middle Jurassic beds of Mount Flora at Hope Bay. This succession of plant-bearing lacustrine conglomerates and shales grades upwards into variegated acid volcanic tuffs and agglomerates (Adie, 1964*a*). In the Church Point—Botany Bay area there is a conglomerate-shale series which is believed to be mainly marine (Bibby, 1966). Aitkenhead (1965) has described a Middle Jurassic succession of conglomerates and shales from the Longing Gap—Shortcut Col area.

The sediments of Starbuck and Stubb Glaciers form a distinct unit below the volcanic rocks. Other sediments described here do not form such a distinct group but they are tentatively correlated with the type outcrop in the Starbuck and Stubb Glaciers area.

1. *Starbuck and Stubb Glaciers area*

Jurassic sedimentary beds are exposed in the upper parts of the Starbuck and Stubb Glaciers area. A "white granite", which has intruded the sediments, has metamorphosed them to phyllitic hornfelses, which show little variation at any one station. The phyllites at station TL.54 on the north side of Starbuck Glacier are typical. Their dip is 15° to 050° mag. and they strike in a direction of 140—320° mag. These rocks are dark grey in colour, rather dense and fine-grained. The bedding is not very well displayed on the broken surface of the rock but it is quite clear on the cut and varnished surface of specimen TL.54.1. In thin section the composition varies from one bed to another ranging from a fairly pure siltstone, composed of angular quartz fragments with a few sericite flakes and a little iron ore, to a muscovite-rich band. The muscovite is probably a metasomatic mineral associated with the intrusion of two quartz-perthite-porphyry dykes nearby, and it forms large plates occupying the whole of the band. Small amounts of biotite ($\alpha$ = straw, $\beta = \gamma$ = brown) and quartz are included in the muscovite. Bands rich in iron ore also contain some biotite and chlorite.

Farther to the west, on the ridge separating Pequod and Starbuck Glaciers (TL.56) the dip remains at 15° but here the strike is 120—300° mag. These rocks are more variable and both conglomerates and phyllites are present, but in general the exposed rocks are more arenaceous. Specimen TL.56.1 is a well-bedded phyllite; it has a prominent pink iron staining, which appears to affect only the fine-grained parts of the rock; these consist of indeterminate opaque material (because of the iron staining) and patches of green chlorite and epidote. The unstained parts are composed of angular turbid plagioclase fragments up to 1 mm. long which have an undulose extinction; they are set in a feldspathic matrix, in which the alignment of the feldspar laths passes round the larger fragments. Quartz only occurs in the fine-grained beds as irregular clear masses associated with chlorite and epidote.

On the other side of the ridge separating Pequod and Starbuck Glaciers volcanic rocks are exposed, but they are approximately 655 ft. (200 m.) higher on the ridge than the sediments at station TL.56. Therefore, in the absence of faulting, the sediments underlie the volcanic rocks.

On the ridge separating Starbuck and Stubb Glaciers, and to the west of the central granitic bluff, the beds comprise larger sedimentary units which can easily be distinguished from a distance (Plate Id). At station TL.59 there are thinly bedded contorted shales which dip at 15–35° in a direction of 110° mag. Within this outcrop there are a number of lenses of a grey sandy mudstone, which form about one-twentieth of the whole outcrop and range in thickness from a fraction of an inch to several feet. The thin section shows that the sandy mudstone is composed of angular grains of quartz, set in a fine-grained sericitic matrix; there are no feldspar fragments. Sphene and iron pyrites are common, the latter having been introduced by a quartz-pyrites vein which cuts the rock.

In the sediments described above, quartz is the dominant mineral while feldspar is either rare or absent. Since the grains are angular, the relative lack of feldspar is probably not because the feldspars have been destroyed during erosion and deposition but because the source rocks probably contained little or no feldspar, e.g. low-grade meta-sediments. These sediments can be followed in the cliffs to the granite exposure of station TL.43 and it is from this exposure that the minimum thickness of 2,000 ft. (610 m.) was calculated.

It is believed that the top of these beds is exposed at the head of Stubb Glacier (TL.45). This exposure consists mainly of agglomeratic crystal tuffs but both to the south and to the west in the same nunatak the beds become thinner and more pronounced, i.e. more sedimentary in character. The succession at this locality is illustrated in Fig. 6. The lower black band was visited by a colleague who collected specimens TL.45.4 and 5. Neither have been sectioned but both of the hand specimens consist of current-bedded alternations of sandstones and shales (Plate VIe, f). In specimen TL.45.4 the angular fragments range in size up to 3 mm. across. The composition of the fragments is not clear but the quartz fragments appear to be subordinate. The fine-grained bands have a dark cherty appearance on the fresh surface. Specimen TL.45.5 is finer-grained than specimen TL.45.4 and angular quartz fragments are dominant, while the shale bands are more finely bedded and are grey-brown in colour.

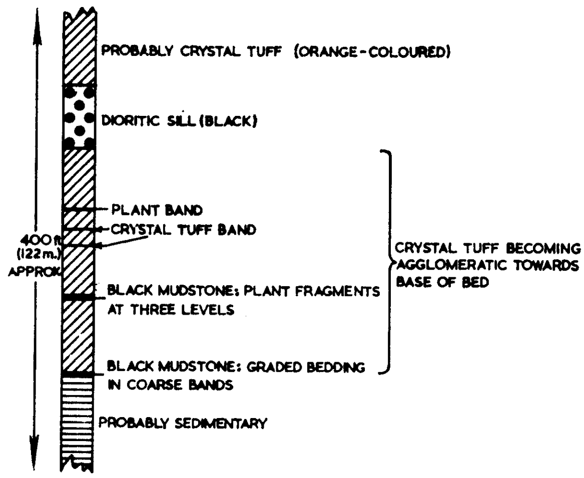


FIGURE 6

A stratigraphic section showing the gradational beds between the top of the Jurassic sedimentary beds and the base of the Upper Jurassic Volcanic Group south of Stubb Glacier (TL.45).

The upper black band is coarse-grained at its base and it contains poorly preserved plant remains at three horizons. Most of the beds consist of a black cherty rock similar to the fine-grained bands in specimen TL.45.4. In the thin section (TL.45.3) quartz is the dominant mineral, occurring both as crystal fragments and as complete crystals which range in form from perfectly euhedral to deeply embayed. The only feldspar present, oligoclase, is unusually free from alteration except for a sericitic infilling along cracks; although it is difficult to distinguish the untwinned crystals from quartz, both Carlsbad and albite twins are occasionally present. Flakes of detrital muscovite are fairly common and sericite is abundant in the very fine-grained groundmass. Zircon is a rare accessory mineral and iron pyrites occurs as quite large crystals scattered throughout the rock. Chloritic patches become increasingly common towards one end of the thin section and they could represent fragments of altered lava.

Close to the previous station (TL.45) there is a small exposure in the headwall of Stubb Glacier. This consists of a fairly coarse breccia, the individual blocks of which are about 6 in. (15 cm.) across. Blocks of a basic vesicular lava, quartz derived from gneisses, vein quartz, porphyritic andesite (TL.46.1) and phyllite were tentatively identified within the breccia.

The porphyritic andesite (TL.46.1) is traversed by two veins, which are about 1 mm. across and perpendicular to one another; one is a hornblende vein and the other is a feldspathic vein. This is a fine-grained rock containing phenocrysts of oligoclase which have poorly developed twinning and a cloudy appearance. Pseudomorphed ferromagnesian phenocrysts are present but their original composition is not clear. The groundmass apparently consists only of plagioclase but the lath texture has been partially destroyed by subsequent alteration though some flow banding is still visible. Accessory minerals include zircon and rounded grains of iron ore which are partly altered to leucoxene; these are common but tend to be associated with xenoliths which are altered to a felt of hornblende crystals. Secondary hornblende ($2V\gamma = 75°$; $\alpha$ = neutral, $\beta = \gamma$ = green) and epidote ($2V\gamma = 89°$) have been introduced throughout the rock. The hornblende is probably associated with the vein in the hand specimen, although this was not included in the thin section. The other vein, which is composed mainly of potash feldspar but which also contains some calcite and epidote, may be responsible for the epidotization. This porphyritic andesite may be a member of the Upper Jurassic Volcanic Group, indicating that volcanism had begun when the breccia was being deposited. However, the abundance of other rock types in the breccia shows that there were only limited exposures of volcanic rocks at that time. Alternatively, the andesite may have been derived from the early Palaeozoic volcanic rocks (Adie, 1954), which were not found in this area.

An outcrop on the south side of Stubb Glacier (TL.41) consists of finely bedded sandstone and mudstone, in which the sandstone bands are 0·5 cm. thick and the mudstone bands are 5 cm. thick; these are overlain by a basic vesicular lava. These beds appear to be the lateral equivalent of the agglomerate and tuff beds at station TL.42, 100 yd. (91·4 m.) west of station TL.41.

A lava bomb embedded in sediments (Plates VIIa, IXc) was found in these agglomerate and tuff beds. The actual outcrop of the sediments was not discovered but it is believed that they are exposed not very far away, probably higher in the nunatak. Although the bomb is only 2 in. (5 cm.) across, seven reaction zones can be recognized at the contact between the lava and the sediments.

Zone "a" is the sediment, a volcanic sandstone consisting of angular fragments of altered plagioclase set in a fine-grained feldspathic matrix. There are occasional clear quartz fragments and patches of leucoxene are common throughout the sediment. In zone "b" some pale green chlorite is present in the groundmass but otherwise there is no change. The next zone ("c") is characterized by the formation of epidote, and in zone "d" epidote ($2V\alpha = 84°$) is the dominant mineral accompanied by only a little chlorite. In spite of its abundance, the epidote crystals are not well formed and they contain inclusions of leucoxene.

Zone "e" is much richer in chlorite than zone "d" and the epidote decreases correspondingly. The next zone ("f") consists almost entirely of coarse prismatic epidote ($2V\alpha = 86°$), which is in complete contrast to the epidote of zone "d". Finally, in the central zone ("g") fibrous hornblende ($\alpha$ = neutral, $\beta$ = olive, $\gamma$ = blue-green; $2V\alpha = 70°$; $\gamma : c = 13°$) and chlorite accompany the epidote.

Hence, two progressive reaction sequences are represented in this contact specimen. The contact between the lava and the sediment therefore lies between zones "d" and "e".

2. *Crane Glacier*

At the entrance to Crane Glacier from Mapple Glacier, at stations D.4695 and 4697, there is a sedimentary succession overlain by volcanic rocks. The fine-grained sediments weather to a light grey colour while the coarser sandy layers are a darker tone. In places the bedding is very finely laminated. Specimen D.4695.1 consists of small angular fragments of quartz and feldspar disseminated throughout a very fine-grained groundmass, which is composed of the same minerals. In addition to the above-mentioned fragments there are corroded crystals of quartz and a single euhedral apatite crystal. Thus, these sediments again contain tuffaceous elements, although they are mixed with normal water-laid deposits.

3. *Punchbowl Glacier*

The sediments of Punchbowl Glacier are described here in two groups. The *first group* is exposed in a nunatak in the centre of the glacier. At least 75 ft. (22·8 m.) of massive greywacke are exposed at station TL.14, where there is only a slight variation in coarseness. Epidote and garnet, probably of metasomatic origin, coat the joint planes of this rock which is shattered and veined by quartz. Immediately above the greywacke is a well-bedded series of sandstones and shales about 100 ft. (30·5 m.) thick and dipping at 35° towards 275° mag. Continuing north-westwards along the nunatak past an area obscured by rubble, the next rock type is a dark agglomerate, in which the thinly bedded parts indicate a dip of 70° towards 350° mag. However, the top of the whole bed is easily distinguishable and dips conformably with the previous exposure, i.e. 35° towards 350° mag. An orange-coloured agglomerate, grading into a (?) welded tuff to the north-west, lies above this and again the measured dip of the (?) welded tuff is 70° towards 320° mag.

On the north-west end of the nunatak and separated by a snow gully from the (?) welded tuff is a biotite-cordierite-hornfels (originally a sediment), in which the arenaceous bands have recrystallized and have possibly been mobilized to give a certain amount of quartz veining. The dip of these sediments is 30° towards 310° mag., i.e. conformable with the previous exposures, although it is probable that there is a minor fault in the gully separating them. These features are explained in diagrammatic form in Fig. 7.

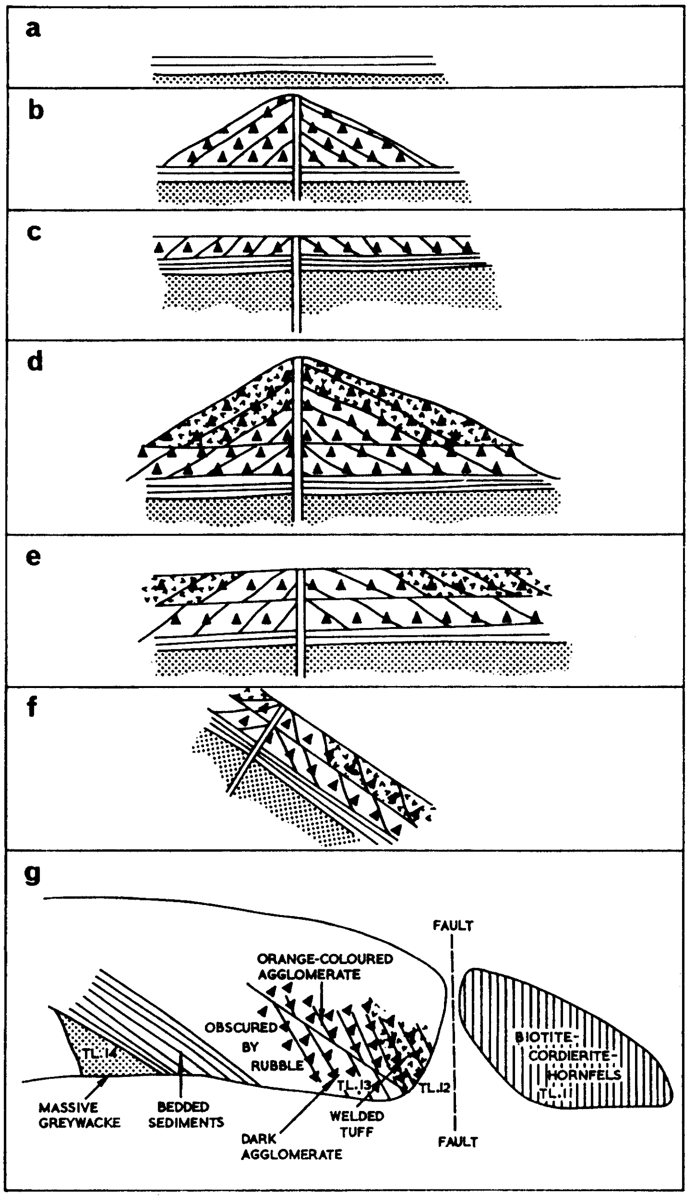


FIGURE 7

Sketch geological sections illustrating the probable sequence of events which occurred between Jurassic times and the present day in the Punchbowl Glacier area (TL.11–14).

a. Well-bedded Jurassic sediments resting on a massive greywacke (stippled).
b. First Upper Jurassic eruption; formation of an agglomeratic cone (solid triangles).
c. Erosion to a horizontal surface.
d. Second Upper Jurassic eruption; formation of an agglomeratic cone (solid triangles) grading into a welded tuff (solid triangles and V's).
e. Erosion to a horizontal surface.
f. Tilting through approximately 35°.
g. Erosion to the present-day level.

The sediments exposed on the north side of Punchbowl Glacier, forming the *second group*, are characterized by a low dip (Plate IIIa). There are mixed arenaceous and argillaceous sediments, which usually alternate rapidly but either type may predominate. These underlie the volcanic rocks of the Foyn Point area.

At station TL.3 the arenaceous beds are medium-grained, massive greenish greywackes with a poorly developed bedding. The thin section shows that the coarser angular fragments, most of which are 0·4 mm.

across, are mainly of sericitized plagioclase. In addition to the feldspar there is a little quartz, some masses of leucoxene, occasional secondary amphibole and some lithic fragments set in an even fine-grained groundmass of quartz and feldspar. The fine-grained beds resemble the matrix of the coarse-grained beds. There are a few angular fragments but on the whole the rock is fine-grained. There appears to have been some secondary silicification. The relationship between the gently dipping Jurassic sedimentary beds is clearly seen at stations TL.5–7 (Plate Vb).

4. *Cape Fairweather*

Sediments are exposed at the base of Cape Fairweather, although a quartz-diorite of the Andean Intrusive Suite forms the central part of the cape. A soft hornfels, richly stained by limonite, is exposed at each of the three stations visited (D.4645, 4665, 4668). Specimen D.4665.1 is a biotite-cordierite-hornfels, in which the cordierite crystals are full of inclusions and the biotites are very small. An unusual point is that this specimen contains up to 20 per cent of iron pyrites disseminated throughout the rock as small granules. Specimen D.4668.1, a biotite-chiastolite-hornfels, is coarser in texture than specimen D.4665.1 and it contains small angular quartz fragments. The rock is rich in chiastolite crystals, each containing a central core of inclusions. The biotite crystals are small and iron ore is much less abundant than in specimen D.4665.1. The composition of these rocks is consistent with low-grade thermal metamorphism of argillaceous sediments and therefore these rocks were probably mudstones originally.

## IV. UPPER JURASSIC VOLCANIC GROUP AND ASSOCIATED INTRUSIVE ROCKS

### A. Volcanic Rocks

Volcanic rocks of the Upper Jurassic Volcanic Group are exposed extensively along the coast and hinterland of Graham Land between Andersson Peak and Crane Glacier. This succession thickens south of Crane Glacier to at least 2,000 ft. (610 m.) and these rocks extend into the plateau of central Graham Land. In the Flask and Leppard Glaciers area this succession maintains its thickness (personal communication from A. F. Marsh), but in the north between the south side of Drygalski Glacier and Sobral Peninsula it thins considerably (Elliot, 1966). On the west coast in this latitude, and on Anvers Island, andesitic rocks are far more abundant than on the Oscar II Coast (Bayly, 1957; Hooper, 1962; Curtis, 1966). The age of the Upper Jurassic Volcanic Group has been inferred from the Hope Bay area, where acid volcanic rocks rest on plant-bearing sediments. The plants and other fossils in these sediments have been dated as uppermost Middle Jurassic and therefore an Upper Jurassic age is inferred for the volcanism. The volcanic rocks of the Oscar II Coast are correlated with the volcanic rocks of Hope Bay and they are probably also Upper Jurassic in age.

In this area the volcanic rocks form steep nunataks but they do not normally give rise to vertical cliffs. The colours resulting from weathering are variable; orange-brown is the commonest colour but quite often large areas may be coloured yellow, green, red and maroon, e.g. at station D.4647, 5 miles (8 km.) north of Cape Fairweather, and on the southern side of Pequod Glacier. It is believed that the crystal tuffs are mainly of *nuées ardentes* type. The original degree of welding in the tuffs is not clear, because thermal metamorphism of these rocks (by the "white granites") has caused widespread recrystallization of the fine-grained groundmass. However, the following features support the view that the volcanic rocks are mainly ignimbrites:

i. The flows apparently did not have brecciated bases.
ii. No scoriaceous surfaces were seen in the field.
iii. The rocks are compact and solid, although this is probably due to subsequent metamorphism.
iv. Glass shards were observed in specimen TL.45.2.
v. The rocks contain inclusions of pumice but fragments of older rocks are uncommon. The pumice fragments are flattened towards the base of the flow (TL.12.1; Plate VIIf).
vi. The rocks are evenly fine-grained and large fragments are rare. However, the fine-grained fragments show no sorting.
vii. There is no indication of mass flow.
viii. Individual units tend to be large and it is difficult to distinguish between tuffs and lavas of the same composition.

Many of these features have been discussed by Enlows (1955) in his description of the welded tuffs of Chiricahua National Monument, Arizona.

This volcanic succession, comprising several thousand feet, must have had its source somewhere in this area but no obvious centres have been discovered. The most likely locations of the centres are where agglomerates are exposed. However, no plugs or infilled volcanic necks were found in the vicinity of the agglomerates; therefore, if volcanic centres exist, they are probably covered by ice. This is not unreasonable, because centres of extrusion might be more readily eroded by ice action. Another possibility is that the centres may be located to the east, beneath the Larsen Ice Shelf, because members of the Upper Jurassic Volcanic Group are exposed on Jason Peninsula (Adie, 1958). Alternatively, there may be centres on the plateau of Graham Land, where it is also feasible, but it would be difficult to prove this because rock exposures are rare on the plateau; in fact, the only exposure visited, at Roundel Dome (D.4669), consisted of Trinity Peninsula Series sediments.

Since the "white granites" and the quartz-perthite-porphyries are probably post-Upper Jurassic but pre-Andean Intrusive Suite in age, and they are chemically similar to the acid members of the Upper Jurassic Volcanic Group, it is most probable that the centres of eruption lie above the "white granite" plutons and the quartz-perthite-porphyry dykes acted as feeders. The probable sequence of events is shown in Fig. 8.

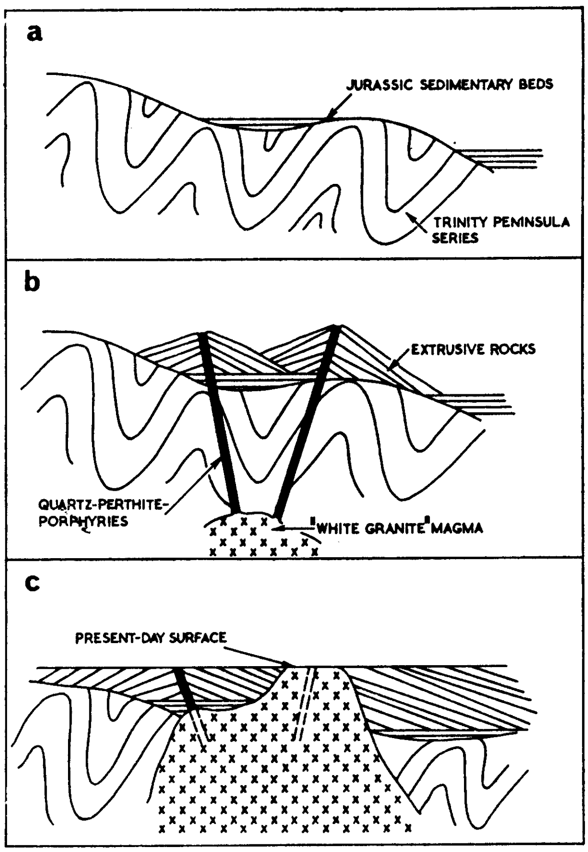


FIGURE 8

Sketch geological sections illustrating the probable relation between the Upper Jurassic Volcanic Group, the quartz-perthite-porphyries and the "white granites" on the Oscar II Coast.

a, Jurassic sedimentary beds deposited in hollows on an erosion surface cut across folded Trinity Peninsula Series sediments.

b. The eruption of crystal tuffs to form cones. The feeders from the "white granite" magma chamber form radiating quartz-perthite-porphyry dykes.

c. The "white granite" magma intrudes the Upper Jurassic volcanic rocks and is eventually exposed at the surface by erosion.

Acid crystal tuffs comprise the bulk of the succession, while agglomerates and acid and andesitic lavas are less common. Petrographic evidence suggests that two primary magmas were probably available for eruption, possibly contemporaneously: the one was the source of the acid volcanic rocks and the other gave rise to the andesitic rocks, but the source of the latter is not altogether clear. No intrusions of andesitic composition have been discovered in this area, although andesitic dykes associated with the Upper Jurassic Volcanic Group are common on the west coast of Graham Land (Goldring, 1962).

The variation in the feldspar content of the acid volcanic rocks requires some explanation. It is possible to erect a three-fold division of these rocks on the basis of feldspar content:

i. Those with plagioclase phenocrysts only (dacites).
ii. Those with potash feldspar phenocrysts only (rhyolites).
iii. Those with both plagioclase and potash feldspar phenocrysts (rhyodacites).

One explanation is that two magmas were available, one containing potash feldspar phenocrysts only and the other containing plagioclase phenocrysts only, which could give rise to these three types of volcanic rock. It is unlikely, however, that the magmas would mix readily enough to give rise to the rock types observed. Another possibility is that three magmas were available, but the hypothesis which best fits the facts is one that considers the derivation of all the types from a single acidic magma.

The course of crystallization of the supposed parent magma of the Upper Jurassic Volcanic Group, which is now represented by the quartz-perthite-porphyry dykes and the "white granite" plutons is discussed on p. 25. It appears that plagioclase was the first feldspar to crystallize, followed by simultaneous crystallization of potash feldspar and plagioclase. Consequently, the difference in feldspar content of the acid volcanic rocks would depend on the degree of crystallization of the parent magma at the time of the eruptions. This, in turn, shows that the feldspar content may have a stratigraphic significance, the early volcanic rocks containing plagioclase only and the later ones containing plagioclase and potash feldspar. The two specimens containing only potash feldspar could have resulted from plagioclase sinking, so that the resulting magma contained potash feldspar alone. However, it is more likely that the rocks and/or the thin sections described here are not truly representative of the overall field situation, since in both rocks crystal fragments are not very abundant.

The hypothesis that the feldspar content in the volcanic rocks has a stratigraphic significance might be only generally true for lavas which were derived from a single magma chamber. If several magma chambers were involved, the magma might have crystallized at different rates depending on the sizes and depths of the individual magma chambers, and the frequency of eruption. Therefore, lavas of similar mineralogy which were derived from different magma chambers cannot necessarily be considered as being contemporaneous.

The Upper Jurassic Volcanic Group is classified here on textural and mineralogical features. Thus, three textural divisions are recognized: lava, crystal tuff and agglomerate. Both acid and intermediate rocks occur, the acid ones comprising the bulk of the succession. The interbedded sediments, which are also described here, should not be confused with the Jurassic sedimentary beds which form a separate stratigraphic succession below the volcanic rocks.

1. *Lavas*

a. *Andesitic lavas.* Because they are infrequent in the Upper Jurassic Volcanic Group and their exposures are isolated on the Oscar II Coast, it is not possible to correlate between the andesitic lavas on such a paucity of evidence. However, it appears that they occur mainly near the base of the volcanic succession in this area.

Specimen D.4681.1, from Melville Glacier, is a dark, grey-green homogeneous rock which is typical of the andesitic lavas in this area. No detail is visible on the broken surface but on a cut and varnished surface a large number of small white phenocrysts of feldspar can be seen. In thin section the small euhedral plagioclase phenocrysts are considerably altered to sericite and epidote. One original ferromagnesian mineral was amphibole but it is now altered to an epidote-quartz intergrowth rimmed by leucoxene, and another was biotite now replaced by penninite. There are numerous other vague masses of chlorite, epidote and sericite which probably represent xenoliths. The groundmass consists of turbid feldspar microlites, which are commonly arranged in a flow structure round the phenocrysts. Small patches of leucoxene occur regularly throughout the groundmass and there is no unaltered iron ore. Accessory apatite crystals are well developed but no zircon was seen.

Specimen TL.31.1, a fine-grained black rock from Starbuck Glacier, contains numerous phenocrysts of a white feldspar (Plate VIIb). The feldspars are displayed well on the joint planes of the rock but they are not shown so clearly on the broken surface. This lava could easily be mistaken for one of the acid crystal tuffs in the field, e.g. specimen TL.44.1 (Plate VIId). Under the microscope the plagioclase phenocrysts, zoned from $Ab_{47}An_{53}$ (core) to $Ab_{52}An_{48}$ (rim), are not as distinctive as they are in the hand specimen. This is an unusual feature in both the acid and intermediate volcanic rocks in this area. The groundmass is composed entirely of feldspar microlites, flakes of biotite ($\alpha$ = pale straw, $\beta = \gamma$ = dark olive-green) and minute granules of iron ore. Biotite often occurs as larger flakes in xenoliths and it is possible that the biotite in the groundmass is also of xenolithic origin. The iron ore content is unusually high; as well as the minute granules in the groundmass, there are many large blebs scattered throughout the rock. No primary quartz is present, although it occurs as secondary silicification and also within the xenoliths.

Specimen TL.32.1, from Starbuck Glacier, is very similar to a non-porphyritic variety of specimen TL.31.1. However, an examination of the cut and varnished surface shows that it is in fact slightly porphyritic. The thin section contains euhedral sericitized feldspars with an approximate composition in the andesine-oligoclase range. Primary ferromagnesian minerals appear to be absent, although secondary hornblende is quite common. The masses of iron pyrites present seem to be associated with a cross-cutting quartz vein, but the numerous small iron ore granules in the groundmass are probably primary. The groundmass consists almost entirely of laths of plagioclase which display a trachytic texture (Plate IXd). Small xenoliths of siltstone are quite common and it is probable that the few quartz phenocrysts in the rock are of xenolithic origin. Accessory apatite is present but no zircon was seen in the thin section.

South of Stubb Glacier a light grey amygdaloidal lava (TL.41.1) rests on sediments. It is not clear whether or not these sediments are the top of the Jurassic beds, because only a few feet of sediments are exposed and the nature of the rocks beneath them is not known. The thin section shows that the lava is more porphyritic than the hand specimen suggests. The feldspars are heavily altered and it is difficult to distinguish them from the groundmass. No ferromagnesian minerals are present, so it appears that the lava consisted mainly of plagioclase. The groundmass is composed of plagioclase laths, which are liberally speckled with leucoxene. The amygdales consist mainly of fibrous hornblende ($\alpha$ = neutral, $\beta$ = olive-green, $\gamma$ = blue-green; $\gamma : c = 16°$; $2V\alpha = 64°$), and some quartz and epidote ($2V\alpha = 84°$).

b. *Dacitic lavas*. At two localities, near Shiver Point (D.4608) and near the mouth of Pequod Glacier (D.4678), there are dacitic lavas which contain quartz and plagioclase but no potash feldspar.

The specimen from near Shiver Point (D.4608.1) is a fine-grained, slightly cleaved, green rock containing a few phenocrysts. A microscopic examination reveals that the rock consists of scattered phenocrysts of quartz, plagioclase and muscovite set in a fine-grained quartzo-feldspathic matrix. Small, unstrained quartz phenocrysts show marginal corrosion and occasional embayment. The plagioclase phenocrysts, with an approximate composition of $Ab_{88}An_{12}$, display albite, Carlsbad and pericline twinning. A few small flakes of sericite, resulting from alteration, are scattered through the mineral. Although there are a few untwinned or simply twinned feldspar crystals in the section, their alteration to sericite suggests that these crystals are plagioclase and that there is no potash feldspar in the rock. Some of the muscovite flakes appear to be primary but others appear to be aggregates probably replacing another mineral; this replacement has proceeded to completion. The tabular and six-sided forms of the pseudomorphed crystals suggests that the original mineral was probably biotite. However, an unusual feature is that there are leucoxene granules in the cores of the crystals (Plate IXe). Deer, Howie and Zussman (1962, p. 22) state that ". . . it has been suggested that at the initial temperature of crystallization muscovite can have a high iron content which on cooling exsolves iron oxide. The cores of the crystals were originally hotter than the margins and so held more iron which is subsequently exsolved. Where muscovite and biotite occur together the iron is all taken by the biotite and the muscovite is free from inclusions . . .". In this case ilmenite was exsolved, and this subsequently altered to leucoxene. Thus, the origin of the muscovite is not completely clear.

Large patches of calcite containing small cubes of iron pyrites and irregular masses of leucoxene also occur in the rock. Since calcite is also present in the crystal tuffs of the same area, it has probably resulted from post-depositional alteration. Lenticular patches of sericite commonly present may be the result of slight brecciation caused by movement during the late stages of cooling. In the thin section there are various small lithic fragments, most of which are altered and unrecognizable. One trachytic xenolith may have been derived from one of the earlier intermediate lavas; another consists of a mass of micro-spherulites, probably recrystallized glass. A specimen of lava (D.4678.2), from near the mouth of Pequod Glacier, is fine-grained and is rich in phenocrysts of quartz, feldspar and ferromagnesian minerals. The quartz and feldspar phenocrysts range in length up to 5 cm. but the ferromagnesian phenocrysts are smaller. The rock weathers to a light pink-brown colour.

Under the microscope the evenness of the groundmass and the unbroken nature of the phenocrysts show that this rock is a lava (Plate IXf). The quartz crystals are marginally corroded and slightly embayed. The plagioclase is considerably altered to sericite, calcite and occasionally epidote; its composition is uncertain but it is probably in the albite-oligoclase range. The ferromagnesian minerals consist mainly of euhedral pseudomorphs of chlorite, prehnite and sphene after biotite. The original cleavage planes have survived and they are occasionally bent. There are also six-sided pseudomorphs of calcite, chlorite and sericite after amphibole, but they are less common than the pseudomorphs after biotite. The groundmass is a fine-grained mosaic of quartz and feldspar. Apatite and zircon are both present as accessory minerals.

c. *Rhyodacitic lavas*. There is an outcrop of porphyritic rhyodacite lava 5 miles (8 km.) north of Cape Fairweather (D.4647). Two specimens of the lava were collected from this locality, and they contain phenocrysts of quartz, feldspar and ferromagnesian minerals set in a rhyolitic matrix. Specimen D.4647.1, a grey-coloured rock, appears to be the unaltered lava, while specimen D.4647.2 is an orange-brown colour. The difference in colour reflects both the total iron content and the ratio of ferrous to ferric iron in the rock. The percentage of Fe'' is similar in both rocks (D.4647.1, 0·41 per cent; D.4647.2, 0·49 per cent) but there is much more Fe''' in the orange-brown specimen (D.4647.1, 0·21 per cent; D.4647.2, 1·22 per cent). This suggests that there has been an enrichment of Fe''' in specimen D.4647.2.

In both thin sections some of the plagioclase phenocrysts are almost completely saussuritized, while others are fairly fresh. Orthoclase-microperthite forms two-thirds of the feldspar phenocrysts in the rock. The quartz crystals are often embayed, and the larger ones are frequently cracked. The ferromagnesian minerals are represented by eight-sided pseudomorphs of chalcedony after pyroxene (D.4647.1) and an aggregate of haematite, chlorite and sericite after pyroxene (D.4647.2; Plate Xa).

2. *Crystal tuffs*

The classification of the crystal tuffs used here is according to the type of feldspar present, i.e. plagioclase only (dacitic), potash feldspar only (rhyolitic), and potash feldspar together with plagioclase (rhyodacitic). Since this classification is unfortunately not applicable to the hand specimens, a field classification could not be attempted. Most of the tuffs are of varying shades of green or grey. Their textures are those of fine-grained tuffs containing quartz and feldspar crystal fragments and a small proportion of lithic fragments.

a. *Andesitic crystal tuff*. Only one specimen (D.4654.1), from near Skilly Peak, has been examined under the microscope and it can be placed in this category. The hand specimen is a greenish, dark grey colour, is fine-grained and contains many small crystal fragments. It has a noticeably higher specific gravity than the specimens of acid crystal tuffs.

There are numerous plagioclase fragments and small flakes of secondary actinolite ($\alpha$ = neutral, $\beta$ = pale green, $\gamma$ = pale green; $\gamma : c = 15°$) are set in the fine-grained matrix. The plagioclase has rather poorly developed twinning, but it is sufficiently well developed to show that its composition is labradorite. Quartz crystals are rare; some may be primary but others are probably sedimentary grains derived from the country rock. Cutting the rock is a 0·5 mm. wide quartz-actinolite vein, in which the actinolite is coarsely developed at the margin, but it is acicular in the centre of the vein where it penetrates the quartz crystals. This vein could have been the source of the actinolite in the groundmass.

b. *Dacitic crystal tuffs*. Specimen D.4718.1, from near Mapple Glacier, exhibits the features commonly seen in the crystal tuffs, so it is described first as a type specimen and then the variations observed in other specimens are discussed. The crystal tuffs, from which specimen D.4718.1 was collected, grade into agglomerates so the pyroclastic nature of the tuffs is clearly demonstrated. The hand specimen is a light grey-green colour and has the texture of a tuff (Plate VIIc). It contains numerous crystal fragments of quartz and feldspar, ranging up to 2 mm. across. Small lithic fragments are also common in this rock.

The thin section shows that the rock is crowded with fragments of quartz and feldspar set in a fine-grained groundmass. The broken appearance of these crystals, especially the quartz, distinguishes the crystal tuffs from the lavas. Albite and Carlsbad twinning are common in the turbid plagioclase crystals ($Ab_{93}An_7$) but no examples of pericline twinning were seen. Simply twinned or untwinned feldspars are not considered to be potash feldspar, because their alteration characteristics closely resemble those of plagioclase, i.e. they are altered to sericite. Quite large crystals of epidote are formed in the feldspar crystals as an alteration product. Conchoidal fracturing of the quartz crystals is very common and complete unbroken crystals are rare. A few crystal fragments retain remnants of deep embayments but they tend to have been destroyed because they are lines of weakness in the crystals. Ferromagnesian minerals are rare; occasional chlorite, pseudomorphing biotite, is the only ferromagnesian mineral in this crystal tuff. Accessory minerals are zircon, which is well developed, a few cubes of iron pyrites and rare crystals of allanite, one of which is 0·5 mm. across. Allanite has only been found in one other crystal tuff, specimen D.4679.1 from Cape Disappointment, although it has been recorded as an accessory mineral in the quartz-perthite-porphyries, the "white granites" and the "red granites" of the Andean Intrusive Suite. The groundmass is fine-grained and quartzo-feldspathic; it has an unsorted fragmental appearance characteristic of a tuff. Minute flakes of sericite are scattered throughout the groundmass and silicification has occurred locally.

Specimen D.4696.1, from south of Crane Glacier, is a fine-grained and light green rock containing crystals of clear quartz. Although feldspar crystals are present in the rock, they are not apparent in the hand specimen. The thin section shows that the rock is relatively deficient in crystal fragments; modal analysis showed only 13 per cent of the rock consists of crystal fragments, while the remaining 87 per cent consists of a fine-grained quartzo-feldspathic groundmass. Flakes of muscovite occur infrequently in this specimen. They are less broken than in the type specimen (D.4718.1) but the groundmass, although it is very fine-grained, has the unsorted fragmental texture of a tuff. The paucity of large crystal fragments, their less broken appearance and the fine grain-size suggest that this crystal tuff was either laid down during relatively quiet conditions or it was deposited at a greater distance from its source than the other crystal tuffs.

Specimen TL.45.2, from south of Stubb Glacier, was collected from a thin band, about 6 ft. (1·8 m.) thick, and it forms part of a sequence of crystal tuffs at the base of the Upper Jurassic Volcanic Group. The band is continuous over approximately 400 yd. (366 m.) and its thickness remains constant along the length of the exposure. The groundmass consists almost entirely of small silicified shards which are deflected round some of the crystal fragments, although there is usually no preferred orientation.

Specimen TL.44.1, also from south of Stubb Glacier, is dark coloured and contains numerous white feldspar fragments which contrast strongly with the dark fine-grained matrix (Plate VIId). Twinned epidote ($2V\alpha = 84°$), which is occasionally accompanied by hornblende ($\alpha$ = neutral, $\beta$ = olive-green, $\gamma$ = blue-green; $\gamma : c = 15°$; $2V\alpha = 73°$), forms aggregates of quite coarse crystals which grow outwards from the centres of the oligoclase crystals (Plate Xb). Although epidote or clinozoisite is often formed as an alteration product of plagioclase, the alteration is more strongly developed in this specimen than in any of the others. Alteration zones are formed round the epidote crystals in the oligoclase. At the rim of the crystal there is the normal oligoclase, which is usually slightly sericitized, but between the oligoclase and the epidote there is a zone of potash feldspar, characteristically dusty with red-brown alteration products. The identity of the potash feldspar was confirmed by staining with sodium cobaltinitrite solution. (This rock is included in the group of dacitic crystal tuffs because the potash feldspar is secondary.) The rock is cut by a narrow vein containing mainly quartz and potash feldspar but also a little hornblende. The vein is bordered on both sides by a zone of leucoxene about 5 mm. wide.

The formation of potash feldspar in these circumstances poses a problem. The percentage of potash which could be held in solid solution is too small to account for the amount of potash feldspar formed by the removal of calcium from the oligoclase. However, it is believed that the formation of the potash feldspar is related to the vein. The introduction of potassium, iron, magnesium and titanium is suggested by the minerals in, and associated with, the vein. Epidote, which requires calcium and iron for its formation, could have obtained calcium from the plagioclase and iron from the vein. The potash could then enter the decalcified plagioclase and would probably replace some of the soda, although some soda could remain in solid solution with the newly formed potash feldspar. The amount of soda which would have to be replaced would depend both on the original lime content of the plagioclase and on the amount of soda which could be held in solid solution in the potash feldspar. Since the lime content would not be very high in the oligoclase and only some of the soda could be retained in solid solution, some soda would have to be displaced from the oligoclase. No new sodic minerals have been formed in the rock, so it is probable that soda has been removed from this area.

It is not clear why the feldspars have been attacked from the cores of the crystals, unless it is because they are likely to be richer in calcium and therefore more suitable for the formation of epidote. This specimen contains a good example of glass which has recrystallized to a mass of micro-spherulites, probably of quartz-orthoclase composition (Plate Xc).

c. *Rhyodacitic crystal tuffs.* The hand specimens of these rocks cover the same range of textures as the dacitic crystal tuffs, i.e. green, grey or black in colour and displaying an unsorted fragmental texture. The thin sections, too, are very similar but with the important difference that these rocks contain a significant amount of potash feldspar, which is often more than the oligoclase present. The potash feldspar is usually altered rather patchily to a red-brown dusty material and a microperthitic texture is developed in some crystals. In some specimens no twinning can be seen in the potash feldspar, whereas in others several examples of simple twins are present. Penninite and serpentine pseudomorphs after amphibole or pyroxene are present in some specimens but no fresh amphiboles or pyroxenes have been recorded. Biotite is common and it is usually partly altered to chlorite.

Specimen D.4603.1 contains biotite and pseudomorphs after amphibole and pyroxene. The biotite has been almost completely replaced and only some of the original red-brown mineral remains. A pale green chlorite appears to be replacing the biotite and iron ore is being exsolved. The amphiboles are completely replaced by penninite, but the pseudomorphs after pyroxene consist of rutile needles growing inwards from the crystal boundary into serpentine (Plate Xd). The texture of this rock is typically tuffaceous (Plate Xe).

The replacement of biotite by pale green chlorite has proceeded further in specimen TL.36.1, in which only faint traces of biotite remain in an otherwise complete crystal of chlorite. A cleaved crystal tuff (D.4671.1) from Pequod Glacier is similar to the other crystal tuffs in mineral composition except that sericite has developed along the cleavage planes.

d. *Rhyolitic crystal tuffs.* Only two rocks have been placed in this group: specimens D.4680.1 and 4700.1. This may not be a true division; plagioclase may only be apparently absent, as in both rocks crystal fragments are rare. Specimen D.4680.1, from Cape Disappointment, is stained brick-red by haematite, which has probably resulted from oxidation at the top of the crystal tuff bed. It has a heterogeneous texture and contains small crystal fragments of quartz and potash feldspar. The thin section shows that crystal fragments of quartz and potash feldspar comprise about 10 per cent of the rock. The potash feldspar shows a microperthitic texture, in which the exsolved albite has well-developed twinning. The groundmass is very fine-grained, probably quartzo-feldspathic and is stained by haematite. Some silicification has occurred. Specimen D.4700.1, from Crane Glacier, is a light green rock which is very fine-grained and finely banded, each band being about 1 mm. thick (Plate VIIe) and showing up in different shades of light green. Rare crystal fragments of quartz and potash feldspar are present and they are set in a fine-grained matrix which probably also consists of quartz and potash feldspar.

### 3. (?) *Welded crystal tuff*

Specimen TL.12.1, from near Punchbowl Glacier, is probably a welded acid tuff. It rests conformably on an agglomerate and its marked planar structure (Plate VIIf) suggests that it has been compressed. The tuff consists of collapsed pumice fragments and occasional crystals of quartz and plagioclase. The groundmass is very fine-grained and consists mainly of minute flakes of sericite, the alignment of which has been deflected round the crystal fragments.

### 4. *Agglomerates*

Coarse agglomerates are rare in this area. Many of the crystal tuffs are slightly agglomeratic, since they contain occasional large pyroclastic fragments, but only those exposures where the large fragments predominate are described here. None of the agglomerates represent infilled volcanic necks because some parts of them are bedded; they have probably been deposited on the slopes surrounding the volcanic centres. The best example is in the vicinity of Punchbowl Glacier, where a bed of orange-coloured agglomerate rests on top of a dark-coloured agglomerate. The depositional character of these agglomerates has been discussed under the Jurassic sedimentary beds (p. 13; Fig. 7). The angular blocks in the agglomerate range in size up to 30 cm. across (Plate IIIb). They show some linearity although the main mass of the rock is unsorted. None of the rocks in the agglomerate could be correlated in the field with any of the underlying rocks. The matrix is similar to the (?) welded tuff (TL.12.1) into which it grades conformably.

Two similar exposures of agglomerate occur on Mural Nunatak (D.4617) and near Pequod Glacier (D.4671). There is a larger outcrop near Mapple Glacier where the pyroclasts range up to 15 cm. across. The percentage of pyroclasts in the crystal tuff matrix is lower than in the examples mentioned above. None of the pyroclasts of the fine-grained quartz-rich intrusive rocks have been identified. There is a 15 cm. thick crystal tuff band in the agglomerate at this exposure, which probably represents a temporary diminution in the volcanic activity.

5. *Interbedded sediments*

The sediments which are locally interbedded with the volcanic rocks were probably deposited during quiescent conditions of the volcanic activity. The Jurassic sedimentary beds that immediately underlie the volcanic rocks form a separate sequence but in the field there is inevitably some confusion between the two types of sediment, especially at the base of the volcanic rocks, where the upward transition from the sediments is gradual. There are two types of sediment: that derived mainly from the surrounding country rock and that derived from the contemporaneous volcanic rocks.

a. *Sediments derived mainly from the country rock.* Specimen D.4617.2, from Mural Nunatak, is a dark sandstone associated with a volcanic breccia, whose fragments are aligned along the bedding planes and range up to 5 mm. in length, although most of them are about 1 mm. long. The larger angular fragments are quartzite, while the smaller ones consist of individual quartz crystals, often showing strain extinction. The quartzite may be pure or it may contain thin argillaceous bands now represented by micaceous minerals. The original rock was quite rich in feldspar but this has been completely altered to sericite. Strongly pleochroic biotite ($\alpha$ = neutral, $\beta = \gamma$ = red-brown) is quite common in the groundmass. In the rock there is a shale lens, rich in iron pyrites and about 10 mm. long and about 2 mm. wide, the ends of which finger into the rest of the rock; therefore, this is a contemporaneous deposit and not a shale fragment derived by erosion.

The rocks exposed north of Pequod Glacier (D.4675) are severely weathered and only occasional solid outcrops project through the scree cover. Specimen D.4675.1 is a soft, dark-coloured shale containing numerous white crystals about 5 mm. long and 0·5 mm. wide which have crystallized along the bedding planes. Since the thin section has been cut across the length of the crystals, only cross-sections are displayed. Each cross-section is approximately square, and this together with the length of the mineral suggests that it was originally andalusite or chiastolite. The mineral itself has been altered to an aggregate of chlorite, sericite, iron pyrites and leucoxene. The groundmass consists mainly of small angular quartz fragments and, to a lesser extent, of sericite, iron pyrites and leucoxene. The rock is cut by a 2 mm. vein, which is displaced about 1·5 mm. along the cleavage so the formation of the cleavage post-dates the veining. A second smaller quartz vein has been introduced along the cleavage.

The sediments in the vicinity of Melville Glacier, from which specimen D.4683.2 was collected, are contorted and overlain by an andesitic lava (D.4683.1); the field evidence indicates that the lava probably flowed into the sediments before they had consolidated. The specimen is a fine-grained shale which is quite well bedded and contains occasional coarse bands. It is cut by a network of quartz veins about 1 mm. wide and normal to the bedding. The groundmass consists of quartz, sericite, small grains of magnetite and probably some feldspar. The magnetite and a small amount of iron pyrites are concentrated along the bedding planes. The partly rounded fragments in the sandstone beds consist of quartz, showing strain extinction, and some secondary epidote. Chlorite occurs within the thin shale bands in the arenaceous beds but not in the thick shale beds. The vein that occurs in the hand specimen contains mainly oligoclase and some interstitial quartz; it has a microgranular texture and sphene, muscovite and zircon are accessory minerals. The contact between the vein and the sediments is sharp and there are no drag effects, but a few small veins have been injected along the bedding planes. It is therefore probable that the rock had already consolidated when the veining occurred.

A conglomerate was found in the scree near the top of Melville Glacier (D.4685). Although the specimen was not found *in situ*, the abundance of conglomerate fragments in the scree strongly suggests that it is exposed higher in the cliff face. It is indurated and consists mainly of vein quartz pebbles approximately 15 mm. in diameter. Pebbles of a bedded sandstone are also common. Only one pebble of an intrusive rock was seen and this appeared to be of microdioritic composition. The matrix of the conglomerate is fine-grained and chloritic.

b. *Sediments derived mainly from contemporaneous volcanic rocks*. The first erosional products derived from the newly erupted volcanic rocks were volcanic sandstones. One example is at station D.4720, near Mapple Glacier, where the rocks are dark green in colour. It is fine-grained but some detail can be seen on the broken surface. The cut and varnished surface is dark green, has the texture of a sandstone and is traversed by cracks which impart a serpentinitic appearance to it. The sediments consist of fragments (probably of lava) with very little interstitial matrix. The fragments are angular, of fairly even grain-size and most are of similar composition. Occasional quartz fragments and even rarer ones of plagioclase are present. The whole of the rock is heavily iron-stained which makes identification of the individual fragments very difficult.

There are interbedded sediments containing plant remains at two stations near Starbuck Glacier (TL.22, 25). Both are very localized and have the following succession:

*Top* Commencement of next volcanic outburst.
Establishment of plant life.
More gentle erosion to shaly or muddy material.
Rapid erosion to sandy material.
*Base* Volcanic activity ceases.

Both of these sections are illustrated in Figs. 9 and 10. Although several plant specimens were collected from these sediments, their preservation was very poor and it has been impossible to identify them.

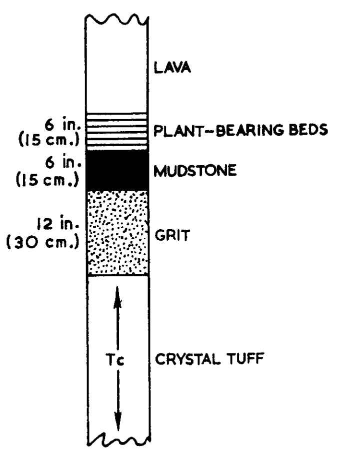


FIGURE 9

A stratigraphic section in part of the Upper Jurassic Volcanic Group, showing a lull in volcanicity during which plant life became established; near Starbuck Glacier (TL.25).

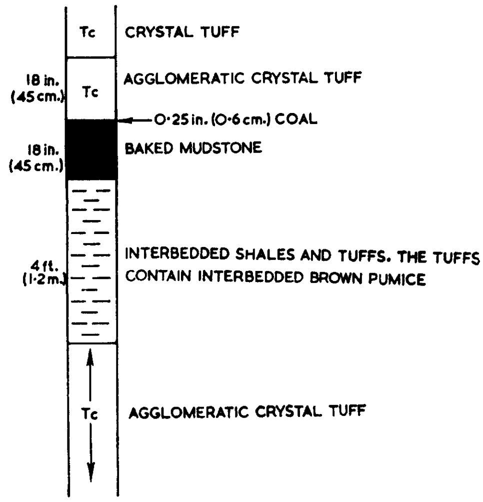


FIGURE 10

A stratigraphic section in part of the Upper Jurassic Volcanic Group, showing a lull in volcanicity during which plant life became established; near Starbuck Glacier (TL.22).

## B. QUARTZ-PERTHITE-PORPHYRIES

Quartz-perthite-porphyry dykes are especially widespread throughout the Oscar II Coast area of Graham Land but they have not been recorded in the Seal Nunataks. There is a general tendency for them to increase in frequency southwards; near Starbuck Glacier they are especially common. All of the exposures observed in the field were of an intrusive nature, usually steeply dipping dykes about 100 ft. (30·5 m.) wide (Plate IIIc). Examples of sills and small boss-like intrusions were also recorded, e.g. at stations D.4674 (near Pequod Glacier) and TL.1 (north coast of Exasperation Inlet). Usually the quartz-perthite-porphyries can be easily recognized from a distance. They are normally light-coloured (one dark-coloured porphyry was observed) and they contrast strongly with the country rock, which invariably consists of members of the Upper Jurassic Volcanic Group. Although these rocks contain phenocrysts of quartz, plagioclase and orthoclase-microperthite, the name "quartz-plagioclase-orthoclase-microperthite-porphyry" is too cumbersome, so the rocks have been termed "quartz-perthite-porphyry". This signifies the importance of the orthoclase-microperthite, and also avoids confusion with the extrusive "quartz-plagioclase-porphyries" described by Adie (1953).

1. *Petrology*

The hand specimens are often very distinctive rocks (Plate VIIIa, b). The main feature about them is the presence of very large feldspar phenocrysts, which may attain lengths of up to 2 in. (5 cm.) in some specimens. At stations TL.1 (north coast of Exasperation Inlet) and D.4674 (south of Pequod Glacier) the margins of the intrusions contain small phenocrysts of plagioclase, orthoclase-microperthite and quartz, although large phenocrysts of orthoclase-microperthite are well developed in other parts of the intrusions. Therefore, the orthoclase-microperthite phenocrysts must have continued to grow at a considerable rate after intrusion relative to the quartz and plagioclase phenocrysts. The feldspars are fairly well formed and they are usually white, although intrusions containing pink feldspars occasionally occur. The quartz phenocrysts are clear and rounded, and they may range in size up to 0·25 in. (0·6 cm.) across. In the coarser-grained specimens the ferromagnesian minerals tend to clot together. The groundmass varies from a very fine-grained rhyolitic to a coarser microgranitic texture and it is usually a light shade of grey.

For the purpose of microscopic description it is most convenient to describe one typical specimen, and then to discuss the different characters displayed by other rocks in the same group. Specimen TL.1.1, from the north coast of Exasperation Inlet, has been selected as a typical example of a quartz-perthite-porphyry. This specimen is a medium-grained rock containing numerous large phenocrysts of quartz, albite and orthoclase-microperthite. Less common is chlorite after biotite. The quartz, frequently enclosing trains of inclusions and small clots of sericite, forms large euhedral phenocrysts which have usually been marginally corroded and occasionally deeply embayed. Only the larger quartz phenocrysts are cracked and show strain extinction; often, but not invariably, the quartz crystals are surrounded by a rim of micrographic intergrowth of quartz and orthoclase-microperthite. Albite ($Ab_{98}An_2$) occurs as individual phenocrysts but it may also display a glomeroporphyritic texture. Albite twinning is well developed but pericline and Carlsbad twinning are rare. Untwinned albite can be distinguished from orthoclase-microperthite because the phenocrysts of albite are uniformly speckled with flakes of sericite and the orthoclase-microperthite has a more red-brown alteration colour than the albite in ordinary light. The very large orthoclase-microperthite phenocrysts in these rocks are well formed and have sharp margins but they are usually surrounded by a rim of micrographic intergrowth with quartz. The orthoclase-microperthite crystals are heavily speckled with a red-brown dust although the rims of the crystals may be clear. No twinning was seen in any of the orthoclase-microperthite phenocrysts of specimen TL.1.1 but it has been observed in other specimens of the same group. A microperthitic texture is well developed in all of the orthoclase crystals. Usually the exsolved albite imparts a patchy appearance to the crystals but albite twinning is sometimes developed in the exsolved patches. Phenocrystic flakes of biotite, now completely altered to a pale green penninite, were originally present in the rock. The crystals were well formed and often with a good termination. However, a very noticeable feature within the pseudomorphs is the growth of a light brown radiating mineral, which is sometimes associated with ilmenite and leucoxene. It has a high relief and birefringence, and it is probably sphene. It is very common and sometimes occurs in the groundmass in the form of a broken amygdale. It is therefore probable that this mineral was formed before the consolidation of the magma and during the alteration of biotite to chlorite.

It is difficult to distinguish precisely between the constituents of the groundmass, most of which consists of a micrographic intergrowth of quartz and feldspar. The feldspar is probably a potash variety, since no twinning is visible and the alteration colour in ordinary light is similar to that of the orthoclase-microperthite phenocrysts. However, this does not exclude the possibility of albite occurring within the groundmass. Flakes of chlorite are dispersed regularly throughout the groundmass. Zircon, apatite, iron pyrites and ilmenite occur as accessory minerals and they are usually associated with the ferromagnesian phenocrysts. In two other specimens (D.4674.1, 4681.2) allanite is present but, although large in size, only one crystal is present in each thin section.

Specimen TL.49.1, from south of Stubb Glacier, is a light grey porphyritic rock containing smaller phenocrysts than those of specimen TL.1.1 and which consist almost entirely of a white feldspar. Quartz phenocrysts are also present but they are both rare and small. A microscopic examination reveals that the phenocrysts are set in a fine-grained groundmass, consisting of quartz and probably both albite and potash feldspar. Unlike most of the other porphyries, the groundmass of this specimen is microgranular and there is no indication of any intergrowth between the two feldspars. The albite phenocrysts are glomeroporphyritic (Plate Xf) but quartz and potash feldspar are not included in these aggregates. Albite, pericline and Carlsbad twinning are developed, the main form being albite twinning. Simple twins are common in the small, rare potash feldspar phenocrysts and there is very little development of a microperthitic texture. The quartz phenocrysts are marginally corroded and they contain small blebs of quartzo-feldspathic material. The ferromagnesian minerals are very similar to those in specimen TL.1.1.

Two dyke rocks, from stations TL.54 and D.4682, contain feldspars which have an unusual strain extinction giving the appearance of brecciation (Plate XIa). Since the twin planes are not distorted, physical displacement has not occurred. The quartz phenocrysts are more cracked than in the type specimen but the orthoclase-microperthite crystals do not appear to have suffered so much. It is probable that these features were caused during intrusion.

A similar feature occurs in the intrusive sheet at station D.4616 near Mural Nunatak, in the Hektoria Glacier area. The sheet dips steeply and it is concordant with the country rock. The hand specimen contains large quartz phenocrysts set in a fine-grained groundmass but under the microscope it is immediately obvious that the rock has been sheared. This is shown by lines of slip cutting through the rock as bands of sericite, which merge into green biotite ($\alpha$ = neutral, $\beta = \gamma$ = pale green), and the presence of bent twin lamellae in the feldspar (Plate XIb). In addition, the quartz phenocrysts have recrystallized into crystal aggregates pseudomorphing an originally complete crystal (Plate XIc). In fact, these look very much like xenoliths of quartzite, except that the crystal form of the quartz phenocrysts has been retained. Since the quartz crystals in the country rock do not show any form of strain extinction, the recrystallization is apparently associated with intrusion. Besides the above-mentioned green biotite there are commonly felted masses of brown biotite ($\alpha$ = pale brown, $\beta = \gamma$ = red-brown), sometimes surrounding masses of iron ore. The groundmass is an irregular granular mixture of quartz and feldspar but occasionally a micrographic texture is developed. Both apatite and zircon are apparently absent. In spite of the unusual texture displayed by the quartz phenocrysts, this rock appears to belong to the quartz-perthite-porphyry group when the modal analyses are considered (Table II).

2. *Crystallization of the feldspars in the quartz-perthite-porphyries in the light of experimental evidence*

It seems desirable to consider the course of crystallization of the feldspars in the quartz-perthite-porphyries because, if this is properly understood, it could lead to a clearer understanding of the Upper Jurassic Volcanic Group and the associated intrusive rocks. The feldspars are particularly interesting as they are the main constituents of the rocks. The facts so far indicated by the petrology are:

i. Two feldspars, plagioclase and orthoclase-microperthite, are present in the rocks.
ii. The microperthitic texture is probably the result of unmixing of a soda-rich potash feldspar.
iii. From field evidence, the potash feldspars continued to grow at a considerable rate after the intrusion of the quartz-perthite-porphyry dykes.

Combining these facts, it appears that the sequence of events was as follows:

i. Crystallization of plagioclase.
ii. Crystallization of some potash feldspar.
iii. Intrusion as dykes.
iv. Rapid crystallization of soda-rich orthoclase.
v. Unmixing of soda-rich orthoclase to give orthoclase-microperthite.

An attempt to explain this sequence of events, using the results of experiments in feldspar crystallization, is given below. Fig. 11 (after Turner and Verhoogen, 1960, figs. 11 and 12) shows the hypothetical intersection of the solvus and solidus in the feldspar system at water pressures consistent with shallow plutonic conditions and volcanic conditions, respectively. It is considered that shallow plutonic conditions are more appropriate to the present examples than deep-seated plutonic conditions, because the plutons are apparently associated with volcanic activity.

## Table II

MODAL ANALYSES OF QUARTZ-PERTHITE-PORPHYRIES FROM THE OSCAR II COAST

| | D.4616.1 | D.4674.1 | D.4674.2 | D.4681.2 | D.4682.2 | D.4683.4 | D.4712.2 | D.4713.1 | TL.1.1 | TL.30.1 | TL.47.1 | TL.49.1 | TL.54.1 | TL.54.3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Phenocrysts* | | | | | | | | | | | | | | |
| Quartz | 15·3 | 10·9 | 11·2 | 16·5 | 10·5 | 0·8 | 11·9 | 11·6 | 13·8 | 14·1 | 13·4 | 2·2 | 14·6 | 9·4 |
| Orthoclase | 16·9 | 3·8 | 5·4 | 8·7 | 15·4 | tr | 22·4 | 11·2 | 12·3 | 13·5 | 15·8 | 0·2 | 21·0 | 3·4 |
| Plagioclase | 6·5 | 20·4 | 28·6 | 14·1 | 15·6 | 15·4 | 12·6 | 12·2 | 10·7 | 8·8 | 13·3 | 17·7 | 9·0 | 19·6 |
| Ferromagnesian minerals* | 3·2 | 4·1 | 4·7 | 2·0 | tr | 2·1 | 1·6 | 1·5 | 4·5 | 0·5 | 0·4 | 3·2 | tr | 5·4 |
| *Groundmass*† | 58·1 | 60·8 | 50·1 | 58·7 | 58·5 | 81·7 | 51·5 | 63·5 | 58·7 | 63·1 | 57·1 | 76·7 | 55·4 | 62·2 |
| *Plagioclase composition* | $An_5$ | $An_5$ | $An_5$ | $An_{10}$ | $An_5$ | $An_3$ | $An_{10}$ | $An_5$ | $An_2$ | $An_8$ | $An_{10}$ | $An_5$ | $An_7$ | $An_7$ |

* Chlorite, epidote or biotite.
† Fine-grained quartz, orthoclase, plagioclase and ferromagnesian minerals.

| | |
|---|---|
| D.4616.1 | Near Mural Nunatak. |
| D.4674.1 | South of Pequod Glacier. |
| D.4674.2 | South of Pequod Glacier. |
| D.4681.2 | South of Melville Glacier. |
| D.4682.2 | South of Melville Glacier. |
| D.4683.4 | South of Melville Glacier. |
| D.4712.2 | South of Mapple Glacier. |
| D.4713.1 | South of Mapple Glacier. |
| TL.1.1 | North coast of Exasperation Inlet. |
| TL.30.1 | North of Starbuck Glacier. |
| TL.47.1 | North of Stubb Glacier. |
| TL.49.1 | South of Stubb Glacier. |
| TL.54.1 | North of Starbuck Glacier. |
| TL.54.3 | North of Starbuck Glacier. |

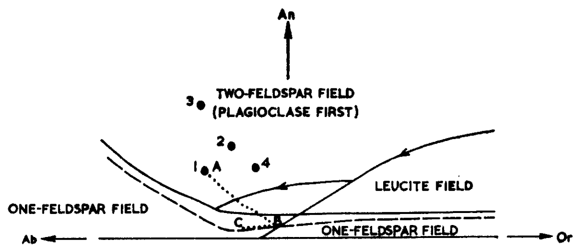


FIGURE 11

Phase diagram for the albite—anorthite—orthoclase system in shallow plutonic and volcanic conditions (after Turner and Verhoogen, 1960, figs. 11 and 12).

– – – – Hypothetical intersection of solvus and solidus at water pressures and temperatures consistent with shallow plutonic conditions.

——— Hypothetical intersection of solvus and solidus at water pressures and temperatures consistent with volcanic conditions.

● Total normative feldspar composition of specimens: 1. TL.49.1; 2. D.4674.2; 3. TL.54.3; 4. TL.1.1.

The total normative feldspar contents of the four quartz-perthite-porphyries, which have been chemically analysed, have been calculated and they are plotted on Fig. 11 (points 1–4). Specimen TL.49.1 (point 1) has been chosen as probably being closest in composition to the original magma, because it is least porphyritic, and therefore factors such as crystal fractionation (of plagioclase) would have had less chance to operate. Specimen TL.49.1 lies within the two-feldspar field, from which plagioclase would be the first feldspar to crystallize. As the plagioclase crystallized under shallow plutonic conditions, the residual magma composition would change along the hypothetical line A—B. At any composition along A—B, this magma could have been intruded either as hypabyssal dykes or even extruded at the surface. The phenocrysts would then be quartz and plagioclase. The residual magma would then crystallize according to the conditions prevailing, i.e. volcanic conditions. Thus a magma of composition B would lie in the one-feldspar field and a soda-rich potash feldspar would crystallize. The resulting rock would consist of plagioclase phenocrysts set in a groundmass of soda-rich potash feldspar, i.e. a dacitic rock. With further crystallization under shallow plutonic conditions, simultaneous crystallization of plagioclase and potash feldspar would occur and the composition of the magma would accordingly change along the hypothetical line B—C. Under volcanic conditions, a magma of this composition would again be in the one-feldspar field and the potash feldspar phenocrysts would continue to grow and the groundmass would also consist of potash feldspar (with quartz).

The field evidence suggests that the orthoclase-microperthite crystals had grown to the same size as the plagioclase phenocrysts before the intrusion of the dykes. Thus intrusion would strongly favour the precipitation of feldspar of one composition (a soda-rich potash feldspar), which would grow preferentially on the orthoclase crystals already co-existing with the magma, producing the very large phenocrysts.

### 3. *Correlation with other porphyries in Graham Land*

a. *Andvord Bay—Charlotte Bay area.* On the west coast of Graham Land, which is only 20–30 miles (32–48 km.) from the Oscar II Coast in this area, Bayly (1957, p. 19–20) described specimen O.568.14 under the heading of "the coarse porphyritic rocks". This isolated intrusion has provided the only specimen which can possibly be correlated with the quartz-perthite-porphyries of the Oscar II Coast. It contains albite phenocrysts set in a matrix of quartz and potash feldspar, so it could correspond to the early quartz-perthite-porphyry (TL.49.1) described here.

b. *West coast of Adelaide Island.* Specimens dredged from off the west coast of Adelaide Island (Tyrrell, 1945, p. 70–75) could also be related to the porphyries discussed here. He described a "granite porphyry containing very abundant phenocrysts of quartz, some a centimetre in length, orthoclase not quite so large and still smaller crystals of albite/oligoclase. A few small crystals of altered biotite and a little iron ore represent the only ferromagnesian constituents. The phenocrysts collectively make up more than half the volume of the rock."

## C. "White Granites"

### 1. *Hektoria Glacier area*

An exposure of "white granite" in the north-east corner of the Hektoria Glacier area was visited at several localities and its overall extent was mapped. In the tops of the cliffs above stations D.4611, 4615 and 4616 there are horizontal tongues of "white granite" extending out from the main intrusive body.

The rocks from near Skilly Peak (D.4658, 4663) are coarse-grained, equigranular and contain quartz and feldspar in equal amounts, while the ferromagnesian minerals form clots which are dispersed through the rock. The plagioclase is albite/oligoclase which is sometimes surrounded by a rim of fresh albite; albite has also crystallized in a brecciated zone in the rock. A myrmekitic texture is well developed at the boundary between the plagioclase, which contains regular strings of quartz (Plate XId), and a microperthitic orthoclase. In specimen D.4663.1 up to 30 per cent of iron ore has been exsolved along the cleavage planes of the biotite ($\alpha$ = yellow-brown, $\beta = \gamma$ = dark brown), with which zircon and apatite are frequently associated, but these accessory minerals were absent from specimen D.4658.1. The order of crystallization of the main minerals appears to have been plagioclase, quartz, biotite and potash feldspar. No attempt at modal analysis was made on either specimen, because of their coarse grain-sizes and because only one rather small thin section was available from each specimen. Therefore, for classification it was necessary to return to the hand specimen, which showed that quartz and potash feldspar are the main minerals, plagioclase is less common and that the biotite is little more than an accessory mineral. Thus both specimens have been classified as granites.

The specimen from station D.4614 is an adamellite. In this rock the plagioclase is a slightly zoned oligoclase surrounded by a rim of clear albite. In ordinary light, the potash feldspar, containing stringers of exsolved albite, is heavily speckled with a dark brown dusty material. A myrmekitic intergrowth is occasionally developed at the contact between the plagioclase and the potash feldspar. There are large, quite fresh crystals of hornblende ($\alpha$ = greenish brown, $\beta$ = green, $\gamma$ = dark green; $\gamma : c = 13°$; $2V\alpha = 56°$) in the rock but they are not as common as the large and strongly pleochroic flakes of biotite ($\alpha$ = yellow-brown, $\beta = \gamma$ = dark brown). Felts of secondary biotite are also present and they appear to be associated with fracturing of the rock. There are several quite large crystals of allanite, which is a common accessory mineral in this specimen, and zircon and apatite are also abundant and tend to be concentrated in the biotite flakes (Plate XIe). The order of crystallization of the main minerals was hornblende, plagioclase, quartz, biotite, potash feldspar and albite rimming.

### 2. *Punchbowl Glacier area*

Two small intrusions that may be related at depth occur close together in the south-west corner of the Punchbowl Glacier area. The hand specimens differ in that one (from station TL.16) contains pink feldspars, quartz, muscovite and biotite, whereas the other (from station TL.17) is a muscovite-granite, which has an off-white colour and contains white feldspars as the dominant minerals, but quartz and muscovite are also common. The feldspars can be identified under the microscope as orthoclase-microperthite, containing beads of exsolved albite some of which may show good twinning, and plagioclase ($Ab_{97}An_3$). The potash feldspar contains a grey-brown dusty alteration product and it appears to be replacing quartz. The muscovite commonly occurs as quite large plates; along its cleavages it frequently contains exsolved iron ore (Plate XIf), which has also grown interstitially and along the cleavage planes of the orthoclase-microperthite crystals. Fluorite, an unusual accessory mineral forming quite large anhedral crystals, appears to be associated with the muscovite, but the fluorite is not visible in the hand specimen. Neither zircon nor apatite were seen in the thin section.

### 3. *Mapple and Melville Glaciers area*

An intrusion in the ridge separating Mapple and Melville Glaciers extends to the south side of Melville Glacier. Two other smaller intrusions occurring between Crane and Mapple Glaciers are probably closely related, although neither was actually visited. There appear to be two phases of intrusion: at station D.4682, where there are a number of quartz-perthite-porphyries, and at station D.4687, where there is a xenolithic granite; a coarse-grained granite similar to that recorded in the Hektoria Glacier area.

Specimen D.4682.1 is coarse-grained and consists mainly of quartz and white feldspar with subordinate biotite. There is a development of a granophyric texture but this is only apparent when the thin section is examined. Zoned plagioclase has a composition varying from approximately $Ab_{60}An_{40}$ (core) to $Ab_{84}An_{16}$ (rim), and it displays Carlsbad, pericline and albite twins. Most of the plagioclase crystals are heavily sericitized in patches and they are accompanied by untwinned orthoclase-microperthite. The large quartz crystals have a strain extinction and they are traversed by cracks filled with sericite. Strongly pleochroic biotite ($\alpha$ = pale straw, $\beta = \gamma$ = dark red-brown) forms quite large plates which have been partly altered to a pale green chlorite. Accessory minerals include iron ore and zircon which are common, a small amount of muscovite, and rare apatite. The order of crystallization was plagioclase, biotite, quartz and orthoclase-microperthite.

At station D.4688, both pink and white varieties of the coarse granite are exposed and these appear to be local variations of the main intrusion. The white variety (D.4688.1) is a typical "white granite", but the pink variety (D.4688.2) differs from it in a number of respects. No intrusive contact between the two varieties of granite was seen in the field and the variation recorded is probably due to late-stage hydrothermal alteration. The most interesting difference is that the chequer-board albite (Plate XIIa, b) present in the pink variety seems to be the equivalent of the orthoclase-microperthite (Plate XIIc) in the white variety. The development of chequer-board albite from potash feldspar is suggested by the fact that one of the crystals of chequer-board albite displays Baveno twinning (Plate XIIb). It is probable that the formation of the chequer-board albite occurred in the late stages of the cooling of the intrusion. Starkey (1959, p. 144), concluding a description of chequer-board albite from New Brunswick, Canada, has stated that ". . . the albite may have arisen by replacement of potash feldspar in the magmatic or deuteric phases of intrusion, and the chess-board pattern subsequently or contemporaneously by stress". Strained quartz and sheared plagioclase crystals (Plate XIId) show that the rock has suffered stress at some period. A myrmekitic intergrowth of quartz and plagioclase commonly occurs in this specimen and it appears that the quartz is growing at the expense of the plagioclase. The appropriate chemical reaction would be:

$$\underset{\text{albite}}{Na_2O.Al_2O_3.6SiO_2} = \underset{\text{quartz}}{6SiO_2}+Na_2O+Al_2O_3.$$

This reaction releases soda which would then be available for the *metasomatism* of the orthoclase-microperthite (cf. Exner, 1949). The potash released by this reaction could combine with alumina to produce muscovite or sericite, both of which are present in the thin section.

Thus

$$Na_2O+\underset{\text{orthoclase}}{K_2O.Al_2O_3.6SiO_2} = \underset{\text{albite}}{Na_2O.Al_2O_3.6SiO_2}+K_2O$$

and,

$$K_2O+3Al_2O_3+6SiO_2+2H_2O = \underset{\text{muscovite}}{K_2O.3Al_2O_3.6SiO_2.2H_2O}.$$

Epidote and calcite are common secondary minerals in the pink variety of granite.

4. *Starbuck and Stubb Glaciers area*

a. *Normal granite.* The largest intrusion of "white granite" on the Oscar II Coast is in the Starbuck and Stubb Glaciers area (Plate IVa). It is probable that this is a single intrusion, which has an irregular outcrop because of its uneven upper contact and because of faulting. The contact with the country rock is sharp and steep at the margins of the intrusion, and sharp and horizontal at the roof; the latter feature is clearly seen at stations TL.43 and 53.

A typical rock is specimen TL.43.1 which is a medium- to coarse-grained, light-coloured granite (Plate VIIIc) containing white feldspars, some of which have a pale green sericitized core. Quartz is abundant but it is not quite equal in amount to the combined feldspars, and biotite has a rather varied distribution through the rock. All the plagioclase crystals ($Ab_{92}An_8$) are sericitized, some slightly and others heavily (accompanied by prehnite), although there is a sericite-free zone around the rims. Orthoclase-microperthite, in which the exsolved albite exhibits well-developed twinning, contains red-brown dusty alteration products. Strained quartz has replaced plagioclase at the contact between the two minerals. Only a small amount of biotite ($\alpha$ = pale yellow-brown, $\beta = \gamma$ = dark brown) remains, most of the mineral having been replaced mainly by chlorite but also by sphene, clinozoisite and prehnite. The order of crystallization of the main minerals appears to have been plagioclase, biotite, quartz and potash feldspar. Zircon, apatite and iron ore are accessory minerals, which are usually associated with the biotite.

A more granodioritic intrusion is exposed near the head of Starbuck Glacier (TL.57). In the hand specimen it is medium- to coarse-grained, feldspar predominates over quartz and it contains a much higher percentage of ferromagnesian minerals (about 10 per cent) than specimen TL.34.1. It also contains rare large phenocrysts of feldspar.

b. *Porphyritic granite.* South of Starbuck Glacier (TL.26) there is a porphyritic granite containing feldspar phenocrysts up to 1 cm. long and quartz phenocrysts up to 0·5 cm. long set in a medium- to coarse-grained matrix. The plagioclase is heavily altered to saussurite and sericite, and its composition is difficult to determine; however, the potash feldspar is relatively unaltered and consists mainly of orthoclase, although stringers of exsolved albite are also present. The potash feldspar tends to form large crystals which often enclose the smaller plagioclase crystals of the medium-grained matrix. This rock is classified as a "white granite" and not as a quartz-perthite-porphyry because it is a plutonic rather than a hypabyssal intrusion, but it is possible that this intrusion may really be intermediate between the quartz-perthite-porphyries and the "white granites". Allanite is a well-developed accessory mineral. The modal analysis of this specimen places it within the normal range of the "white granites" when it is plotted on a quartz—plagioclase—potash feldspar triangular variation diagram (Fig. 12).

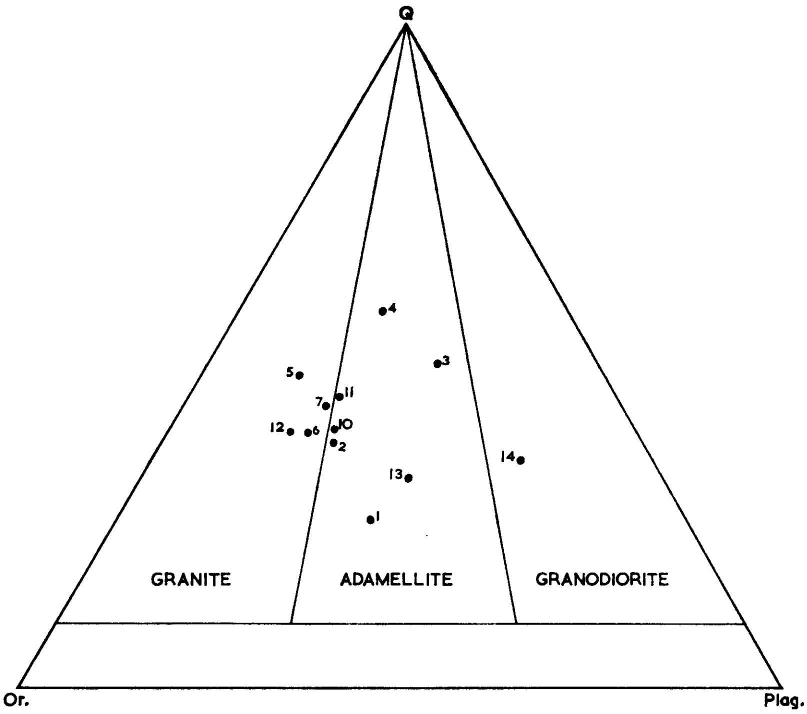


FIGURE 12

A quartz—orthoclase—plagioclase variation diagram based on modal analyses of "white granites" from the Oscar II Coast (Table III).

The granite is again porphyritic south of Starbuck Glacier (TL.43). The minerals have similar microscopic characteristics to those in the typical granites, although the modal analysis of specimen TL.43.2 (Table III) shows a higher percentage of plagioclase (32·6 per cent) than the non-porphyritic granites. However, xenoliths are common in this vicinity and it is possible that these have affected the plagioclase content in a manner similar to that seen in specimen TL.34.2a (p. 32).

c. *Granophyre.* Although a granophyric texture is sometimes exhibited on a small scale in several granites, the specimens from south of Starbuck Glacier (TL.33) show an extensive development of granophyric texture (Plate XIIe). The hand specimen (TL.33.1) has a porphyritic appearance, the

## TABLE III

### MODAL ANALYSES OF "WHITE GRANITES" FROM THE OSCAR II COAST

| | D.4614.1 | D.4682.1 | D.4688.1 | D.4714.2 | TL.17.1 | TL.26.2 | TL.34.1 | TL.34.2a | TL.34.2b | TL.38.2 | TL.38.3 | TL.39.1 | TL.43.2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quartz | 24·8 | 36·1 | 48·8 | 55·6 | 44·0 | 38·6 | 41·6 | 33·4 | 41·0 | 38·4 | 43·6 | 37·9 | 30·4 |
| Potash feldspar | 38·5 | 37·4 | 20·3 | 23·5 | 36·5 | 42·4 | 36·5 | 16·7 | 30·1 | 37·8 | 35·1 | 43·6 | 32·9 |
| Plagioclase | 30·3 | 22·2+ | 29·9 | 18·5 | 12·0 | 17·2 | 17·2 | 44·4 | 11·7 | 22·0 | 18·7 | 15·3 | 32·1 |
| Biotite | 6·1 | 4·3 | 1·0 | 0·2 | — | 1·8 | 4·7 | 5·5 | 15·9 | 1·8 | 0·2 | 2·6 | 4·1 |
| Muscovite | — | tr | tr | — | 7·5 | — | tr | — | 0·8 | — | tr | — | — |
| Epidote | — | — | tr | tr | — | tr | — | — | — | — | 2·4 | — | tr |
| Other minerals | 0·3* | — | — | 2·2† | tr‡ | tr§ | — | tr‖ | 0·5‡ | — | — | 0·6† | 0·5‖ |
| *Plagioclase composition* | $An_{20}$ | $An_{40-16}$ | $An_{14}$ | $An_{2}$ | $An_{3}$ | $An_{10}$ | $An_{8}$ | $An_{12}$ | $An_{7}$ | $An_{5}$ | $An_{5}$ | $An_{7}$ | $An_{8}$ |

* Hornblende.
† Xenolith.
‡ Fluorite.
§ Allanite.
‖ Prehnite.
+ Zoned.

D.4614.1 Adamellite, north of Hektoria Glacier.
D.4682.1 Adamellite, south of Melville Glacier.
D.4688.1 Adamellite, north of Melville Glacier.
D.4714.2 Adamellite, south of Mapple Glacier.
TL.17.1 Muscovite-granite, near mouth of Punchbowl Glacier.
TL.26.2 Porphyritic granite, north of Starbuck Glacier.
TL.34.1 Granite, south of Starbuck Glacier.
TL.34.2a Granodioritic zone near xenolith, south of Starbuck Glacier.
TL.34.2b Xenolith in granite, south of Starbuck Glacier.
TL.38.2 Adamellite, north of Starbuck Glacier.
TL.38.3 Adamellite, north of Starbuck Glacier.
TL.39.1 Granite, south of Starbuck Glacier.
TL.43.2 Porphyritic adamellite, south of Starbuck Glacier.

phenocrysts of quartz, plagioclase and orthoclase being set in a fine-grained, light grey matrix. In fact, the groundmass is not as fine-grained as it appears to be in the hand specimen; the intergrowth of quartz and potash feldspar is medium-grained. The feldspars are euhedral but the quartz crystals have been corroded. In addition to the larger phenocrysts, there are also smaller crystals mainly of quartz, but there is also some potash feldspar. Xenoliths, consisting of felts of chlorite, are common and the accessory minerals are zircon, apatite, allanite and iron pyrites.

d. *Pegmatites and mineralization.* In the Oscar II Coast area pegmatites are best developed on the north side of Starbuck Glacier (TL.38), where small amounts of pegmatite have developed on joint planes, occasionally in cavities and rarely as veins. Quartz and pink feldspar are usually present, and they may be accompanied by epidote, muscovite, fluorite and iron pyrites. Specimen TL.38.3 is a granite, bounded by a joint plane coated with pegmatitic quartz, feldspar and epidote. Epidotization of the granite has accompanied the development of the pegmatites. Epidote formed granular aggregates when it replaced plagioclase, but when it grew independently it formed prismatic crystals. A pale green chlorite was also apparently introduced. Fluorite can be seen in the hand specimens TL.38.4 and 5 together with quartz and epidote.

The red staining of the whole exposure north of Starbuck Glacier (TL.38) may be associated with the development of the pegmatites, but it could also be the result of the intrusion of doleritic dykes which are unusually abundant at this locality.

A block of cupriferous vein material was found in the scree south of Starbuck Glacier (TL.43) which probably originated from a vein higher in the cliffs. In the specimen collected (TL.43.7) the copper minerals are chalcopyrite, which has been partly altered to bornite, and green amorphous malachite. Poorly developed crystals of fluorite are common and they are accompanied by quartz and epidote.

e. *Xenoliths.* The number of xenoliths present in the granite varies considerably at different localities. Some parts of the intrusion appear to be free from xenoliths, whereas others are particularly rich in fragments of the country rock. South of Starbuck Glacier (TL.43) the granite is unusually rich in xenoliths, three specimens of which have been collected; two are medium- to fine-grained intrusive rocks and the third, which is more altered, is represented by a clot of biotite flakes about 2 in. (5 cm.) across.

One of the xenoliths from south of Starbuck Glacier (TL.34.2) is a medium-grained rock that is darker coloured than the surrounding granite. The xenolith is partly altered at the edges but the bulk of it appears to be fresh. A thin section (TL.34.2b) shows that the xenolith consists of quartz, potash feldspar, plagioclase and chlorite. The potash feldspar is microperthitic (the exsolved albite is not twinned) and it carries red-brown dusty alteration products which can be clearly seen in ordinary light. The smaller plagioclase crystals ($Ab_{93}An_7$) form a lower percentage of the rock and quartz comprises about 40 per cent of the xenolith. There are numerous small ragged chlorite flakes (containing sphene) which have probably formed from biotite. Secondary muscovite and slightly pink fluorite are also present, the latter frequently occurring in the cores of the chlorite. Zircon, apatite and allanite are accessory minerals.

The effect of assimilation is well shown in specimen TL.34.2, the contact between a granite and a xenolith which was originally about 15 cm. across. A zone of epidote extends about 2·5 cm. from the contact, which is definite but not sharp, and beyond that the granite appears to be normal. However, a modal analysis (Table III) of the thin section (taken about 4 cm. from the xenolith) shows that the percentage of potash feldspar decreases from 36·5 per cent in specimen TL.34.1, a normal granite, to 16·7 per cent in the thin section of specimen TL.34.2a, while the plagioclase percentage increases from 17·2 per cent to 44·4 per cent. There does not appear to be any significant change in the percentages of quartz or the ferromagnesian minerals.

Although the xenolith has a composition approximating to the enclosing granite, the mineralogy of the surrounding granodiorite suggests that chemical reconstitution has taken place within the xenolith. Four mineralogical zones have been recognized in the vicinity of the xenolith:

i. Uncontaminated granite.
ii. Granodiorite zone.
iii. Epidote zone.
iv. Xenolith.

Nockolds (1933, p. 583) has considered that chemical reconstitution in a xenolith engulfed by a magma is caused by the diffusion of elements, such that a reaction between the xenolith and the magma proceeds

TABLE IV

CHEMICAL ANALYSES OF VOLCANIC AND INTRUSIVE ROCKS FROM THE OSCAR II COAST

| | *Upper Jurassic Volcanic Group* | | | *Quartz-perthite-porphyries* | | | | *"White granites"* | | *Andean Intrusive Suite* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| $SiO_2$ | 73·76 | 74·63 | 68·79 | 70·35 | 69·93 | 70·49 | 67·72 | 69·66 | 74·84 | 75·97 | 73·83 |
| $TiO_2$ | 0·10 | 0·31 | 0·40 | 0·25 | 0·40 | 0·21 | 0·31 | 0·31 | 0·17 | 0·07 | 0·15 |
| $Al_2O_3$ | 14·87 | 13·79 | 16·43 | 15·69 | 15·61 | 16·19 | 16·43 | 16·10 | 13·39 | 13·55 | 14·87 |
| $Fe_2O_3$ | 0·26 | 0·21 | 0·85 | 0·43 | 0·60 | 0·76 | 1·07 | 0·42 | 0·14 | 0·26 | 0·95 |
| FeO | 0·97 | 0·41 | 2·84 | 1·85 | 2·19 | 1·01 | 1·85 | 2·03 | 0·95 | 0·45 | 0·95 |
| MnO | 0·02 | 0·01 | 0·07 | 0·02 | 0·04 | 0·03 | 0·04 | 0·05 | 0·03 | 0·03 | 0·05 |
| MgO | 0·15 | 0·45 | 0·32 | 1·17 | 0·30 | 1·11 | 1·41 | 1·08 | 0·31 | 0·05 | 0·29 |
| CaO | 0·77 | 0·56 | 1·95 | 1·86 | 1·73 | 1·46 | 2·81 | 1·32 | 1·23 | 0·30 | 0·59 |
| $Na_2O$ | 1·12 | 0·92 | 2·15 | 2·57 | 3·14 | 4·20 | 2·20 | 3·43 | 2·52 | 3·67 | 3·91 |
| $K_2O$ | 7·15 | 7·93 | 3·04 | 4·53 | 4·75 | 4·10 | 4·84 | 4·87 | 5·36 | 4·68 | 4·07 |
| $H_2O+$ | 0·64 | 0·57 | 1·32 | 0·76 | 1·09 | 0·20 | 0·62 | 0·68 | 0·43 | 0·31 | 0·42 |
| $H_2O-$ | 0·08 | 0·06 | 0·07 | 0·08 | 0·06 | 0·04 | 0·06 | 0·02 | 0·01 | 0·11 | 0·05 |
| $P_2O_5$ | 0·02 | 0·08 | 0·11 | 0·10 | 0·08 | 0·07 | 0·10 | 0·08 | 0·03 | 0·02 | 0·03 |
| $CO_2$ | 0·03 | 0·22 | 1·16 | 0·13 | 0·24 | Nil | 0·14 | 0·17 | 0·22 | 0·07 | 0·01 |
| TOTAL | 99·94 | 100·15 | 99·50 | 99·79 | 100·16 | 99·87 | 99·60 | 100·22 | 99·63 | 99·54 | 100·17 |
| | | | | | ANALYSES LESS TOTAL WATER (Recalculated to 100) | | | | | | |
| $SiO_2$ | 74·33 | 74·98 | 70·11 | 71·10 | 70·63 | 70·76 | 68·47 | 69·99 | 75·46 | 76·66 | 74·05 |
| $TiO_2$ | 0·10 | 0·31 | 0·41 | 0·25 | 0·40 | 0·21 | 0·31 | 0·31 | 0·17 | 0·07 | 0·15 |
| $Al_2O_3$ | 15·00 | 13·86 | 16·75 | 15·85 | 15·77 | 16·25 | 16·61 | 16·18 | 13·50 | 13·67 | 14·91 |
| $Fe_2O_3$ | 0·26 | 0·21 | 0·87 | 0·43 | 0·61 | 0·76 | 1·08 | 0·42 | 0·14 | 0·26 | 0·95 |
| FeO | 0·98 | 0·41 | 2·89 | 1·87 | 2·21 | 1·01 | 1·87 | 2·04 | 0·96 | 0·45 | 0·95 |
| MnO | 0·02 | 0·01 | 0·07 | 0·02 | 0·04 | 0·03 | 0·04 | 0·05 | 0·03 | 0·03 | 0·05 |
| MgO | 0·15 | 0·45 | 0·33 | 1·19 | 0·30 | 1·11 | 1·43 | 1·09 | 0·31 | 0·05 | 0·29 |
| CaO | 0·77 | 0·56 | 1·99 | 1·88 | 1·75 | 1·46 | 2·84 | 1·33 | 1·24 | 0·30 | 0·59 |
| $Na_2O$ | 1·13 | 0·93 | 2·19 | 2·60 | 3·17 | 4·22 | 2·22 | 3·45 | 2·54 | 3·70 | 3·93 |
| $K_2O$ | 7·21 | 7·98 | 3·10 | 4·58 | 4·80 | 4·12 | 4·89 | 4·89 | 5·40 | 4·72 | 4·09 |
| $P_2O_5$ | 0·02 | 0·08 | 0·11 | 0·10 | 0·08 | 0·07 | 0·10 | 0·08 | 0·03 | 0·02 | 0·03 |
| $CO_2$ | 0·03 | 0·22 | 1·18 | 0·13 | 0·24 | Nil | 0·14 | 0·17 | 0·22 | 0·07 | 0·01 |
| | | | | | | NORMS | | | | | |
| Q | 37·48 | 37·81 | 41·67 | 31·73 | 28·87 | 25·36 | 27·86 | 25·97 | 36·68 | 36·01 | 33·58 |
| or | 42·28 | 46·90 | 17·98 | 26·79 | 28·09 | 24·25 | 28·63 | 28·80 | 31·70 | 27·68 | 24·07 |
| ab | 9·46 | 7·77 | 18·17 | 21·72 | 26·54 | 35·50 | 18·59 | 28·99 | 21·30 | 31·02 | 33·04 |
| an | 3·52 | 0·92 | 1·71 | 7·83 | 6·60 | 6·83 | 12·47 | 5·01 | 4·54 | 0·93 | 2·68 |
| hy | 1·81 | 1·21 | 4·71 | 5·59 | 3·68 | 3·71 | 5·77 | 5·66 | 2·18 | 0·68 | 1·53 |
| mt | 0·38 | 0·30 | 1·23 | 0·62 | 0·87 | 1·10 | 1·55 | 0·61 | 0·20 | 0·38 | 1·38 |
| il | 0·19 | 0·59 | 0·76 | 0·48 | 0·76 | 0·40 | 0·59 | 0·59 | 0·32 | 0·13 | 0·29 |
| ap | 0·05 | 0·19 | 0·26 | 0·24 | 0·19 | 0·16 | 0·24 | 0·19 | 0·07 | 0·05 | 0·07 |
| cc | 0·07 | 0·50 | 2·64 | 0·29 | 0·55 | — | 0·32 | 0·39 | 0·50 | 0·16 | 0·02 |
| C | 3·98 | 3·34 | 9·07 | 3·67 | 2·86 | 2·32 | 2·98 | 3·34 | 1·72 | 2·11 | 3·04 |
| | | | | | | CATION PERCENTAGES | | | | | |
| $Si^{+4}$ | 34·42 | 34·83 | 32·10 | 32·83 | 32·63 | 32·90 | 31·60 | 32·51 | 34·93 | 35·45 | 34·45 |
| $Al^{+3}$ | 7·87 | 7·30 | 8·70 | 8·31 | 8·26 | 8·57 | 8·70 | 8·52 | 7·09 | 7·17 | 7·87 |
| $Fe^{+3}$ | 0·18 | 0·15 | 0·60 | 0·30 | 0·42 | 0·53 | 0·75 | 0·29 | 0·98 | 0·18 | 0·67 |
| $Mg^{+2}$ | 0·09 | 0·27 | 0·20 | 0·71 | 0·18 | 0·67 | 0·86 | 0·65 | 0·19 | 0·03 | 0·17 |
| $Fe^{+2}$ | 0·75 | 0·32 | 2·21 | 1·44 | 1·70 | 0·79 | 1·44 | 1·58 | 0·74 | 0·35 | 0·74 |
| $Na^{+1}$ | 0·83 | 0·68 | 1·60 | 1·91 | 2·33 | 3·12 | 1·63 | 2·54 | 1·87 | 2·72 | 2·90 |
| $Ca^{+2}$ | 0·55 | 0·40 | 1·46 | 1·34 | 1·25 | 1·04 | 2·28 | 0·95 | 0·89 | 0·21 | 0·42 |
| $K^{+1}$ | 5·93 | 6·58 | 2·52 | 3·76 | 3·94 | 3·40 | 4·02 | 4·04 | 4·45 | 3·88 | 3·38 |
| $Ti^{+4}$ | 0·06 | 0·19 | 0·24 | 0·15 | 0·24 | 0·13 | 0·19 | 0·19 | 0·10 | 0·04 | 0·09 |
| $Mn^{+2}$ | 0·02 | 0·01 | 0·06 | 0·02 | 0·03 | 0·02 | 0·03 | 0·04 | 0·02 | 0·02 | 0·04 |
| $P^{+5}$ | 0·01 | 0·03 | 0·04 | 0·04 | 0·03 | 0·03 | 0·04 | 0·03 | 0·01 | 0·01 | 0·01 |
| $O^{-2}$ | 49·26 | 49·02 | 49·21 | 49·06 | 48·75 | 48·80 | 48·32 | 48·49 | 48·51 | 49·87 | 49·25 |
| Position [(⅓Si+K)−(Ca+Mg)] | +15·76 | +17·52 | +11·56 | +12·65 | +13·39 | +12·66 | +10·79 | +13·28 | +15·01 | +15·46 | +14·27 |
| Fe | 91·17 | 63·51 | 90·65 | 71·02 | 92·17 | 66·33 | 71·80 | 74·21 | 90·06 | 94·64 | 89·24 |
| Mg | 8·83 | 36·49 | 9·35 | 28·98 | 7·83 | 33·67 | 28·20 | 25·79 | 9·94 | 5·36 | 10·76 |
| Fe | 11·95 | 5·88 | 39·41 | 21·43 | 24·74 | 15·51 | 25·17 | 20·55 | 20·90 | 7·40 | 17·94 |
| Mg | 1·16 | 3·38 | 2·81 | 8·74 | 2·10 | 7·87 | 9·89 | 7·14 | 2·31 | 0·42 | 2·16 |
| Alk | 86·89 | 90·74 | 57·78 | 69·83 | 73·16 | 76·62 | 64·94 | 72·31 | 76·79 | 92·18 | 79·90 |
| Ca | 7·52 | 5·22 | 26·16 | 19·11 | 16·62 | 13·76 | 28·75 | 12·61 | 12·34 | 3·08 | 6·27 |
| Na | 11·35 | 8·88 | 28·67 | 27·25 | 30·98 | 41·27 | 20·55 | 33·73 | 25·94 | 39·94 | 43·28 |
| K | 81·13 | 85·90 | 45·17 | 53·64 | 52·40 | 44·97 | 50·70 | 53·66 | 61·72 | 56·98 | 50·45 |

*Andean Intrusive Suite*
10. D.4622.1 Microgranite, near Hektoria Glacier.
11. D.4630.1 Adamellite, near Hektoria Glacier.

"*White granites*"
8. D.4614.1 Adamellite, near Hektoria Glacier.
9. TL.34.1 Granite, near Starbuck Glacier.

*Quartz-perthite-porphyries*
4. D.4674.2 South of Pequod Glacier.
5. TL.1.1 North coast of Exasperation Inlet.
6. TL.49.1 South of Stubb Glacier.
7. TL.54.3 North of Starbuck Glacier.

*Upper Jurassic Volcanic Group*
1. D.4607.1 Dacite, near Shiver Point.
2. D.4647.1 Rhyolite, north of Cape Fairweather.
3. TL.2.1 Dacite crystal tuff, north coast of Exasperation Inlet.

(Analyses by M. Fleet.)

towards equilibrium. He has maintained that where the xenolith is more basic than the enclosing magma, potash, soda and perhaps alumina are introduced into the xenolith, whereas lime, magnesia and ferrous iron enter the magma.

For its formation, the epidote zone would need an influx of Ca, Fe and Mg which could be provided by the xenolith. The increased plagioclase content of the granodiorite zone could be accounted for by an influx of Ca (from the xenolith) and Na (from the surrounding magma). The potash feldspar, which would otherwise have crystallized in the granodiorite zone, has entered the xenolith. However, the lack of potash feldspar in the granodiorite zone is probably the result of plagioclase crystallizing first and occupying the available space, rather than a deficiency in the constituents of the potash feldspar, which would have been readily available from the surrounding magma.

Nockolds (1933, p. 563) has pointed out that fixation of volatiles occurs readily in the presence of xenoliths, this being shown by an increase in the amount of apatite. In this instance it appears that fluorine has been fixed as fluorite, which is present in both the xenolith and the contact zone.

## D. Geochemistry

Nine new chemical analyses, representative of the Upper Jurassic volcanic and intrusive rocks of the Oscar II Coast, are given in Table IV. They include three acid volcanic rocks, four quartz-perthite-porphyries and two "white granites".

Corundum appears in the norms of all the rocks which were analysed and it probably reflects the sericitization of the feldspars which is a common feature in most of the specimens. 2·64 per cent normative calcite, in specimen TL.2.1, combined with high (41·67 per cent) normative quartz, also indicates that this rock has been altered. Values of over 40 per cent normative orthoclase in specimens D.4607.1 and 4647.1 suggest that these rocks have undergone potash metasomatism.

The analysis results have been plotted on triangular variation diagrams with the coordinates (Fe″+Fe‴)—Mg—Alk and Ca—Na—K (Fig. 13), and curves have been drawn through the plotted points in order to

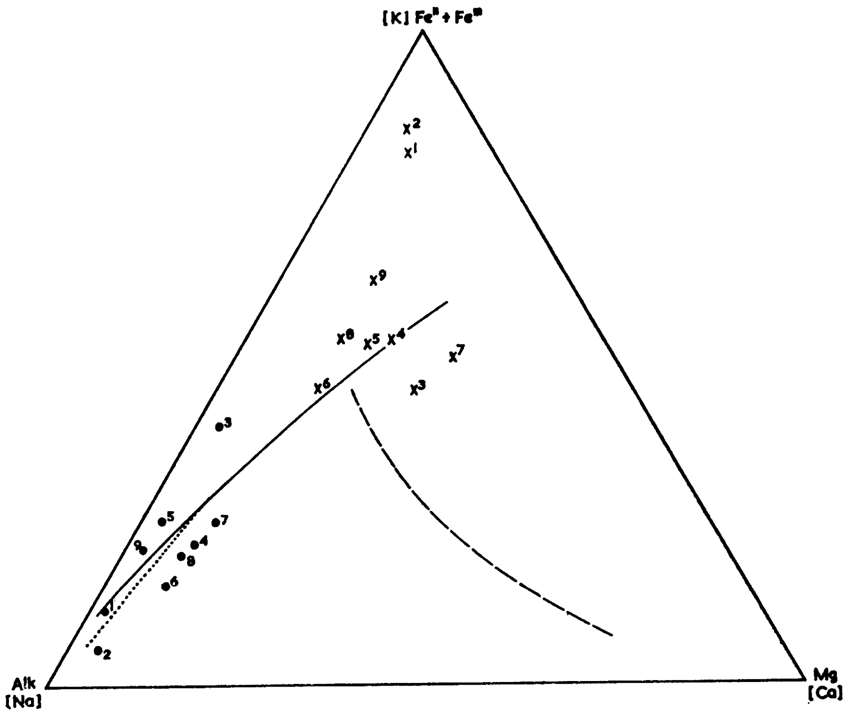


FIGURE 13

Triangular variation diagrams plotted on the coordinates (Fe″+Fe‴)—Mg—Alk (●) and Ca—Na—K (×), showing the new analyses of Upper Jurassic rocks from the Oscar II Coast (Table IV) in relation to the Upper Jurassic Volcanic Group of Graham Land (Adie, 1964*b*, fig. 2). The curve for the Upper Jurassic volcanic rocks from the Oscar II Coast is shown by the dotted line. The curves for the Upper Jurassic Volcanic Group of Graham Land are shown by solid and pecked lines.

compare them with the Upper Jurassic Volcanic Group of Graham Land (Adie, 1964*b*, p. 542, fig. 2). The weight percentages of the major elements have also been plotted against the modified Larsen function $[(\frac{1}{3}Si+K)-(Ca+Mg)]$, used by Nockolds and Allen (1953) in their study of some igneous rock series, to obtain the variation trends of the major elements (Fig. 14).

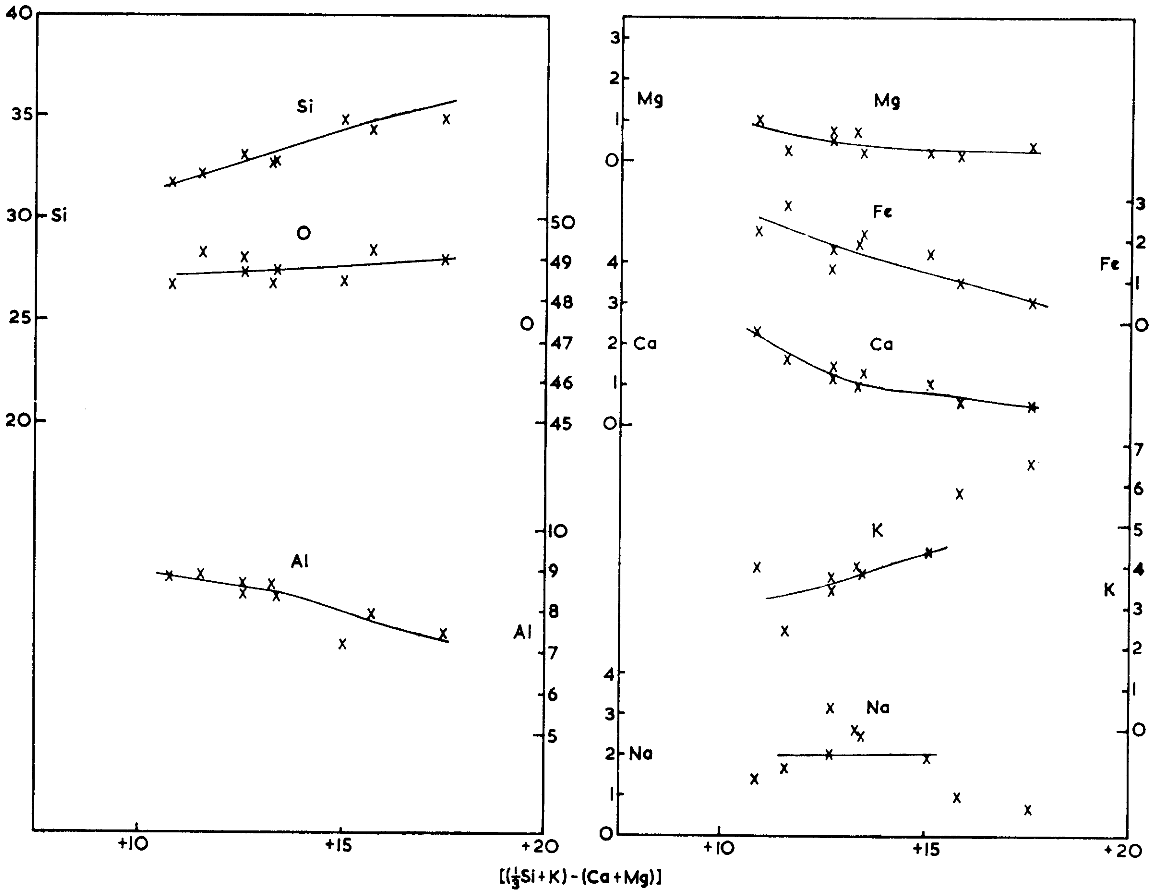


FIGURE 14

Variation diagrams for the major elements (all weight per cent) of the Upper Jurassic rocks from the Oscar II Coast plotted against $[(\frac{1}{3}Si+K)-(Ca+Mg)]$.

The (Fe″+Fe‴)—Mg—Alk triangular variation diagram (Fig. 13) indicates that the plots appear to form two smooth curves which are approximately parallel to those given by Adie (1964*b*) for the Upper Jurassic Volcanic Group of Graham Land. The significance of this difference, if any, is not clear. Insufficient analyses of rocks from the Oscar II Coast are available but a line drawn through the mean of the two curves would pass close to Adie's curve. The main discrepancy between the two sets of analyses lies in the magnesium content and this may reflect the difference between the results obtained by the classical gravimetric and rapid methods of analysis. In any case, the magnesium results in the present analyses were found to be the least consistent, so there is probably no significant difference between Adie's curve and that for the rocks of the Upper Jurassic Volcanic Group of the Oscar II Coast.

In the Ca—Na—K diagram (Fig. 13) the plots spread towards the potassium corner of the diagram and it is not possible to draw a curve through these points. It is perhaps significant that these rocks are, on the whole, richer in potassium than the Upper Jurassic Volcanic Group of Graham Land discussed by Adie (1964*b*). An inspection of the analyses shows that the alkalis total a fairly constant 8 per cent, suggesting that a replacement of soda by potash has occurred. Thus the scatter of the points on the diagram is probably because of potash metasomatism.

In the graphs of the weight percentages of the elements Si, O, Al, Mg, Fe″+Fe‴, Ca, K and Na plotted against the modified Larsen function (Fig. 14), the plotted points follow smooth curves. The possibility of potash metasomatism affecting these rocks is important, because a false value for potassium could affect the modified Larsen function to an extent equal to the amount of potassium added to, or subtracted from, the rock. The potassium and sodium curves yield interesting information on this problem. Two of the specimens (D.4607.1, 4647.1) at the acid end of both curves lie on neither curve, since they are rich in potassium and deficient in sodium. Moreover, these two specimens do not fit some of the other curves very well. However, if approximately 2 and 1 per cent, respectively, are deducted from the potassium value, and a corresponding amount is added to the value for sodium, the appropriate Larsen functions are recalculated and the points re-plotted, the two specimens either fall on or close to the other curves. Therefore, it is inferred that in these two specimens potassium has replaced sodium to the extent of 2 and 1 per cent, respectively, relative to the whole group. It is not possible to decide whether or not the whole group has been metasomatized.

In comparing the present curves with those given by Nockolds and Allen (1953), it is necessary to realize that the directions of the curves for the rocks of the Oscar II Coast area may not be particularly accurate, since these rocks only have a limited compositional range. In general, these curves are similar to those for the calc-alkaline rocks described by Nockolds and Allen (1953). The only apparent difference is in the relationship between the Si and O curves, which are almost parallel to one another in the diagrams given by Nockolds and Allen but converge towards the acid end of the diagram in Fig. 14. However, the directions of the curves depend on the respective vertical scales for the percentages of Si and O, and since the vertical scales used in Fig. 14 are not proportionally the same as those used by Nockolds and Allen, no direct comparison between the curves can be made. The Si : O ratio at the acid end of the curves of the rocks from the Oscar II Coast is 1 : 1·38, which is in good agreement with the value of about 1 : 1·4 quoted by Nockolds and Allen (1953).

## V. ANDEAN INTRUSIVE SUITE

THE Andean Intrusive Suite, which is widespread throughout the Antarctic Peninsula, has been described comprehensively by Adie (1955). This suite has also been described by other authors from specific areas of Graham Land: Graham Coast (Curtis, 1966), Loubet Coast (Goldring, 1962), Anvers Island (Hooper, 1962). Adie has considered that the Andean Intrusive Suite is a normal calc-alkaline intrusive suite ranging in composition from basic gabbros to alkali-granites. In the field the age of these rocks cannot be demonstrated clearly on the Oscar II Coast, but there is no reason to doubt Adie's (1955) view that this suite was probably intruded during the late Cretaceous or early Tertiary periods.

Rocks of the Andean Intrusive Suite have been emplaced extensively in the Hektoria Glacier area, where they frequently intrude the Trinity Peninsula Series. The Upper Jurassic Volcanic Group has been intruded by a granite near Andersson Peak, and the Jurassic sedimentary beds have been intruded by a diorite at Cape Fairweather. In the area between Crane and Stubb Glaciers the Andean Intrusive Suite was not seen, although plutons of the earlier "white granite" are abundant in this area.

### 1. *Basic intrusive rocks*

The only specimen of gabbro from the Oscar II Coast area was collected from Rugate Ridge (D.4637). The hand specimen (D.4637.1) is dark-coloured, medium- to coarse-grained and slightly porphyritic. Under the microscope the phenocrysts of plagioclase are zoned from $Ab_{46}An_{54}$ at the core to $Ab_{57}An_{43}$ at the rim. Serpentinitic pseudomorphs, which are probably after olivine phenocrysts, are quite common. A second generation of crystals consists of plagioclase laths ($Ab_{60}An_{40}$), rather small prismatic colourless augites ($\gamma : c = 41°$; $2V\gamma = 60°$) and serpentine similar to that recorded in the altered phenocrysts. Anhedra of iron ore are very common.

### 2. *Intermediate intrusive rocks*

a. *Diorites*. Three specimens of diorite (TL.10.2, near Punchbowl Glacier; D.4636.2, 4638.1, Rugate Ridge) have been collected and sectioned. All these specimens are similar to one another and they only differ in minor details. The plagioclase crystals in these specimens are cracked, usually heavily altered to sericite and saussurite and zoned from $Ab_{55}An_{45}$ (core) to $Ab_{68}An_{32}$ (rim). A pale-coloured augite ($\gamma : c = 45°$; $2V\gamma = 60°$) occurs in specimens TL.10.2 and D.4638.1, and in both cases it is surrounded by a green hornblende ($\alpha$ = neutral, $\beta$ = pale green, $\gamma$ = pale green; $\gamma : c = 15°$; $2V\alpha = 70°$) that has been partly altered to a brown hornblende which is, however, best developed in specimen D.4636.2, where it has a pleochroism scheme $\alpha$ = light brown, $\beta$ = greenish brown, $\gamma$ = dark brown, and $\gamma : c = 15°$, $2V\alpha = 70°$. Biotite ($\alpha$ = pale straw, $\beta = \gamma$ = dark brown) is uncommon in the diorites but it forms small partly chloritized flakes in specimen TL.10.2 and large plates completely pseudomorphed by chlorite and leucoxene in specimen D.4636.2. Iron ore forms large irregular masses and in specimen D.4638.1 it is skeletal; other accessory minerals are apatite (which is common) and zircon.

By K-Ar determinations on biotite and hornblende, Rex (1967) has obtained respective ages of $99 \pm 4$ and $94 \pm 5$ m. yr. for specimen TL.10.2; he also obtained an age of $98 \pm 10$ m. yr. on hornblende separated from specimen D.4636.2.

b. *Quartz-diorites.* Specimen TL.10.1, from near Punchbowl Glacier, was collected from a dyke about 20 cm. wide, which cuts a complex intrusion composed of numerous partly digested xenoliths and differentiation products. This complex intrusion appears to be widespread, and it probably extends as far as station TL.9, where the photograph in Plate Va was taken.

The grain-size of this dyke is mainly coarse but there are a few small medium-grained (0·02 mm.) areas of quartz and biotite. The plagioclase crystals and some of the larger quartz crystals are cracked and show strain extinction. Therefore, it is probable that the vein was injected as a crystal mush (with very little liquid) when the main intrusion had already solidified but was still hot. The plagioclase is zoned from $Ab_{56}An_{44}$ (core) to $Ab_{70}An_{30}$ (rim); the cores of the crystals are euhedral but the rims are anhedral. Biotite ($\alpha$ = pale straw, $\beta = \gamma$ = dark brown) has been partly replaced by a pale green chlorite. Large masses of iron ore, apatite and zircon are accessory minerals.

Specimen D.4664.1, from the base of Cape Fairweather, is a fairly homogeneous quartz-diorite. The hand specimen is a coarse-grained rock, typically dioritic in appearance and it contains plagioclase, hornblende and biotite. The plagioclase crystals are zoned from $Ab_{55}An_{45}$ (core) to $Ab_{80}An_{20}$ (rim) and some of them have been altered to sericite and calcite, while others are fresh. Hornblende ($\alpha$ = pale yellow-brown, $\beta$ = greenish brown, $\gamma$ = brown; $\gamma : c = 18°$; $2V\alpha = 73°$) is common and it has frequently been altered to chlorite. Eight-sided cross-sections occur rarely and a few pyroxene remnants are included in the hornblende, so the latter has probably replaced pyroxene; this replacement is almost complete. The biotite ($\alpha$ = pale straw, $\beta = \gamma$ = dark brown) has been partly altered to a pale green chlorite. Interstitial quartz forms about 10 per cent in the mode (Table V) and the accessory minerals are iron ore, apatite, zircon, sphene and orthoclase.

Specimens D.4642.2 and 3, from near Hektoria Glacier, and D.4666.2, from Cape Fairweather, are similar to specimen D.4664.1 except that brown hornblende has developed in all three specimens; sphene is very common in specimen D.4642.2 and skeletal iron ore, bright lemon-coloured epidote and serpentine after (?) pyroxene occur in specimen D.4666.2.

Rex (1967) has determined the ages of some of the quartz-diorites by the K-Ar method on biotite as $98 \pm 4$ (TL.10.1) and $100 \pm 4$ (D.4664.1) m. yr., and on hornblende as $97 \pm 4$ (D.4664.1), $105 \pm 4$ (D.4642.2) and $92 \pm 5$ (D.4642.3) m. yr.

c. *Pegmatitic differentiate.* Specimen D.4667.1 (Plate VIIId), from near the summit of Cape Fairweather, appears to be a pegmatitic differentiate of the quartz-diorite exposed at station D.4664. A thin section reveals that most of the rock consists of plagioclase and hornblende with smaller amounts of quartz (which has partly replaced plagioclase), apatite, zircon, sphene and iron ore. The plagioclase crystals are strongly zoned from $Ab_{50}An_{50}$ (core) to $Ab_{85}An_{15}$ (rim) and parts of them have been heavily altered to sericite and prehnite. The amphibole consists of a brown hornblende core ($\alpha$ = yellow-brown, $\beta = \gamma$ = dark red-brown; $\gamma : c = 16°$; $2V\alpha = 72°$), some of which has been altered to chlorite and sphene, and green hornblende ($\alpha$ = neutral, $\beta$ = green, $\gamma$ = brownish green; $\gamma : c = 29°$; $2V\alpha = 77°$).

### 3. *Acid intrusive rocks*

One of the most distinctive features of the acid intrusive rocks is their red colour and hence their field name "red granites". Although the red colour of these rocks makes it easy to identify them from many miles away, they tend to crop out in the plateau scarp which is usually inaccessible; even though large areas of "red granites" have been mapped, it was only possible to visit them and to collect specimens at a few localities.

a. "*Red granites.*" The contact between the "red granite" and the Trinity Peninsula Series north of Hektoria Glacier (D.4613) is sharp and steeply dipping. At the contact itself, the granite (D.4613.2)

TABLE V

MODAL ANALYSES OF ANDEAN INTRUSIVE SUITE ROCKS FROM THE OSCAR II COAST

| | D.4664.1 | TL.10.1 | D.4630.1 | D.4622.1 | D.4651.1 |
|---|---|---|---|---|---|
| Quartz | 9·6 | 21·4 | 23·9 | 30·1 | 31·0 |
| Orthoclase | 0·4 | — | 29·5 | 52·8 | 45·4 |
| Plagioclase | 70·5 | 66·5 | 43·2 | 15·3 | 22·5 |
| Hornblende | 10·9 | 0·2 | — | — | — |
| Biotite | 7·9 | 11·1 | 3·4 | 1·8 | 1·1 |
| Iron ore | 0·6 | 0·7 | tr | tr | tr |
| Sphene | 0·1 | — | — | — | — |
| Calcite | tr | — | — | — | — |
| Apatite | tr | tr | tr | — | tr |
| Zircon | tr | 0·1 | tr | — | tr |
| Allanite | — | — | tr | — | — |
| *Plagioclase composition* | $An_{44-30}$ | $An_{40-26}$ | $An_8$ | $An_7$ | $An_{30-15}$ |

D.4664.1 Quartz-diorite, Cape Fairweather.
TL.10.1 Quartz-diorite, north of Punchbowl Glacier.
D.4630.1 Adamellite, Hektoria Glacier.
D.4622.1 Microgranite, Hektoria Glacier.
D.4651.1 Granite, near Andersson Peak.

consists almost entirely of a granophyric intergrowth of quartz and potash feldspar (Plate XIIf). Biotite ($\alpha$ = pale straw, $\beta = \gamma$ = dark red-brown) is the only ferromagnesian mineral present and it has been partly altered to chlorite. A few yards from the contact the hand specimen (D.4613.1) becomes coarser-grained and darker in colour, but it still remains leucocratic; there are only occasional ferromagnesian minerals in the rock. The thin section shows that the granophyric texture is still widespread, and when sodium cobaltinitrite staining is used to distinguish between the feldspars it is clear that most of the feldspar is a potash variety. The plagioclase has poorly developed twinning and its composition has not been determined, but its mean refractive index (close to that of quartz) indicates that it is approximately oligoclase ($Ab_{80}An_{20}$). One crystal of allanite was recorded but no other accessory minerals are present in the thin section.

In specimen D.4630.1, from near Hektoria Glacier, the grain-size is coarser, probably because this specimen was collected from near the centre of the intrusion. The feldspars, which are up to 1 cm. in length, consist of white plagioclase and pink orthoclase; the ferromagnesian minerals tend to form clots.

Under the microscope the rock displays a coarse granitic texture in which many of the crystals are cracked, and it is probable that there was some movement when crystallization had almost reached completion. The large pink crystals observed in the hand specimen are orthoclase-microperthite, in which the exsolved albite is occasionally twinned. The plagioclase, of approximate composition $Ab_{92}An_8$, has been altered to sericite, saussurite and prehnite, although some crystals are fairly fresh. Flakes of penninite, probably after biotite, are well terminated, and some good pseudo-hexagonal sections are displayed in the thin section. Zircon is a fairly common accessory mineral.

Specimen D.4651.1, from near Andersson Peak, is finer-grained than specimen D.4630.1. It contains quartz crystals up to 1 mm. in length and feldspar crystals up to 3 mm. across. The plagioclase is white but the potash feldspar is pink-coloured; since potash feldspar constitutes about 45 per cent of this rock, the outcrop has an overall pink colour. A few flakes of mica are present. In thin section the plagioclase is zoned from $Ab_{70}An_{30}$ (core) to $Ab_{85}An_{15}$ (rim) and it is usually heavily dusted with inclusions. The potash feldspar also contains numerous red-brown dusty inclusions and the exsolved perthitic albite shows good twinning in some crystals. There is some development of an intergrowth between the potash feldspar and the quartz, which exhibits strain extinction. The 1 per cent of biotite in the mode of this rock is strongly pleochroic ($\alpha$ = orange-brown, $\beta = \gamma$ = deep red-brown) and it is partly altered to a deep green chlorite. The accessory minerals are iron ore, zircon and rare apatite.

b. *Microgranites.* A dyke of red microgranite about 165 ft. (50 m.) wide is exposed on a ridge near Hektoria Glacier over a distance of about 2·5 miles (4 km.). The hand specimen (D.4622.1) is medium-grained, red-coloured and contains quartz and feldspar phenocrysts. When sodium cobaltinitrite staining is used to distinguish between the feldspars, it is clear that the groundmass contains quartz, plagioclase and potash feldspar. The potash feldspar phenocrysts form clusters and the quartz phenocrysts have been encroached upon by the groundmass, in which occasional circular patches of a micrographic intergrowth between quartz and potash feldspar occur locally. Small flakes of penninite ($\alpha$ = straw, $\beta = \gamma$ = dark green) and iron ore are distributed evenly through the rock.

Near Skilly Peak (D.4655) there is a dyke of medium- to coarse-grained microgranite, about 12 ft. (3·6 m.) wide, which is composed of a very friable assemblage of quartz, a white feldspar and muscovite. Rex (1967) has given its age as $99 \pm 4$ m. yr.

4. *Geochemistry*

Two new chemical analyses of rocks of the Andean Intrusive Suite are given in Table IV. These are a microgranite (D.4622.1) and an adamellite (D.4630.1), both from near Hektoria Glacier.

The analytical results have been plotted on triangular variation diagrams with the coordinates (Fe″+Fe‴)—Mg—Alk and Ca—Na—K (Fig. 15) in order to compare them with previous analyses o the Andean Intrusive Suite of Graham Land (Adie, 1955). The (Fe″+Fe‴)—Mg—Alk diagram shows that the analyses plot near the acid end of Adie's curve and they are in close agreement with it. However, when the results are plotted on the Ca—Na—K diagram there appears to be no agreement, since the new

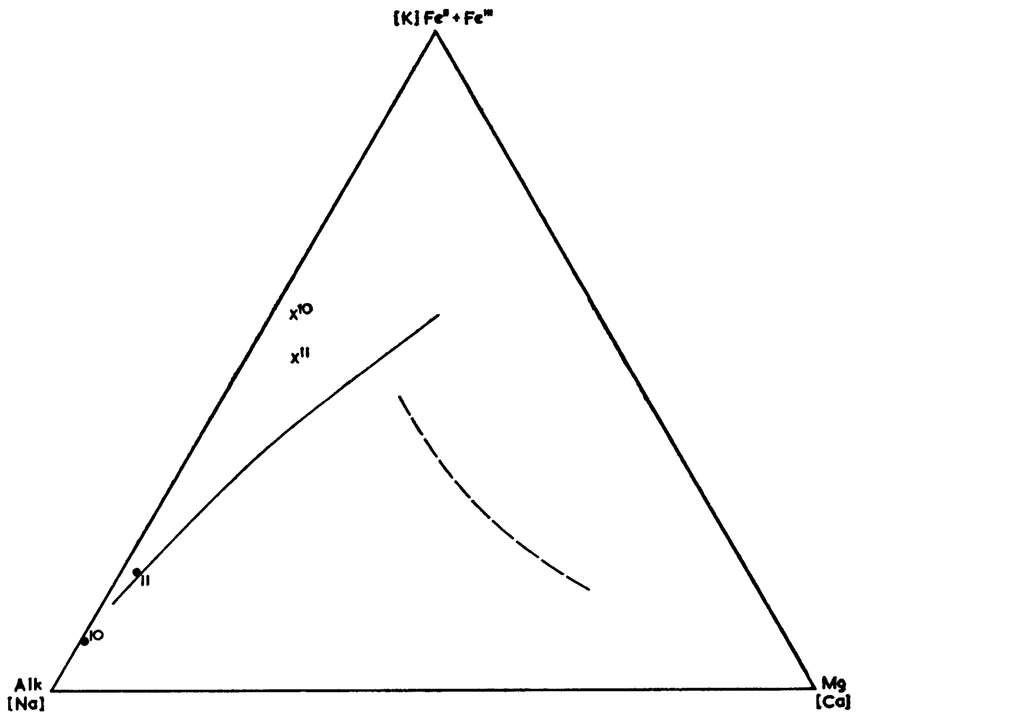


FIGURE 15

Triangular variation diagrams plotted on the coordinates (Fe″+Fe‴)—Mg—Alk (●) and Ca—Na—K (×), showing the new analyses of Andean Intrusive Suite rocks from the Oscar II Coast in relation to the Andean Intrusive Suite of Graham Land (Adie, 1964*b*, fig. 5). The curves for the Andean Intrusive Suite of Graham Land are shown by solid and pecked lines.

analyses are relatively deficient in calcium and potassium compared with the previous ones. The compositions of the plagioclases determined optically are $Ab_{92}An_8$ and $Ab_{93}An_7$, respectively; since most of the calcium in these rocks should be concentrated in the feldspars because there are no other calcic minerals in them, it is unlikely that there are analytical errors. Moreover, the triangular variation diagrams given by Nockolds and Allen (1953) for the calc-alkaline rocks show a marked increase in potassium relative to sodium at the acid ends of the curves, a feature which is not indicated by the new analyses. Therefore, the most likely explanation of the discrepancy between the new analyses and the previous ones (Adie, 1955) is that there has been some degree of modification of the proportions of calcium, sodium and potassium in these rocks by metasomatic processes.

## VI. JAMES ROSS ISLAND VOLCANIC GROUP

VOLCANIC rocks of olivine-basalt composition form the greater part of the Seal Nunataks (Fig. 16), which are a group of volcanic islands projecting through the Larsen Ice Shelf. These rocks apparently rest

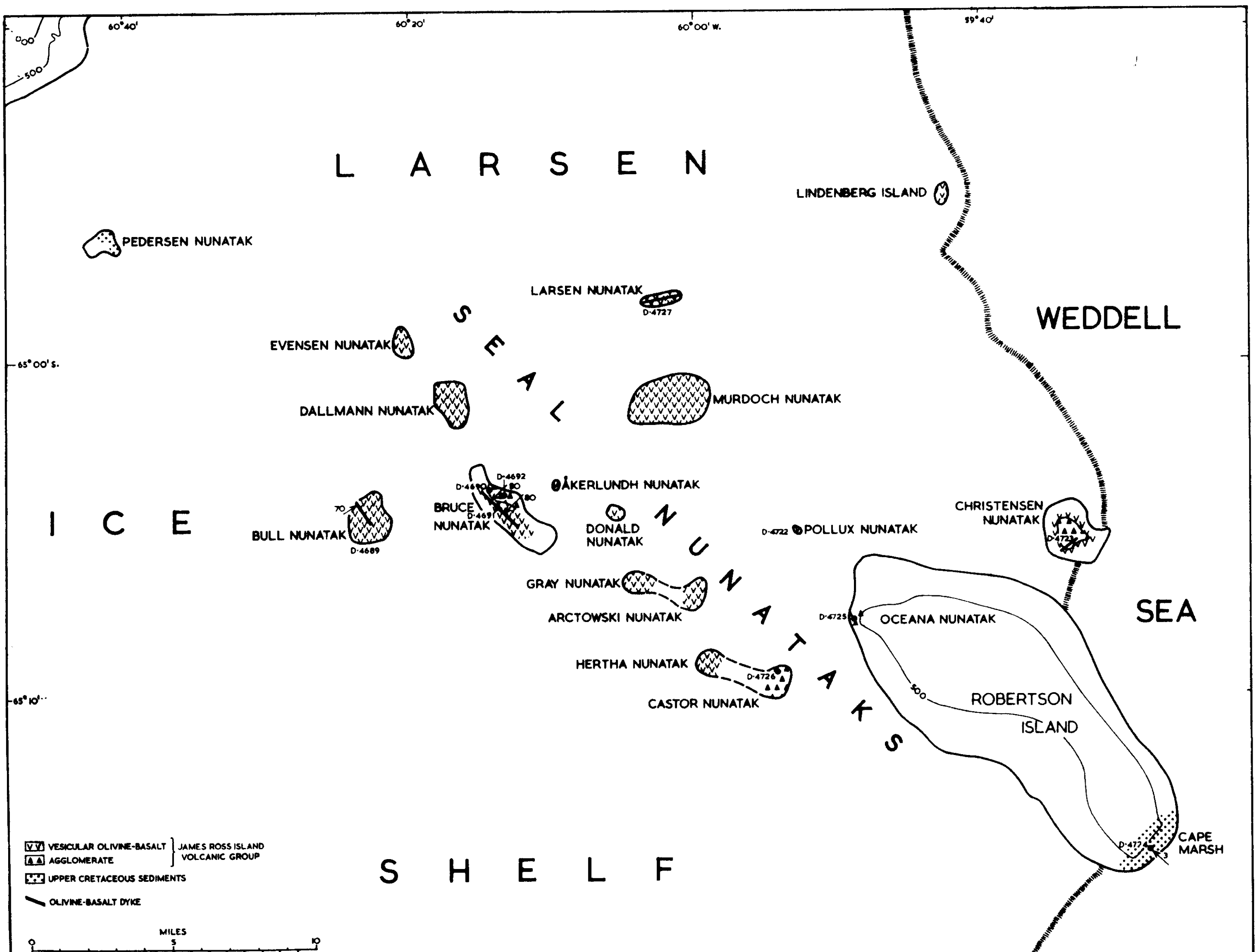


FIGURE 16

Geological sketch map of the Seal Nunataks. The contours are at 500 and 1,000 ft. (152 and 305 m.).

unconformably on Upper Cretaceous calcareous siltstones containing *Rotularia callosa* Ball, which are exposed at Cape Marsh (at the eastern end of Robertson Island) (Fleet, 1966), and they have been correlated with the mid-Tertiary James Ross Island Volcanic Group (Adie, 1964*a*, p. 150), the type locality of which is James Ross Island, approximately 100 miles (160 km.) north-east of the Seal Nunataks. The equivalents of the James Ross Island Volcanic Group are also exposed in the South Shetland Islands (Hawkes, 1961) and on Anvers Island (Hooper, 1962). Only those nunataks visited by the author are considered here, although all the Seal Nunataks have been visited by geologists at some time.

Larsen (1894, p. 340), who landed on the ice shelf between Robertson Island and Christensen Nunatak, reported that the latter nunatak, and possibly Lindenberg Island, were both active at that time. However, this report has not been confirmed by more recent work; in fact, the probable upper age limit of these volcanic rocks is indicated by the presence of the Pliocene Pecten Conglomerate which rests on a wave-cut platform on olivine-basalts at Cockburn Island (Adie, 1964*a*, p. 150).

## 1. *Agglomerates*

These are coloured yellow-brown to red when viewed from a distance, and they seem to occur in isolated localities, e.g. Castor Nunatak, Bruce Nunatak, Oceana Nunatak, Christensen Nunatak (D.4723; Plate IIId). The largest outcrop occupies the whole of Castor Nunatak. The rocks are very friable and strongly stained by limonite and, although the coarser parts are unsorted, some bedding may be present in the fine-grained parts.

The agglomerates of Bruce Nunatak demonstrate an interesting example of slumping. At station D.4692 thin vertical walls of agglomerate project above the general level of the rubble, but on closer examination it is clear that the bedding is horizontal (Fig. 17), i.e. normal to the planes of the walls. It is suggested that

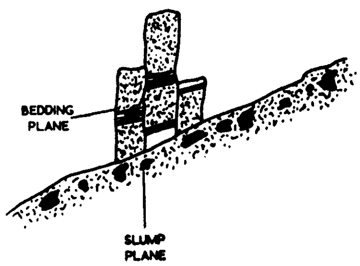


FIGURE 17

A sketch of some slumped beds in the agglomerates of the James Ross Island Volcanic Group at Bruce Nunatak (D.4692). The walls project about 5 ft. (1·5 m.) above the surface.

this feature has resulted from slumping. P. H. H. Nelson (personal communication) has observed a similar phenomenon on a larger scale on James Ross Island.

Nodules, consisting mainly of olivine crystals (Plate VIIIe), were frequently seen in the agglomerates exposed on Bruce Nunatak (D.4692), but they were not seen in the agglomerates of any of the other nunataks. The almost spherical nodules range up to 5 mm. across and they are enclosed in an olivine-basalt glass. In specimen D.4692.2 they are an overall green colour but on close inspection four different minerals, all of which are fresh and unaltered, can be distinguished: pale yellow-green olivine, olive-coloured enstatite, emerald-coloured diopside and black picotite. The crystals of olivine, enstatite and diopside are approximately 1 mm. across but the picotite crystals are rather smaller (about 0·1 mm.). The distribution of the minerals in these nodules is fairly homogeneous and there does not appear to be any preferred orientation of the crystals.

In thin section, olivine, enstatite and diopside are colourless, whereas the picotite is brown-coloured. Olivine ($2V\gamma = 87°$; $Fo_{88}Fa_{12}$), forming about 70 per cent of the nodule, was apparently the first mineral to crystallize. Enstatite ($2V\alpha = 67°$) crystallized next and this was followed by diopside ($2V\alpha = 59°$; $\gamma : c = 40°$). The pyroxenes form about 25 per cent of the nodule, the clinopyroxene being more abundant than the orthopyroxene. Finally, isotropic picotite grew interstitially to the other minerals and forms about 5 per cent of the rock. Most crystals of each mineral show signs of cracking; the cracks range from open breaks which may have occurred during the preparation of the thin section to cracks which have been sealed by the continued growth of the cracked mineral.

Nelson (1966, p. 25) has described similar nodules from basaltic dykes on James Ross Island. He believes that the crystals accumulated during a quiescent period and were then brought to the surface by the magma. However, Ross and others (1954), who have discussed the origin of olivine nodules in basaltic rocks, are of the opinion that they were derived from the peridotite zone of the Earth's crust. The nodules from Bruce Nunatak are similar to those from other parts of the world discussed by Ross and others, because they contain the four minerals olivine, enstatite, diopside and picotite, and they are associated with basaltic rocks. Therefore, the nodules from Bruce Nunatak should also be considered to have been derived from the peridotite zone of the Earth's crust.

2. *Lavas*

The lavas are highly vesicular olivine-basalts, in which phenocrysts of a yellow-green olivine are normally clearly visible in the hand specimen. The degree of vesicularity is quite varied but usually the vesicles are about 1 mm. across and they frequently show a planar arrangement in the hand specimen. A specimen of brick-red scoriaceous ropy lava (D.4723.2) which becomes browner in colour towards the centre was collected from Christensen Nunatak. The olivine-basalt on Christensen Nunatak forms a solid outcrop, which is unusual in the Seal Nunataks, because these outcrops usually consist entirely of loose fragments of vesicular lava.

Crumbly fragments of a white mineral included in the lavas are frequently found, especially on Pollux Nunatak (D.4722). The specimen collected (D.4722.1) appears to consist almost entirely of quartz, so it is probably a fused sandstone.

Very fine-grained rocks, which occur as small xenoliths and usually show signs of having been completely engulfed by the magma, are quite common (Plate VIIIf). Their colour ranges from off-white to dark grey and some bedding may still be apparent. A light-coloured specimen (D.4689.4) consists of cordierite microlites which have been identified by X-ray powder analysis. The formation of buchites as a result of inclusion and fusion of argillaceous material in an igneous rock (Wyllie, 1959, p. 1039) suggests that the Upper Cretaceous sediments exposed at Cape Marsh may have a westerly extension beneath the Seal Nunataks.

3. *Dykes*

a. *Seal Nunataks.* Along the crests of most of the Seal Nunataks there is evidence of scoriaceous dykes, in which the vesicle trains are parallel to the dyke walls. The best example of such a dyke is at Christensen Nunatak (D.4723; Plate Vc), although this particular dyke does not form a prominent ridge. The strike direction of the dykes is approximately north-west to south-east or west-south-west to east-north-east, and the fact that the Seal Nunataks are elongated in one or other of these two directions suggests that they were formed as a result of eruptions through these fissures.

b. *Oscar II Coast.* Numerous dykes, probably of Tertiary age, have been intruded into the rocks of the Oscar II Coast. Most of these dykes are doleritic, but there are some porphyritic dolerites and also some microdiorites. These dykes have intruded granites of the Andean Intrusive Suite but no upper age limit can be determined on the Oscar II Coast.

*Doleritic dykes* are widespread throughout this area. Although most of the dykes are about 7 ft. (2 m.) wide, they can vary in width between a few millimetres and 16·5 ft. (5 m.). Often the dykes divide and re-join but equally often they maintain the same width over great distances. Plate IVb illustrates a typical doleritic dyke which has been intruded into a "white granite" south of Starbuck Glacier.

Specimen D.4673.3, a dark greenish aphanitic rock from near Pequod Glacier, is typical of the dykes on the Oscar II Coast. It contains a few lath-shaped plagioclase phenocrysts, probably in the oligoclase/andesine range, which have been partly replaced by calcite and green chlorite. The only indication that any ferromagnesian minerals were present in the original magma are occasional patches of chlorite and calcite. The groundmass is fine-grained and it consists of numerous plagioclase microlites and small patches of calcite. There is no iron ore in the rock.

A porphyritic dolerite (D.4673.1) has been intruded into sediments interbedded with the Upper Jurassic Volcanic Group north of Pequod Glacier. This unusual rock was at first believed to belong to the quartz-perthite-porphyries, because the hand specimen is greyish and contains numerous 0·5 cm. long feldspar phenocrysts. However an examination under the microscope immediately reveals that it is a porphyritic dolerite. The labradorite ($Ab_{35}An_{65}$) phenocrysts are large, euhedral and extensively cracked. On the whole the crystals are clear but they contain many distinct flakes of sericite. In the groundmass there are small, hardly altered laths of labradorite ($Ab_{45}An_{55}$), which are ophitically enclosed by a colourless augite.

Possible pseudomorphs after olivine are common. They consist of a core of calcite surrounded by a weakly birefringent fibrous mineral which is probably serpentine. There is no expelled iron ore and the crystal form resembles amphibole. However, since the augite in the groundmass is unaltered, it is reasonable to expect that the altered phenocrysts are of a mineral higher in Bowen's reaction series than augite, i.e. olivine.

Several red-brown crystals of picotite occur in the thin section; they are frequently black-rimmed and isotropic. The picotite is enclosed by both the plagioclase and the pseudomorphs after olivine. The occurrence of picotite is particularly interesting, because this mineral also occurs in the olivine nodules from Bruce Nunatak (p. 40). A little iron pyrites is present in the rock.

A vesicular dolerite dyke on the western end of Mural Nunatak, near Hektoria Glacier, forms a prominent cleft as a result of differential erosion between the dyke and the country rock. A specimen of zeolite filling the vesicles was shown by X-ray powder analysis to be stilbite.

*Microdioritic dyke rocks* from near Skilly Peak (D.4660) and north of Hektoria Glacier (D.4614) have been sectioned.

The dyke from which specimen D.4614.3 was collected has intruded a "white granite" but it is in turn cut by a basaltic dyke. The hand specimen is a fine-grained greenish rock containing greenish feldspar phenocrysts. In thin section the rock consists mainly of plagioclase and hornblende crystals. The plagioclase phenocrysts are strongly zoned from $Ab_{46}An_{54}$ (core) to $Ab_{72}An_{28}$ (rim) and they are shattered and sericitized. The composition of the plagioclase in the groundmass is probably about $Ab_{60}An_{40}$ but it is difficult to determine it accurately. A pale green hornblende ($\alpha$ = neutral, $\beta$ = pale green, $\gamma$ = pale green; $\gamma : c = 23°$; $2V\gamma = 74°$) is the only primary ferromagnesian mineral in the rock. Quartz in the mode is present to the extent of 2 per cent (Table VI) and it is interstitial to plagioclase and hornblende. Iron ore is common.

Specimen D.4660.1 from near Skilly Peak is also a porphyritic rock. In most respects it is similar to

TABLE VI

MODAL ANALYSES OF BASIC HYPABYSSAL ROCKS FROM THE OSCAR II COAST

| | D.4614.3 | D.4660.1 |
|---|---|---|
| Plagioclase | | |
| phenocrysts | 37·1 | 22·6 |
| groundmass | 40·9 | 45·0 |
| total | 78·0 | 67·6 |
| Hornblende | 19·0 | 19·6 |
| Biotite | — | 9·2 |
| Iron ore | 1·1 | 3·2 |
| Quartz | 1·9 | 0·4 |
| *Plagioclase composition* | $An_{54-28}$ | $An_{63-45}$ |

D.4614.3 Porphyritic microdiorite, near Hektoria Glacier.
D.4660.1 Porphyritic microdiorite, near Skilly Peak.

specimen D.4614.3 except that biotite is present in a significant amount. The plagioclase phenocrysts again have a euhedral unzoned core of labradorite ($Ab_{37}An_{63}$) surrounded by a strongly zoned rim (to $Ab_{55}An_{45}$). An interesting feature of the plagioclase phenocrysts is that some of them contain blebs of chlorite and other inclusions such as iron ore and sericite, which are concentrated in the cores of the feldspars but which do not occur in the relatively clear zoned rims. The plagioclase (approximately $Ab_{55}An_{45}$) forming the groundmass consists of fairly coarse interlocking laths in which there is a little zoning. Small hornblende crystals ($\alpha$ = neutral, $\beta$ = pale green, $\gamma$ = pale green; $\gamma : c = 22°$; $2V\gamma = 77°$) ophitically enclose the feldspars and are accompanied by small flakes of biotite ($\alpha$ = straw, $\beta = \gamma$ = dark brown). Quartz occurs rarely as an interstitial mineral, iron ore is an abundant accessory mineral and a small amount of secondary epidote is also present.

## VII. STRUCTURAL GEOLOGY AND GEOLOGICAL HISTORY

DURING the Carboniferous (Adie, 1957*a*, p. 2) a succession of geosynclinal sediments (the Trinity Peninsula Series) accumulated on the Oscar II Coast in part of a major trough which extended southwards across western Antarctica and northwards into the Scotia arc. These unfossiliferous sediments, the oldest rocks which have been mapped in the Oscar II Coast area, were probably derived from a landmass consisting mainly of metamorphosed sedimentary rocks because feldspar fragments are rarely found in them. However, Aitkenhead (1965) and Elliot (1965, 1966) have mapped the Trinity Peninsula Series in more northerly parts of the Antarctic Peninsula in much greater detail and they consider that the source of these sediments was a terrain consisting mainly of granitic and volcanic rocks with subordinate metamorphic rocks. Therefore, it is probable that the provenance of the rocks exposed in the Oscar II Coast area was perhaps locally different from the more northerly areas of the Antarctic Peninsula. Following the accumulation of a great thickness of alternating sandstones and shales, compression occurred (probably in pre-Jurassic times) and the Trinity Peninsula Series was regionally metamorphosed and isoclinally folded about west-south-west to east-north-east axes.

The isoclinal folding is well developed in the Trinity Peninsula Series exposed in the Hektoria Glacier area. The sediments have a consistent vertical or near-vertical dip and their strike direction is sub-parallel to the axis of the Antarctic Peninsula. South of the upper reaches of Crane Glacier, the folding of the Trinity Peninsula Series is less intense and, although the strike direction of these sedimentary rocks is still approximately the same, i.e. south-west to north-east, their average dip is only about 50° to the north-west.

Uplift of the folded Trinity Peninsula Series probably began in early Jurassic times and the Jurassic sedimentary beds were deposited in hollows on the eroded surface of the Trinity Peninsula Series. These beds were probably laid down mainly in shallow-water conditions, because plant remains and conglomerates are present in them. The deposition of the erosion products of the Trinity Peninsula Series probably continued during the volcanicity which marked the beginning of the Upper Jurassic, but the volcanic rocks soon became dominant. There were occasional lulls in the volcanicity and during these some plant life was able to establish itself; but the plants were soon overwhelmed by the next volcanic outburst.

The extruded rocks were predominantly of acid composition and most of them were probably *nuées ardentes* flows; lavas and agglomerates occurred only locally. The eruptive centres of the acid volcanic rocks were probably situated above the sites of the present-day plutons of "white granite" and they were fed by quartz-perthite-porphyry dykes.

On the western side of the Antarctic Peninsula, almost contemporaneous with the volcanism on the east coast, there were considerable outpourings of andesitic rocks, suggesting that there were two volcanic provinces in the Antarctic Peninsula. The apparent boundary between the volcanic provinces lies approximately along the axis of the Antarctic Peninsula. As the volcanism continued, the parent magma of the acid volcanic rocks rose nearer to the existing land surface and eventually intruded the volcanic rocks of which it was the source. Since the "white granites" have extensively intruded the volcanic rocks, it is probable that the roof over these granites, at the time of their crystallization, was considerably thicker than it is at the present day. Most of the cover probably consisted of later volcanic rocks which have since been eroded away.

The next stage in the geological history of the Oscar II Coast was uplift of the Jurassic sedimentary and volcanic rocks and the underlying Trinity Peninsula Series, and this was accompanied by gentle folding and the injection into the core of the Antarctic Peninsula of the Andean Intrusive Suite, a calc-alkaline intrusive suite ranging from basic gabbros to alkali-granites, which resulted in thermal metamorphism of the sediments into which they were intruded.

The folding of the Jurassic rocks is not as clearly defined as the earlier isoclinal folding, but on the whole a north-west to south-east strike direction is probably representative. It is probable that a number of apparent dips have been recorded in the volcanic rocks, i.e. beds may have been deposited on a surface which could have had an initial slope of anything up to 35°, and this leaves any generalization open to criticism. This is probably the reason for some of the high dip values, because an original dip of 35° might have been tilted a further 35° to give a resultant dip of 70° (see also p. 13). Alternatively, horizontal bedding might have been produced by a tilt of 35° in the opposite direction. Thus, at least some of the volcanic rocks probably do not give a true indication of the dip of the beds, and therefore the intensity and direction of the folding.

While the Andean Intrusive Suite was being emplaced in the Antarctic Peninsula, fossiliferous sediments of late Cretaceous age were being deposited eastward of the rising landmass. These sediments were probably deposited over a wide area but they only occur in isolated, widely separated localities and their easternmost exposure is at Cape Marsh, Robertson Island (Fleet, 1966, p. 89).

The mid-Tertiary period was marked by the commencement of another volcanic cycle but this time the volcanic rocks were olivine-basalts. Several fissure eruptions began along north-west to south-east and west-south-west to east-north-east directions, and the Seal Nunataks were formed. A large number of doleritic dykes of similar composition to the lavas of the Seal Nunataks were intruded into the mainland of the Antarctic Peninsula and they are considered to be contemporaneous with the volcanism. The strike directions of the dykes in the Seal Nunataks are similar to the strike directions of the faults in the Crane and Stubb Glaciers area (west-south-west to east-north-east); perhaps this faulting was also contemporaneous with or prior to the volcanism.

Faults are rarely exposed in this area because the fault zones are more susceptible to erosion and the resulting gullies are usually filled with ice. Therefore, most of the faults in the Oscar II Coast area must be inferred but, since there are very few marker horizons, it is probable that many faults still remain undetected.

Only one example of an exposed fault was mapped in the field. Near the head of Punchbowl Glacier there is a gully containing fault-breccia which strikes at 100°—280° mag. in a diorite of the Andean Intrusive Suite. Also near Punchbowl Glacier (TL.11–12), there is an inferred fault which brings basal Upper Jurassic tuffs against Jurassic sediments (Plate IVc; Fig. 7) and the line of the fault lies along a snow-filled gully. There may be another fault in the same nunatak where the contact between an agglomerate and sediments is obscured by rubble.

The faults inferred in the area between Crane and Stubb Glaciers are apparently on a much larger scale. "White granites" of Upper Jurassic to (?) early Cretaceous age have clearly been displaced (Fig. 4) in the Melville and Mapple Glaciers area, and it is probable that a series of step-faults occupies the sites of each of these glaciers; faults may also be present along the sites of the unnamed glaciers, e.g. the tributary glacier connecting Mapple Glacier to Crane Glacier. Crane Glacier appears to be the site of the largest fault in the area. Gash fissures seen at various localities close to Crane Glacier indicate that the rocks to the south have been down-faulted. Since the area north of Crane Glacier has not been visited, it is not possible to make direct comparisons with the area south of it. However, when viewed from a distance, the rocks in the area between Punchbowl Glacier and Crane Glacier appear to be similar to the proved Trinity Peninsula Series rocks near Punchbowl Glacier, so it is considered that the rocks on the north side of Crane Glacier probably also belong to the Trinity Peninsula Series. This would suggest that Crane Glacier occupies the site of a fault, because the Trinity Peninsula Series is absent from the area immediately south of the lower reaches of the glacier. The direction of the plateau escarpment, which forms the northern edge of Crane Glacier (Plate Ia), also suggests the presence of a major fault. There is no evidence that the plateau escarpment is fault-controlled in other parts of the Oscar II Coast.

The volcanic rocks of the James Ross Island Volcanic Group are the youngest rocks exposed near the Oscar II Coast. Subsequent to this period of volcanism, probably during late Tertiary times (Linton, 1964, p. 96), the Antarctic Peninsula was eroded to a peneplain and then uplifted and moulded to its present form by the Pleistocene—Recent glaciation.

## VIII. ACKNOWLEDGEMENTS

THE field work on which this report is based was undertaken in 1962–63 with the assistance and co-operation of members of the British Antarctic Survey stations at Hope Bay and Stonington Island. I wish to record my thanks to Professor F. W. Shotton, who provided the laboratory facilities in the Department of Geology, University of Birmingham. I am grateful to Dr. R. J. Adie for his guidance and criticism during the preparation of this report, and to my wife who drew the maps and diagrams.

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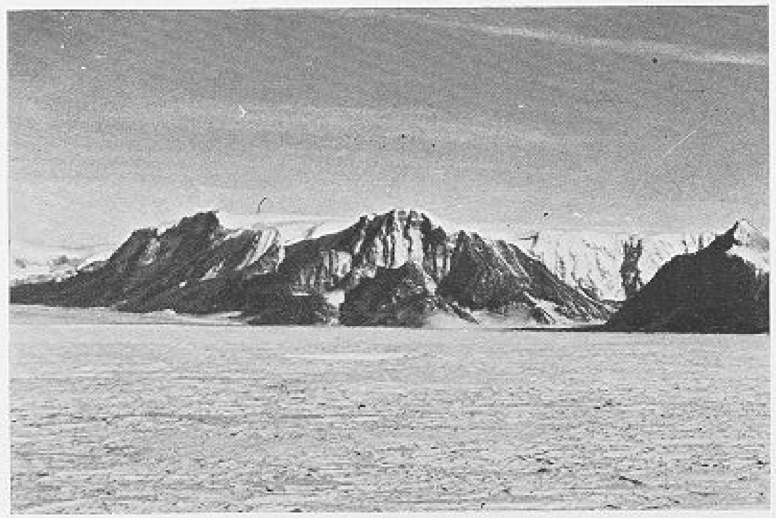
## PLATE I

a. A view to the west from Exasperation Inlet, showing the 2,000 ft. (610 m.) plateau edge. Crane Glacier is just to the left of the photograph.

b. The subdued plateau escarpment at the head of Pequod Glacier viewed from the east.

c. The flat-topped granitic bluff in Starbuck Glacier is a remnant of an originally much more extensive plateau. The two arms of the glacier re-join behind the bluff, which is about 1,000 ft. (305 m.) high.

d. Jurassic sedimentary beds on the ridge separating Starbuck Glacier from Stubb Glacier. The ridge is about 350 ft. (107 m.) high.



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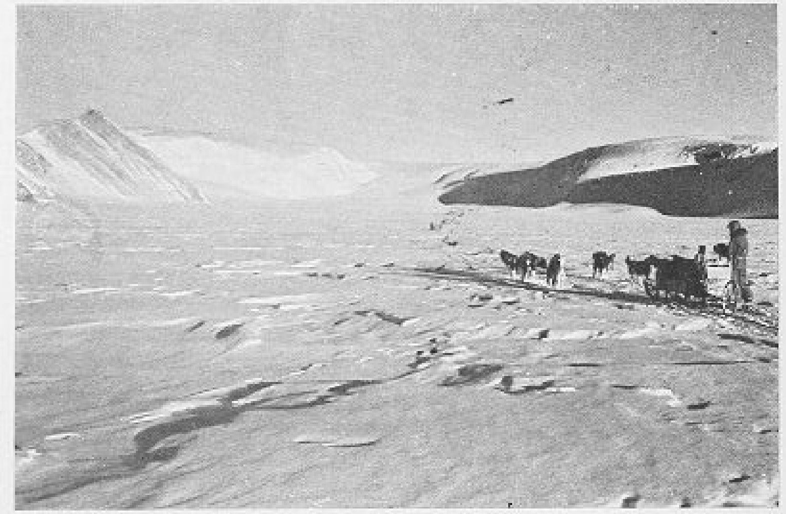

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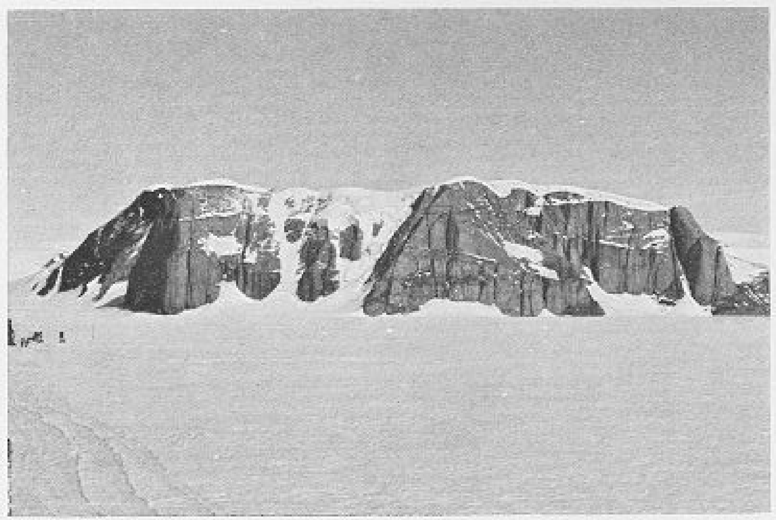

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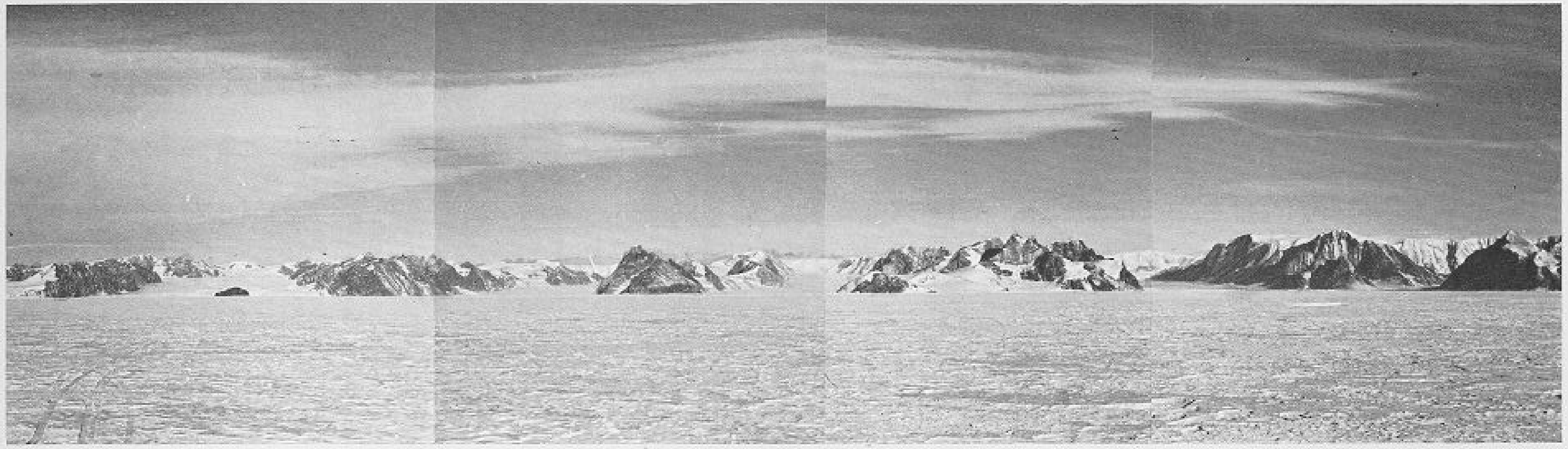
PLATE I

PLATE II

a. A panorama of the area between Crane and Stubb Glaciers from the east in Exasperation Inlet.

b. The edge of the Larsen Ice Shelf viewed from the summit of Christensen Nunatak. In the middle distance is the northernmost of the Seal Nunataks, Lindenberg Island. The Graham Land plateau is on the horizon about 50 miles (80 km.) away.

c. An area of broken ice caused by the pressure of the Larsen Ice Shelf as it moves eastwards against the northern side of Larsen Nunatak.



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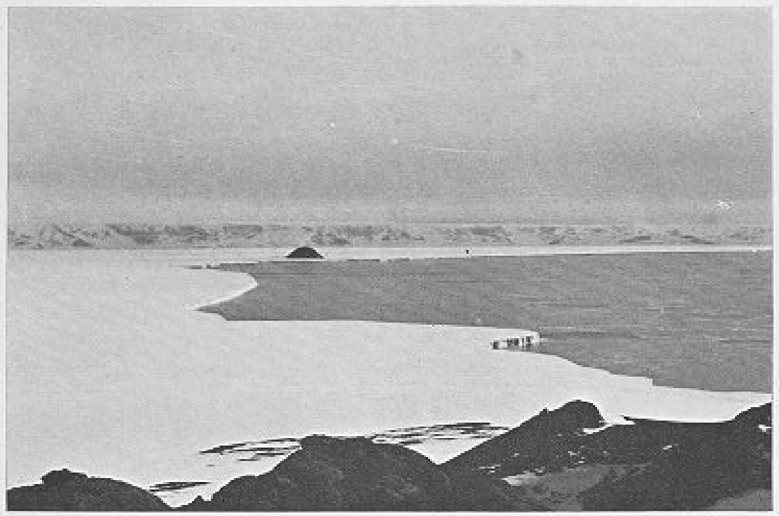

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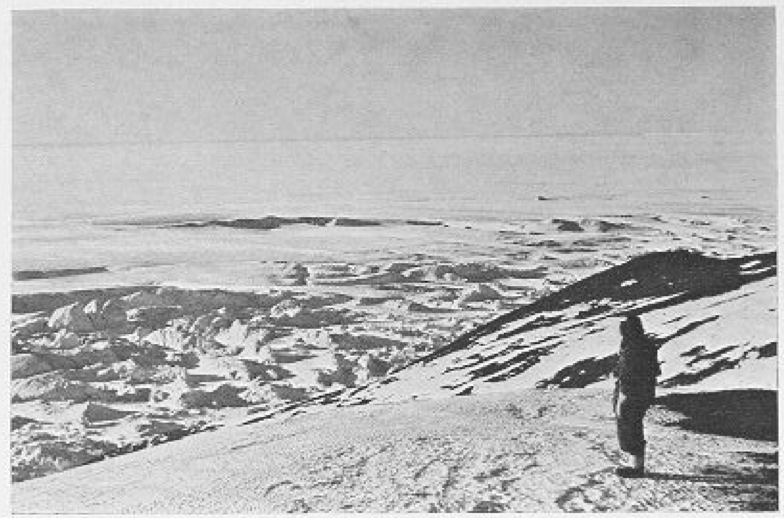

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PLATE II

PLATE III

a. A view to the north across Punchbowl Glacier, showing gently inclined Jurassic sedimentary beds.

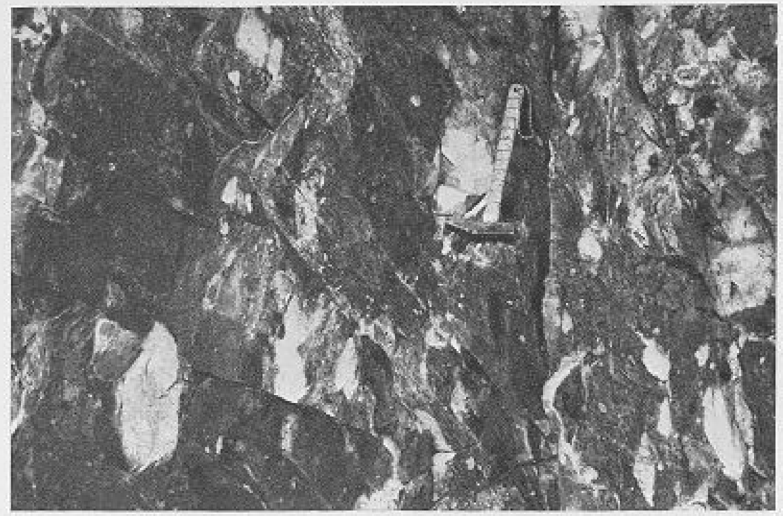
b. An exposure of Upper Jurassic agglomerate near Punchbowl Glacier (TL.12). The hammer shaft is about 14 in. (36 cm.) long.

c. Steeply dipping quartz-perthite-porphyry dykes intruded into the Jurassic sedimentary beds at the head of Starbuck Glacier. The ridge is about 350 ft. (107 m.) high.

d. The agglomerates of the James Ross Island Volcanic Group which cap Christensen Nunatak (D.4723); about 30 ft. (9·1 m.) are shown in the photograph.

PLATE III

a



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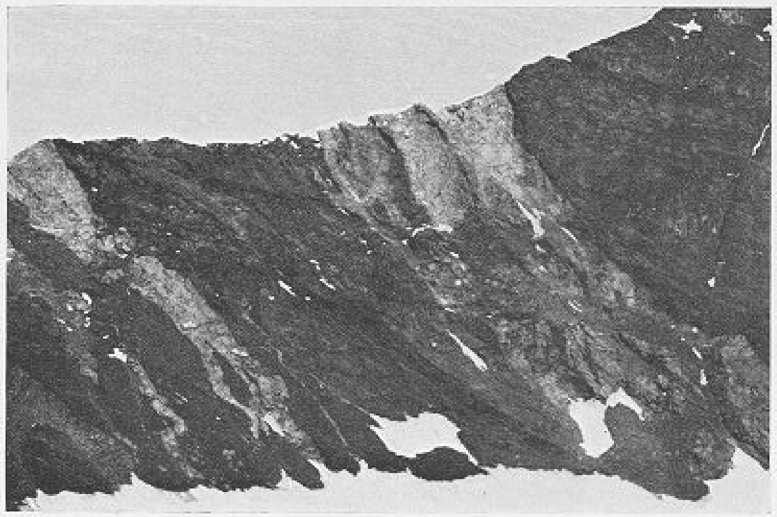

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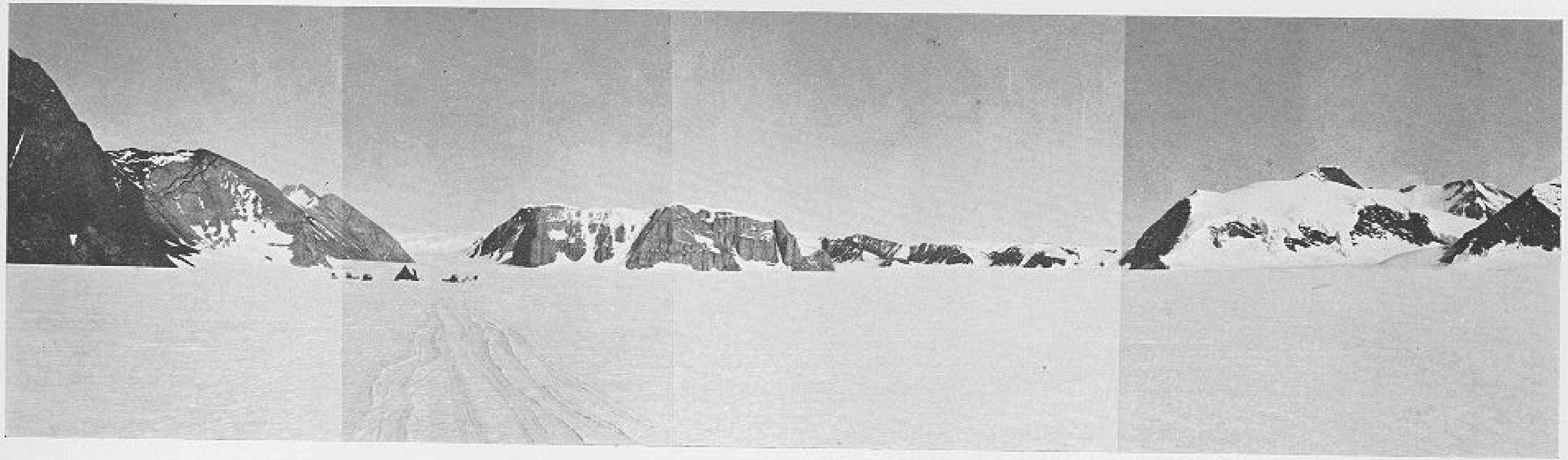
PLATE IV

a. A panorama of the upper reaches of Starbuck Glacier from the east. The light-coloured rock is a "white granite", which has intruded both the Upper Jurassic Volcanic Group (left) and the Jurassic sedimentary beds (right).

b. A dolerite dyke cutting a "white granite"; south of Starbuck Glacier (TL.26).

c. A snow-filled gully which is the site of a faulted contact between Jurassic tuffs and sediments; near Punchbowl Glacier (TL.11–12). See also Fig. 7.



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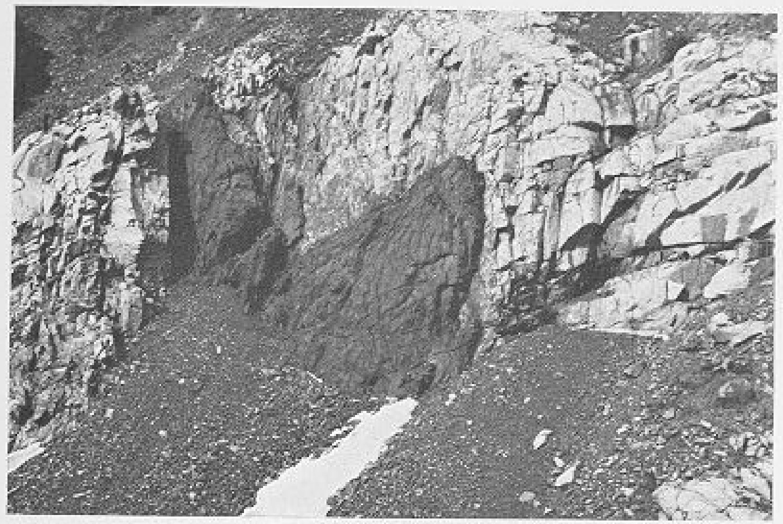

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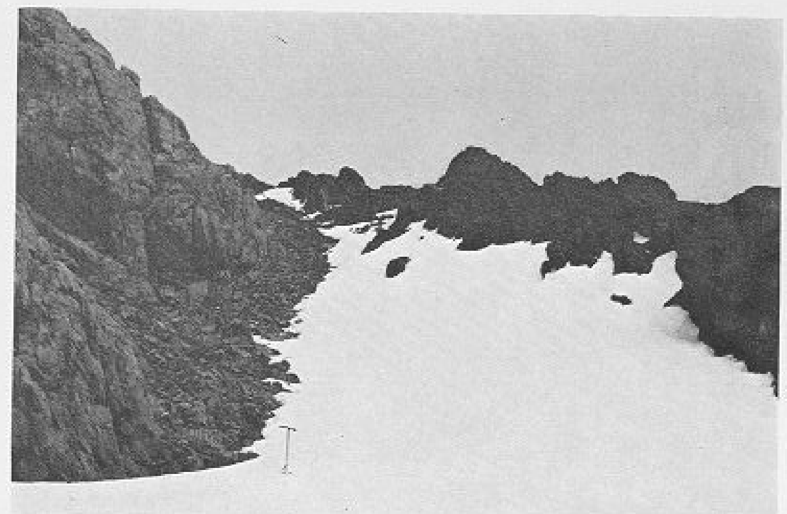

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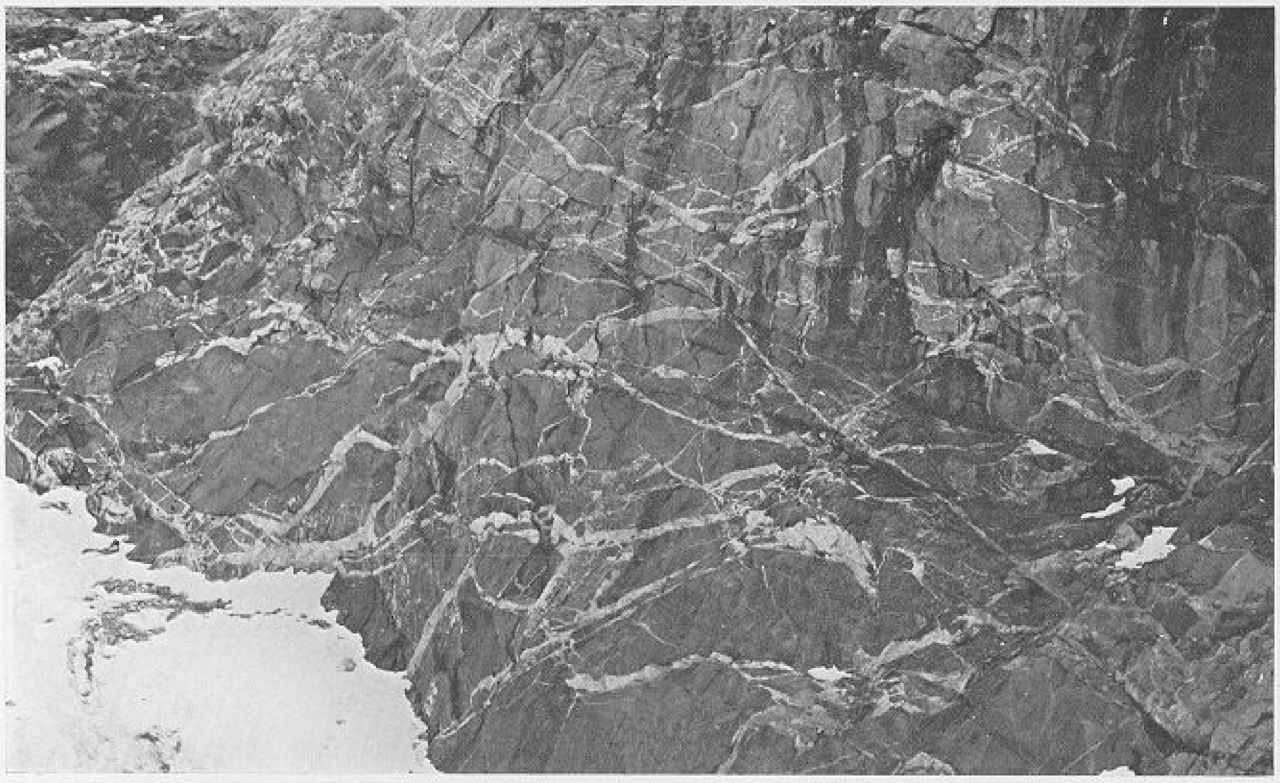
PLATE IV

## PLATE V

a. A diorite of the Andean Intrusive Suite which has been brecciated and intruded by a network of veins of a late differentiate of the diorite, probably granodiorite, near Punchbowl Glacier (TL.9). The veins range in width up to about 40 cm.

b. A succession in the Jurassic sedimentary beds at their contact with the Trinity Peninsula Series north of Punchbowl Glacier (TL.5–7).
a. Vertical sediments. b. Top part shaly and softer than underlying and overlying beds. c. Pink-brown beds. d. Lower part black and perhaps lacustrine sediments. e. Grey rocks with occasional dark well-stratified parts.

c. A vesicular olivine-basalt dyke intruded into James Ross Volcanic Group agglomerates at Christensen Nunatak (D.4723). The hammer shaft is about 14 in. (36 cm.) long.



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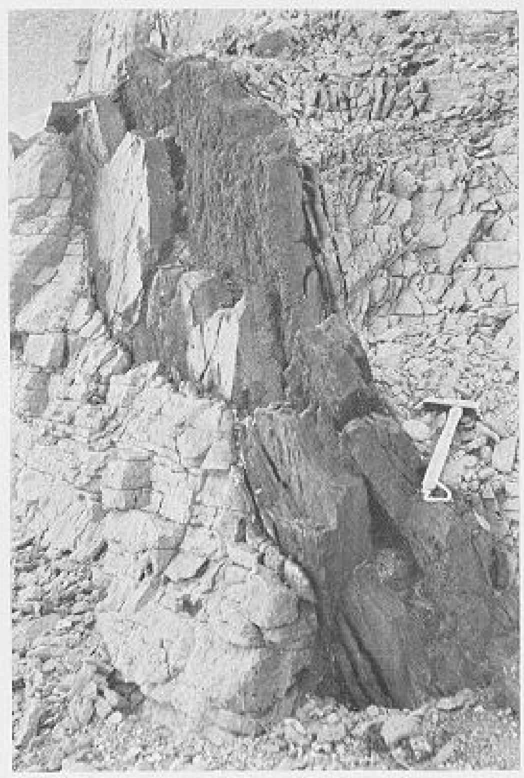

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PLATE VI

a. Complex small-scale folds caused by slumping in sediments of the Trinity Peninsula Series. The light-coloured beds are mainly of quartz and the dark-coloured ones are biotite-cordierite-hornfelses; near Mural Nunatak (D.4611.1; ×1·6).

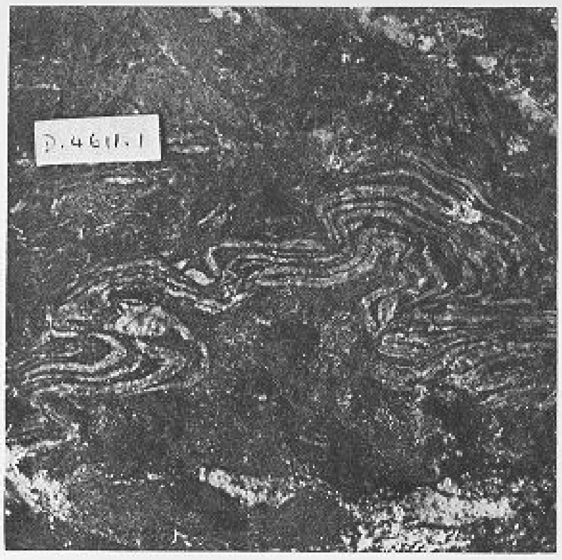
b. Small-scale open cylindrical folds on a joint plane of a meta-siltstone of the Trinity Peninsula Series; Roundel Dome (D.4669.1; ×1·3).

c. A cut and varnished surface of a phyllite from the Trinity Peninsula Series; near Mural Nunatak (D.4616.2; ×2·7).

d. A cut and varnished surface of an Upper Jurassic volcanic sandstone; near Punchbowl Glacier (TL.13.1; ×3·5).

e. Broken surface of a specimen of alternating sandstones and shales from the lower black mudstone shown in Fig. 6; south of Stubb Glacier (TL.45.4; ×1·9).

f. Broken surface of a specimen of alternating sandstones and shales from the lower black mudstone shown in Fig. 6; south of Stubb Glacier (TL.45.5; ×1·8).



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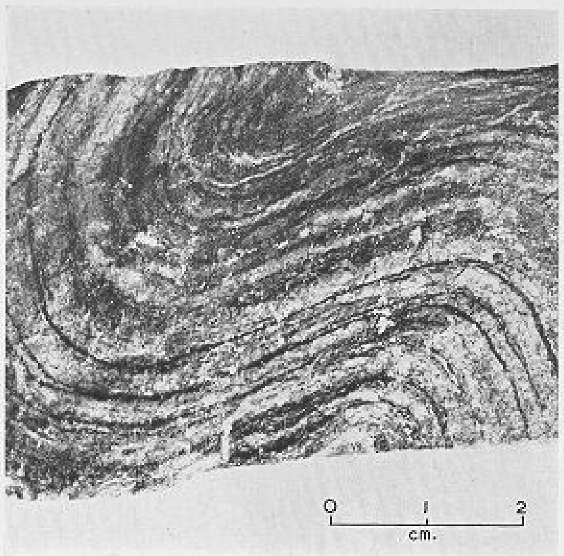


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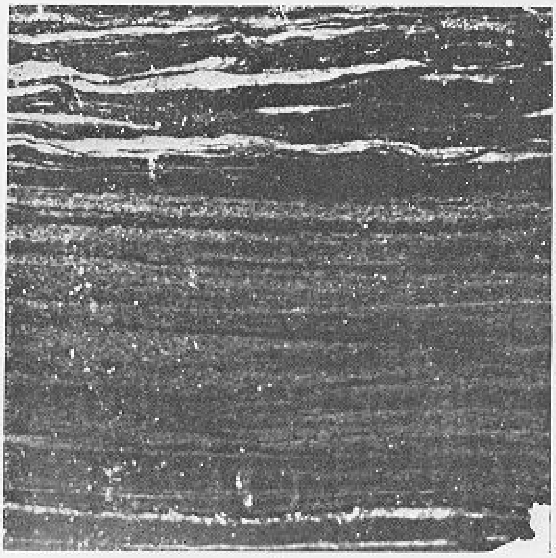

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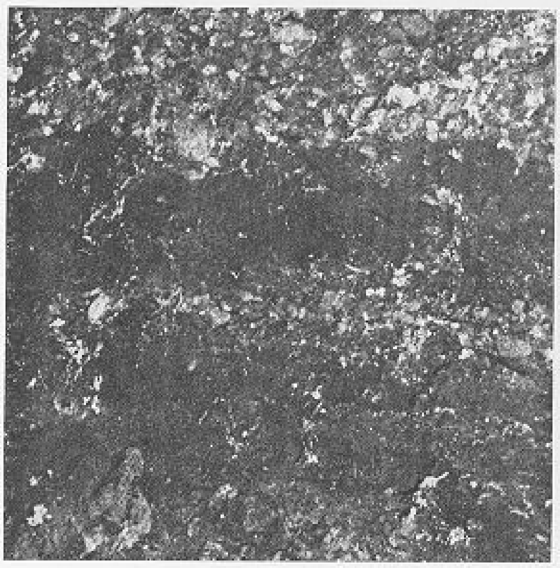

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PLATE VII

a. The varnished surface of a section through a small lava bomb showing its associated reaction zones; from the top of the Jurassic sedimentary beds south of Stubb Glacier (TL.42.1; ×1·7).
a. Volcanic grit. b. Volcanic grit with chlorite. c. First appearance of epidote; some chlorite; rich in leucoxene. d. Almost pure epidote; a little chlorite. e. Epidote-chlorite. f. Coarse-grained pure epidote. g. Hornblende and epidote; a little chlorite.

b. A broken surface of an Upper Jurassic porphyritic andesitic lava showing white phenocrysts of labradorite; south of Starbuck Glacier (TL.31.1; ×7·1).

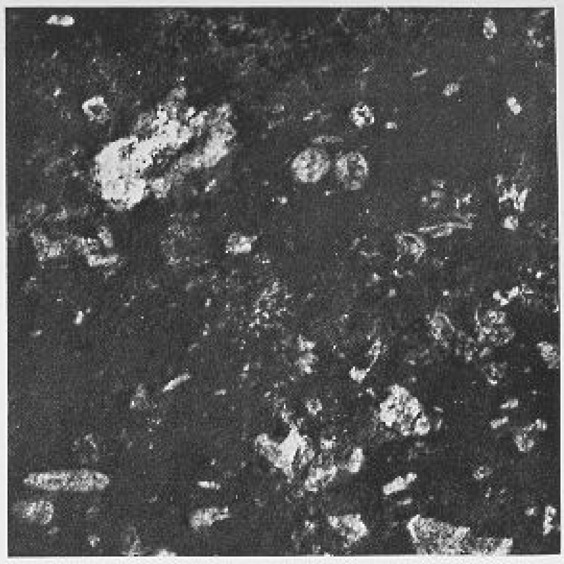
c. A cut and varnished surface of an Upper Jurassic acid crystal tuff; near Mapple Glacier (D.4718.1; ×4·0).

d. A cut and varnished surface of a dark-coloured Upper Jurassic acid crystal tuff traversed by a vein of quartz, potash feldspar and hornblende; near Stubb Glacier (TL.44.1; ×3·5).

e. A banded Upper Jurassic acid crystal tuff; south of Crane Glacier (D.4700.1; ×3·6).

f. A cut and varnished surface of an Upper Jurassic (?) welded crystal tuff; near Punchbowl Glacier (TL.12.1; ×2·4).


a



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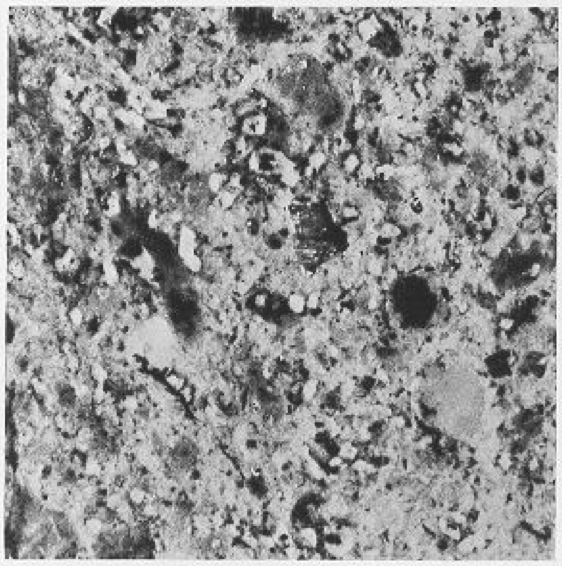

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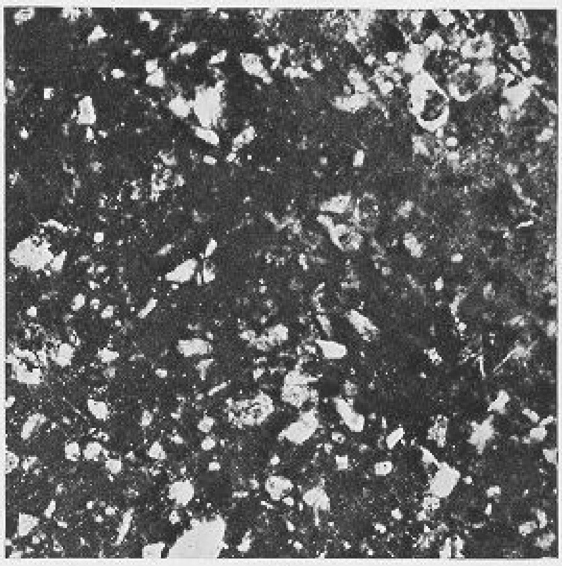

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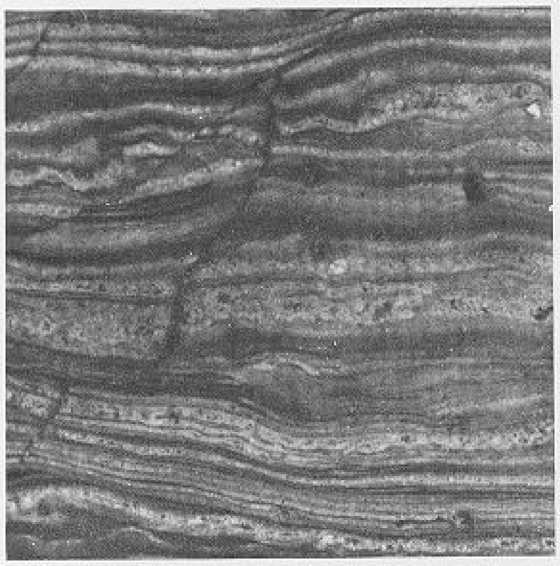

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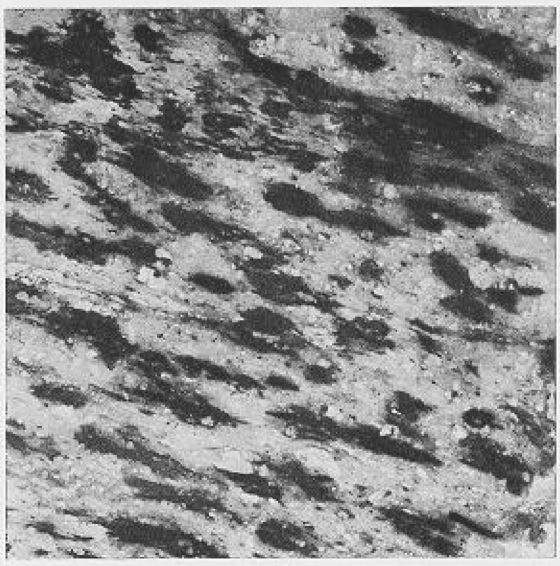

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## PLATE VIII

a. A cut and varnished surface of a quartz-perthite-porphyry; near Mapple Glacier (D.4714.1; ×4·0).

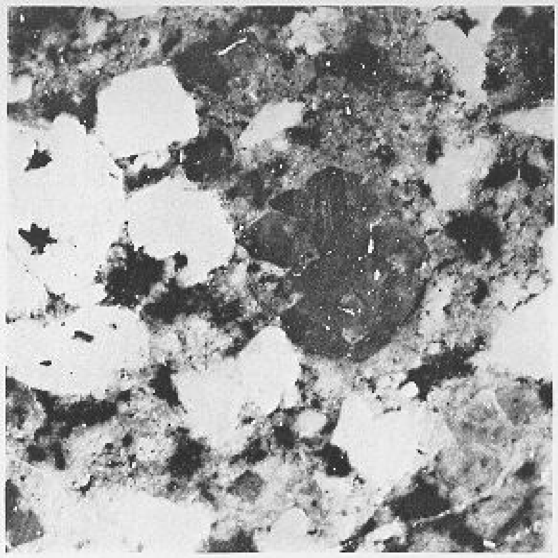
b. A cut and varnished surface of a quartz-perthite-porphyry; south of Melville Glacier (D.4681.2; ×3·4).

c. A broken surface of a specimen of "white granite"; near Starbuck Glacier (TL.34.1; ×3·9).

d. A pegmatitic differentiate of an Andean Intrusive Suite diorite consisting mainly of hornblende and plagioclase; Cape Fairweather (D.4667.1; ×1·7).

e. A nodule composed of olivine, enstatite, diopside and picotite enclosed in an olivine-basalt glass from the James Ross Island Volcanic Group agglomerates; Bruce Nunatak (D.4692.2; ×0·9).

f. A buchite enclosed in an olivine-basalt glass from the James Ross Island Volcanic Group; Bull Nunatak (D.4689.4; ×1·4).



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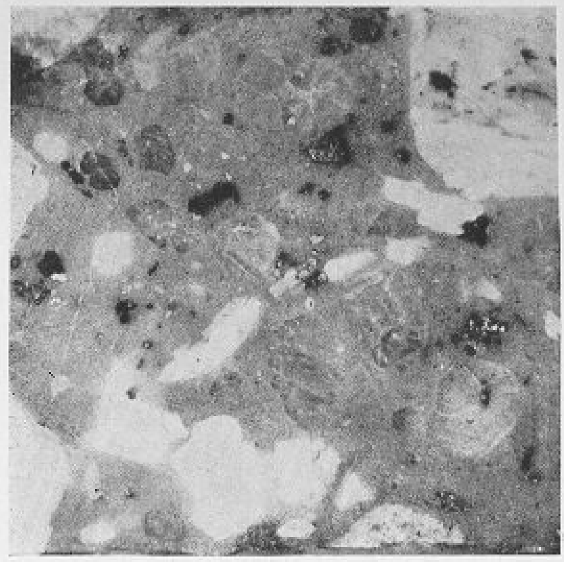

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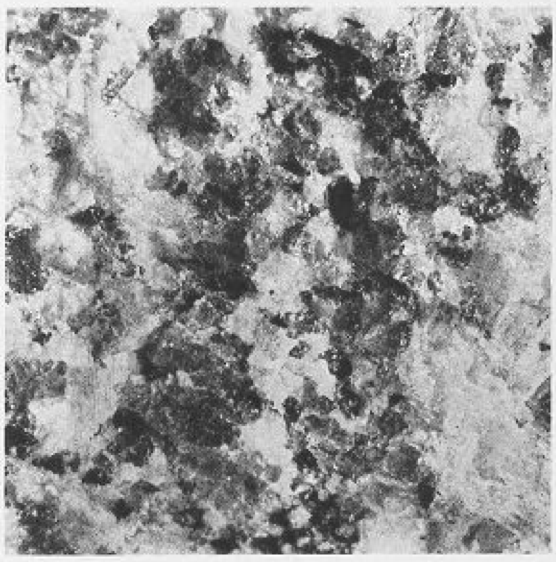

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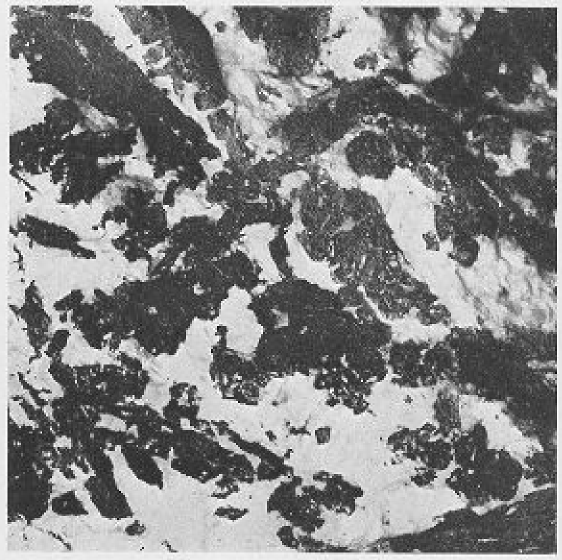

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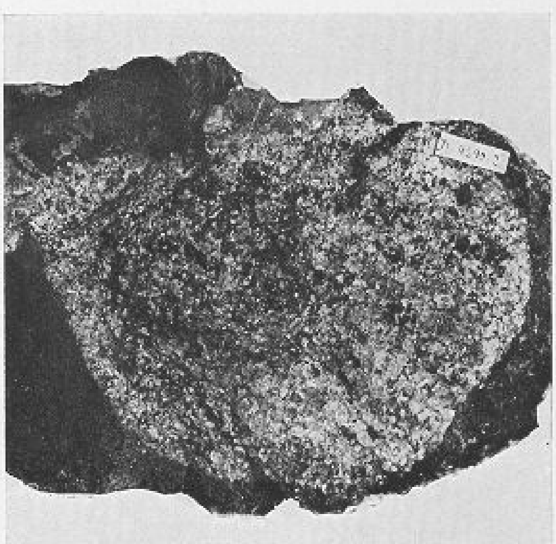

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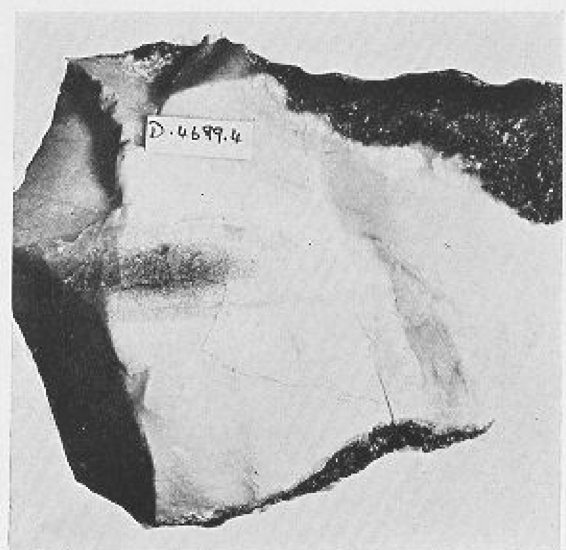


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PLATE IX

a. Contorted sandstones and shales of the Trinity Peninsula Series in which the quartz has recrystallized enclosing lenses of opaque material; north of Punchbowl Glacier (TL.7.1; X-nicols; ×5·6).

b. Contorted sandstones and shales of the Trinity Peninsula Series in which the quartz has recrystallized enclosing lenses of opaque material; north of Punchbowl Glacier (TL.7.1; X-nicols; ×24).

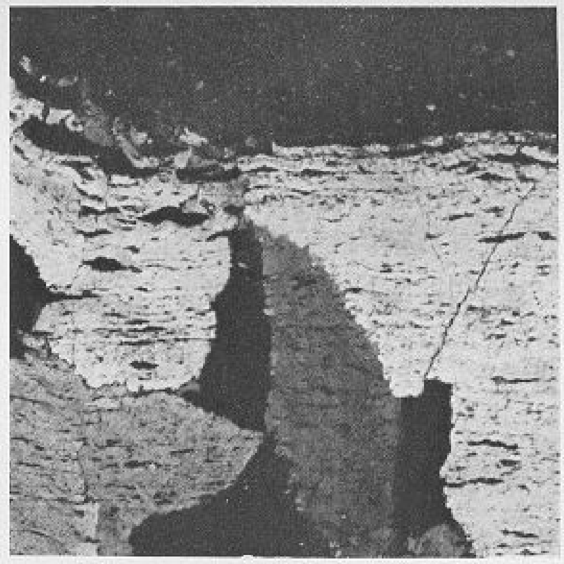
c. A lava bomb and its associated reaction zones (see Plate VIIa); south of Stubb Glacier (TL.42.1; X-nicols; ×5·2).
b. Volcanic grit with chlorite. c. Epidote, chlorite and leucoxene. d. Almost pure epidote with a little chlorite. e. Epidote-chlorite. f. Coarse-grained pure epidote.

d. An Upper Jurassic andesitic lava; south of Starbuck Glacier (TL.32.1; X-nicols; ×85).

e. Minute granules of leucoxene included in muscovite in an Upper Jurassic acid lava; Shiver Point (D.4608.1; ordinary light; ×80).

f. A photomicrograph of an Upper Jurassic acid lava illustrating an even-grained groundmass; near Pequod Glacier (D.4678.2; X-nicols; ×10·6).

a



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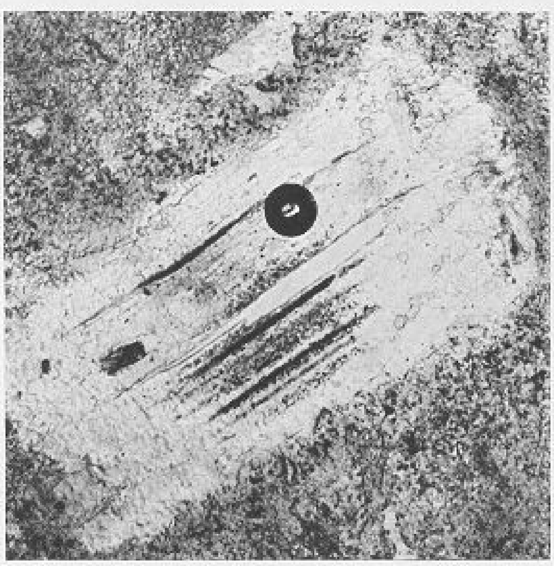

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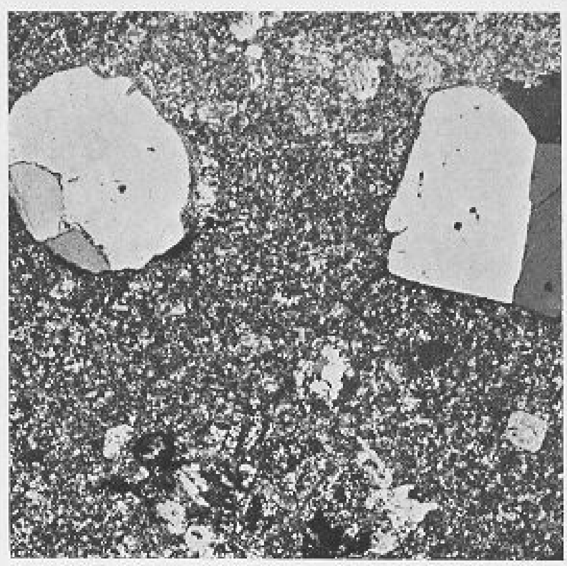

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## PLATE X

a. Haematite, chlorite and sericite pseudomorphing pyroxene in an Upper Jurassic acid lava; north of Cape Fairweather (D.4647.2; X-nicols; ×150).

b. Epidote (e) replacing plagioclase (p) in an Upper Jurassic acid crystal tuff. Potash feldspar (k) has been formed as an intermediate product; head of Stubb Glacier (TL.44.1; X-nicols; ×145).

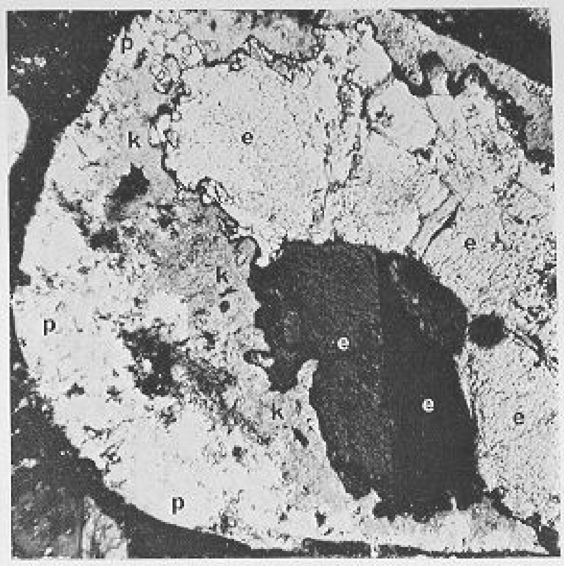
c. Volcanic glass which has recrystallized to (?) quartz-orthoclase micro-spherulites in an Upper Jurassic acid crystal tuff; head of Stubb Glacier (TL.44.1; X-nicols; ×230).

d. Pyroxene pseudomorphed by rutile needles growing into serpentine in an Upper Jurassic acid crystal tuff; Shiver Point (D.4603.1; X-nicols; ×155).

e. Unsorted fragmental texture of an Upper Jurassic acid crystal tuff; Shiver Point (D.4603.1; X-nicols; ×5·3).

f. Glomeroporphyritic plagioclase in a quartz-perthite-porphyry; south of Stubb Glacier (TL.49.1; X-nicols; ×6·8).

a

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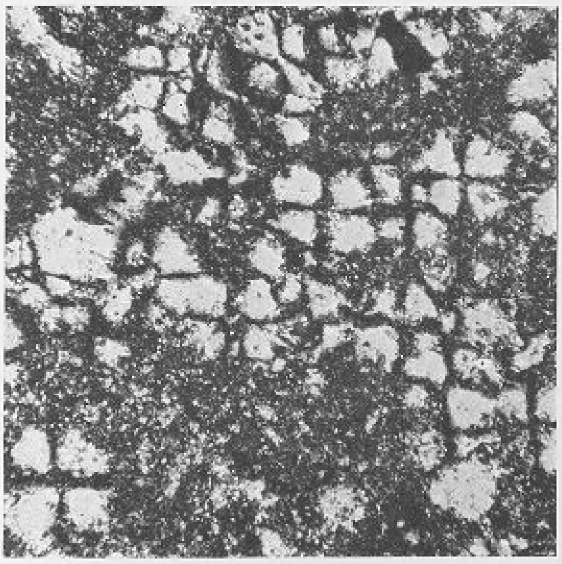

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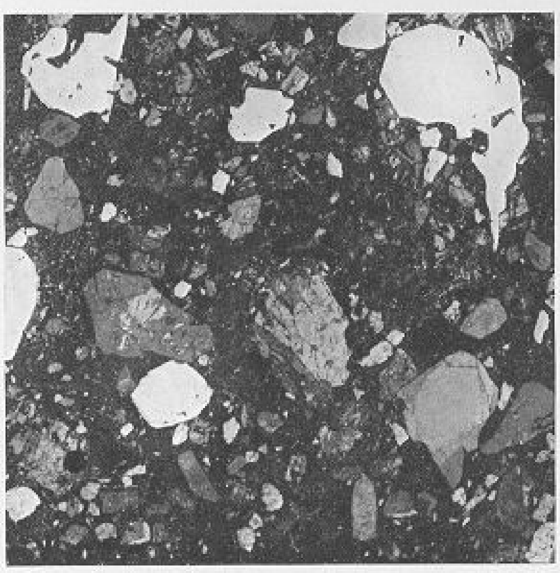

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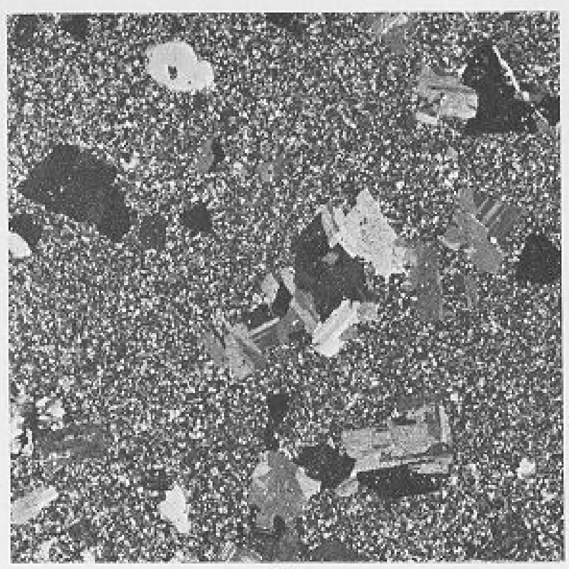


f

## PLATE XI

a. Strain extinction in a plagioclase phenocryst in a quartz-perthite-porphyry; north of Starbuck Glacier (TL.54.3; X-nicols; $\times 21$).

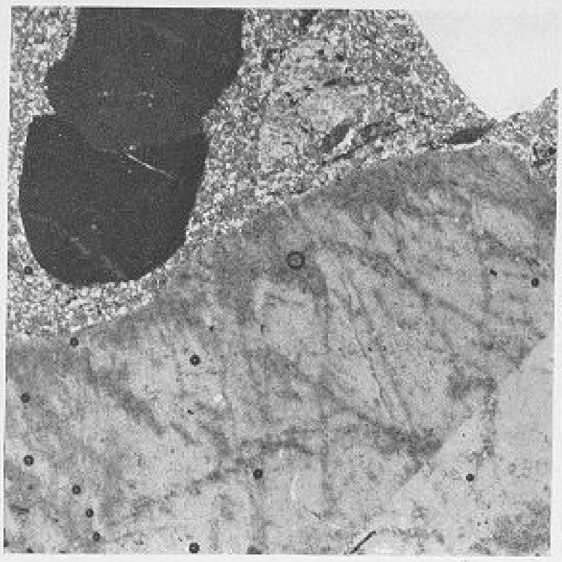
b. Bent and dislocated plagioclase twin lamellae in a quartz-perthite-porphyry; near Mural Nunatak (D.4616.1; X-nicols; $\times 18$).

c. Quartz phenocrysts which have recrystallized into a large number of individual crystals in a quartz-perthite-porphyry; near Mural Nunatak (D.4616.1; X-nicols; $\times 17$).

d. Myrmekite developed along a boundary between potash feldspar (dark-coloured) and plagioclase (light-coloured) in a "white granite"; near Skilly Peak (D.4658.1; X-nicols; $\times 170$).

e. Accessory crystals of apatite and zircon crowded into a crystal of biotite in a "white granite"; near Hektoria Glacier (D.4614.1; ordinary light; $\times 210$).

f. Iron ore (black) exsolved along the cleavage planes of a muscovite crystal and fluorite (high relief) in a "white granite"; near Punchbowl Glacier (TL.17.1; ordinary light; $\times 60$).



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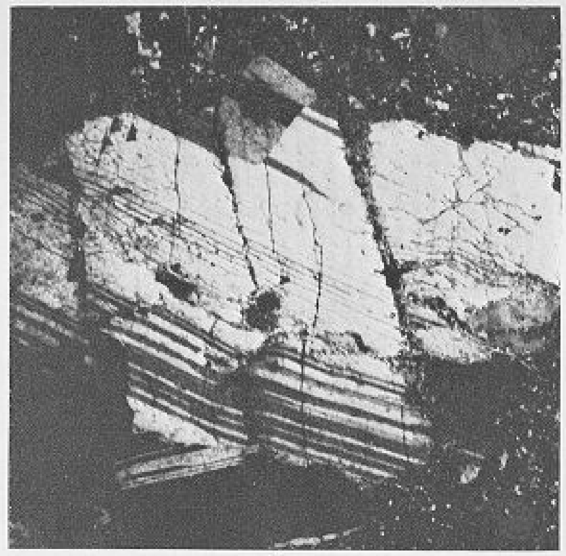

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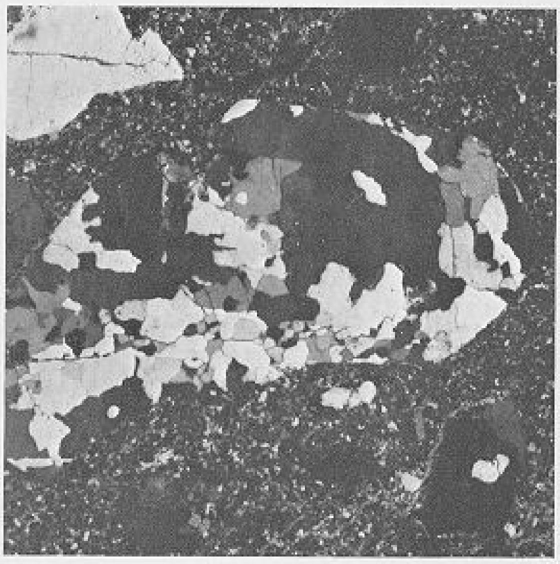

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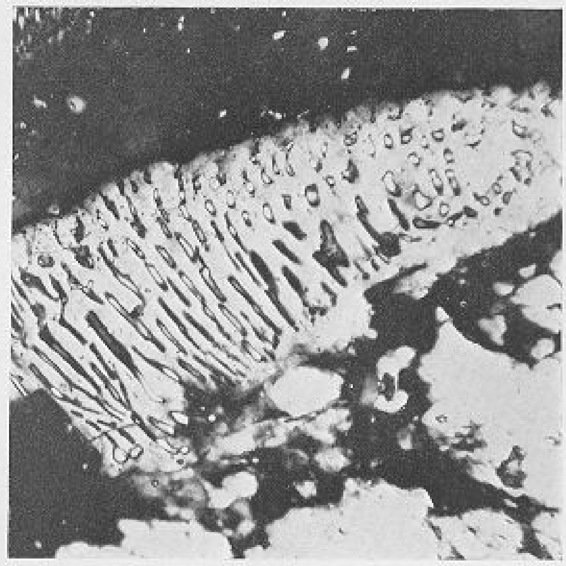

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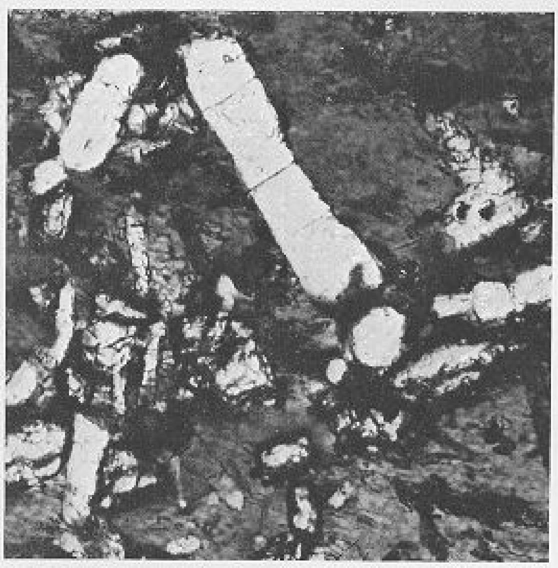

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PLATE XII

a. Chequer-board albite in a "white granite"; north of Melville Glacier (D.4688.2; X-nicols; ×175).

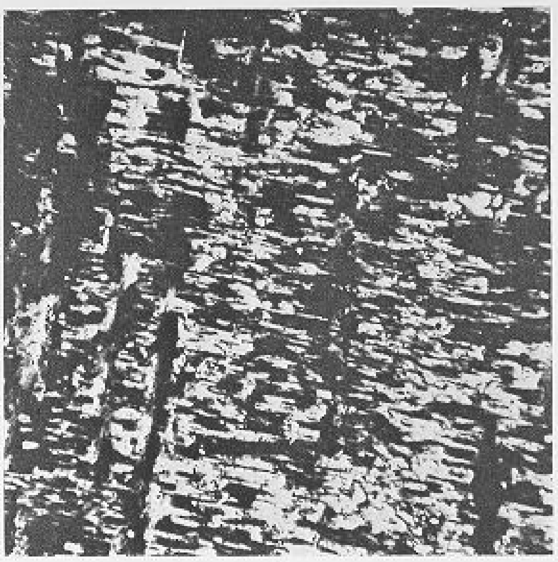
b. Chequer-board albite and a Baveno twin in a "white granite"; north of Melville Glacier (D.4688.2; X-nicols; ×50).

c. Microperthite in a "white granite"; north of Melville Glacier (D.4688.1; X-nicols; ×50).

d. A plagioclase crystal sheared along several planes in a "white granite"; north of Melville Glacier (D.4688.1; X-nicols; ×175).

e. A micrographic intergrowth of quartz and potash feldspar in a "white granite"; south of Starbuck Glacier (TL.33.1; X-nicols; ×70).

f. A micrographic intergrowth of quartz and potash feldspar in a "red granite" of the Andean Intrusive Suite; near Hektoria Glacier (D.4613.1; X-nicols; ×60).



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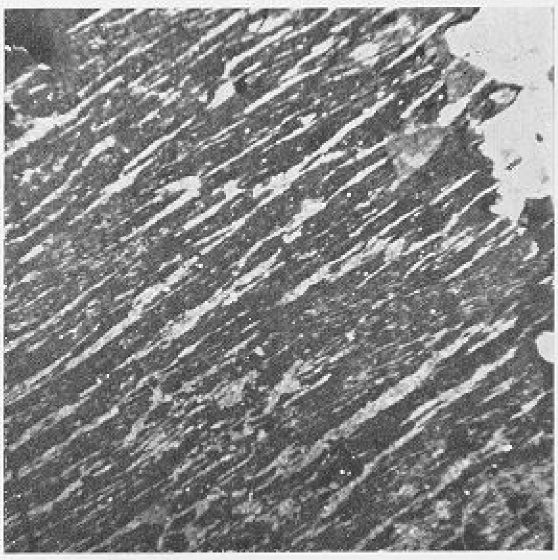

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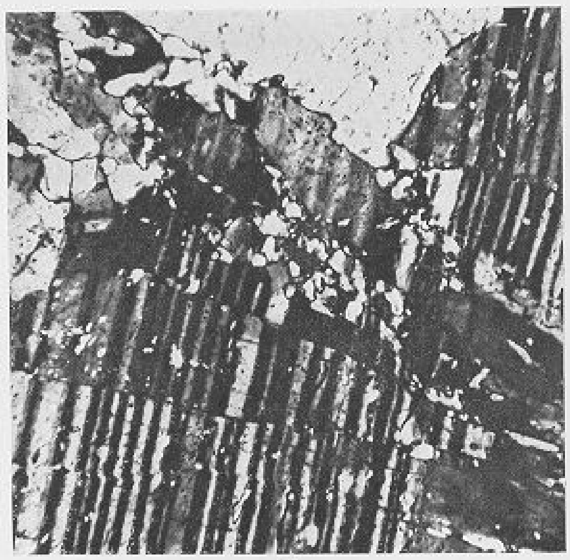

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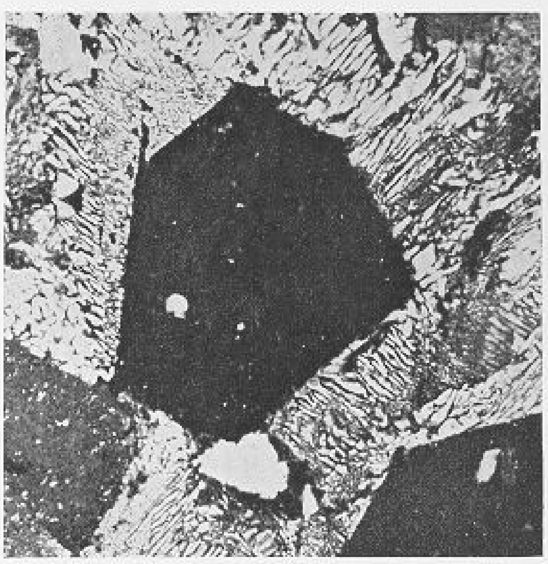

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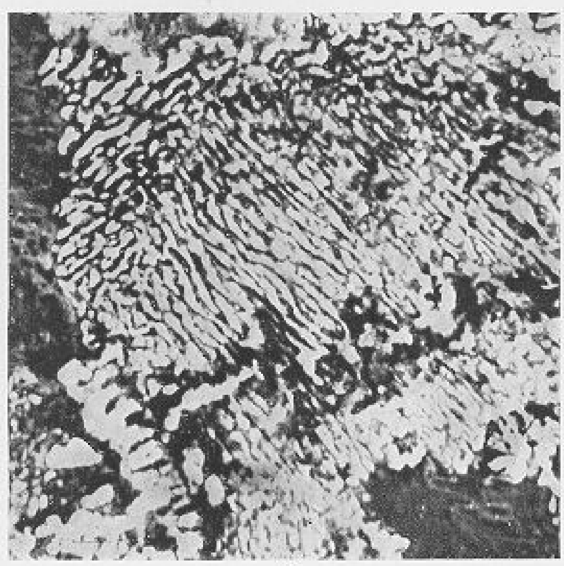

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