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ABSTRACT

THE distribution, characteristic features and regional variation of the sedimentary, volcanic, metamorphic and intrusive rocks in the area south of Mobiloil Inlet are described in detail; they indicate a complex geological history, in which the general pattern of events was determined by the evolution of an orogenic belt. This belt was initiated not later than the Upper Palaeozoic by the deposition of a thick succession of sediments (predominantly siltstones and shales) and associated basic volcanic rocks in a geosynclinal trough whose axis trended north-west to south-east. Acid lavas, which were subsequently altered to keratophyres by deep burial, were extruded from a volcanic island arc which was situated on the north-eastern margin of the trough along a supposed geanticlinal zone. Muddy sandstones possessing typical shallow-water structures also occur below the volcanic rocks in this zone; these are believed to be equivalent in age to the deeper-water facies. In the early Jurassic, the sedimentary pile was deeply buried, strongly folded and regionally metamorphosed. The metamorphic grade is negligible near the coast but it increases towards the former axis of the geosynclinal trough, and at the highest grades *lit-par-lit* injection, migmatization and synkinematic intrusion are prominent. Regional introduction of soda followed by potash occurred during the metamorphism, giving a conspicuous porphyroblastic texture to many of the medium- and high-grade rocks. The profound changes in palaeogeography produced by this phase of orogenesis resulted in the rapid accumulation of predominantly arkosic sediments on and adjacent to the former island arc. These volcanic-rich sediments are characterized by a remarkable suite of authigenic minerals, including prehnite, epidote, sphene, fluorite and calcite, which resulted from the instability of volcanic debris under conditions of deep burial following deposition. Major thrusting in the early Cretaceous involved movements directed towards the north-east, and this gave rise to the complex repetition of strata in some places and the local development of mylonites and crush rocks. A second phase of regional folding was cogenetic with the thrusting. The youngest sediments are carbonaceous mudstones with a poorly preserved fauna; they appear to post-date the thrusting and owe their preservation to Tertiary block-faulting which was associated with the uplift of the Antarctic Peninsula. Igneous rocks of varying structures and textures, and ranging in composition from gabbro to granite, intruded the rocks of the metamorphic complex over a considerable period of time, possibly extending from the Jurassic to the Tertiary.

CONTENTS

I. INTRODUCTION

THE geological mapping on which this report is based was carried out separately by the authors in 1960 and 1961 on an area covering 5,400 km.^{2} to the south of Mobiloil Inlet on the east coast of the Antarctic Peninsula (Figs. 1 and 2). The area is bounded to the north by Mobiloil Inlet and the Mercator Ice

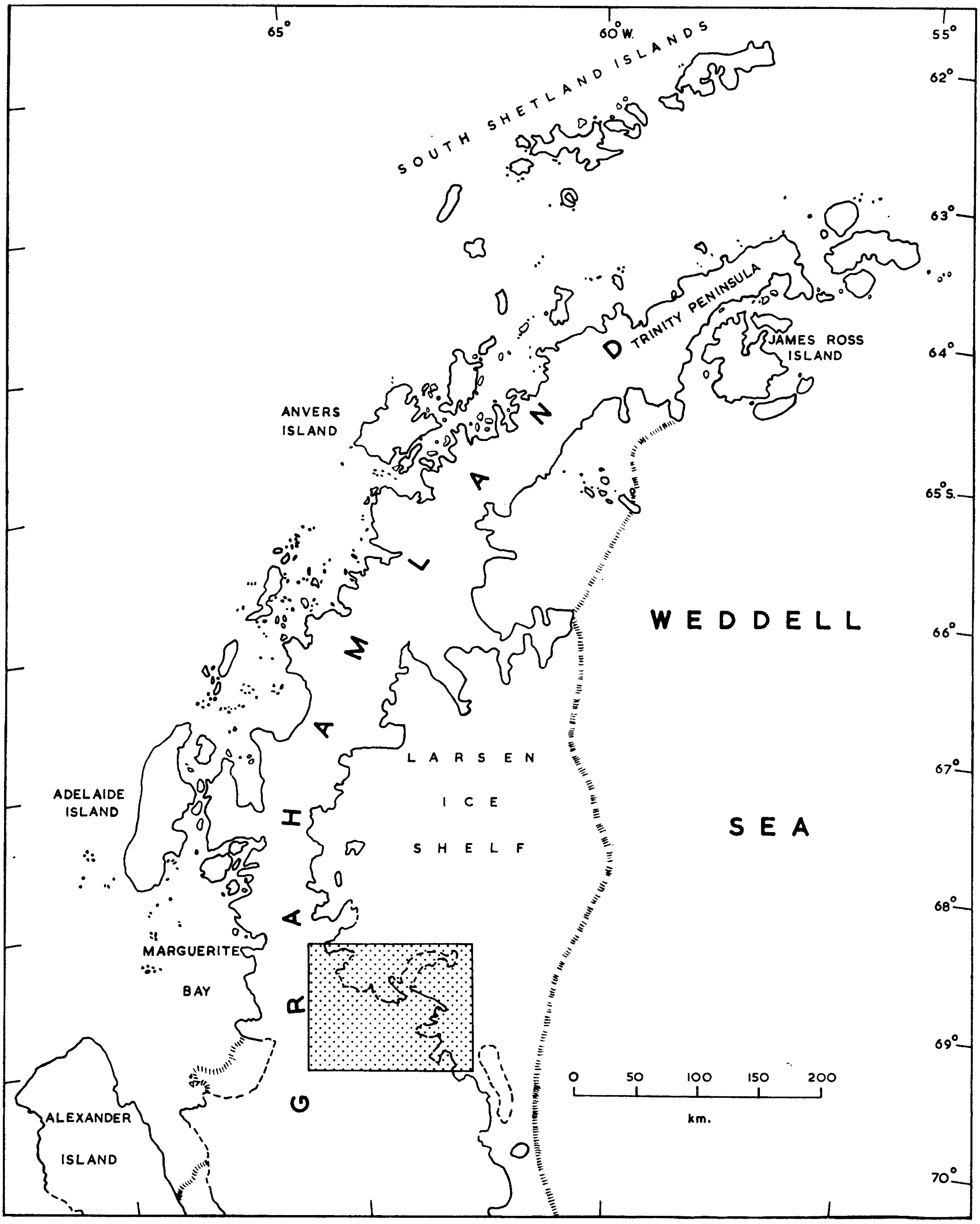
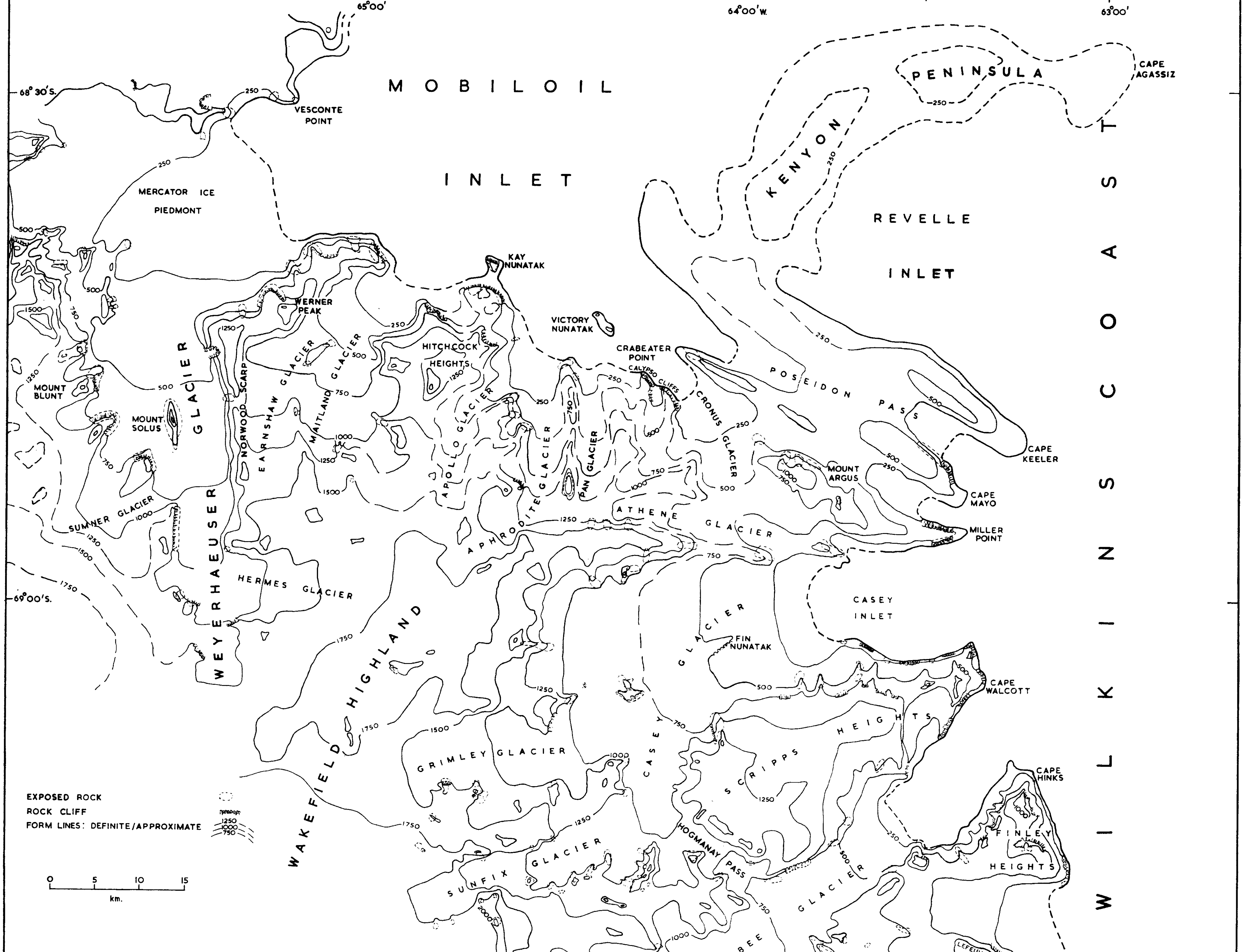


FIGURE 1
Map of the Antarctic Peninsula showing the location of the area described in this report.


WILKINS COAST
MOBILOIL INLET
REVELLE INLET
KENYON PENINSULA
CAPE AGASSIZ
VESCONTE POINT
MERCATOR ICE PIEDMONT
KAY NUNATAK
VICTORY NUNATAK
CRABEATER POINT
CALYPSO CLIFFS
POSEIDON PASS
CAPE KEELER
CAPE MAYO
MILLER POINT
MOUNT ARGUS
CRONUS GLACIER
PAN GLACIER
APHRODITE GLACIER
ATHENE GLACIER
APOLLO GLACIER
HITCHCOCK HEIGHTS
WERNER PEAK
MAITLAND GLACIER
EARNSHAW GLACIER
NORWOOD SCARP
MOUNT BLUNT
MOUNT SOLUS
SUMNER GLACIER
HERMES GLACIER
WEYERHAEUSER GLACIER
WAKEFIELD HIGHLAND
CASEY INLET
FIN NUNATAK
CASEY GLACIER
GRIMLEY GLACIER
SCRIPPS HEIGHTS
CAPE WALCOTT
HOGMANAY PASS
SUNFIX GLACIER
BEE GLACIER
CAPE HINKS
FINLEY HEIGHTS
LEFEU
68° 30'S.
69° 00'S.
65° 00'
64° 00'W.
63° 00'
250
500
750
1000
1250
1500
1750
2000
EXPOSED ROCK
ROCK CLIFF
FORM LINES: DEFINITE/APPROXIMATE
0 5 10 15
km.

Piedmont, to the west by Weyerhaeuser Glacier and Wakefield Highland, and to the east by the northern Wilkins Coast. The southern margin is defined by Sunfix Glacier, Hogmanay Pass and the lower reaches of Lurabee Glacier.

Geologically, this area is in an interesting and important position with respect to the large-scale features of the Antarctic Peninsula, since it occupies part of the zone between lat. 68°30′ and 69°30′S. where the peninsula widens from about 75 to 200 km. This considerable increase in width from north to south over a relatively short distance must reflect geological structures of fundamental significance. In relation to this, the well-defined linear topographical features such as Gibbs Glacier, which cuts obliquely across the peninsula north of the Mercator Ice Piedmont, and the scarps on the southern and south-eastern margin of Mobiloil Inlet and on the northern Wilkins Coast, are unmistakable physiographic expressions of major fault systems. Major geomorphological changes occur throughout this zone of widening. North of lat. 68°30′S., the plateau is narrow with an average elevation of 2,000 m. and, from the abrupt scarp edges, valley glaciers which are heavily crevassed and have steep headwalls descend to the eastern and western coasts. South of lat. 68°30′S. the topography changes. The widening plateau virtually loses its scarp edges and the headwalls of the broad valley glaciers such as Bingham, Lurabee and Casey Glaciers merge almost imperceptibly with the upland plateau at an altitude of about 2,500 m. (Plate Ia). These glaciers provide reasonable routes on their upper reaches but where they debouch on to the eastern ice shelf they are heavily crevassed and rifted. Large mountain blocks and smaller frost-shattered nunataks rise above the central upland ice, and intersecting glaciers have left residual ridges.

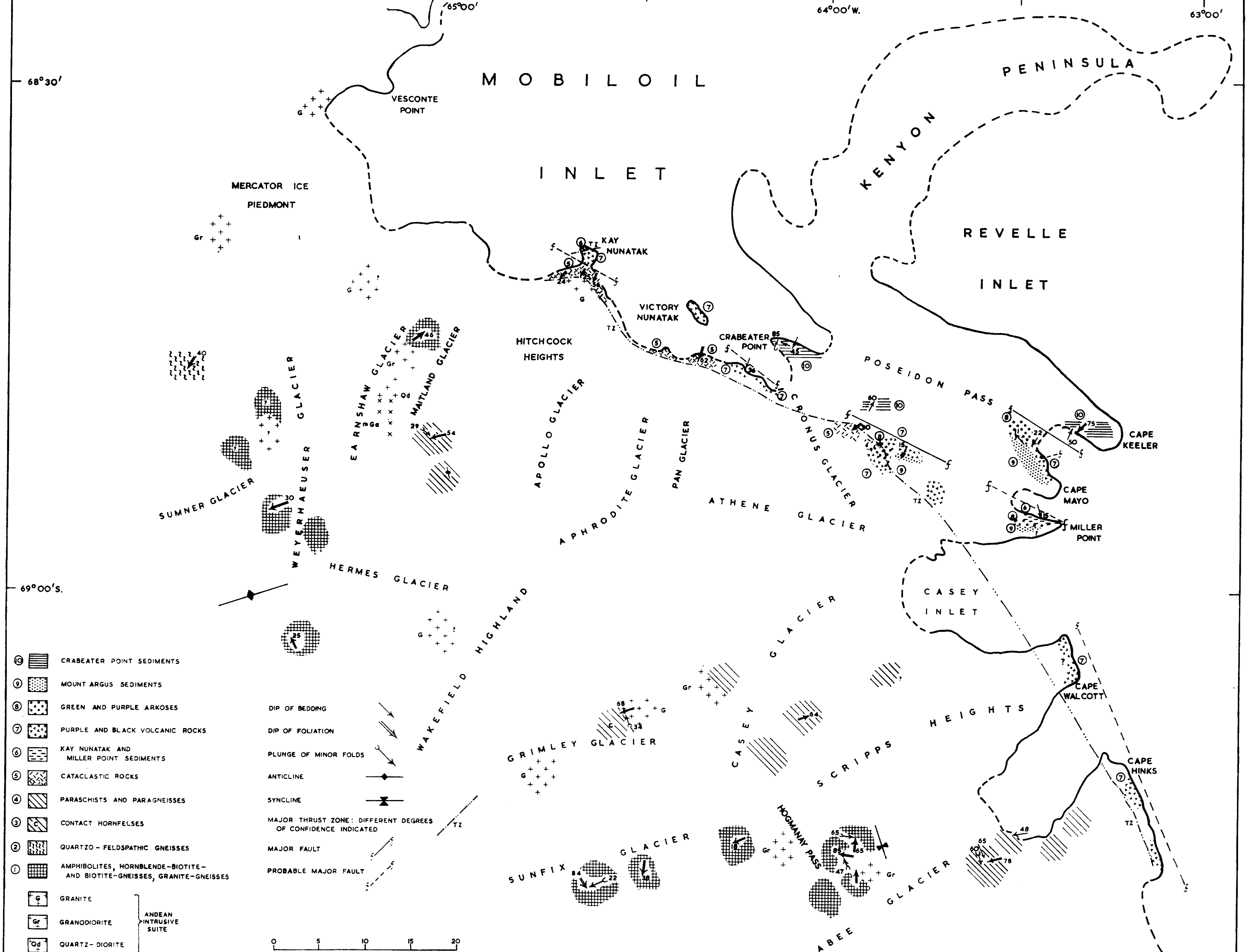
In the area forming the subject of this report, the inland plateau is called the Wakefield Highland. On its northern margin, numerous, steep and heavily crevassed glaciers flow northwards into Mobiloil Inlet, while in the central and southern parts of this area the plateau is drained to the east by large glaciers such as Casey and Lurabee Glaciers and their tributaries (Plate Ib and c).

Geological investigations on the east coast of the Antarctic Peninsula south of lat. 68°00′S. were initiated by Knowles (1945) during the United States Antarctic Service Expedition, 1939–41. He summarized the geology of the coastal areas as far as lat. 72°00′S. and described low-grade parametamorphic rocks, particularly slates, which occur in well-defined formations along a 145 km. stretch between lat. 68°00′ and 69°30′S. Although no fossiliferous material was obtained, the metasediments were considered to be equivalent to the Middle Jurassic plant beds at Hope Bay. Knowles also referred to major block-faulting producing fault ridges and valleys in the Kenyon Peninsula area. During the combined sledge journey of the Ronne Antarctic Research Expedition–Falkland Islands Dependencies Survey in 1947–48, Mason (1950) made brief geological notes and collected several specimens from the east coast between Cape Agassiz (lat. 68°30′S.) and Cape Adams (lat. 75°05′S.). These specimens were subsequently examined by Adie (1957*a*), who concluded that the sediments, including arkoses, greywackes and slates, belonged to the Trinity Peninsula Series, a major sedimentary succession in the northern part of the Antarctic Peninsula which is now assigned to the Carboniferous. He also described in detail the interesting contact metamorphic effects produced in the slates and greywackes by dioritic and related intrusions.

The laboratory work for this report was carried out in the Department of Geology, University of Birmingham, where all the relevant specimens and thin sections are housed.

II. STRATIGRAPHY AND GENERAL FIELD RELATIONS

THE distribution of the various rock types in the area south of Mobiloil Inlet is shown in Fig. 3. As in many other parts of the Antarctic Peninsula, the unravelling of the stratigraphy is seriously hampered by the isolated nature of the exposures, the virtual inaccessibility of large parts of individual outcrops and the extreme paucity of faunal evidence. The stratigraphy is further complicated by facies variation in the sediments, large-scale thrusting and major block-faulting. The existing field relationships of the major rock groups at specific localities are shown in Fig. 4. The original stratigraphical sequence, tectonic history and suggested correlations (Table I) are based on a detailed analysis of all the field and petrographic evidence available but, since several interpolations have been made, the stratigraphy will almost certainly require modification when further evidence becomes available. More detailed discussion on the problems related to the stratigraphy is given at appropriate places in the text.


65°00'
64°00'W.
63°00'
68°30'
69°00'S.
MOBILOIL INLET
KENYON PENINSULA
REVELLE INLET
VESCONTE POINT
MERCATOR ICE PIEDMONT
KAY NUNATAK
VICTORY NUNATAK
CRABEATER POINT
HITCHCOCK HEIGHTS
POSEIDON PASS
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SUMNER GLACIER
HERMES GLACIER
WAKEFIELD HIGHLAND
CASEY INLET
CASEY GLACIER
CAPE WALCOTT
SCRIPPS HEIGHTS
CAPE HINKS
GRIMLEY GLACIER
SUNFIX GLACIER
HOGMANAY PASS
ABEE GLACIER
TZ
G
Gr
Od
mGd
⑩ CRABEATER POINT SEDIMENTS
⑨ MOUNT ARGUS SEDIMENTS
⑧ GREEN AND PURPLE ARKOSES
⑦ PURPLE AND BLACK VOLCANIC ROCKS
⑥ KAY NUNATAK AND MILLER POINT SEDIMENTS
⑤ CATACLASTIC ROCKS
④ PARASCHISTS AND PARAGNEISSES
③ CONTACT HORNFELSES
② QUARTZO-FELDSPATHIC GNEISSES
① AMPHIBOLITES, HORNBLENDE-BIOTITE- AND BIOTITE-GNEISSES, GRANITE-GNEISSES
G GRANITE
Gr GRANODIORITE
Qd QUARTZ-DIORITE
ANDEAN INTRUSIVE SUITE
DIP OF BEDDING
DIP OF FOLIATION
PLUNGE OF MINOR FOLDS
ANTICLINE
SYNCLINE
MAJOR THRUST ZONE: DIFFERENT DEGREES OF CONFIDENCE INDICATED
MAJOR FAULT
PROBABLE MAJOR FAULT
0 5 10 15 20

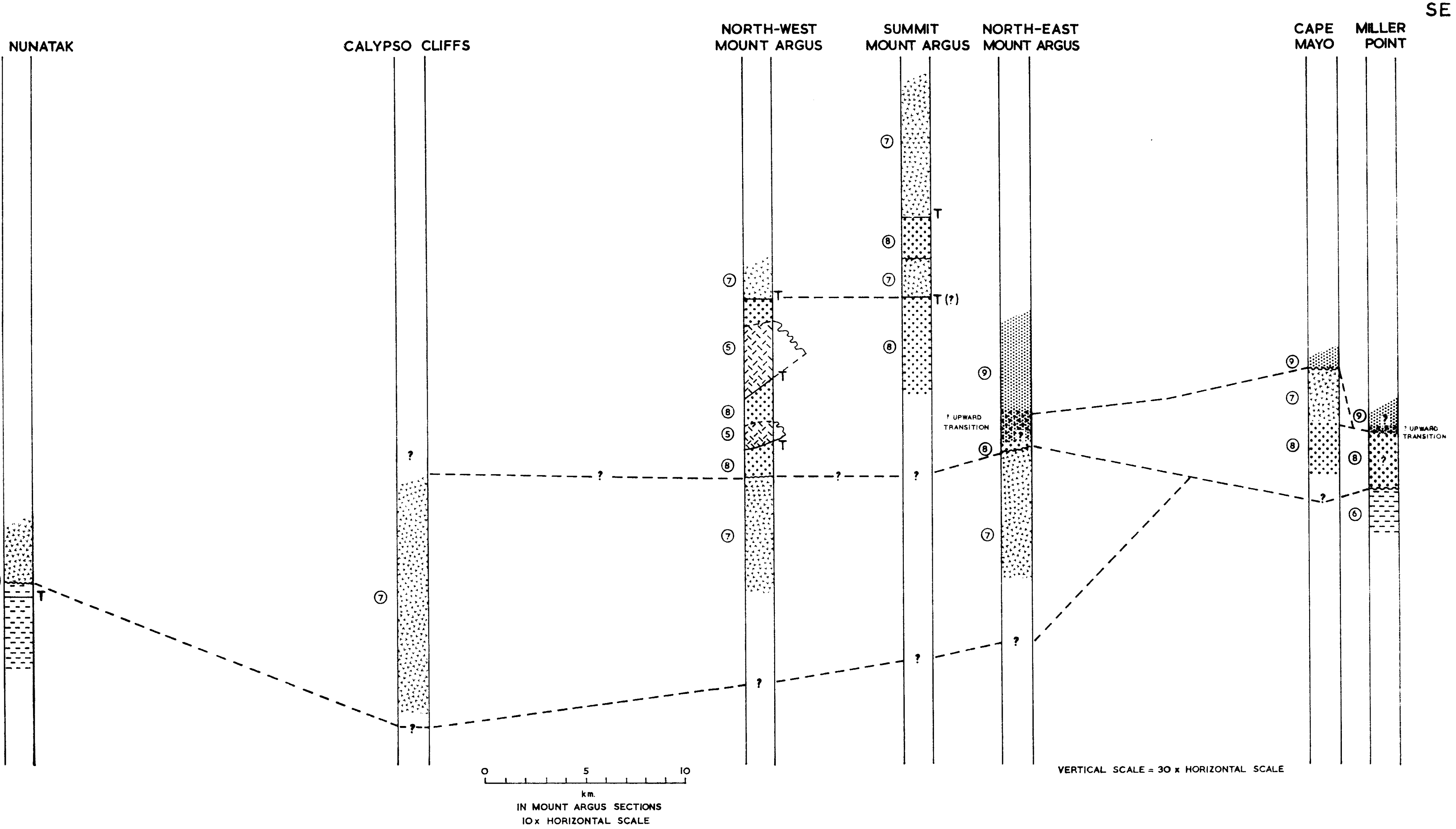


FIGURE 4

Column sections illustrating the varied sequences at different localities and suggested correlations. (The legend is the same as that for Fig. 3.)

TABLE I

STRATIGRAPHICAL SUCCESSION IN THE AREA SOUTH OF MOBILOIL INLET

Mobiloil Inlet	*North-west Mount Argus*	*South-east Mount Argus*	*Poseidon Pass*	*Miller Point*	*Cape Hinks*	*Lurabee, Casey and Grimley Glaciers*	*Maitland Glacier*
						↑ Granite ↑ Granodiorite	↑ Granodiorite
			Crabeater Point sediments				
Diorite							
			∿∿∿∿∿				
			→ Mount Argus sediments	(?) Mount Argus sediments			
		Mount Argus sediments →	∿∿∿∿∿				
(?) Green and purple arkoses	Green and purple arkoses		Black volcanic rocks	→ (?) Green and purple arkoses			
		?					
			→ Green and purple arkoses →				
	∿∿∿∿∿	∿∿∿∿∿					
							Metagabbro
				(?)∿∿∿∿∿		*Ortho*gneisses	*Ortho*gneisses
Purple and black volcanic rocks	Purple and black volcanic rocks	Purple and black volcanic rocks			Purple and black volcanic rocks	↑	↑
(?)∿∿∿∿∿	∿∿∿∿∿				∿∿∿∿∿		
Kay Nunatak sediments	Cataclastic sediments			Miller Point sediments	Metasediments	Metasediments, *para*schists and *para*gneisses	*Para*schists and *para*gneisses
						∿∿∿∿∿	∿∿∿∿∿
						(?) *Ortho*gneiss	(?) *Ortho*gneiss
						Amphibolite and mica-schist (age unknown)	

A. KAY NUNATAK SEDIMENTS

At the type locality (Plate Id), where they have an estimated thickness of 150 m., these sediments are represented by pale grey to grey-green impure quartzites with thin shaly partings, interbedded with dark green or grey sandy shales. The quartzites commonly have narrow zones parallel to the bedding in which elongated rounded shale pellets are abundant. Some of these zones occur just below the contact with a shale band, indicating that they may represent soft-sediment structures. However, they are more probably the product of erosion of a nearby mudstone with the shaly fragments being rapidly incorporated into an adjacent sand layer. The shallow-water environment implied by this interpretation is consistent with the presence of other features such as ripple marking, false bedding (Plate IIa) and possible swash marks. Near the top of the succession the quartzites are purple in colour, and this strong pigmentation appears to be related to the proximity of the purple volcanic rocks. A few slightly gritty bands are present, and conglomerates with angular pebbles of pale and purple quartzite set in a deep purplish matrix occur below the contact with the overlying volcanic rocks.

Although there is some petrographic evidence to suggest that these shallow-water sediments show a continuous upward gradation into the purple volcanic rocks, the conglomeratic facies near the top of the succession indicates the possible presence of an unconformity. However, the actual contact has been greatly complicated by low-angle thrusting and much faulting; since the main thrust zone nowhere coincides with the contact between the sedimentary and volcanic rocks, the true significance of the conglomerates is obscure. For example, at the north-eastern tip of the Kay Nunatak (station E.1674), the gently dipping conglomerates are separated from the underlying steeply dipping and strongly folded quartzites by a prominent thrust, while the contact between the purple quartzites and the massive purple lava flows is a faulted one.

Slightly metamorphosed sediments, believed to be equivalent to those at Kay Nunatak, occur at Miller Point; at one locality (station E.1620) on the north-facing scarp, the succession summarized in Table II was recorded. The rocks comprising the lower part of the succession at Miller Point can be correlated with the quartzite–shale sequence at Kay Nunatak but the thick sequence of schistose, strongly coloured purple and green conglomerates forming the bulk of the succession has no known counterpart at the latter locality. It is difficult to assess the significance of the conglomerates at Miller Point, since no structural evidence of an unconformity was found. While the grey conglomerates may be part of the Kay Nunatak sediments, the distinctive purple and green conglomerates may represent the basal facies of the younger purple and green arkoses. This possibility is referred to again on p. 12.

TABLE II

SUCCESSION ON NORTH-FACING SCARP NEAR MILLER POINT

Lithology	*Approximate thickness* (m.)
Massive buff-coloured rocks (*Not examined*)	
Schistose green conglomerate	Not determined
Schistose purple conglomerate. Green, purple and grey pebbles in purple matrix	30
Massive grey conglomerate. Distorted pebbles of shale, siltstone and sandstone in mottled grey-green and purple matrix	40
Psammitic and semi-pelitic rocks consisting mainly of impure quartzites with thin shaly partings. Several bands of micaceous flaggy rocks. Colour ranges from dark grey at base to pale buff at top	35

The semi-pelitic sediments at Miller Point closely resemble the low-grade metamorphosed sediments exposed on the lower reaches of Lurabee Glacier, and it is mainly on this basis that the Kay Nunatak sediments are correlated with these metasediments (Table I).

B. PURPLE AND BLACK VOLCANIC ROCKS

Volcanic rocks, consisting predominantly of purple and black acid lava flows, form extensive outcrops along a relatively narrow coastal zone between Kay Nunatak and Cape Hinks. Fig. 3 shows that there is a strong correlation between the known and probable occurrences of the volcanic rocks and the presence of major faults. What can be inferred from this is uncertain because the present distribution of volcanic rocks is partly a function of thrusting and, in addition, the main activity along the faults clearly occurred after the volcanicity had ceased. However, the block-faulting may represent the re-activation of earlier lines of crustal weakness with which the volcanic activity was closely associated. The overall lithological and petrographic uniformity, and the preponderance of lava flows over clastic deposits, tend to confirm a fissure-eruption origin for the volcanic rocks.

1. *Mobiloil Inlet*

On the south side of Mobiloil Inlet, the purple and black volcanic rocks have been recorded at three localities: Kay Nunatak, Victory Nunatak and Calypso Cliffs (Plate IIb). Purplish brown porphyritic lavas, which are faulted against sediments, occur at the base of Kay Nunatak at its north-eastern tip. Most of the cliffs on the nunatak are practically inaccessible but evidence from scree material and the general appearance of the rocks indicate that the volcanic succession consists largely of similar lavas. As mentioned on p. 9, the original stratigraphical contact between the purple volcanic rocks and the underlying sediments has been considerably disturbed by thrusting and faulting, and existing evidence is insufficient to determine whether there is a continuous upward gradation or whether the contact is unconformable.

On the western buttress of Victory Nunatak, massive purple lavas of fresh appearance are followed to the east by sub-horizontal banded flows, several of which have quartz-epidote inclusions. About midway along the north-east coast, porphyritic lavas are cut by a prominent vent agglomerate, in which angular accidental fragments consisting of purple, grey and pale green quartzite are embedded in a purple matrix. The smaller fragments are aligned parallel to the vent walls. To the east of the agglomerate, very fine-grained dark amygdaloidal flows were recorded.

On the mainland coast 5 km. south-east of Victory Nunatak, an apparently unbroken succession of volcanic rocks at least 400 m. thick forms Calypso Cliffs. The rocks are predominantly acid in composition and include amygdaloidal lavas, massive grey to purplish grey porphyritic lavas, and finely banded semi-vitreous black or greenish flows with which thin bands of vitric tuff are interbedded.

2. *Mount Argus*

The purple and black volcanic rocks are widely exposed on Mount Argus, and on the western part of this massif they occur in at least three distinct levels of the succession (Fig. 4); the significance of this is discussed in the section on structures (p. 49). The lowest volcanic rocks were examined on the large buttress terminating the ridge extending northwards from the summit. On this buttress over 200 m. of massive purplish black and dark greenish porphyritic lavas are exposed. Several of the lavas are vitreous and closely resemble pitchstone. Calcite veining is prominent and it occurs particularly in numerous minor shear zones. The second layer crops out on the precipitous north wall of the main summit mass and probably also on a prominent subsidiary peak north-west of the summit. At neither locality were the volcanic rocks investigated. The upper volcanic rocks occur on the three distinct peaks which together form the main summit mass of Mount Argus (Plate IIc and d) and they are composed of a minimum of 250 m. of deep purplish brown porphyritic lavas and subsidiary indurated lithic tuffs. These rest on the underlying purple and green arkoses with an angular unconformity of varying magnitude, but the contact is at least partly tectonic in origin. On the south-eastern side of the summit, the porphyritic lavas have been strongly sheared and possess a conspicuous fracture cleavage.

The buttress marking the sharply truncated end of the ridge trending northward from the summit is one of five which together define the remarkably linear north-western scarp edge of the Mount Argus massif (Fig. 5). Although the three buttresses on the eastern part of this scarp edge (Plate IId) were not visited, they are clearly composed of volcanic rocks; it is impossible to establish the correlation, if any, between them and the volcanic rocks on the summit ridge.

A continuous succession of volcanic rocks is exposed on a large isolated north–south-trending ridge 6 km. south-east of Mount Argus. Dark grey to purplish grey lavas, a few of which are semi-vitreous and

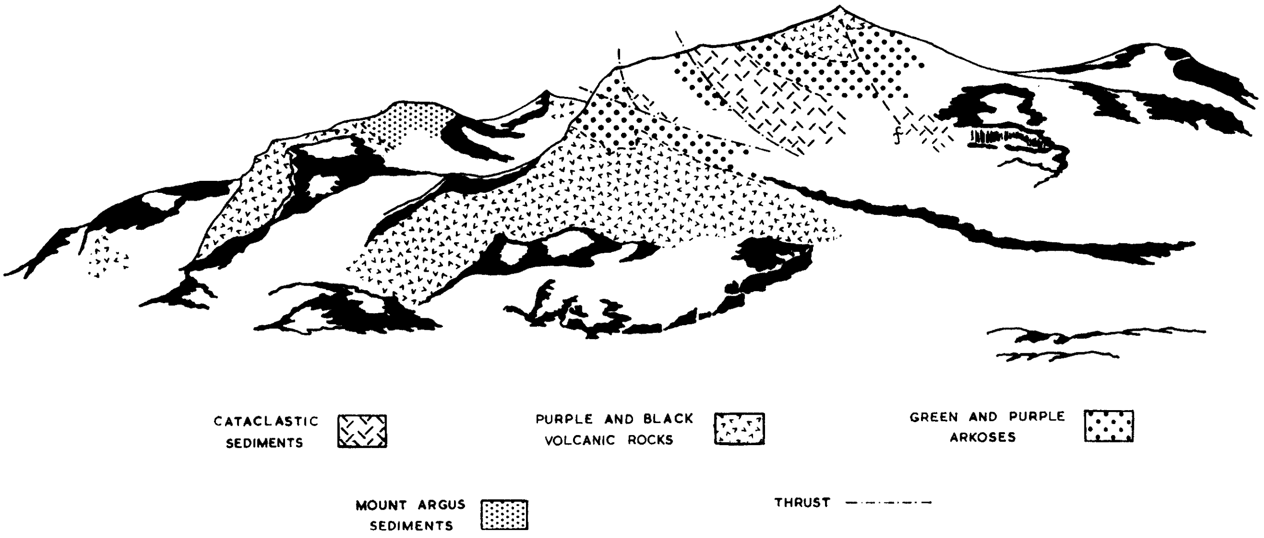


FIGURE 5

Panoramic drawing of part of the north-eastern scarp of Mount Argus showing the relationships between the main rock types.

flow-banded, form a comparatively small part of the succession and they are interbedded with strongly coloured massive purple or brown porphyritic flows. On the higher parts of the ridge purplish brown amygdaloidal lavas predominate. Highly indurated lithic tuffs occur in minor amounts. The thickness of volcanic rocks on this ridge is about 400 m.

3. *Northern Wilkins Coast*

The northernmost occurrence of volcanic rocks along this coastal strip is on the cliff face west-northwest of Cape Mayo (Plate IIIa), where black to dark grey porphyritic and amygdaloidal lavas, locally veined by quartz and calcite, are exposed. These lavas are generally massive but at one locality they have a well-developed pillow structure. They are overlain by well-bedded sediments and, to the west of an inferred vertical fault near the eastern part of the cliff, the lavas rest with apparent slight unconformity on another sequence of well-bedded and variegated sediments. No evidence of thrusting was observed. These volcanic rocks become progressively thinner westwards and they appear to pinch out completely near the western end of the cliff face.

It is doubtful whether volcanic rocks are present at Miller Point but the massive black rocks which form Cape Walcott are almost certainly volcanic. At Cape Hinks, dark grey to purplish grey porphyritic lavas are interbedded with light grey to buff-coloured flows. In the vicinity of wide shear zones, which are prominent at Cape Hinks, the lavas have been transformed into mottled and heavily limonite-stained green schists. Above the volcanic rocks, at a height of about 600 m., there is a 50 m. light-coloured band containing huge angular fragments. This breccia is unlikely to be an agglomerate and it is probably of tectonic origin.

C. GREEN AND PURPLE ARKOSES

Unfossiliferous tuffaceous sediments possessing a strong green or purple coloration have so far only been definitely recorded at Mount Argus where they form an important part of the complex succession (Figs. 4 and 5). The marked angular unconformity, with which the arkoses overlie the black volcanic rocks on the north-eastern edge of Mount Argus, is almost certainly a stratigraphical boundary even though it has undoubtedly been considerably modified by later thrusting. This unconformable relationship with the volcanic rocks, considered in conjunction with petrographic data (p. 19), precludes the arkoses from being a facies variation of the Kay Nunatak sediments. The repetition of the arkoses in the succession is almost certainly of tectonic origin and does not indicate different periods of sedimentation giving identical lithological groups. Such a conclusion seems particularly valid for the section exposed on the north-eastern scarp of Mount Argus. Because of structural complexities, the true thickness of the arkoses is unknown.

In general, the basal arkoses are predominantly purple and the higher members are mostly green, but both types occur throughout the succession and rapid alternations are common. Several bands take the form of thin lenses and small-scale interdigitation of purple and green beds was observed in places, especially where the sediments are finer-grained. Numerous reduction spots are present in several of the purple beds; larger and more diffuse green patches and lenses mark concentrations of epidote. In the lower part of the succession the arkoses tend to be gritty and thin bands of breccia containing angular fragments of purple, green and white quartzite with imbricate structure are present. In addition, there are bands containing isolated pebbles of local derivation, clearly indicating penecontemporaneous erosion. Sedimentary structures observed include false bedding and poorly developed convolute bedding.

On the north wall of the central summit the arkoses possess a strong fracture cleavage near the contact with the overlying volcanic rocks, and this may have important structural implications (p. 49).

Other localities where there are possible occurrences of the green and purple arkoses include Miller Point, Cape Mayo and Mobiloil Inlet. The thick succession of green and purple conglomerates at Miller Point has already been mentioned (p. 9) and their coloration is so strikingly similar to that of the arkoses that their equivalence is strongly suspected, in spite of the different facies. In addition, several of the quartzite and shale pebbles in the conglomerates are closely similar to corresponding fragments present in the thin breccia bands at Mount Argus. If the green and purple conglomerates have been correctly interpreted, the volcanic rocks at Miller Point are absent and the contact between the purple conglomerates and the underlying Kay Nunatak sediments must be either an unconformity or a thrust.

Variegated fine-grained quartzites with a conspicuous false bedding, which are exposed on the cliffs on the south side of Poseidon Pass, are provisionally correlated with the purple and green arkoses. The quartzites are coloured yellow, buff, grey, pale purple and green, and are overlain by dark blue-black lavas. Although the contact appears to be slightly unconformable, there is clearly no major break, since contact relations show that the lavas flowed over wet unconsolidated sediments.

Well-banded green or buff-coloured rocks, which can be observed in the mountainous area immediately south of Mobiloil Inlet (Plate IIIb and c), may also belong to the same succession.

D. MOUNT ARGUS SEDIMENTS

On the north-eastern part of the Mount Argus massif, over 250 m. of highly indurated sediments, which weather characteristically into large blocks, overlie volcanic rocks. Although it was not visited, the contact is probably either an unconformity or a fault. The succession consists of dark grey, massive tuffaceous sandstones interbedded with thin beds of siliceous slate, volcanic conglomerate, pebbly siltstone, cherty argillite and silicified tuff or hälleflinta. The siliceous rocks are generally pale green or buff-coloured, while the siltstones usually have a dark greenish hue. Diffuse white spots of prehnite are very prominent in the less siliceous sediments and their arrangement in some beds gives a pseudo-graded bedding which occasionally corresponds to true grading.

The stratigraphical position of the Mount Argus sediments is uncertain and the interpretation of their observed relationship to the volcanic rocks depends largely on whether the repetition of the volcanic rocks in the Mount Argus succession is partly or wholly the result of thrusting, or whether it represents two or more volcanic episodes. If only one period of volcanic activity occurred, the Mount Argus sediments are either a facies variation of the green and purple arkoses, or they are a considerably younger succession than the arkoses. Lithological and petrographic comparison between the Mount Argus sediments and the supposed arkoses near Cape Mayo supports the first alternative.

If they are younger than the arkoses, the Mount Argus sediments must post-date the active thrusting movements and lie above the uppermost thrust layer of volcanic rocks. In this case, there must be a major fault with a downthrow of over 500 m. to the north-east immediately north of the Mount Argus summit area; the precipitous north wall might well be an expression of such a fault. Similar reasoning applies if there has been repeated volcanicity.

Resting on the wedge of volcanic rocks west of Cape Mayo are well-bedded sediments; except near the top of Poseidon Pass, these sediments are practically inaccessible. However, samples of fallen blocks show gross lithological similarities with the Mount Argus sediments and, in particular, the black volcanic lapilli in the sediments at both localities are identical. The correlation is further substantiated by the presence of spongy prehnite in sediments belonging to the same sequence near the head of Poseidon Pass.

Assuming that the correlations suggested above are substantially correct, the green and purple arkoses and the Mount Argus sediments at Cape Mayo were deposited in vertical sequence separated by a comparatively minor phase of volcanicity. The unidentified volcanic rocks underlying the Mount Argus sediments at Mount Argus are not considered, on the basis of existing evidence, to be equivalent to the Cape Mayo lavas because the latter pinch out westwards.

E. CRABEATER POINT SEDIMENTS

The rounded ridge which extends south-eastwards from Crabeater Point is composed mainly of thinly bedded carbonaceous mudstones with subordinate feldspathic and calcareous sandstones. Lime-mud nodules and "beef" bands are common, the latter being particularly well developed in the carbonaceous sediments. On the crest of the ridge near Crabeater Point and on the associated scree slopes, small gastropods of uncertain genera, poorly preserved lamellibranchs, including several belonging to *Inoceramus* sp. and one or two unidentifiable forms, together with a few ammonite fragments, were found. A recent and more detailed search at this locality by M. R. A. Thomson has shown that crinoids, trace fossils and a varied micro-fauna are also present. This fossil assemblage has been described by Thomson (1967) and provisional identification gives a Cretaceous age for the sediments.

Except on its north-eastern side near Crabeater Point, the ridge is heavily ice-covered and virtually devoid of rock outcrops. However, on the south-western side of the ridge about 13 km. from Crabeater Point, there are two small exposures of dark grey or black shale interbedded with indurated fine-grained siliceous bands. There is little doubt that these quartzite-shale beds are part of the same sequence. Since Kenyon Peninsula is morphologically identical to the ridge extending south-eastwards from Crabeater Point, the Cape Keeler sediments, which include muddy limestone and conglomerate, are also considered as belonging to the Crabeater Point sediments and not to an earlier formation (cf. Adie, 1957*a*). Considerable justification for this correlation is provided by distinctive microscopic characteristics, particularly the presence of highly twisted biotites which are prominent in several of the Crabeater Point sediments (p. 22) but which are unknown from other sediments in the Mobiloil Inlet area.

F. CATACLASTIC ROCKS

Highly deformed rocks of various types have been recorded from Mount Argus, the western flank of Pan Glacier and from the cliffs to the south and south-east of Kay Nunatak. These cataclastic rocks are of varying age so that they do not constitute a stratigraphical unit.

On the buttress marking the north-western tip of Mount Argus, over 300 m. of sheared grey and green siliceous siltstones and shales are exposed (Plate IIIb). Fracture cleavage is prominent, especially in the more argillaceous types, and in general it is sub-parallel to the original bedding. Some of these well-cleaved argillaceous rocks have a phyllitic appearance. Many of the rocks are heavily quartz-veined and intense iron-staining occurs in several thick bands. About 3 km. to the east, these deformed sediments are commonly purplish brown in colour and are repeated by thrusting, a wedge-shaped band of green and purple arkoses separating the two outcrops.

Foliated quartz-diorites, which are believed to have been deformed by the same thrusting movements as affected the various rock groups on Mount Argus, were recorded on two prominent buttresses between Pan and Aphrodite Glaciers 7 km. west of Calypso Cliffs. The relationship of these deformed intrusive rocks to the volcanic rocks on the coast is not known, though to the south of Calypso Cliffs there is slight evidence to suggest that the diorites overlie the volcanic rocks, the contact possibly being a thrust.

At the eastern end of the cliffs south of Kay Nunatak, finely banded siliceous rocks are overlain by thinly bedded or laminated grey siltstones and dark grey shales or slates which are very similar to the cataclastic sediments on Mount Argus. The total succession is about 200 m. thick. These sediments are tightly folded in places. Farther west, prominently banded and intensely deformed rocks of both sedimentary and igneous origins are present (Plate IIId). The lower part of the succession comprises finely banded mylonites derived from quartzites and semi-pelitic sediments, which are similar to those exposed farther east except that they were initially metamorphosed and have been more severely deformed. The more siliceous rocks are tightly folded on a small scale. These mylonites are succeeded upwards by finely foliated augen-gneisses and crush rocks of a dioritic origin, which in turn are succeeded by highly sheared white and grey quartzo-feldspathic gneisses interlaminated with numerous bands and lenses of chlorite-schist. Near the top of the succession, there are less deformed white granitic rocks with dark sub-horizontal bands which are probably altered basic sheets. The whole sequence has a low uniform dip to the south.

Some of the sediments belonging to this group of cataclastic rocks can be readily matched with the metasediments exposed in the lower reaches of Lurabee Glacier; consequently, they are regarded as belonging to the same sequence. The origin of the augen-gneisses, the intensely sheared quartzo-feldspathic gneisses and the white granitic rocks south of Kay Nunatak is more obscure but the most likely interpretation is that dioritic and granitic rocks intruded the sediments and were subsequently deformed with them.

G. METAMORPHIC ROCKS

Metamorphic rocks of possibly two or more generations, and comprising schists and gneisses of both sedimentary and igneous origins, occupy a large part of the area south of Mobiloil Inlet. Apart from dioritic and one or two boss-like granite intrusions, the whole hinterland is formed by a metamorphic complex with associated injection phenomena.

The lowest grade of metamorphism is located in the lower reaches of Lurabee and Casey Glaciers, where at least 500 m. of predominantly quartzo-feldspathic and semi-pelitic sediments with intercalated metabasites are exposed. In many places, the sediments are strongly folded and an associated fracture cleavage is present but original sedimentary structures such as graded bedding and slumping have been preserved locally. On the southern side of Lurabee Glacier, the sediments continue towards Cape Hinks where they appear to overlie the volcanic rocks. The contact is probably a thrust; however, apart from a thick band of extremely coarse breccia, no conclusive evidence for thrusting has been found.

Farther west towards the plateau the grade of metamorphism increases, leading to the development of *para*schists and *para*gneisses in which the original sedimentary structures have been obliterated. A further increase in metamorphic grade, together with the introduction of quartzo-feldspathic material, produces more varied rock types including amphibolites, biotite- and hornblende-schists, epidosites, and dioritic and granitic gneisses with associated augen-gneisses.

H. INTRUSIVE ROCKS

Nearly all of the recorded outcrops of intrusive rocks which post-date the metamorphic rocks occur in a north-west to south-east belt from the south-west corner of the Mercator Ice Piedmont to Hogmanay Pass. This belt is broadly parallel both to the trend of the metamorphic belt and to the regional fold axis.

The commonest rock type is granodiorite, which is distinguishable from the widespread biotite-gneisses and related rocks of the metamorphic complex by its general lack of foliation and by marked zoning in the plagioclase feldspar. The granodiorites grade into quartz-diorites and each intrusion contains abundant inclusions of the older rocks. These are mostly small biotite-rich xenoliths of uncertain origin, but in the quartz-diorite which forms the northern end of the nunatak at the confluence of Earnshaw and Maitland Glaciers there are large stoped blocks of well-foliated biotite-gneiss. On the large prominent nunatak near the confluence of Grimley and Casey Glaciers, a granodiorite intrusion contains rafts and xenoliths of metasedimentary rocks.

A small boss-like intrusion of coarse-grained pink granite or adamellite crops out near Grimley Glacier on its southern flank. Farther down the glacier on its northern flank, there is a similar granite which may be part of the same intrusion and which is in contact with a sequence of medium- to high-grade hornfelses produced by thermal metamorphism. The development of these hornfelses, the clean cross-cutting contact against the country rocks and the absence of any gneissose structure indicate that the granite is a high-level intrusion, which is much younger than the foliated and deformed granitic rocks occurring in the metamorphic complex.

On the north-western flank of Maitland Glacier, a poorly foliated gabbro appears to intrude the dioritic gneisses and associated schists. The precise nature of the contact is obscure and, although the gabbro has been altered to some extent, it may represent a very early phase of an intrusive suite to which the granites and diorites also belong.

III. SEDIMENTARY ROCKS

ALMOST all of the sandstones in the sedimentary sequences south of Mobiloil Inlet are characterized by a high matrix content so that, if Pettijohn's (1954) classification is followed, they would be termed greywackes despite considerable differences in structure and general lithology. Also, the matrix in several sandstones is very complex and clearly of diverse origin arising in part from post-depositional processes, such as the decay and disintegration of volcanic and sedimentary fragments and the extreme alteration and break-down of feldspar, so that the ratio of sand grains to detrital matrix is not always significant. In view of these and other factors which have been discussed by Klein (1963), Folk's (1954) mineralogical classification has been adopted in this report, although this also has its limitations. Using the end-members suggested by Folk, a QFM diagram containing a plot of selected clastic sediments from the Mobiloil Inlet area is given in Fig. 6 and the modal analyses from which these plots were made are given in Table III.

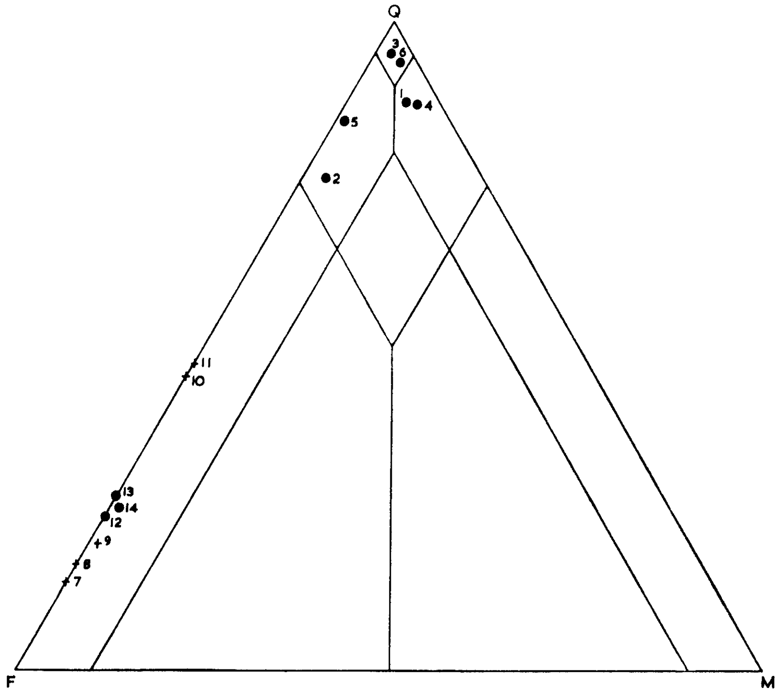


FIGURE 6

Plot of sediments from Mobiloil Inlet using Folk's (1954) classification. Numbers refer to the order of analyses in Table III.

A. GENERAL PETROGRAPHY

1. *Kay Nunatak sediments*

Apart from conglomerates, the Kay Nunatak sediments are composed mainly of sandstones and sandy mudstones, which when plotted on the QFM diagram show a marked concentration near the quartz pole. Most of the grains range from medium to very fine sand or coarse silt on the Wentworth scale but a small proportion of grains in a few sandstones are coarser. The degree of roundness varies considerably and the finer-grained particles which have not been modified by post-depositional processes range from angular to rounded (Powers, 1953), the sub-angular class always predominating. The coarse grains are generally rounded or well rounded. All of the rocks sectioned have a detrital silty to clayey matrix exceeding 5 per cent of the total constituents (Plate Va) and they are therefore texturally immature (Folk, 1959, p. 100). In the finer-grained sandstones, the sand-sized fraction is well sorted and, since the degree of sorting does not vary systematically with the percentage of matrix, textural inversion is indicated.

a. *Sandstones.* As shown in Table III, quartz is greatly predominant over other *mineral grains* in the sandstones of the Kay Nunatak sediments. Much of it is strained and the considerable variation in extinction characteristics probably indicates a multiple source rock. Grains may be either single or composite (Folk, 1959, p. 71), and in both types extinction ranges from straight to strongly undulose. Deformation

TABLE III

MODAL ANALYSES OF SEDIMENTS FROM THE MOBILOIL INLET AREA

	Kay Nunatak sediments						*Green and purple arkoses*					*Mount Argus sediments*		
	E.1602.6	E.1602.8	E.1674.8	E.1674.10	E.1674.12	E.1620.3	E.2135.2	E.2135.3	E.2140.3	E.1616.2	TL.304.1	E.2134.3	E.2134.5	E.2139.3
Quartz	24·0	62·6	77·0	34·0	78·4	49·5	1·9	2·7	7·9	3·6	4·6	2·0	2·4	7·6
Feldspar	1·0	17·2	2·2	1·2	13·2	1·1	10·0	11·6	17·5	3·4	3·0	2·3	4·3	5·5
Igneous rock fragments	0·3	—	—	—	*	—	2·2	2·6	15·5	1·0	1·0	4·2	2·3	17·3
Sedimentary rock fragments	*	—	—	—	—	—	—	—	1·1	—	*	—	1·1	2·8
Mica and chlorite	2·1	2·6	1·6	4·7	0·6	2·0	—	—	0·2	—	—	*	*	0·2
Heavy minerals†	3·8	0·4	0·8	2·5	0·8	0·5	1·7	0·9	0·1	0·2	*	0·4	0·1	0·5
Matrix‡	68·8	17·2	18·4§	57·6	7·0	46·9	84·2	82·2	57·7	91·8	91·4	91·1	89·8	66·1
Locality	Kay Nunatak					Miller Point	Mount Argus			Cape Mayo		Mount Argus		

*Present but not recorded.
†Very difficult in some cases to distinguish detrital and authigenic grains.
‡Includes authigenic minerals such as feldspar, prehnite, epidote and sphene.
§Includes 8·7 per cent haematite cement.

lamellae were observed in some grains and, since they occur in rocks possessing an appreciable matrix which would have readily accommodated the generally weak post-depositional stresses, the quartz was clearly derived from a strongly deformed rock. There is no apparent relationship between the intensity of strain and the degree of angularity. Where the matrix is subordinate, recrystallization or secondary overgrowth has taken place, yielding an equigranular mosaic of interlocking grains which may show a distinct directional fabric. In the slightly metamorphosed sandstones of Miller Point, the alignment of the quartz grains is comparatively strong.

Several different varieties of feldspar are present and, with a few exceptions, plagioclase is more abundant than potassium feldspar. The plagioclase is always highly sodic, the composition generally falling within the range $Ab_{95}An_5$ to $Ab_{85}An_{15}$. There are at least two distinctive varieties which often occur together. The first is very fresh with well-developed secondary glide twinning; the second is characterized by a lack of twinning and moderate to intense alteration to sericite or epidote. Zoning is absent in both types. Some of the twinned grains have bent or fractured lamellae but, since these only occur in the partially recrystallized sandstones, this distortion may be the result of stresses during lithification. The potassium feldspar comprises microcline, orthoclase and a little microperthite and, although all three varieties may be dusted with alteration products, most of the grains are remarkably fresh. An interesting feature concerning the potassium feldspar is that it is absent in the sandstones which have a low feldspar content; its proportion increases with increasing total feldspar content. In addition, microcline, showing excellent cross-hatch twinning, is restricted to the more feldspathic sandstones.

Muscovite, in long ribbon-like and often slightly twisted flakes, occurs as a minor constituent in all of the sectioned sandstones. Although this mica has been recorded as contributing to the M pole of the QMF diagram (Fig. 6), it is uncertain how much of the muscovite is detrital in origin and how much represents recrystallized matrix. It is possible that a significant proportion of the muscovite represents recrystallized matrix. In the reddish brown ferriferous sandstones, the muscovite is closely associated with the iron ore. Chlorite is subordinate to the muscovite. Optically, it is pale green or pale brown and faintly pleochroic, although bright green, moderately pleochroic varieties are also present in small amounts.

The heavy mineral suite is remarkably constant; tourmaline, zircon, sphene, rutile and ilmenitic magnetite occur together in nearly all the sediments. The tourmaline is a pale green to olive-coloured schorlite with a moderate pleochroism and like the zircon it is commonly zoned. Some of the sphene has clearly developed from irregular leucoxene grains which have been derived from the ilmenitic ore. Other heavy minerals comprising (?) goethite, apatite and garnet are relatively scarce and the latter was only recorded in one gritty sandstone.

With the exception of rounded elongated pebbles of dark grey mudstone which are believed to represent intraformational erosion, the sandstones contain very few *lithic fragments*, and those which are present never exceed sand-grade size. Particles consisting of a very fine microcrystalline quartz mosaic with wavy extinction were recorded as chert, whereas similar fragments dusted with iron ore and possibly containing some feldspar were assumed to be of volcanic origin. Rare rounded patches of fine scaly chlorite might also represent altered volcanic fragments. In the purple-brown muddy sandstones occurring in thin beds near the top of the succession at Kay Nunatak, numerous, elongated and slightly curved fragments of doubtful origin are present (E.1674.9). They are virtually isotropic with a vague fibrous appearance and are intensely stained with haematite. They are tentatively regarded as fragments of devitrified glass although none possesses a distinctive shard shape. This constitutes the only evidence that the sediments at Kay Nunatak grade upwards into the overlying volcanic rocks.

The modal analyses in Table III show that the proportion of matrix varies enormously. Although a small part of the matrix may have been produced by the chemical and mechanical break-down of unstable grains, it is clear that nearly all of it is detrital in origin, since even in those sandstones with a high matrix content the feldspar grains are commonly very fresh. Detailed analysis of the matrix is impossible using the normal microscope but much of it is silty and appears to be composed largely of sericite and silica with varying amounts of haematite dust. An important feature is the absence of any appreciable reaction between the matrix and the grains. Where the matrix content is low, its place may be partly taken by a haematite cement (E.1674.8 and 9).

b. *Conglomerates*. As noted on p. 9, the field relations of the conglomerates at Kay Nunatak are obscure and it is not known whether they are an integral part of the Kay Nunatak sediments or whether they mark the basal facies of a later unconformable series. The same problem exists at Miller Point, where there is a thick succession of conglomerates which vary considerably in colour. However, in spite of these colour differences, the conglomerates of Miller Point are remarkably uniform and, as in the conglomerates at Kay Nuntatak, many of the fragments are similar to the subjacent sandstones. For this reason, they are considered together in this section.

The conglomerates lying just below the volcanic succession at Kay Nunatak contain angular fragments of white or pale quartzite and moderately rounded purple muddy sandstones embedded in a deep reddish brown matrix. Under the microscope, the white granules and pebbles of quartzite are relatively pure and consist essentially of an irregular mosaic of recrystallized strained quartz and sparse feldspar with a little interstitial matrix or haematite cement. A few fragments are of stretched metaquartzite. The quartzite fragments possess a prominent heavy mineral suite which is virtually identical to that present in the sandstones already described except that the tourmaline displays greater variation, some of it having a turquoise colour with intense pleochroism. The matrix of the purplish muddy sandstone pebbles is rich in sericite, haematite and leucoxene. There are scarce fragments of probable volcanic origin. The conglomerate matrix is essentially a muddy sandstone and both in texture and composition it strongly resembles many of the underlying sandstones.

The conglomerates at Miller Point contain numerous granules and pebbles of muddy sandstone and relatively rare quartzite which are very similar to those present in the Kay Nunatak conglomerates, but they also contain several other types of phenoclast. These include siltstone, micaceous metaquartzite, clay-shale, siliceous shale, argillaceous chert and almost pure chert in which the grain-size is less than 15 μm. Large irregular masses of secondary calcite are commonly present in the phenoclasts, particularly those which are cherty, and a partial haematite cement takes the place of the normal sericitic matrix in some of the sandstone and siltstone fragments. Rare volcanic fragments were recorded in one conglomerate. The conglomerate matrix is generally poorly sorted and the sand fraction consists mainly of quartz and subsidiary feldspar together with isolated chlorite flakes, some ragged sphene and scarce heavy minerals. Most of the feldspar is subhedral albite with irregular twinning, which in some cases approaches a chequer-board pattern. These feldspars can be matched with those widely present in the green and purple arkoses. This may indicate that the conglomerates at Miller Point belong to the arkoses, as suggested on p. 12. Much secondary calcite, partially stained by amorphous reddish brown (?) limonite, occurs in the matrix of several conglomerates, and the purple conglomerates are locally extremely rich in haematite.

2. *Cataclastic sediments*

The cataclastic sediments comprise the cleaved siltstones and associated sediments which crop out on the north-western corner of Mount Argus together with the quartzites and slates exposed on the eastern end of the cliffs south of Kay Nunatak. Although the sediments at the latter locality are generally darker and richer in argillaceous material than those at Mount Argus, there is little doubt that they are equivalent.

a. *Mount Argus.* The cataclastic sediments at Mount Argus are composed of siltstones and sandy siltstones interlaminated with thin silty shales or discontinuous shaly partings. In many respects, particularly in mineral composition, these sediments are the fine-grained equivalents of the sandstones belonging to the Kay Nunatak sediments, although there are significant differences in structure. The detrital mineral grains are mainly of coarse silt size with an overall range of fine sand to fine silt. The degree of sorting is generally high and well-developed micro-grading was observed.

In the siltstones and silty shales, by far the most important non-micaceous mineral is quartz, which occurs as sub-angular to rounded grains possessing prominent strain extinction patterns despite its small grain-size. The scarce feldspar comprises albitic plagioclase together with a little orthoclase. The micaceous material is dominated by shredded sericite exhibiting partial recrystallization into discrete muscovite flakes, although detrital muscovite is also present. Pale green chlorite may occur in appreciable amounts. Iron ore is invariably present and in the purple siltstones and shales it is abundant, amounting to an estimated 15 per cent of the total rock. Much of the iron ore is deep red-black haematite but it also includes yellowish red (?) goethite and varying amounts of ilmenitic magnetite partly altered to leucoxene. Some of the haematite occurs in narrow slightly curved strips which are commonly intergrown with muscovite in the same manner as observed in several of the sandstones of the Kay Nunatak sediments. In most of the quartz-rich bands and lenses the grains are completely cemented by haematite. The heavy mineral suite is almost identical to that present in the Kay Nunatak sediments and includes tourmaline, zircon, rutile, a little sphene and rare apatite. The numerous small tourmaline grains are coloured blue-green, olive, pale orange or buff with a marked pleochroism and zonal structure. Secondary calcite is prominent in the less iron-rich sediments. The only lithic fragments recorded were small shaly pellets of local origin.

b. *Kay Nunatak.* Thin-section examination of sediments from this locality shows a general predominance of micaceous and clayey material, shales and slates being interleaved with thin bands or lenses of silty shale and siltstone. In the lower part of the succession, fine-grained banded siliceous rocks are prominent. Typical specimens from the argillaceous rocks consist mainly of dispersed silt-sized grains of deformed quartz and albitic plagioclase set in a strongly orientated matrix of shredded sericite, muscovite and indeterminate muddy material, accompanied by abundant streaky iron ore. Much of this ore has been altered to amorphous leucoxene and granular turbid sphene. Although there is a greater proportion of feldspar than in the corresponding sediments at Mount Argus, quartz is generally still the main non-micaceous mineral. Detrital heavy minerals include well-rounded zircon, tourmaline, sphene and apatite.

Apart from the commonly observed tight folding, the richly argillaceous rocks do not show much evidence of severe stress in thin section. However, in the bands of silty shale and siltstone, many of the quartz grains are strongly elongated, suggesting that the sediments have in fact been considerably deformed and the siliceous bands have a mylonitic texture. The finely banded nature of these siliceous rocks is the result of rhythmic variations in grain-size and the concentration of abundant sphene and epidote in well-defined layers. Evidence for the late introduction of fluorine and boron into these deformed siliceous rocks is shown by the conspicuous growth of apatite and schorlite in sponge-like grains. Apatite is particularly abundant, and in one of the coarser bands in specimen E.1675.5 it attains nearly 10 per cent of the total constituents. Some of the tourmaline may represent the recrystallization of detrital grains, but boron metasomatism is clearly demonstrated by a crush-breccia (E.1675.8), in which fine-grained quartzite fragments are cemented by abundant calcite and tourmaline.

3. *Green and purple arkoses*

The sediments considered here were originally described as arkoses in the field but subsequent microscopic examination has shown that the matrix percentage in many cases exceeds the 75 per cent which marks the arbitrary division between sandstones and mudstones. However, in Folk's mineralogical classification, the relative proportion of the sand-sized grains and fragments brings these sediments into the arkose category (Fig. 6) and hence the field term is retained. The green and purple arkoses have petrographic features which are considered to be sufficiently distinctive to separate them from the Kay Nunatak sediments. Because of uncertainties in interpreting the field relations, this conclusion has very important stratigraphical implications. The main differences between the arkoses and the sandstones of the Kay Nunatak sediments are summarized in Table IV.

TABLE IV

COMPARISON BETWEEN SANDSTONES OF THE KAY NUNATAK SEDIMENTS AND THE GREEN AND PURPLE ARKOSES

	Sandstones of the Kay Nunatak sediments	*Green and purple arkoses*
Quartz : feldspar ratio	Always >3 : 1	Usually <1 : 2 except at Cape Mayo
Feldspar type	Mainly plutonic igneous	Mainly volcanic
Lithic fragments	Exotic lithic fragments very rare	Rock fragments commonly abundant. Most are lavas
Heavy minerals	Tourmaline invariably present	Tourmaline in only a few sections
Matrix	Detrital	Complex. Largely the product of the chemical and mechanical break-down of unstable material
Authigenesis	Not important	Development of distinctive authigenic minerals such as epidote and sphene. Also authigenic feldspar

Detrital quartz is always present in the arkoses. As shown in Table III, its amount relative to feldspar varies considerably and those arkoses in which quartz exceeds feldspar are usually poor in or devoid of lithic fragments. The quartz has a widely varying morphology, ranging from rounded and almost spherical grains to sharply triangular particles. These variations are unrelated to the grain-size which is generally that of medium to coarse sand. Much of the quartz bears the marks of extreme deformation and strain lamellae are usually curved and distorted. Although the arkoses are commonly cleaved by shearing stresses associated with thrusting, it is doubtful whether the intense strain patterns are other than pre-depositional, since the detrital feldspar and volcanic fragments accompanying the quartz show little sign of having been strongly deformed.

There are several varieties of feldspar grains, of which albite-twinned sodic plagioclase ($Ab_{90}An_{10}$) and chequer-board albite are by far the most abundant. There are also grains which have a blocky twinning rather than a true chequer-type twinning. Variable amounts of orthoclase are commonly intergrown with the chequer-board albite and scattered grains of microperthitic or cryptoperthitic orthoclase may represent completely replaced albite of this kind. Microcline is rare. Apart from a light dusting of sericite, all of the feldspar is remarkably fresh. Furthermore, it is sharply angular, it forms isolated polycrystalline aggregates, and its mean grain-size usually exceeds that of quartz. Taken together, these factors furnish overwhelming evidence of a volcanic source rock and brief transportation.

The only other detrital grains in the arkoses belong to the heavy mineral class. Dusty and granular haematite occurs abundantly in the purple-coloured arkoses, while rounded to ragged grains of titaniferous magnetite are more widely distributed. The titaniferous ore is either partly or completely altered to very fine granular material often possessing a distinct though turbid pleochroism. This pleochroic mineral may be brookite or rutile (Deer and others, 1962, p. 30) but it is more probably sphene. Tiny individual grains or dust-like particles of sphene, exhibiting varying degrees of turbidity, are abundant in all of the arkoses. Whether this sphene dust is detrital or authigenic is conjectural but the former is regarded as being more probable (Brown and Thayer, 1963, p. 423). Turbid grains of epidote also occur widely and, like the sphene, they are of doubtful origin. Sparse, well-rounded clear grains of both epidote and sphene are of unquestionable detrital origin. The other heavy minerals are tourmaline, zircon and rare allanite. The tourmaline is irregular in its distribution and in many sections it was not recorded. It is most abundant in the Cape Mayo arkoses and in the fine-grained relatively well-sorted siltstones forming a small part of the succession at Mount Argus.

Except in the very coarse sandstones and breccias, almost all the recognizable *lithic fragments* in the green and purple arkoses are volcanic. They comprise devitrified acid glassy lavas, now represented by a fine-grained micro-intergrowth of feldspathic and quartzo-feldspathic material in which feldspar micro-phenocrysts and needle-like crystallites are embedded giving a modified hyalopilitic texture. Structurally, the devitrified groundmass consists of scaly or fibrolamellar aggregates but in some fragments it is radiolitic (Johannsen, 1948) and there are rare fragments of finely banded microspherulitic rhyolite. The scaly aggregates are composed of potash feldspar, the radiolitic and spherulitic material being a cryptocrystalline intergrowth of both quartz and potash feldspar. However, in some fragments, devitrification has yielded pure siliceous aggregates which may be either of quartz or chalcedony. Most of the volcanic fragments are dusted with haematite and in some cases the altered groundmass is completely obscured by intense haematite staining. The delicate structures exhibited by the haematite are closely similar to those observed in many of the purple lavas of Mobiloil Inlet and Mount Argus.

The coarser sediments near the base of the succession at Mount Argus contain lithic fragments of both sedimentary and volcanic origins. These include elongated shales or mudstones, silty shales, muddy sandstones and a few fragments of almost pure orthoquartzite. The sandstones are generally characterized by a high quartz to feldspar ratio, a sericite-rich matrix and prominent small grains of tourmaline, which links them firmly with the sandstones of the Kay Nunatak sediments.

As shown in Table III, the arkoses have a high *matrix* content. There are several indications that a significant part of the matrix is the result of post-depositional alteration of volcanic and, to a lesser extent, sedimentary fragments. These factors include the following: complete gradation from well-defined and easily recognizable volcanic fragments to those whose origin and nature have been all but obliterated; the preservation in iron ore of very delicate structures which must have originated in a volcanic rock but which now appear to be an integral part of the general matrix; relict (?) perlitic texture; the rare occurrence of highly embayed quartz grains in assumed volcanic fragments which merge imperceptibly with the enclosing matrix; and finally, marked patchiness in the sericite distribution in some thin sections. The predominance of volcanic detritus in the matrix is indicated by the microcrystalline to cryptocrystalline low-polarizing mosaic of quartz and feldspar in which small faint shard shapes can be detected (e.g. E.2140.2). Several of the arkoses (e.g. E.2140.3) are very rich in sericite. The effects of shearing stress are much more clearly defined in these sericitic sandstones, and incipient recrystallization to muscovite is also apparent.

4. *Mount Argus sediments*

When plotted on the QMF diagram (Fig. 6), the Mount Argus sediments are similar to the green and purple arkoses as far as the relative proportions of the grains and lithic fragments are concerned. Other properties common to both sedimentary sequences include the general abundance of tuffaceous material, the prominent strain extinction patterns in the detrital quartz grains, very fresh, generally angular grains of orthoclase and albitic plagioclase including a little chequer-board albite, certain distinctive diagenetic reactions, and the widespread occurrence of turbid sphene dust. It is on the basis of all these factors that the Mount Argus sediments are tentatively regarded as a facies variation of the arkoses. The two sedimentary successions differ in several respects of which the following are probably the most important:

i. Many are extremely tough, massive chert-like rocks usually black or dark grey in colour.
ii. Haematite is never present in the matrix.
iii. The volcanic rock fragments include rock types not recorded in the arkoses.

As in the arkoses, the detrital *mineral grains* are dominated by quartz and feldspar, but the grain-size, ranging from fine sand to silt, is generally smaller. Both minerals exhibit extreme variations in shape, and sub-spherical, triangular, cuspate, spatulate and ribbon-like forms are present. Two varieties of quartz occur in several sections: the first is typically pellucid except for a very light dusting, whereas the second type always has uniform extinction but is crowded with turbid inclusions of unidentifiable material. From other evidence (p. 30), the second variety, which is always subordinate to the first, is of volcanic origin. The plagioclase ranges from albite to sodic oligoclase in composition. Normal polysynthetic twinning on the albite law is usually present but several grains display an irregular blocky twinning bearing certain resemblances to chequer-board twinning. Orthoclase is relatively uncommon. It includes both microperthite and cryptoperthite, and a few grains have a perfect lath shape.

Heavy minerals of detrital origin are not abundant and the two which occur most widely are allanite and zircon, the former being the more important. A little muscovite occurs in a few of the thin sections. Nearly all of the sediments in the Mount Argus sequence are rich in extremely diffuse particles and aggregates of turbid sphene and clinozoisite, some of which may be detrital though this is uncertain. Well-rounded detrital grains of epidote and sphene are rare.

Of the *rock fragments*, several of volcanic origin are broadly similar to those present in the arkoses and they consist of altered acid lavas. The products of devitrification of the groundmass range from almost pure spherulitic orthoclase to pure silica, in which small laths of clear albite and rare plagioclase microphenocrysts are embedded. The siliceous alteration products show a complete gradation from fibrous chalcedony to uniformly extinguishing quartz and, as stated by Pelto (1956), the distinction between the two is arbitrary. The quartz generally forms a medium-grained mosaic with frayed interlocking margins and it is characteristically full of inclusions especially specks of altered iron ore. The arrangement of these inclusions leaves no doubt that the quartz was derived by devitrification of a glassy lava, since the outline of the original texture is perfectly preserved.

The tuffaceous sediments also contain altered acid to intermediate lavas not represented in the arkoses. One such lava type differs from those previously described in having microphenocrysts, swallow-tailed crystallites and longulites of some ferromagnesian mineral pseudomorphed by pale green cryptocrystalline (?) chlorite. Relict ophitic textures are readily recognizable in these lavas, and the devitrified groundmass consists of an aggregate of imperfect spherulites of low-polarizing orthoclase, in which feldspar microlites with serrated edges can often be seen. Another type of volcanic fragment looks like a chert, suggesting that it may be silicified tuff.

Small, isolated shaly pellets in an advanced state of assimilation by the enclosing matrix occur in most of the sediments; otherwise, sedimentary fragments are restricted to the sandstones and conglomerates. Several chips of orthoquartzite in varying stages of disruption were recorded in one tuffaceous sandstone (E.2139.3), while in the conglomerate (E.2139.1) there are small fragments of micaceous sandstone with detrital tourmaline.

Because the *matrix* is so extremely fine-grained, its constitution is impossible to determine by normal optical means. In a few rocks, it is colourless or transparent under ordinary light but it has a low birefringence and appears to consist of a cryptocrystalline aggregate of quartz probably accompanied by feldspar. Appreciable amounts of sericite and clay minerals are usually present and in some cases clayey material predominates, giving the matrix a brown muddy appearance. The clay minerals cannot be identified optically, although the common fibrous or spherulitic habit suggests that montmorillonite may be the most important one present. Superficially, the matrix is comparatively uniform and there is not the same convincing evidence as in the arkoses that it is largely composed of disintegrated volcanic fragments. However, there are a few sediments, notably specimen E.2134.3, in which there are abundant glass shards pseudomorphed by quartz and albite. Furthermore, a number of diagenetic reactions discussed in detail later (p. 22) reveal underlying inhomogeneities of considerable significance and these show that the original matrix was generally rich in vitroclastic material. The clay minerals probably resulted from the alteration of glassy fragments.

5. *Crabeater Point sediments*

These sediments are dominated by dark carbonaceous shales and silty shales consisting essentially of angular detrital quartz and albitic plagioclase grains set in an indeterminate matrix. In addition to forams, there are small patches of authigenic quartz and albite, several of which have shard shapes. A few sandstones also occur in the succession and one of these (TL.310.26) is a calcareous arkose in which detrital feldspar far exceeds quartz. Some fresh twinned grains of oligoclase are present but much of the feldspar is so highly altered to sericite and calcite that its original nature cannot be determined. The quartz is outstanding in that most of it is exceptionally clear, it has a cracked appearance and extinguishes uniformly. All of these factors indicate a volcanic origin and provide a sharp contrast with the quartz grains present in the other sedimentary successions. Biotite is a prominent constituent occurring in several forms including extremely twisted flakes moulded round detrital grains, radiating aggregates, diffuse interstitial patches and regular cleavage flakes. Small lithic pellets of intensely altered lava with a vague trachytic texture and charged with iron ore are present but other dark patches composed of calcite, granular iron ore and carbonaceous material are of a doubtful origin. The heavy minerals include allanite, epidote and apatite. The interstitial matrix is sericitic with much secondary calcite, carbonaceous dust and iron ore, including some pyrites.

The cherty bands interbedded with black shales about 13 km. south-east of Crabeater Point consist of isolated angular grains of evenly extinguishing quartz and small turbid plagioclase crystals set in a cryptocrystalline siliceous matrix locally impregnated with secondary calcite. The matrix also contains tiny dispersed flakes of sericite, small grains of iron ore (including leucoxene) and a few granules of (?) epidote. Patches of intergrown albite and quartz are thought to be authigenic. One or two pellets of brown mud are also present.

B. DIAGENESIS

According to the definitions of Pettijohn (1957, p. 649) and Dapples (1959, p. 36), diagenetic changes occur in all of the sediments of the Mobiloil Inlet area, but in the sandstones of the Kay Nunatak sediments and in the cataclastic sediments such changes are restricted mainly to recrystallization of clay minerals and sericite to muscovite, and partial cementation by haematite. In this section, detailed discussion will be limited almost entirely to authigenesis or the spontaneous growth of new minerals. Authigenesis is particularly prominent in the Mount Argus sediments and in the green and purple arkoses. A detailed study of these authigenic minerals and the chemical re-organizations which produced them is of considerable value in estimating the original composition and texture of the sediments concerned, and in assessing their post-depositional history.

1. *Quartz and feldspar*

Secondary enlargement of detrital quartz grains was observed in a few of the more texturally mature sandstones of the Kay Nunatak sediments but, apart from this, pure authigenic quartz is uncommon. However, intergrowths of authigenic quartz and albite resulting from reaction between the micro- or cryptocrystalline quartzo-feldspathic matrix and migrating solutions are very prominent in the arkoses and in the Mount Argus sediments. The albite is nearly always far more abundant than the quartz and the latter is commonly absent altogether. The larger clusters of authigenic albite with little or no associated quartz are formed of an interlobate mosaic of mutually interfering laths with gradational margins (Plate Vb).

Several thin sections of arkose (especially specimens E.2135.2 and 3) show a rather different type of authigenic albite. Here the clots of authigenic albite are more compact and have sharper margins than those just described. They tend to have a rounded outline and consist of several disorientated laths set in a base of relatively uniform albite (Plate Vc and d). Rarely, the disorientated laths occur in a base of orthoclase. In later stages of development, the laths decrease in number and become progressively closer to parallelism with each other while the uniform albite grows at the expense of the laths. Small amounts of orthoclase are usually intergrown with the albite. This growth of albite, which may possess chequer-board twinning, is somewhat similar to that found in the New Zealand keratophyres described by Battey (1955). He attributed the process to soda metasomatism whereby nucleation of albite took place about numerous centres in the keratophyre matrix, followed by organization into a single porphyroblastic crystal of chequer-board albite achieved by successive recrystallizations. The sequence of events envisaged by Battey is consistent with the properties of the chequer-board albite in the arkoses, except that in the latter at least some of the albite porphyroblasts appear to have developed from devitrified lava fragments. These reactions demonstrate that in the sedimentary matrix, there was free mobility of ions, particularly silicon and alkalis. The unusual chemical activity probably reflects the dominance of volcanic detritus in the matrix.

2. *Prehnite*

Authigenic prehnite only occurs in the Mount Argus sediments. Although the prehnitization is clearly related to the presence of volcanic detritus, other factors must also govern its occurrence since there are highly tuffaceous sediments which lack prehnite. In the thin sections examined, prehnite is apparently restricted to sediments in which the matrix has a relatively high argillaceous content. All stages of prehnitization are demonstrated in these sediments and the first is represented by nebulous patches in the matrix possessing a finely mottled appearance under crossed nicols. In these patches the matrix is impregnated with much very fine-grained granular or scaly material which is mostly prehnite but which also includes some sericite and rare muscovite. The prehnite is not uniformly distributed throughout the patches and it tends to be concentrated along the margins of small lithic fragments of probable volcanic origin. Similar concentrations of this finely granular prehnite along interlacing arcuate lines reveal underlying inhomogeneities in the matrix which are otherwise undetectable.

The next significant stage brought about the development of discrete units having an average length of 0·05 mm. These units formed independently since they are somewhat scattered; nevertheless, they generally occur in well-defined clusters, each unit always having the same optical orientation as its neighbour in the same cluster. The earliest formed organized units of prehnite commonly have outlines identical to glass shards and, although in a number of cases this shape is a function of the detrital grains and fragments around which the prehnite units have been moulded (Fig. 7a), most of the units are actual shard pseudomorphs. Once established, these units appear to have initiated growth of identically orientated prehnite in the immediately adjacent matrix. In this piecemeal manner, large spongy aggregates of prehnite (Plate Ve and f) were built up, each one behaving optically as a single unit. Those which have attained an advanced stage of development are relatively compact but their composite nature is perfectly preserved by an intricate network of curving lines marking the mutual boundaries of individual units within the aggregate. Under high power, these lines consist of original matrix incompletely prehnitized and apparently they are never eliminated. Successive stages in the evolution of prehnite are illustrated in Fig. 7a–e and various aspects of its structure are shown in Plate VIa and b.

Detrital grains and lithic fragments incorporated into the prehnite aggregates give a poikiloblastic texture as in specimen E.2134.6. However, many plagioclase grains in this setting are either partially or completely prehnitized and this secondary prehnite is always in the same orientation as that in the enclosing aggregate. Similarly, several volcanic fragments show partial or complete alteration to prehnite and it is noteworthy that, in both the plagioclase and the volcanic fragments, secondary replacement by prehnite never occurs outside the spongy prehnite aggregates.

In the nebulous patches marking incipient prehnitization of the matrix, the tiny grains and scaly particles have low polarizing colours and incomplete extinction. The earliest formed coherent units have maximum interference colours of first-order yellow or orange and they are very grainy and turbid, a feature inherited from the original matrix. During the subsequent growth of low-polarizing prehnite in the adjacent matrix, the first units became less grainy and their maximum interference colour was raised to first-order red. Consequently, although all the components of prehnite in each composite aggregate are in the same orientation, they do not exhibit identical optical properties. This disparity between the interference colours was maintained throughout the subsequent development of the prehnite, so that in the final compact aggregates the distribution and size of the first units are preserved by areas of relatively high birefringence. Since many of these initial units are shard pseudomorphs the latent vitroclastic or bogen texture of the sedimentary matrix is well displayed not only by the network of curving lines already referred to but also in many cases by shard-like shapes having second-order blue or green interference colours against a yellow or orange background.

The differences in birefringence, which are unrelated to differences in optical orientation, may be partly caused by progressive changes in composition such as substitution of Fe''' for Al, but it is not regarded as an important factor since the interference colours for a given orientation are clearly related to the degree of granularity in the prehnite. This is shown in at least two ways. First, the areas with highest birefringence in any prehnite aggregate are those which are least turbid; secondly, the prehnite derived from plagioclase grains enclosed in a prehnite aggregate always has a higher birefringence despite its similar orientation, and it is never turbid.

Although in the preceding discussion emphasis has been placed on the fact that all the components in any aggregate take up the same optical orientation, the aggregate as a whole exhibits the complex extinc-

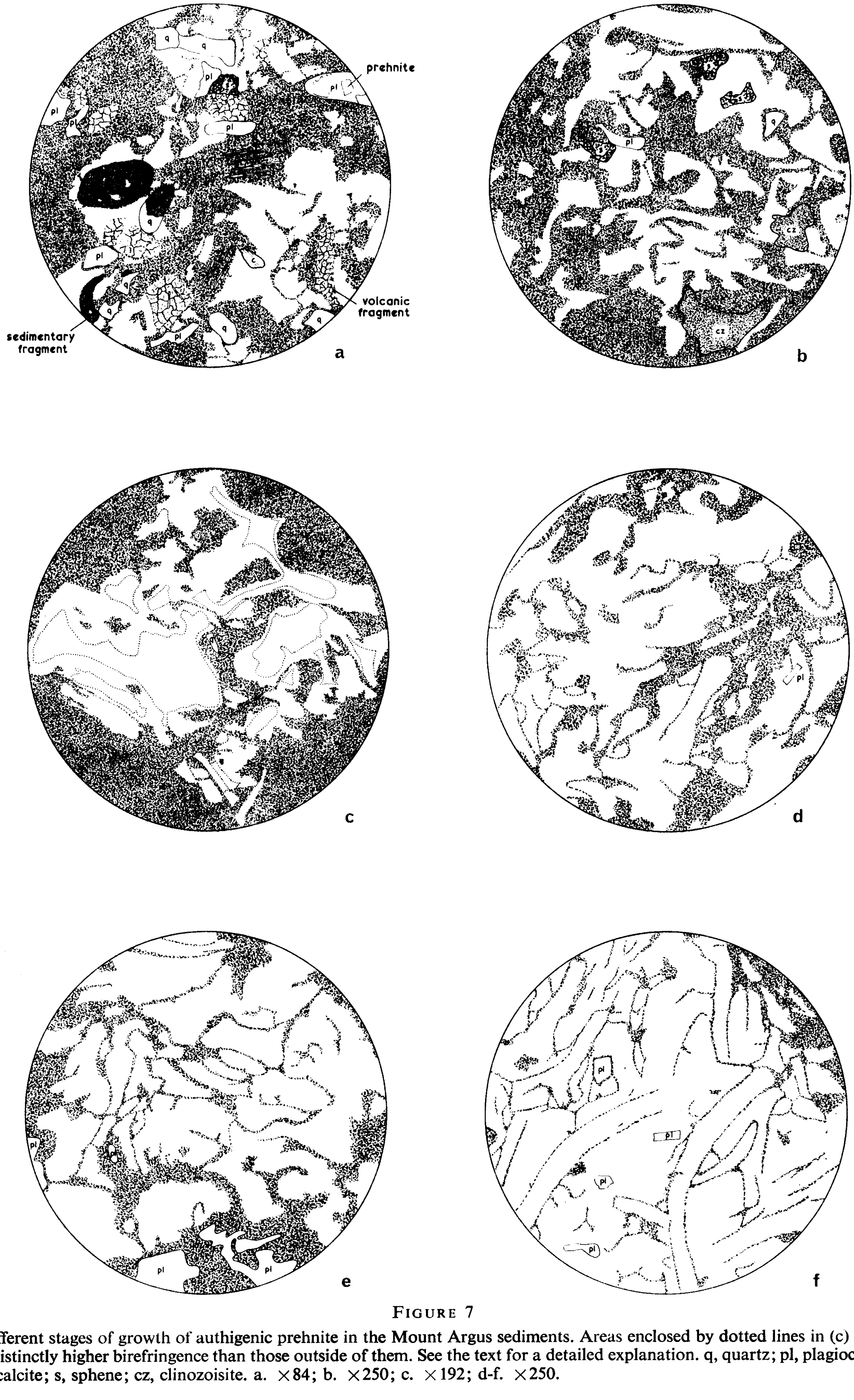


FIGURE 7

Different stages of growth of authigenic prehnite in the Mount Argus sediments. Areas enclosed by dotted lines in (c) have a distinctly higher birefringence than those outside of them. See the text for a detailed explanation. q, quartz; pl, plagioclase; c, calcite; s, sphene; cz, clinozoisite. a. ×84; b. ×250; c. ×192; d-f. ×250.

tion patterns commonly observed in prehnite. These patterns include wavy and undulatory extinction, bow-tie structure, vague spherulitic structure, etc. The prehnite has $2V\gamma = 68° \pm 1°$. The {001} cleavage is invariably absent except where the prehnite is secondary after plagioclase.

Prehnitization of sediments has been reported from a number of localities including Oregon (Dickinson, 1962; Brown and Thayer, 1963), Navarino Island off southern Chile (Watters, 1965), South Georgia (Tyrrell, 1915, 1930; Trendall, 1953, 1959), Alexander Island (Taylor, 1966; Horne, 1967*b*), New Zealand (Coombs, 1954; Brothers, 1956) and New South Wales (Crook, 1960). The sediments concerned have several important features in common. First, they are all rich in intermediate to acid volcanic detritus, notably altered glass; secondly, with rare exceptions, they are all Mesozoic in age; thirdly, they all lie on the circum-Pacific arc; and finally, none of the sediments has been affected by igneous intrusions. However, in many of the occurrences listed above, prehnite is also present in veins as well as primary irregular growths. Veins of this kind are completely absent from the Mount Argus sediments. Prehnitization of the volcanic greywackes in South Georgia is clearly identical to that described above and Tyrrell's (1930, p. 38) description, "The prehnitization spreads like a disease through the affected rocks" is most apt. Tyrrell (1915) also referred to the variations in birefringence in a single patch of prehnite.

3. *Epidote and clinozoisite*

Authigenic epidote is found only in the green and purple arkoses, whereas clinozoisite, like prehnite, is restricted to the Mount Argus sediments. Most of the epidote of undoubted authigenic origin occurs in very diffuse aggregates composed of small units which are commonly shard-shaped. In many respects, these aggregates are identical to those of prehnite, and the origin and development of the authigenic epidote clearly followed a similar course. There are, however, certain important differences. First, the individual units belonging to a single aggregate all have different optical orientations. Secondly, the aggregates, irrespective of their size and degree of development, are never compact. A few plagioclase grains within the aggregates show partial alteration to epidote. Under ordinary light, the epidote has an extremely muddy and grainy appearance which in some cases all but obscures the interference colours. In reflected light, it is greyish white, possibly indicating the presence of granular leucoxene.

Clinozoisite generally occurs as small scattered grains; several of these are turbid but others are fresh and possess a somewhat ragged outline. When observable, the interference colours are bright blue or purple, although greyish brown patches which migrate along the grain on rotation of the microscope stage are also present. Brown and Thayer (1963) regarded this feature as diagnostic of pumpellyite, but in the few grains where the two cleavages were observed the cleavage angle corresponds more to clinozoisite than to pumpellyite.

Extremely turbid clinozoisite pseudomorphs of glass shards are scattered through the matrices of several rocks. Like the prehnite, the clinozoisite has not replaced the glass shards directly but it represents authigenic growth in the fine-grained matrix whereby the original outline of devitrified and completely altered glass shards is reproduced. Large diffuse aggregates of this intensely muddy clinozoisite were only seen in one sediment (E.2134.1), although some of the material is unidentifiable. The aggregates have much in common with the epidote aggregates derived from altered shards and they are thought to have had a similar genesis. Small allanite crystals are embedded in the clinozoisite. Prehnite is associated with the clinozoisite and the observed relationships clearly indicate that the prehnite has grown at the expense of, though not directly replacing, the clinozoisite. This reaction is not surprising, since the chemical compositions of the two minerals are almost identical, the main difference being the greater amount of (OH) in the prehnite.

4. *Sphene*

The general form and differing modes of occurrence of authigenic sphene are identical to those displayed by epidote except that the aggregates tend to be very small generally. The sphene is present in both the arkoses and the Mount Argus sediments. The turbid variety is difficult to distinguish from the turbid epidote and the difficulty is increased by the fact that the two minerals are locally intergrown. In general, however, the epidote and sphene show a marked antipathy.

5. *Fluorite*

Authigenic fluorite was only recorded in thin bands of volcanic conglomerate interbedded with the tuffaceous rocks of the Mount Argus sediments. In the hand specimen, the conglomerate consists of rounded to well-rounded grey, green and dark grey pebbles set in a tuffaceous matrix. Many of the pebbles are of an aphanitic siliceous rock resembling porcellanite but there are also pale yellowish grey pebbles, which on weathered surfaces have been largely etched out producing a honeycomb structure.

In thin section, fragments of cryptocrystalline silicified tuff, altered fine-grained acid lava and scarce sedimentary rock together with detrital quartz and feldspar grains are set in a matrix which consists mainly of an intergrowth of recrystallized quartz and albite. Several of the highly siliceous pebbles contain small, isolated nebulous patches of fluorite but in general fluoritization is confined to the matrix of the conglomerate. Different stages in the growth of the fluorite are exhibited; the incipient areas are characteristically diffuse, whereas the best-developed patches though clearly composite are compact with sharp well-rounded margins (Plate VIc). The fact that these circular areas of fluorite are "pseudo-pebbles" and do not represent the complete fluoritization of original pebbles of silicified tuff is demonstrated by the presence of detrital particles of deformed quartz, feldspar and acid lava within the fluorite. Furthermore, the fluorite pebbles have crenulated margins, with several detrital grains partly embedded in the fluorite and partly enclosed by the adjacent unaltered matrix. The fluorite "pseudo-pebbles" are those which weather out in a peculiar fashion in the hand specimen.

The fluorite is brownish in colour and is muddy in appearance. The turbidity, which results from the fine-grained nature of the material being replaced, tends to modify or obscure the physical and optical properties of the fluorite. Thus the relief is increased and the octahedral cleavage is commonly absent, while under crossed nicols innumerable pin-points of dull grey-coloured light are discernible. However, several detrital feldspar grains incorporated into the areas of fluoritization show partial replacement by fluorite and in this setting it is clear, uniformly isotropic and shows a perfect cleavage.

The development of authigenic fluorite is closely comparable with the diagenetic reactions already described. That devitrified glass is the main source of material for the fluoritization is strongly suggested by the isolated occurrence of undoubted shard shapes in the fluorite "pseudo-pebbles" and also by the presence of one small fragment of spherulitic obsidian, in which the original glassy base has been completely and uniformly replaced by fluorite.

6. *Calcite*

Calcite occurs in most of the sedimentary groups in the Mobiloil Inlet area, although it has a fairly limited distribution. There are two main occurrences of calcite attributable to diagenetic reactions. The first of these is the formation of calcite "beef" in the carbonaceous mudstones of the Crabeater Point sediments. The other occurrence of calcite is of authigenic origin. The best examples of authigenic calcite are found in the Mount Argus sediments near Cape Mayo, where it is in stable association with authigenic prehnite. In common with the latter, the calcite forms large diffuse aggregates but, although shard shapes can be distinguished, they are not as common as in the prehnite aggregates. Otherwise, the calcite aggregates are very similar to those of prehnite in their general characteristics.

7. *Conclusions*

Apart from the quartz and albite, all of the authigenic minerals described here are lime-bearing phases, they all possess a volatile constituent such as (OH), CO_2 or fluorine, and they are all replacement products in part at least of volcanic detritus. The spontaneous development of the minerals and the general absence of veining suggest that the lime was contributed by the devitrified and altered volcanic debris in the sediments and was not introduced from an external source. The authigenic fluorite is difficult to explain but the fluorine, like the other volatiles, may well have originated from the trapped sea-water.

The close association of calc- and calc-alumina silicates with different degrees of hydration suggests that the development of these hydrous mineral phases is not a direct function of depth as postulated by Coombs and others (1959). Dickinson (1962) and Brown and Thayer (1963) also found that the distribution of prehnite and associated authigenic minerals in sediments varied unsystematically and concluded that the initial rock composition was the most important factor governing the distribution. This conclusion is consistent with the observation that prehnite is restricted to rocks which have a relatively rich argillaceous content and that, whereas prehnite and clinozoisite are commonly associated, prehnite and epidote never occur in the same rock.

Although the authigenic minerals do not fit into a progressive series related to increasing depth of burial, the diagenetic reactions almost certainly took place at considerable depth. Packham and Crook (1960) have stated that there is a good correlation between the energy index and the depth of burial of the various authigenic minerals. The energy index of a mineral decreases with increasing reaction energy, and it is significant that sphene which has the lowest energy index (1·36) of all authigenic silicates is common in the arkoses and the Mount Argus sediments.

The diagenetic reactions furnish valuable evidence concerning the original texture of the sediments, since the development of several minerals (notably prehnite and epidote) reveals a vitroclastic structure which had previously been completely destroyed during devitrification and alteration.

C. PROVENANCE AND DEPOSITIONAL ENVIRONMENT

Insufficient statistical work has been done on the sedimentary rocks to make an accurate assessment of provenance and environment of deposition but certain salient facts emerge from the preceding descriptions and these are now briefly discussed.

The five sedimentary successions mapped in the Mobiloil Inlet area can be divided into three categories which reflect fundamental differences in provenance. The first category comprises the Kay Nunatak sediments and the cataclastic sediments in which volcanic detritus is generally absent or extremely rare. The predominance of quartz in the detrital grains indicates a source terrain of granitic and sedimentary rocks, the latter probably being subsidiary. Several features, such as the marked deformation of the quartz, the generally high proportion of plagioclase relative to the total feldspar content, the albitic composition of the plagioclase, the almost complete absence of biotite and the relative abundance of sericite and muscovite, provide a possible link between the sediments and an intrusive rock known to occur along the northern margin of the Mercator Ice Piedmont. This plutonic rock was recorded as a sheared muscovite-granite; in thin section (E.1631.2) it is very fresh, but fractured crystals of twinned albite account for nearly two-thirds of the total feldspar, the remainder being orthoclase.

The second category of sedimentary rocks includes the green and purple arkoses and the Mount Argus sediments. These sediments had a mainly volcanic provenance but the ubiquitous strongly deformed quartz grains indicate that some of the detritus originated from plutonic or metamorphic rocks. The marked similarities between the volcanic fragments in the arkoses and the volcanic rocks occurring *in situ* in Mobiloil Inlet and Mount Argus give a clear indication of the main source rock for the arkoses. Many of the volcanic fragments in the Mount Argus sediments are almost identical to the Cape Mayo lavas.

The third category is represented by the Crabeater Point sediments which were derived from a mixed source terrain composed mainly of sedimentary and volcanic rocks. The latter, however, were different in character from the Mobiloil Inlet lavas, and this is shown by the presence of volcanic quartz in the sandstones near Crabeater Point. Quartz phenocrysts are conspicuously absent from the volcanic rocks of the Mobiloil Inlet area.

The sandstones and associated rocks of the Kay Nunatak sediments are considered to have been deposited in relatively shallow water, and the textural anomalies reflect the complex nature of this environment. The siltstones and shales, which are regarded as equivalent to the Kay Nunatak sediments, are broadly similar to the siltstone-shale sequences which form an important part of typical geosynclinal deposits (e.g. Aitkenhead, 1965). Thus they were probably deposited in a deep-water environment. The paucity of rock fragments in the siltstones and the apparent absence of any pebbly mudstones in the succession show that the depositional area was not subject to any sudden influx of detritus by turbidity currents.

Since the matrix in the green and purple arkoses and in the Mount Argus sediments is partly mechanical and partly chemical in origin, the textural immaturity is not in itself a valid criterion for determining the depositional environment. Nevertheless, the abundance of aphanitic volcanic fragments and the angularity of many detrital grains preclude prolonged transportation and weathering. The sedimentary structures, the breccia bands with imbricate structures and the rhythmic alternation of green and purple facies in the arkoses indicate a very unstable depositional environment with periods of rapid burial interrupted by short periods of relative stability. Such conditions may have occurred marginally to a major fault zone. The authigenic mineral assemblage confirms that the sediments were relatively deeply buried.

According to Thomson (1967), the general lithology of the Crabeater Point sediments, especially the high carbonaceous content, indicates that the sediments were laid down in a stagnant restricted environment of a shallow-water nature. The sporadic distribution of fossils shows that marine organisms were washed in from the sea but they did not survive long in the hostile environment.

IV. VOLCANIC ROCKS

A. GENERAL PETROGRAPHY

Almost all of the recorded outcrops of volcanic rocks south of Mobiloil Inlet are restricted to a comparatively narrow, slightly arcuate zone more than 95 km. long, stretching from Kay Nunatak to Cape Hinks. In all the examined sections, tuffaceous rocks are either absent or accessory, and the lavas are very similar in lithology, petrography and chemistry along the entire zone. The only volcanic rocks outside this narrow zone are at Cape Mayo and on the nearby cliffs to the north-west where submarine lavas crop out. The Cape Mayo lavas are almost certainly younger than those within the arcuate zone and they are also different in chemistry, but their similarity in other respects, particularly in texture, demonstrates that they are genetically related to them, and for this reason all the lavas are considered together.

1. *Lavas*

a. *Phenocrysts.* As far as phenocrysts are concerned, the lavas have a very simple mineralogy; the only recognizable phenocrysts are of sodic plagioclase which is always present though in varying amounts. Although the lavas are silicic, quartz is never present as phenocrysts. Where the plagioclase is scarce, it tends to occur as individual crystals, but in most lavas there is a marked glomeroporphyritic texture. The crystals are mostly subhedral to euhedral though conspicuous marginal embayment is fairly common and a few phenocrysts have been deeply corroded. There is little variation in composition, the anorthite content never falling outside the range of 5 to 15 per cent. Primary twinning is rare. Secondary glide twinning on the albite law is present in those lavas which show evidence of deformation resulting mainly from flow, and in some cases this twinning is distorted and sharply truncated by cross-fractures. Secondary twinning of possible replacement origin and with a characteristic blocky development occurs in many phenocrysts. Potassium feldspar, considered to be cryptoperthitic orthoclase because of its irregular extinction, partially replaces many of the albite phenocrysts. This replacement, which is clearly a late-stage process since it occurs initially along a network of cracks, may reach an advanced stage in a few crystals with the intergrown phases forming complex chevron patterns, but complete orthoclase pseudomorphs were never observed. Apart from the orthoclase, the plagioclase phenocrysts have many kinds of inclusions and alteration products. Whereas most of the purplish black lavas occurring at Calypso Cliffs and on the lowermost exposures at Mount Argus contain comparatively fresh plagioclase with only slight alteration, the phenocrysts in the strongly coloured purple and brown lavas are generally strongly altered. The main alteration products include calcite, sericite, scaly prehnite, chlorite, epidote and indeterminate dust. The most important inclusions are of altered glass which may have a lobate, vermicular or lamellar form. Other inclusions comprise skeletal or granular haematite, leucoxene, sphene and apatite.

Besides the glomeroporphyritic clusters, several of the lavas contain much larger ovoid masses consisting mainly of anhedral or rounded albitic plagioclase crystals with abundant inclusions of chlorite, iron ore and sphene. These plagioclase-rich nodules may be partly cemented by haematite or chlorite and they are possibly fragments of early formed crystal cumulates carried up in the lava.

Apart from plagioclase, no other definite phenocrysts have been recorded in the black and purple lavas. However, there are well-rounded areas of chlorite rimmed and veined by oxidized iron ore and these strongly resemble altered olivine. Similar patches composed largely of fibrous or scaly sericite and with some intergrown chlorite also occur, particularly in the bright purple-brown lavas. The chlorite consists of a fine-grained aggregate of fibrous or partially spherulitic scales which are distinctly pleochroic from pale yellow to emerald green and which have a very weak birefringence. Although some of these rounded areas of chlorite or sericite with iron ore probably represent strongly resorbed and replaced phenocrysts or xenocrysts of an original iron-rich mineral, possibly fayalite, many have characteristics which are not fully consistent with this interpretation. For example, they are unevenly distributed in any one rock, most of them being closely concentrated in or near a few polycrystalline clusters of plagioclase; several are characterized by shallow bulbous projections and rounded or angular re-entrants, producing a general shape which bears little resemblance to any original or modified crystal form; and those enclosed in the plagioclase aggregates tend to be squeezed between individual crystals. Additional evidence is provided by rounded pools and irregular intersertal masses of the same chlorite unaccompanied by ore; these are clearly not secondary after an original mineral phase. Battey (1956) reported a similar occurrence of chlorite in spilites from New Zealand and he considered it to be a product of primary crystallization of a residual magma greatly enriched in iron. A similar explanation may account for the chlorite areas in the lavas just described, although the precise relationship between those heavily veined and those lacking iron ore is difficult to establish. A small number of chlorite patches are partly replaced by albite and quartz, and in this respect they are similar to the spilites of the Builth Volcanic Series of Wales (Nicholls, 1959).

b. *Groundmass.* The general uniformity of the lavas in the Mobiloil Inlet area is particularly well shown by the groundmass. Initially, most if not all of the lavas had a glassy base which subsequently devitrified into a cryptocrystalline quartzo-feldspathic intergrowth liberally peppered with iron ore. Some of the latter was originally contained in the glass and liberated during devitrification. Small plagioclase laths and crystallites are commonly embedded in the groundmass with a resultant hyalopilitic texture, and rarely the texture approaches intersertal. Apart from the Cape Mayo lavas, the iron ore is largely oxidized to haematitie; in the lavas at Victory Nunatak the groundmass is almost completely obscured by intense haematite staining. Leucoxene and sphene are the alteration products of granular iron ore in some cases.

All of the basic textural types described by Reed (1895) from the felsites near Fishguard, and by Battey (1955) from the New Zealand keratophyres are represented; these are the microlitic, felsitic, micropoikilitic, radiolitic and spherulitic textures.

A typical groundmass texture is illustrated in specimen E.2143.1, in which the altered glass is light brown, grey polarizing and cryptocrystalline with an aggregate structure. The extinction is characteristically irregular or wavy. There are scattered small laths and swallow-tailed crystallites of plagioclase in approximate parallelism. Iron ore, mostly haematite, is fairly abundant but it is not uniformly distributed and occurs in several different forms. These include: a general light dusting; minute specks forming dense clouds several of which are shard-shaped; curved needles and rods resembling trichites; and comparatively coarse particles concentrated mainly at the margins of vaguely circular patches with a spherulitic structure which may represent areas of incipient crystallization prior to devitrification. Appreciable quantities of fine scaly chlorite and (?) kaolinite accompany the iron ore in places. A number of strongly pigmented purple lavas are texturally similar to the black or purplish black lavas such as the one just described, except that the groundmass is generally much richer in oxidized iron ore. A good example of this type is specimen E.2132.2. In this lava the cryptocrystalline alteration product of the original glass is fibrous, and the clear uniaxial figure with a positive sign obtained from the larger units in the aggregate structure suggests a preponderance of silica, probably chalcedony. The groundmass is heavily charged with haematite which occurs as extremely minute specks, rendering the altered glass pale pink or reddish brown in colour, and also as feathery growths (Plate VId). Although the iron ore in the groundmass appears to be uniformly distributed in ordinary light, marked and systematic concentrations of the dusty material observable under crossed nicols reveal a micro-brecciated structure which is matched by detectable differences in the degree of devitrification.

Another minor variation in texture is illustrated by several lavas at Calypso Cliffs (e.g. E.1612.4). Here, the groundmass consists mostly of the normal cryptocrystalline material arranged in fascicules but a little is composed of a very fine micro-mosaic of quartz and albitic plagioclase. The cryptocrystalline areas are crowded with small (?) gas bubbles (0·03 mm.) which are distinctly brown in colour compared with the adjacent material, although they do not contain any recognizable iron ore. The bubbles are generally circular or slightly oval in shape except near phenocrysts where they are considerably flattened. Inclusions of altered glass in the plagioclase phenocrysts also contain these bubbles.

In all of the lavas described so far the devitrification products are represented almost entirely by a cryptocrystalline intergrowth of quartz and feldspar, which usually exhibits a relatively coarse aggregate structure or mosaic. An important modification of this general texture has affected several lavas from widely separated localities, including Kay Nunatak (E.1601.3), Calypso Cliffs (E.1609.2), Mount Argus (E.2136.3), Cape Mayo (E.1618.1) and Cape Hinks (E.1621.3). This textural change, involving postdevitrification enrichment in alkalis and silica, provides the most convincing evidence for the unity of the volcanic rocks in the Mobiloil Inlet area. The various stages in the alteration of the original devitrified base are best illustrated in specimen E.1609.2. Initially, the introduction of silica resulted in progressive enlargement of the quartz component locked in the cryptocrystalline quartzo-feldspathic intergrowth, and at the limit of resolution, the quartz appears as tiny bubbles, irregularly shaped blebs and delicate fibres. With a little further development, the quartz becomes organized into long rods of remarkably constant width, which are arranged in radiating, birfurcating and criss-cross patterns to form a highly intricate plexus (Plate VIe and f). All the quartz rods enclosed in a single unit in the original mosaic are in the same optical orientation so that the texture becomes effectively micrographic. The longer rods may have two or more different orientations along their length depending on how many units they cross. Further silicification leads to the formation of isolated amoeboid pools of clear quartz containing inclusions of the groundmass, and at an even later stage these combine into medium-grained polycrystalline aggregates, the central parts of which are almost inclusion-free.

During the later stages of the above sequence, the intersertal groundmass material generally loses its characteristic mottled and fibrous appearance and albite twinning of a chequer-board type develops in its place. This chequer-board albite is observed in many different stages of organization (Plate VIIa–d), although the precise mechanism whereby coherent, subhedral or euhedral crystals were formed from the small shapeless remnants of the groundmass is not readily apparent. Albitized remnants which belonged to a single unit in the former mosaic usually but not invariably assume similar orientations even when the remnants appear to be disconnected. It seems that in most cases the development of crystals with a recognizable form was achieved by the preferential growth of the largest remnants at the expense of the smaller ones. However, a few large crystals of chequer-board albite consist of optically disorientated sub-individuals, suggesting that "aggregation" with subsequent recrystallization may also have taken place. This chequer-board albite, formed by the metasomatic recrystallization of the original devitrified groundmass, is invariably intergrown with orthoclase, and the potassium necessary for this phase was clearly derived from the altered glass.

As in the post-depositional growth of albite in the green and purple arkoses (p. 22), there is some similarity between the reactions outlined above and those described from the New Zealand keratophyres (Battey, 1955), although there are important differences in detail. The greatest correspondence is in the micropoikilitic type, in which Battey referred to little irregular pools of clear quartz between adjacent cryptographic areas. The latter consist of quartz and potassium feldspar in eutectic proportions, and Battey demonstrated that there was selective replacement of glass by potash, a reaction which also appears to have taken place in the Mobiloil Inlet lavas. The chequer-board albite possibly indicates the introduction of soda as well as silica.

Some of the lavas at Cape Mayo have also undergone advanced silicification but apparently without any associated influx of soda, since no chequer-board albite is present. The early aggregate structure in the groundmass has been replaced by a medium-grained quartz mosaic containing only a few small remnants of turbid, altered feldspathic material (E.1618.1). This mosaic is heavily charged with inclusions of iron ore dust, leucoxene, epidote, chlorite and tiny fibres of biotite (Plate VIIe and f). The turbid grains of detrital quartz recorded in the Mount Argus sediments (p. 21) were undoubtedly derived from these silicified lavas. The quartz mosaic incorporates a former plexus of quartz rods similar to that already described and, although the rods always have the same orientation as the host quartz, they stand out clearly because of their pellucid and inclusion-free nature.

A completely different type of groundmass is illustrated by one of the purplish black lavas at Mount Argus (E.2143.4) and, though this is the only known example, the texture merits a brief description. In the hand specimen, the lava closely resembles a porphyritic pitchstone with a somewhat sheared appearance. The thin section shows that the glassy base has been completely replaced by extremely fine-grained chlorite which in colour, pleochroism and birefringence is identical to the chlorite present in other settings in the volcanic rocks. The unusually regular and beautiful perlitic structure of the original glass has been perfectly preserved (Plate VIIIa) and it is enhanced by restricted alteration to fibrous sericite along the cracks and by the concentric arrangement of narrow ellipsoidal zones in which the chlorite possesses a distinctive lamellar structure. The general ellipsoidal pattern exhibited by the perlitic texture is mainly a flow phenomenon, although subsequent stress may have increased the flattening. Several ellipsoids are distorted near plagioclase phenocrysts, but perlitic cracks in the pools of chloritized glass enclosed by fractured and strained phenocrysts show little or no evidence of deformation. Locally, the chlorite is extensively altered to sericite.

c. *Accessory minerals.* Minerals occurring in accessory amounts include phases which were introduced by late-stage activity as well as the primary crystallization products of magma. Only the latter are considered here, but in some cases a distinction between the two categories is difficult to make. This is particularly so with iron ore which is the most abundant accessory mineral. In addition to veining the chlorite pseudomorphs and forming numerous crystallites in devitrified glass, iron ore occurs as large ragged patches of definite primary origin. The ore is mostly titaniferous magnetite, either marginally altered to haematite or replaced to a varying degree by leucoxene and sphene. Skeletal grains are commonly intergrown with chlorite or calcite, and in general the ore is closely associated with chlorite patches.

The other main accessory mineral is apatite; it is usually of a primary origin and forms subhedral to euhedral prisms which are concentrated in or near chlorite patches, large grains of iron ore and clusters of plagioclase phenocrysts. Most of the apatite exhibits normal optical properties but in a few rocks it is slightly pleochroic from ω = very pale yellow to ϵ = yellow-orange. The more strongly pleochroic types have deep blue to turquoise interference colours.

Epidote is a minor accessory mineral in only a few lavas and it is thought to be entirely secondary in origin.

d. *Amygdales and veins.* The widely occurring amygdales and veins have the same basic mineral assemblage of quartz and chlorite, several being monomineralic and composed of either species. However, in most rocks the quartz and chlorite are either accompanied or replaced by one or more of the following minerals: sericite, calcite, iron ore, albite, epidote, allanite, apatite and sphene, but the observed maximum number of phases in association never exceeds four. In the large amygdales the minerals are regularly arranged in concentric zones of varying width and in a differing sequence. Amygdales containing calcite are usually those in which fine scaly sericite takes the place of some or all of the chlorite. Deep reddish brown, strongly pleochroic allanite is comparatively rare in the amygdales but it is a prominent constituent of some veins, and it is surrounded by intensely pleochroic haloes in chlorite. In the Cape Mayo lavas, several amygdales have a selvage of granular leucoxene and sphene followed inwards by a narrow partial zone of scaly biotite.

The chlorite in the amygdales and veins has identical properties to that of the pseudomorphs and other rounded patches and, as far as its genesis is concerned, it may be significant that allanite prisms are present in all of the different settings.

2. *Tuffs*

Tuffaceous rocks are not important in the volcanic succession of Mobiloil Inlet and, since those which occur are closely similar in composition to the associated lavas, they will only be discussed briefly.

An indurated lithic tuff (E.2133.1) associated with purple-brown lavas to the south-east of Mount Argus consists of rounded fragments of altered lava, much ragged iron ore and scattered crystals of albite and clear quartz set in a muddy matrix rich in sericite. All of the fragments are of devitrified and silicified acid lava comprising a micrographic intergrowth of quartz and feldspathic material, and exhibiting identical textural features to the silicified lavas described above (p. 30). The fragments range widely in size so that the tuff is unsorted. The iron ore is partly oxidized and the matrix contains some haematite dust, leucoxene, sphene and chlorite together with a little apatite. Secondary silicification of the matrix has occurred in patches.

A vitric tuff from Calypso Cliffs (E.1611.2) is composed almost entirely of fragments of devitrified lava. Bent and distorted crystals of fresh albite are set in an extremely fine-grained quartzo-feldspathic groundmass in which the former perlitic texture is remarkably well preserved. Chloritized glass fragments are common and there are a few small particles of chalcedony. Both the large grains of iron ore and the much smaller dust-like particles in the matrix are altered to leucoxene with intergrown sphene. Well-formed prisms and needles of apatite are orange-coloured and moderately pleochroic. Amygdales, lithophysae, spherulites and veins are present.

B. GEOCHEMISTRY

The results of six analyses of lavas from the Mobiloil Inlet area are given in Table V. In terms of silica percentage, the rocks fall into the category of rhyolite or rhyodacite, but it is clear from the values of other oxides that the lavas are not the direct crystalline products of a magma of that composition. Of particular significance in this context is the general preponderance of potash over soda and the absence of any marked systematic relationships when the relevant oxides are plotted on a variation diagram (Fig. 8).

TABLE V

CHEMICAL ANALYSES OF VOLCANIC ROCKS FROM THE MOBILOIL INLET AREA

	E.1612.1	E.1618.3	E.1621.3	E.2135.12	E.2136.3	E.2143.1
SiO_2	74·12	67·83	69·69	66·13	68·75	66·95
TiO_2	0·69	0·96	0·74	1·01	0·95	1·04
Al_2O_3	11·12	11·67	12·72	13·29	12·87	13·32
Fe_2O_3	3·08	1·39	3·70	7·26	4·62	3·08
FeO	1·19	5·80	1·08	0·68	1·40	3·92
MnO	0·04	0·23	0·09	0·11	0·13	0·30
MgO	0·65	2·50	0·89	1·53	1·26	1·72
CaO	1·11	3·46	1·44	1·80	1·63	1·09
Na_2O	1·13	2·43	2·16	2·42	3·52	2·82
K_2O	6·07	1·68	6·33	4·58	4·67	4·71
$H_2O\pm$	0·73	1·50	0·88	1·26	0·67	1·40
P_2O_5	0·12	0·13	0·11	0·19	0·18	0·20
CO_2	0·13	0·94	0·16	0·33	—	0·08
TOTAL	100·18	100·52	99·99	100·59	100·65	100·63
			NORMS			
Q	41·88	35·21	29·32	29·62	25·65	27·04
or	35·62	10·02	37·29	27·28	27·83	27·83
ab	9·44	20·45	18·35	20·45	29·89	23·60
an	3·98	10·56	5·83	5·83	5·28	3·34
en	1·61	6·22	2·21	3·82	2·51	4·32
fs	—	8·31	—	—	—	3·56
di	—	—	—	—	1·30	—
mt	2·08	2·08	1·62	—	2·08	4·40
hm	1·60	—	2·56	7·19	3·19	—
il	1·37	1·82	1·37	1·67	1·82	1·97
ru	—	—	—	0·16	—	—
ap	0·25	0·28	0·25	0·40	0·40	0·43
cc	0·30	2·10	0·40	0·70	—	0·20
C	1·33	1·94	0·41	2·14	—	2·45
H_2O	0·73	1·50	0·88	1·26	0·67	1·40
Fe	23·73	36·69	21·53	32·06	24·38	29·39
Mg	6·78	22·30	7·64	12·06	9·57	13·03
Alk	69·49	41·01	70·83	55·87	66·05	57·58
Ca	10·87	35·23	11·30	15·38	11·93	9·09
Na	19·57	44·32	30·43	37·50	46·91	43·06
K	69·56	20·45	58·26	47·12	41·15	47·85

E.1612.1	Keratophyre, Calypso Cliffs.
E.1618.3	Silicified lava, Cape Mayo.
E.1621.3	Keratophyre, Cape Hinks.
E.2135.12	Keratophyre, Mount Argus (uppermost outcrop).
E.2136.3	Keratophyre, Mount Argus (uppermost outcrop).
E.2143.1	Keratophyre, Mount Argus (lowest outcrop).
	(All analyses by A. G. Fraser.)

Although the petrography of these lavas is similar to that of the New Zealand keratophyres described by Battey (1955), none of the analyses is unusually rich in soda. However, the New Zealand keratophyres

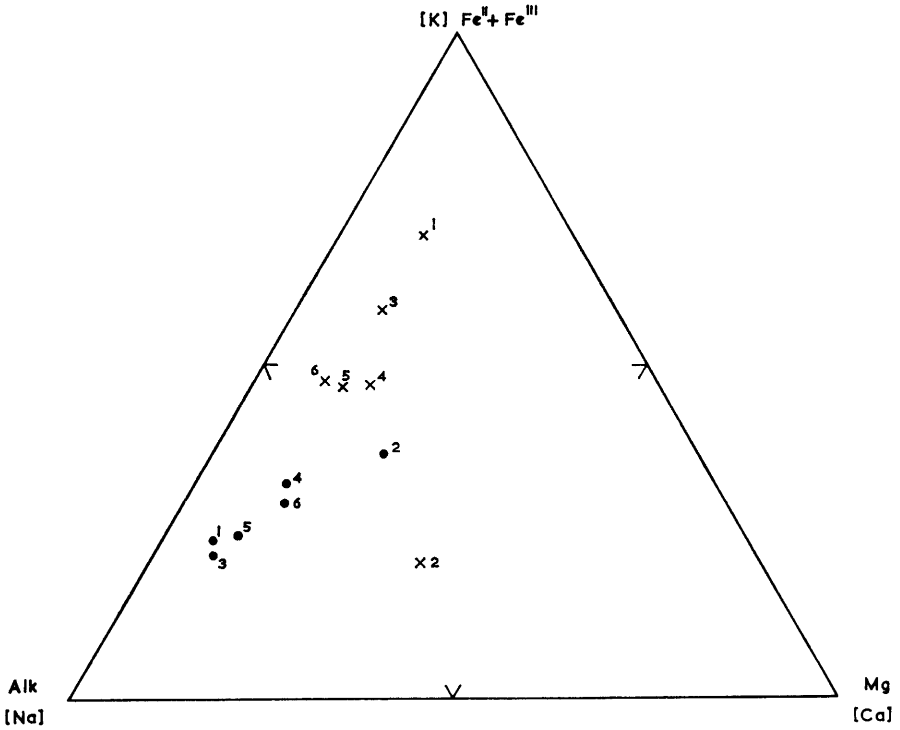


FIGURE 8

Triangular variation diagram with plots of volcanic rocks. Numbers refer to the order of analyses in Table V.

● (Fe″+Fe‴)–Alk–Mg.

× K–Na–Ca.

show a large range in alkali ratio and Battey (1955) has demonstrated that this variation is also typical of keratophyres from European localities. Hence, there would seem to be sufficient justification in naming the Mobiloil Inlet rocks keratophyres on the assumption that the complementary sodic types are present. But even if this latter requirement is not fulfilled, the lavas are clearly distinguishable from the high-temperature products of an acid magma, and in accordance with Battey's (1955, p. 123–24) suggestion they are best designated as potassic keratophyres.

The high total iron content of the keratophyres is a noteworthy aspect of their chemistry and the high oxidation ratio of all but analyses E.1618.3 and E.2143.1 in Table V is even more significant, since it shows convincingly the efficacy of the migrating alkaline and silicic solutions in providing free oxygen. Compared with the other analyses, the lava from Cape Mayo (analysis E.1618.2) shows certain differences, notably the low oxidation ratio, the relatively high lime and magnesia, and the low total alkalis; the term keratophyre cannot be applied to this rock since it represents the silicification of a more basic rock. This contrast in chemistry between the Cape Mayo lavas and those occurring elsewhere in the arcuate zone is evidence for the inference from field relations that the Cape Mayo volcanic rocks belong to a later phase of activity. Conversely, the general uniformity of the keratophyres is important concerning the stratigraphical problems at Mount Argus, in so far as it lends weight to the view that the repetition of volcanic rocks at that locality is of a structural origin and is not indicative of repeated volcanicity.

The obvious similarity between the keratophyres of the Mobiloil Inlet area and those of New Zealand (p. 30) allows more precise conclusions to be drawn concerning their post-depositional history than might have been possible otherwise. According to Battey (1955), the field relations of the New Zealand rocks indicate that they were deeply buried for some time, and it was under such conditions that the redistribution of silica and alkalis was promoted. The lavas of Mobiloil Inlet were probably subjected to broadly similar conditions, a fact which is in good agreement with the diagenetic reactions exhibited in the green and purple arkoses overlying the volcanic rocks at Mount Argus.

V. METAMORPHIC ROCKS

In accordance with current usage (e.g. Sutton, 1965), regional metamorphism is regarded here as essentially a heat phenomenon. Consequently, the cataclastic sediments exposed on Mount Argus and at the east end of the cliff face south of Kay Nunatak, together with the strongly cleaved shales at Crabeater Point, are not considered here because they have not been affected significantly by thermal processes. This is shown particularly by the absence of reactions involving primary recrystallization. The mylonites and associated rocks south of Kay Nunatak are arbitrarily included, for, in spite of the fact that their present textures are a function of intense shearing, it is clear that these rocks were initially metamorphosed to an appreciable extent. Metamorphic rocks in the area south of Mobiloil Inlet occur in a broad belt to the south and west of a line joining Kay Nunatak and Cape Hinks, with the grade of metamorphism increasing, probably irregularly, in a general south-westerly direction, but the western margin of this metamorphic belt has not been located since it lies outside the area investigated. The heavily glaciated nature of the terrain and the intense frost-shattering, which has reduced the highly cleaved rocks to rubble, preclude anything other than a generalized account of the metamorphism. Relationships between different rock types are either obscure or unknown in a number of cases and no definite origin or mode of formation can be postulated for several of the rock types. For this reason, the metamorphic rocks have been subdivided mainly on the basis of lithology.

A. GENERAL PETROGRAPHY

1. *Paraschists and Paragneisses*

Rocks included in this category are those of undoubted sedimentary origin; this does not imply that the schists and gneisses considered separately are necessarily of a different origin but that the evidence there is not conclusive.

The lowest-grade metasediments in the lower reaches of Lurabee Glacier near the junction between the land ice and the ice shelf (E.1656) consist of finely banded flaggy quartz-mica-schists with secondary cleavage in the micaceous layers. In thin section, bands composed of a fine-grained granoblastic mosaic of quartz, subsidiary oligoclase and a little microcline, together with dispersed sericite flakes, alternate with layers rich in biotite, muscovite, sericite and chlorite. Granular turbid leucoxene and sphene, some of which is clearly derived from ilmenite, and ragged grains of epidote are abundant. Other heavy minerals include zircon, tourmaline, iron ore and a little apatite. Calcite is a prominent accessory.

Apart from the biotite which marks the initial stages of regional metamorphism, the metasediments are almost identical to the cataclastic sediments at Mount Argus and also to some of the impure quartzites at Miller Point. Furthermore, the tourmaline is the same variety as that recorded in these unmetamorphosed sediments, although the occurrence of slender prismatic crystals commonly associated with secondary epidote suggests that regional introduction of tourmaline, similar to that found in the Dalradian schists of north-east Scotland, has taken place.

Approximately 4 km. to the south-west, the semi-pelites have been raised to a higher grade and this has resulted in a greater degree of recrystallization and grain growth, and the appearance of numerous tiny garnets, many of which have a perfect dodecahedral outline (E.1655.5 and 6). Otherwise, these rocks are similar to the metasediments to the north-east, although the regular banding of the latter has been considerably disrupted during tight folding and a strong strain-slip cleavage is present. The growth of undeformed biotite along this secondary cleavage and other textural relationships show that the development of biotite post-dated the main shearing stresses. The biotite is reddish brown with moderate pleochroism and tiny zircons are surrounded by intensely pleochroic haloes. Iron ore, including some haematite, is abundant and the sphene is fresh and clear.

Small, spongy and rather turbid patches, barely identifiable as albitic plagioclase in an embryonic stage of development, mark an important feature of these higher-grade rocks since they represent the incipient introduction of soda on what is apparently a regional scale.

Porphyroblastic growth of sodic plagioclase has proceeded to a greater degree in some of the *para*-schists exposed on a rounded hill on the north-west margin of Scripps Heights (E.1649), and in specimens E.1649.3 and 4 the porphyroblasts are clearly evident in the hand specimen. They are characterized in thin section by a sieved appearance, attributable mainly to innumerable small rounded blebs and vermicular inclusions of quartz (Plate VIIIb and c). Most of them also contain inclusions of all the other minerals present in the rock but in widely varying proportions. Some porphyroblasts possess faint albite twinning which gives a composition in the range $Ab_{90}An_{10}$ to $Ab_{85}An_{15}$. The *para*schists containing these oligoclase porphyroblasts are of a higher metamorphic grade than those in the Lurabee Glacier area and they comprise quartzo-feldspathic hornfelses and semi-pelitic schists, some of which are calcareous. The main mineral assemblage of the semi-pelites (excluding porphyroblasts) is quartz-oligoclase-biotite-hornblende-epidote. Microcline of exceptional clarity is commonly present and in specimen E.1649.1, where it tends to be porphyroblastic, it occurs almost to the exclusion of oligoclase. Magnetite is fairly abundant, its estimated modal percentage exceeding 4 per cent in several cases. The iron-rich nature of these *para*schists is reflected to some extent in the optical properties of the ferromagnesian constituents; biotite has the pleochroism scheme α = pale lime, $\beta\,(=\gamma)$ = brownish green or khaki, and the hornblende has a high dispersion combined with a moderate $2V\alpha$, which strongly suggests that the ferrohastingsite molecule is present. The body colour and pleochroism vary in intensity in different rocks with α = greenish yellow, β = green and γ = blue-green. Although the green tinge in the biotite could be indicative of low TiO_2 rather than high Fe_2O_3 (Hayama, 1959), the fact that the iron ore is probably titanium-bearing, and that the biotite in rocks containing little or no free iron ore exhibits a typical brown colour, favours a high Fe_2O_3 content. The oligoclase has distorted secondary twinning and its composition grades into acid andesine locally. Slight zoning was observed in several grains. Green pleochroic epidote is generally abundant and the accessory minerals which invariably occur include granular sphene and apatite. A concordant vein in specimen E.1649.8 consists of poikiloblastic plates of hornblende, turbid oligoclase, much granular epidote, and clinopyroxene, with associated apatite, calcite and quartz. The hornblende is the same as that occurring in the host rock and its strong pleochroism, fairly high dispersion and moderately low 2V (Table VI) indicate its affinities to ferrohastingsite. The clinopyroxene is light green in colour and slightly pleochroic with $\gamma: c = 35$–40° and $2V\gamma = 65^\circ \pm 1^\circ$. Since the dispersion is weak, the optics probably reflect a sodic rather than an iron-rich content; the pyroxene is therefore considered to be sodian augite.

TABLE VI

VALUES OF 2V OF HORNBLENDES FROM THE METAMORPHIC ROCKS

Rock type	*Specimen number*	$2V\alpha$
Quartzo-feldspathic gneiss	E.1643.1	19°±5° 21°±5°
Sodian augite-schist	E.1643.6	27°±5° 30°±5°
*Para*schist	E.1649.8	34°±5° 37°±5° 41°±5°
Hornblende-biotite-gneiss	E.1660.1	57°±2°

The lack of precision in these measurements results largely from strong absorption which makes accurate orientation subnormal to the acute bisectrix extremely difficult.

A tightly folded, well-banded quartzo-feldspathic hornfels (E.1649.7) interbedded with the semi-pelitic schists is composed mainly of a fine-grained xenomorphic granular mosaic of pellucid microcline, quartz and subsidiary oligoclase, with a liberal sprinkling of iron ore. The microcline is slightly porphyroblastic locally; rounded patches, lenses and discontinuous veins consist of relatively coarse quartz and microcline. There are numerous layers containing small greenish brown biotite flakes, a little chlorite, epidote and allanite, the latter occurring mostly as the cores of epidote grains. Sphene is a marginal alteration product of the ilmenite and nearly all of the apatite present is concentrated at the peripheries of ore grains. This rock is similar to a leptite (Eskola, 1914, p. 131), suggesting that it may be a metamorphosed volcanic ash.

The *para*schists at station E.1649 also include finely banded epidote-rich rocks which consist of nearly equal amounts of quartz and microcline with minor oligoclase and much granular epidote arranged in layers. Poikiloblastic plates of muscovite are widely scattered and there is rare iron ore.

Schists and gneisses of undoubted sedimentary parentage are exposed near the upper reaches of Maitland Glacier (E.1667) where they appear to be intruded by a gabbroic stock. The principal rock types here include oligoclase-porphyroblast gneisses and well-banded quartz-feldspar-mica-gneisses which are tightly folded locally and are commonly interbanded with quartz-epidote-gneisses containing only a little feldspar. Spotted mica-schists and quartzose schists with a saccharoidal texture are also present.

Although many of the quartz-feldspar-mica-gneisses are to some extent porphyroblastic, the dominant structure is a well-defined banding which may be exceptionally regular as in specimen E.1667.10. The light bands consist essentially of a fine-grained granoblastic mosaic of oligoclase and quartz, and the darker bands are rich in slightly chloritized biotite and epidote in varying proportions; several narrow bands are almost entirely of epidote. In several gneisses the quartz-oligoclase bands contain a little interstitial clear microcline and there are incipient oligoclase porphyroblasts crammed with quartz inclusions and locally intergrown with microcline. In one well-banded gneiss (E.1667.5) the fine-grained quartz-oligoclase bands have been greatly enriched in microcline, and large but very diffuse microcline porphyroblasts, most of which are no more than complex aggregates of disorientated grains, are also present.

The oligoclase-porphyroblast gneisses are very distinctive rocks (E.1667.1) containing white or pale flesh-coloured oligoclase porphyroblasts up to 1 cm. or more in length and set in a dark micaceous matrix. In thin section, the oligoclase has a composition of $Ab_{72}An_{28}$ and several of the porphyroblasts have exceptionally fine twinning on both the albite and pericline laws. Those in a relatively early stage of development contain numerous rounded inclusions of quartz and a few grains of oligoclase formerly present in the matrix. The remainder of the gneiss comprises a granoblastic fabric of quartz and subsidiary oligoclase accompanied by much biotite, muscovite and epidote with accessory amounts of apatite, calcite, sphene, iron ore and zircon. The biotite is extensively altered to chlorite in places with the concomitant release of epidote and turbid leucoxene. Rare grains of a brownish mineral with a fairly high relief and displaying very weak birefringence are possibly garnet, although the birefringence reveals a vaguely fibrous structure which is unlike the normal strain anisotropism of that mineral. The porphyroblastic gneisses at this locality clearly represent a further stage in the growth of sodic plagioclase porphyroblasts in the *para*schists and *para*-gneisses. Identical rocks have been described by Read (1927, p. 338) from the metamorphic complex of Cromar, Deeside, in Aberdeenshire, and on the basis of the field relations and chemistry he favoured an origin involving the introduction of soda from trondhjemitic material present in the adjacent injection complex, rather than intraformational re-distribution of soda present in the original sediments.

Mica-schists present in the succession at the head of Maitland Glacier have a distinctive spotted appearance produced by the porphyroblastic development of scapolite (E.1667.3). These lustrous schists are richly micaceous with muscovite in excess of the dark brown to greenish brown biotite. Although it occurs in contorted layers, most of the mica crystallization appears to have post-dated the deformation. An appreciable meionite content in the scapolite is inferred from the moderately high birefringence (approx. 0·020), and this is consistent with the presence of abundant calcite, which, though occurring throughout the schist, is concentrated at the margins of the porphyroblasts. Although non-metasomatic scapolite has been recorded from regionally metamorphosed lime-bearing sediments in several parts of the world (Deer and others, 1963*b*, p. 331), a metasomatic origin for the scapolite in these micaceous *para*schists is strongly suggested by the presence of the same mineral in an altered basic igneous rock (? dyke) at the same locality.

The quartz-epidote-gneisses are similar to those in the *para*schist sequence at Scripps Heights (E.1649) except that feldspar is either absent or subsidiary. The epidote content of these gneisses is generally not sufficient to warrant the term epidosite, though it may be as high as 40 to 50 per cent in some cases. Not enough is known about their extent and detailed field relations to ascribe a definite origin to them. Tyrrell (1930) described quartz-epidote rocks from South Georgia and he attributed their formation to the extreme alteration of spilites and related rocks. Altered rocks of a possible volcanic origin are intercalated with the *para*schists in some places (e.g. E.1649.5) but there is no evidence that these have given rise to epidotic rocks. Francis (1958) believed that the epidosites in Glen Urquhart, Inverness-shire, are skarn rocks resulting from chemical interaction between two unlike sedimentary formations in contact under conditions of increased temperature and associated activity of volatiles. Since the sediments concerned include limestones, such an origin is unlikely to account for the quartz-epidote rocks in the Mobiloil Inlet area, where limestones have not been recorded in the metamorphic complex. A possible clue to their origin is provided by the widespread occurrence of metabasites, which were altered during metamorphism to a lower-grade mineral assemblage including significant amounts of epidote (p. 43). By a process of metamorphic differentiation, some epidote could have been concentrated into masses of limited extent to give epidote-rich gneisses.

The only other recorded outcrop in which metamorphic rocks of undoubted sedimentary origin are exposed occurs about 3 km. south of station E.1667, where there is a small hill composed of angular blocks of biotite-schist and biotite-gneiss. One pink-coloured porphyroblastic biotite-gneiss from this locality (E.1666.1) is comparable in many respects with the oligoclase-porphyroblast gneisses from farther north.

2. *Quartzo-feldspathic gneisses*

Grey and buff-coloured granulitic gneisses containing only minor amounts of dark minerals form the major part of the succession of banded gneisses exposed on the prominent eastern buttress of Mount Blunt on the west flank of Weyerhaeuser Glacier (E.1643; Plate IVa). Similar rocks, which are interbanded with and subordinate to biotite-gneisses, were also recorded on a scarp face (E.1644) 10 km. south of Mount Solus.

The quartzo-feldspathic gneisses have a constant essential mineralogy of moderately strained quartz, somewhat turbid acid oligoclase and perfectly fresh microcline (Plate VIIId). The general texture is xenomorphic granular and grains are commonly sutured and slightly elongated. The microcline is approximately equal to or greater than the combined quartz and oligoclase, and it ranges from extremely lobate interstitial masses to rounded plates and porphyroblasts. Much of it is microperthitic and the commonly occurring ribbons of pure albite situated between adjacent microcline grains are also considered to have originated by exsolution. Oligoclase is weakly porphyroblastic in one or two of the gneisses. Large coarse-grained aggregates or augen of microcline accompanied by varying amounts of quartz and oligoclase are common though a few are dominated by oligoclase; the relative proportions apparently depend on the extent to which the latter has been replaced by microcline. Small dispersed flakes of partly chloritized biotite with a strong preferred orientation may be present but this mineral is usually unimportant. Irregularly scattered poikilitic plates of muscovite occur in several of the gneisses. A prominent though not very abundant dark mineral in some rocks (E.1643.1, 5 and 7) is ferrohastingsite characterized by strong pleochroism, intense dispersion and smallish 2V (Table VI). Alteration to biotite is patchy; however, there is more extensive replacement by a strongly pleochroic chlorite having α = yellowish brown and $\beta\ (= \gamma)$ = bright green. Most of the ferrohastingsite in specimen E.1643.1 is concentrated in a narrow zone at the contact between the quartzo-feldspathic gneiss and biotite-schist, whereas in specimen E.1643.7 it is most abundant in a pale cream-coloured concordant band, about 7 cm. wide, in which it forms conspicuous ragged black spots. Here, the ferrohastingsite is extremely poikiloblastic. Iron ore, which is predominantly granular ilmenite showing slight marginal alteration to sphene, is an essential or prominent accessory mineral in all of the gneisses. Sphene, epidote and allanite are all widely distributed. The allanite occurs both as discrete grains and as large cores in epidote; in either setting it is closely associated with iron ore. A similar relationship also applies to apatite. Large, sieved brownish garnets and diffuse concentrations of garnet and epidote in varying proportions figure in specimens E.1643.8 and 9, and E.1644.7. The sieved garnets have a narrow rim of altered oligoclase. The only other occurrence of garnet in the quartzo-feldspathic gneisses is at the contact with a biotite-schist (E.1643.1), where it is intimately associated with ferrohastingsite.

One of the outstanding features of the quartzo-feldspathic gneisses is the abundance of microcline (Table VII). This may mean that the original rocks were very rich in potash which was re-distributed during metamorphism, or that potassium metasomatism took place on a regional scale. Perhaps both factors have operated. Apart from possessing a coarser grain-size, the quartzo-feldspathic gneisses are almost identical to the leptite from Scripps Heights (E.1649.7), so that they are best described as leptite-gneisses. Although they are of doubtful origin, a tentative correlation with the volcanic rocks to the north and east outside the metamorphic belt is suggested by certain characteristics, not least by the high microcline content, since these lavas have a substantial potash content (Table V). Other factors favouring

TABLE VII

MODAL ANALYSES OF GNEISSES

	E.1643.3	E.1660.5	E.1652.3	E.1660.1	E.1644.4	E.1645.1	E.1652.1	E.1661.1
Quartz	24·2	9·8	17·4	14·2	24·3	29·2	16·1	3·2
Microcline	44·8	1·9	8·1	16·0	26·6	31·9	38·5	46·3
Plagioclase†	25·5	44·6	48·2	58·2	36·6	23·0	31·7	40·7
Myrmekite	—	*	0·6	1·2	2·7	1·5	3·7	5·7
Hornblende	—	14·8	10·7	3·0	3·3	—	—	—
Muscovite	0·7	—	—	—	—	0·1	0·4	0·3
Biotite	—	27·3	12·9	5·6	4·5	12·8	8·8	2·9
Chlorite	0·8	—	—		—	—		—
Iron ore	3·0	—	—	*	0·7	*	0·2	0·3
Sphene	0·5	0·5	1·5	0·4	0·9	0·6	0·1	0·1
Epidote	0·3	0·9	0·1	0·6	0·3	0·3	—	—
Allanite	*	*	*	0·8	—	*	0·2	0·2
Apatite	0·2	0·2	0·5	*	0·1	0·5	0·3	0·3
Zircon	*	—	—	—	—	0·1	—	—

*Present but not recorded.

†Includes alteration products, mainly sericite.

E.1643.3	Quartzo-feldspathic gneiss, western flank of Weyerhaeuser Glacier.
E.1660.5	Hornblende-biotite-gneiss, southern flank of Sunfix Glacier.
E.1652.3	Hornblende-biotite-gneiss, Hogmanay Pass.
E.1660.1	Hornblende-biotite-gneiss, southern flank of Sunfix Glacier.
E.1644.4	Hornblende-biotite-gneiss, western flank of Weyerhaeuser Glacier.
E.1645.1	Biotite-gneiss, western flank of Weyerhaeuser Glacier.
E.1652.1	Biotite-gneiss, Hogmanay Pass.
E.1661.1	Biotite-gneiss, southern flank of Sunfix Glacier.

this correlation include the aggregates of relatively coarse feldspar which are unlikely to be accounted for entirely by porphyroblastic growth; the abundance of iron ore coupled with a scarcity of ferromagnesian minerals; and the presence of pre-metamorphic veins of iron ore, chlorite, allanite and sphene. The feldspar aggregates may correspond in part to the polycrystalline groupings in the original volcanic rocks, and the fact that the aggregates are composed mainly of microcline rather than oligoclase can be explained by replacement, a reaction for which there is good textural evidence.

In addition to the presence of gneisses having close similarities with leptites, the quartzo-feldspathic gneisses on Weyerhaeuser Glacier have a further though tenuous link with the succession at Scripps Heights by the fact that rocks carrying sodian augite occur in both localities (cf. E.1649.8; p. 35). One such rock (E.1643.6) from a thin discordant band in the quartzo-feldspathic gneisses is schistose and is composed largely of rounded oligoclase plates and xenoblastic to poikiloblastic crystals of sodian augite. The latter has a pleochroism scheme α = light green, β = bluish green, γ = yellowish green, $2V\gamma \simeq 65°$ and $\gamma : c = 51°$. The dispersion is moderate. Small patches of ferrohastingsite are closely associated with the pyroxene. The occurrence of soda-bearing augites in regionally metamorphosed rocks is usually ascribed to soda metasomatism (e.g. McLachlan, 1951) and, while this agency cannot be shown to have been the vital factor in this case, the paragenesis of the pyroxene is consistent with the soda enrichment which has clearly taken place on a regional scale.

3. *Amphibolites and hornblende-schists*

a. *Amphibolites.* Hornblendic dykes, which are probably related to a nearby gabbro intrusion, were recorded in the Maitland Glacier area. Since these rocks do not strictly form part of the metamorphic complex, they are described in a later section (p. 46). Apart from these dykes, amphibolites were only found in exposures adjacent to Sunfix Glacier and Hogmanay Pass. Amphibolites were undoubtedly more widespread than their present limited distribution indicates but regional injection of acid material has led almost invariably to considerable modifications in mineralogy, particularly the development of biotite and an increase in the quartzo-feldspathic content.

On the southern flank of Sunfix Glacier, garnet-amphibolite (E.1661.5) is interbanded with hornblende-biotite- and biotite-gneisses which have been intruded *lit-par-lit* by granitic material. Concordant granite-gneisses containing little biotite occur in the same locality. Between 60 and 65 per cent of the garnet-amphibolite is composed of fresh hornblende which forms sub-idioblastic to xenoblastic prismatic crystals commonly containing inclusions of quartz and plagioclase, and possessing a strong preferred orientation. The optical properties, particularly the pleochroism ($\alpha =$ pale greenish yellow, $\beta =$ green, $\gamma =$ bluish green) and the low extinction angle $\gamma : c = 12°$, suggest that the amphibole may be a ferro-actinolite (Deer and others, 1963*a*, p. 257), although this identification is not readily compatible with the paragenesis. The plagioclase has a composition of $Ab_{30}An_{70}$ and, apart from slight and limited alteration to sericite, it is completely fresh. It is mostly xenomorphic and small quartz inclusions are common. Granular quartz is somewhat more abundant than the plagioclase. Garnet porphyroblasts are large but sparse; in thin section they are pale pink, sieved with quartz and have inclusions of iron ore. Scattered flakes of golden brown biotite commonly lie at high angles to the foliation. The main accessory mineral is ilmenitic magnetite which is extensively altered to haematite. The genesis of this amphibolite is not certainly known but there is little doubt that it was derived from a basic igneous rock. The mineral assemblage, especially the stable association of amphibole and labradorite/bytownite, is noteworthy and it is probably related to a moderately high grade of metamorphism combined with a low sodium content in the original rock.

b. *Hornblende-schists.* Hornblende-schists, like the amphibolites, are uncommon in the metamorphic complex and, except for xenoliths (e.g. E.1659.5), those which were recorded have uncertain field relationships. On the west flank of Weyerhaeuser Glacier 10 km. south of Mount Solus, hornblende-schists are associated with leucocratic hornblende-biotite-gneisses and quartzo-feldspathic gneisses. In contrast to the strongly coloured hastingsite and ferrohastingsite, which figure in most rocks at this locality, the amphibole in the hornblende-schist (E.1644.5) is a common hornblende with a typical pleochroism. While this may simply demonstrate the influence of host-rock composition on mineralogy, the higher modal percentage of hornblende in the schist may also be an important factor, and it is probably significant that there is considerable iron ore in the gneisses with ferrohastingsite, whereas in the hornblende-schist there is almost none. The hornblende forms bladed crystals with lamellar twinning but there are also isolated porphyroblasts. Slightly chloritized biotite is closely associated or intergrown with the hornblende and the remaining essential constituents are quartz and andesine accompanied by a little fresh microcline. Small calcic cores in several of the plagioclase crystals provide strong evidence of an igneous origin for this hornblende-schist.

c. *Cummingtonite-gneisses.* Included here are cummingtonite-biotite-gneisses from the northern end of Hogmanay Pass where a sequence of amphibolites and related rocks has been intruded by a granodiorite. The complete assemblage in this gneiss is quartz, andesine ($Ab_{63}An_{37}$), cummingtonite, biotite and magnetite, the latter being abundant (>5 per cent) in several bands but it is comparatively scarce or absent in the cummingtonite-rich bands and in the quartzose segregations. The bladed crystals of cummingtonite have the characteristic fine lamellar twinning and are colourless with $2V\gamma \simeq 80°$ and $\gamma : c = 20°$. Slight normal zoning and rare weak oscillatory zoning were observed in the plagioclase. Apart from a little apatite, lime-bearing accessory minerals (especially epidote), which are so prominent in most of the metamorphic rocks in this area, are conspicuously absent.

4. *Hornblende-biotite-gneisses*

Together with the biotite-gneisses (p. 40), these are abundant and widespread rocks in the metamorphic belt south of Mobiloil Inlet and, although it is often impossible either from the fragmentary field evidence or from the petrographic data to determine their origin, it is clear that they are polygenetic. Despite the considerable variations within this group of gneisses, they are considered together since no sub-division can be erected which satisfies both the field characteristics and the general petrology. Both porphyroblastic (or augen) and non-porphyroblastic types can be distinguished in the field, but the mineralogical composition does not fit into this broad sub-division. The apparently artificial separation of hornblende-biotite-gneisses from biotite-gneisses is justified to a large extent by the fact that the hornblende-biotite assemblage appears to be a stable one even when there has been intense potassium metasomatism. The modal analyses of almost all the gneisses described here are given in Table VII.

There are two main areas in which the hornblende-biotite-gneisses occur; the first comprises the southern margin of Sunfix Glacier including the Hogmanay Pass area, and the second includes the middle and upper reaches of Weyerhaeuser Glacier. It is probable that the gneisses form a continuous south-east to north-west belt across the snow-buried Wakefield Highland. Hornblende-biotite-gneisses were also recorded near Maitland Glacier.

Hornblende-biotite-gneisses (E.1660.5), which represent the least altered rocks in this category, are exposed south of Sunfix Glacier. Poikiloblastic hornblende and fresh biotite constitute nearly half the total rock and they are accompanied by quartz and weakly zoned fresh andesine. The presence of inclusions such as quartz, biotite and epidote indicates crystalloblastic growth which has resulted here and there in large porphyroblasts of acid andesine. Potassium feldspar and myrmekite are scarce. Compositionally, the rock is an epidiorite and it is of undoubted igneous origin.

A coarser-grained hornblende-biotite-gneiss from Hogmanay Pass (E.1652.3) has a prominent augen texture, which in thin section is due both to single porphyroblasts of dusty acid andesine and, more commonly, to polycrystalline aggregates of antiperthitic andesine associated with much quartz, myrmekite and microcline. Compared with the previous gneiss, the hornblende has a more intense coloration, stronger pleochroism and a lower 2Vα, all of which point to the presence of the ferrohastingsite molecule.

Hornblende-biotite-gneisses, which have undergone considerable enrichment in feldspar, were found near Sunfix Glacier and Weyerhaeuser Glacier. These have hornblende and biotite in approximately the same proportions as in the gneiss from Hogmanay Pass in spite of their much lower colour index. In specimen E.1660.1, porphyroblasts of basic oligoclase ($Ab_{73}An_{27}$) enclose finely divided epidote and are patchily altered to sericite. The relatively coarse mosaic of strained quartz and andesine ($Ab_{65}An_{35}$) has been invaded by clear microcline in many places with the consequent corrosion of andesine and the development of fine myrmekitic intergrowths. Partially chloritized biotite and hornblende with some affinity to ferrohastingsite are the remaining essential minerals.

Well-banded augen-gneisses from the western margin of Weyerhaeuser Glacier (E.1644.2 and 4) have undergone more intense microclinization and the augen are undeformed lenticles composed of microcline aggregates with intergranular narrow ribbons of albite accompanied by quartz, myrmekite and a little oligoclase. A few oligoclase porphyroblasts occur independently. In its optical properties the hornblende is close to ferrohastingsite, and a greenish tinge related to a high iron content is apparent in some of the biotite. Apart from significant amounts of iron ore, the accessory minerals are the same both in type and in setting as in the other gneisses, with sphene dominant.

An important feature concerning the above series from epidiorites rich in ferromagnesian minerals to banded leucocratic gneisses of granitic composition (Table VII) is the small variation in the relative proportions of biotite and hornblende, which not only provides further evidence for the stability of this assemblage but also suggests that many of the biotite-gneisses may have been derived independently.

5. *Biotite-gneisses*

The biotite-gneisses, including porphyroblastic and non-porphyroblastic types, have a similar distribution to the hornblende-biotite-gneisses, although they occur in greater abundance in the Maitland Glacier area. A sequence of increasing feldspathization, comparable to that displayed in the hornblende-bearing gneisses, can be traced in the biotite-gneisses but, as in the former, no systematic regional variation is discernible. Near the junction of Sunfix Glacier and Hogmanay Pass, the biotite-gneiss contains abundant xenoliths of hornblende-mica-schist.

Finely banded biotite-gneisses of a possible sedimentary origin crop out on a nunatak at the confluence of Earnshaw and Maitland Glaciers (E.1670). These rocks consist of biotite, quartz, andesine and microcline, much of the latter being clearly of replacement origin though there is no porphyroblastic development. Epidote, sphene and apatite are prominent accessory minerals. Small pink garnets are visible in one or two biotite layers in the hand specimen but none appears in thin section except at the contact with a thin epidosite band where there are also minute amounts of amphibole.

In a typical biotite-gneiss (E.1645.1) from the western flank of Weyerhaeuser Glacier, microcline, ranging from small interstitial blebs to porphyroblasts more than 1 cm. long, is approximately equal in amount to the quartz and slightly in excess of the combined oligoclase and myrmekite content. A well-foliated biotite-gneiss (E.1659.4) from the southern margin of Sunfix Glacier has an almost identical mineralogy but texturally it is hemigranoblastic. The epidote group is represented entirely by allanite which gives pleochroic haloes in biotite.

In the Hogmanay Pass area, the biotite-gneisses include finely banded leucocratic varieties (E.1652.1) very rich in microcline. Dusty albite occupies the interstices between adjacent plates of clear microcline or forms a narrow selvage on oligoclase when the latter is in contact with microcline but myrmekite is commoner in this setting. Much of the allanite occurs in comparatively large subhedral to euhedral crystals with a weak pleochroism. Late muscovite replaces oligoclase and microcline to a minor degree.

The biotite-gneisses have been described in order of increasing feldspar and decreasing biotite content (Table VII). This sequence corresponds approximately to one of progressive migmatization, a process which eventually leads to poorly foliated feldspathic gneisses containing only minor quantities of biotite. Such a stage is illustrated by a leucocratic gneiss from an exposure on the southern side of Sunfix Glacier, where the field evidence indicates that the original rocks were biotitic schists and gneisses (e.g. E.1661.2). The leucocratic gneiss (E.1661.1) is composed of a hemigranoblastic fabric dominated by pellucid microcline and oligoclase, with subordinate biotite, quartz and accessories. The quartz occurs mainly as rounded remnants in microcline or as vermicular inclusions in oligoclase deeply corroded by microcline.

In a few widely separated localities, thin bands of quartz-epidote-gneiss are interbanded with the biotite-gneisses. The prominence of quartz-epidote rocks in the various outcrops of *para*schists and *para*gneisses might suggest that a significant part of the biotite-gneisses is of a sedimentary origin. However, there is no confirmatory evidence for this.

6. *Granite-gneisses*

Although the leucocratic varieties of hornblende-biotite-gneiss and many of the biotite-gneisses are granitic in composition, it is impossible to map them as granite-gneisses in the field, since they are all part of an injection complex comprising varying rock types which have been permeated and intruded *lit-par-lit* by granitic material. Nevertheless, cross-cutting granite-gneisses with sharp contacts were recorded in the hornblende-biotite- and biotite-gneisses at several localities. These discordant gneisses (E.1663.1) have a low mafic content and they consist essentially of an inequigranular interlobate mosaic of quartz, microcline and rather turbid corroded oligoclase. Biotite, much of which has been altered to chlorite, accounts for less than 2 per cent of the total constituents. Sphene, allanite and iron ore are also accessory.

In spite of their cross-cutting nature, the granite-gneisses are texturally indistinguishable from the biotite-gneisses of a granitic composition, so that they are clearly an integral part of the injection complex and belong to a somewhat later phase of intrusion.

7. *Contact hornfelses*

On the northern flank of Grimley Glacier, highly puckered mica-schists and gneisses with intercalated buff-coloured quartzo-feldspathic hornfelses represent regionally metamorphosed *para*schists which have been subjected to contact metamorphism by the intrusion of a late granite. Pegmatites and quartz veins from the granite are generally tourmaline-bearing. The pelitic rocks in this succession are muscovite-biotite-sillimanite-gneisses with a marked lepidoblastic texture. Andesine and strain-free quartz form a highly inequigranular granoblastic fabric containing variable amounts of fairly fresh orthoclase-microperthite. The biotite, in which γ = deep reddish brown, is riddled with tiny zircon inclusions and the fibrous sillimanite has grown at its expense. The fact that the sillimanite has nucleated during a pneumatolytic phase of metamorphism is demonstrated convincingly not only by the presence of tourmaline and apatite in significant quantities but also by the prolific growth of late muscovite. Since the sillimanite was derived from the break-down of biotite, it is possible that the orthoclase has arisen from the complementary reaction but textural evidence indicates that this was not an important source.

The quartzo-feldspathic rocks associated with the mica-schists have a quartz-oligoclase-orthoclase assemblage, in which orthoclase is slightly in excess of plagioclase. There is also a little muscovite, biotite and fibrous sillimanite.

In view of the uncertain status of orthoclase in these contact metamorphic rocks and the established fact that sillimanite may develop in rocks of lower grade than that in which it typically occurs if fluxes such as boron, fluorine and water are present, it is difficult to assess the metamorphic grade. However, there is no reason to believe that it is any higher than the hornblende-hornfels facies (Turner and Verhoogen, 1960).

8. *Mylonites and cataclastic gneisses*

The finely banded, green, buff and dark grey mylonites which occur at the base of the outcrop of deformed rocks south of Kay Nunatak are of an undoubted sedimentary origin. Under the microscope they are extremely fine-grained (average grain-size $<0\cdot05$ mm.) with an essential mineral assemblage of strongly crushed and stretched quartz, albite and finely divided sericite. Iron ore is invariably present though in many cases it is almost entirely altered to ragged grains of leucoxene/sphene, which are closely associated with turbid granular clinozoisite of doubtful origin. Chlorite and pale brown biotite may be present. The main accessory minerals are calcite, tourmaline, apatite, fresh sphene, epidote and zircon; many of these are at least partly of post-deformation origin. The feldspar includes some orthoclase, most of which occurs in lenses and veins where it is accompanied by quartz. Tight zig-zag folding in the more siliceous members of the mylonite succession have their axial planes parallel to the strong directional fabric defined by the mineral grains. The somewhat less severely crushed rocks, such as those occurring at station E.1673, contain a few lensoid remnants of relatively undeformed rock which are very similar to the metamorphosed sediments from the Lurabee Glacier area.

Above the mylonites is a sequence of acid *ortho*gneisses which, as a result of intense cataclastic deformation, are now represented by streaky augen-gneisses. Thin bands of mylonite, similar to those described above, and chlorite-schist have been incorporated into the succession of cataclastic gneisses. A typical gneiss from this group (E.1671.1; Plate VIIIe) consists essentially of sodic plagioclase with fractured and distorted albite twinning, quartz and zoned clinozoisite. Wisps and clots of sericite are wrapped round the augen. Although the augen, so conspicuous in the hand specimen, are partly relict crystals of plagioclase which have survived granulation, porphyroblastic development of albite has also occurred, the textural relations showing that this reaction began during the late stages of deformation and continued after the cessation of movements. The porphyroblastic albite usually has irregular chequer-type twinning and it is moderately sericitized. The early feldspar may have been more calcic before cataclasis, since much of the clinozoisite appears to be a secondary alteration product of it. The main accessory mineral is sphene and there is also rare zircon.

Other cataclastic gneisses are similar to that described above except that porphyroblastic microperthite occurs as well as albite and it may even predominate. Several of the gneisses are rich in mica, including reddish brown biotite, muscovite and fine sericite. However, most of the biotite has been drastically altered to chlorite, sphene, epidote and sericite.

Chlorite-schists, forming irregular thin bands and long lenticles in the cataclastic gneisses, are the product of extreme deformation and they may have been derived from basic igneous rocks. Microscopically, they consist of colourless chlorite, sericite and calcite with a little finely comminuted quartz. Fine streaks of altered iron ore together with some limonitized pyrite of hydrothermal origin are also present.

On the higher parts of the cliffs south of Kay Nunatak there are pure white granites mineralogically identical to the most acid members of the underlying cataclastic augen-gneisses. Since they are considerably less deformed than the latter, the textural relationships are clearer. Slightly twisted and fractured crystals of albite ($Ab_{95}An_5$) with normal albite twinning are extensively replaced by chequer-board albite and both types have finely frayed margins against the strained and granulated quartz. These white granites appear to be structurally concordant with the underlying augen-gneisses and there is little doubt of their equivalence. The difference in degree of deformation is probably related to distance from the thrust zone.

Cataclastic diorites recorded from the western flank of Pan Glacier to the west of Calypso Cliffs have certain affinities to the streaky augen-gneisses, although the deformation has been less intense. The main effect of stress is shown in the quartz which has been strongly crushed and stretched into ribbons.

9. *Metabasites*

Metabasites, a collective term for metamorphosed basic igneous rocks of various types, were recorded in every outcrop consisting of *para*schists and *para*gneisses. Unfortunately, the rubbly nature of the exposures prevented the field relationships from being established in every case, but the known evidence suggests that they are either concordant sheets or lavas. Their characteristic green colour reflects the dominance of amphibole, epidote and chlorite.

The metabasites present in the lowest-grade metasediments near Lurabee Glacier have a mineral assemblage of actinolite-epidote-chlorite-biotite-quartz-albite (-calcite-sphene). In specimen E.1656.1, brown to olive-green hornblende occurs as remnant patches in the pale green actinolite. The biotite recrystallizing from the chlorite is light brownish red with a moderate pleochroism. The former plagioclase phenocrysts are almost completely pseudomorphed by calcite or, in some cases, epidote. The large, ragged sphene grains have clearly been derived from ilmenitic iron ore.

Farther west, where the metamorphic grade is somewhat higher, the metabasites have the same mineral assemblage as that described above, except that the plagioclase is more calcic ($Ab_{62}An_{38}$) and the amphibole is probably hornblende, although some of the optical properties are transitional between actinolite and hornblende. The pleochroism scheme is α = pale lime, β = light green and γ = light bluish green, $\gamma : c = 19°$ and $2V\alpha \simeq 80°$. The original phenocrysts of calcic plagioclase now consist of mottled oligoclase containing much epidote or calcite; in addition, there is some evidence of incipient porphyroblastic growth of oligoclase.

Greenschists are associated with the *para*schists and *para*gneisses near the head of Maitland Glacier, and the mineral assemblage actinolite-chlorite-epidote-quartz-albite (E.1667.11) is typical of basic rocks in the greenschist facies of metamorphism. The strongly orientated slender prisms of actinolite are weakly pleochroic and several contain poikilitic inclusions of quartz. Small flakes of fresh biotite are present.

Metabasites were also found in the succession of highly deformed rocks south of Kay Nunatak. Those forming low-dipping sheets in the uppermost white albite-granite have not been severely deformed and mineralogical changes have been comparatively small. However, the former texture has been destroyed and it has been replaced by a faintly schistose fabric. Brown turbid augite is extensively replaced by a colourless fibrous amphibole belonging to the tremolite-actinolite series, but labradorite, though shattered and veined, is fairly fresh with good albite twinning. Both clinozoisite (2V+) and epidote are present in abundance, either as individual crystals which are commonly strongly zoned or as numerous diffuse patches of uncertain genesis. The relationship between the two modes of occurrence is not clear. A colourless, non-pleochroic scaly chlorite with a very low birefringence is closely associated with the clinozoisite-epidote. Muscovite and very turbid leucoxene/sphene, which is secondary after ilmenite, are important accessory minerals. The high percentage of clinopyroxene and actinolite indicate that the original rock was fairly basic. The most unusual feature of this metabasite is the co-existence of labradorite with the actinolite-chlorite-epidote assemblage, an association implying disequilibrium which suggests in turn that shearing stress connected with major thrusting rather than metamorphism was responsible for the mineralogical changes.

A greenish grey, strongly schistose metabasite (E.1671.2), which has undergone intense shearing and crushing, occurs in the succession of cataclastically deformed gneisses on the extreme western end of the cliff face south of Kay Nunatak. The thin section shows a fine-grained actinolite-epidote-schist with subsidiary amounts of muscovite, chlorite and turbid leucoxene/sphene and rare indeterminate plagioclase. Apart from the absence of clinopyroxene and the negligible amount of feldspar, this mylonitized basic rock has obvious affinities with the one described previously.

B. Discussion

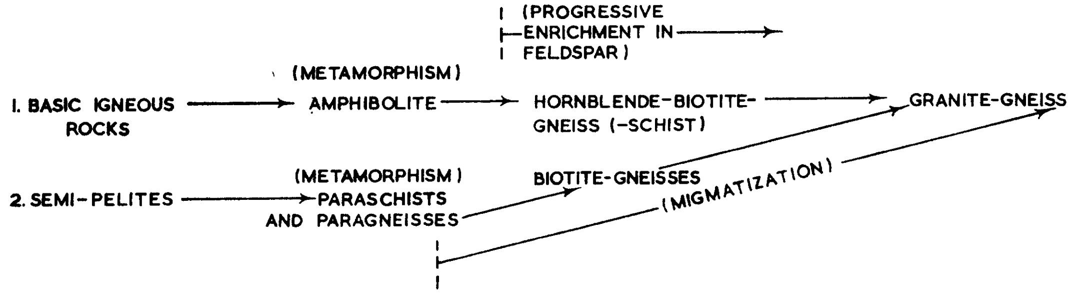
In spite of the fact that there is clearly a progressive increase in metamorphic grade from north-east to south-west across the metamorphic belt, it is impossible to express this increase quantitatively in anything but the broadest detail, since there is a conspicuous absence or paucity of normal metamorphic indicators. This has resulted not only from a scarcity of rocks with a composition favouring the generation of index minerals but also from the allochemical nature of the metamorphism, and in particular alkali metasomatism. Although pelitic rocks are present, garnet is very rare, and staurolite, andalusite and kyanite are absent. Presumably, the failure of these minerals to develop reflects the potash-rich nature of the sediments. In the following discussion, the classification of metamorphic facies for regional metamorphism given by Turner and Verhoogen (1960) is adopted; the contact hornfelses are not discussed further here.

The lowest-grade rocks near Lurabee Glacier belong to the greenschist facies of metamorphism, and the mineral assemblages of the pelitic rocks are sufficiently critical to allow sub-division into the quartz-albite-epidote-biotite sub-facies for the rocks at station E.1656, and the quartz-albite-epidote-almandine sub-facies for the higher-grade rocks to the south-west at station E.1655. These sub-facies are confirmed in detail by the associated metabasites, since the transition from the lower to the higher sub-facies in basic rocks is marked by the conversion of actinolite to hornblende (Turner and Verhoogen, 1960, p. 539). The metamorphic grade of the *para*schists on the north-west margin of Scripps Heights is a little more difficult to assess. Hornblende is abundant in the lime-bearing semi-pelites and, according to Harker (1950, p. 263), this mineral comes in about the middle of the garnet grade as applied to pelitic rocks. Turner and Verhoogen (1960, p. 544) considered the almandine-amphibolite facies to have its lower limit at the middle of the almandine zone, so that the hornblende-bearing assemblages are tentatively assigned to the lower part of the staurolite-almandine sub-facies. The occurrence of clinopyroxene (E.1649.8) tends to confirm this designation. The pelitic rocks near the head of Maitland Glacier are considered to have a metamorphic grade at least as high as that at station E.1649 at Scripps Heights, although the associated metabasite (p. 43) suggests a grade corresponding to the quartz-albite-epidote-biotite sub-facies.

Distinctive mineral parageneses are lacking in the microcline-rich quartzo-feldspathic gneisses on the west flank of Weyerhaeuser Glacier. However, the occurrence of rocks carrying hornblende and in one case sodian augite, together with the sporadic distribution of garnet (believed to be grossularite in view of its close association with epidote), indicates that the gneisses are most likely to belong to the staurolite-almandine sub-facies of the almandine-amphibolite facies. The same facies is denoted by the cummingtonite-gneisses near Hogmanay Pass but the sub-facies is indeterminable. The garnet-amphibolite at station E.1661 has no epidote and the plagioclase is correspondingly lime-rich; the mineral assemblage is therefore analogous to that listed by Turner and Verhoogen (1960, p. 550) for basic rocks in the sillimanite-almandine-orthoclase sub-facies, the highest grade in the almandine-amphibolite facies.

The widespread and abundant development of alkali-feldspar porphyroblasts in the metamorphic rocks provide overwhelming evidence of regional alkali metasomatism even though, as is probable, many of the original rocks contained appreciable amounts of both soda and potash. There is also no doubt that this introduction of alkalis is genetically related to the emplacement of granitic bodies found both as *lit-par-lit* and cross-cutting intrusions near the axis of the metamorphic belt, but there is insufficient evidence to interpret this relationship precisely. Textural criteria suggest that, in general, the soda enrichment preceded that of potash; furthermore, in terms of geographical extent, the outward limit of potash metasomatism appears to have been inside the limit for soda as shown by low-grade *para*schists in which porphyroblastic oligoclase has little or no associated potash feldspar. Thus, in the pelitic and semi-pelitic rocks, it is possible to trace a progression from quartz-muscovite-biotite-schists through oligoclase-porphyroblast schists and gneisses more or less devoid of potassium feldspar to augen-gneisses of approximate granitic composition rich in both oligoclase and potassium feldspar. This series is remarkably similar to the one given in detail by Goldschmidt (1921) for pelitic rocks in the Stavenger district of Norway, and it is clear that this transition occurred in the same general tectonic and metamorphic framework as that postulated for the metamorphic belt south of Mobiloil Inlet.

Amphibolites and related rocks of an igneous origin have undergone a similar process of feldspathization, the end product being, as before, a gneiss of approximate granitic composition. This suggests that there are two main convergent series in the metamorphic rocks:



As emphasized already (p. 40), not all of the hornblende-biotite- and biotite-gneisses fit into this simplified scheme and many of the biotite-gneisses are of an uncertain origin.

The copious development of myrmekite in the high-grade feldspathic gneisses does not necessarily invalidate the view that the potash metasomatism succeeded that of soda since myrmekite has been interpreted by Osterwald (1955) as a result of replacement of plagioclase by potassium feldspar, the necessary silica being introduced during metamorphism. That this may have occurred in the feldspathic gneisses described earlier is supported by the observation that myrmekitic intergrowths are best developed in rocks in which the plagioclase has been most deeply corroded by the potassium feldspar. Nor does Shelley's (1964) proposed mechanism for myrmekite formation conflict with the suggested time relations of soda and potash metasomatism; on the contrary, it tends to confirm them.

Iron-rich assemblages, notably ferrohastingsite and green biotite, are prominent in rocks of different origins within the metamorphic complex, but that their distribution cannot be related directly to metamorphic grade can be demonstrated in several ways, not least by the fact that rocks containing iron-rich hornblendes are commonly associated with rocks carrying normal hornblende. The bulk composition of the rocks is therefore clearly a more important factor than metamorphic grade in the genesis of these minerals. If the greenish colour of the biotite is a reliable expression of its iron content, it is found that there is an excellent correlation between the iron content of the biotite and hornblende (as indicated by the optical properties) and the extent to which potassium feldspar has developed as a result of potash metasomatism. In other words, ferrohastingsite and ferriferous biotite are most conspicuous in rocks rich in microcline. In the case of the hornblende, the increase in iron content is accompanied by an increase of Na in the "X" position of the formula. The few exceptions to this correlation reflect the non-availability of free iron capable of entering into the minerals concerned; thus microcline-rich rocks containing normal brown biotite have no iron ore. The chemical processes underlying the above relationships are obscure though it is conceivable that the soda entering the hornblende structure has been derived from oligoclase replaced by the microcline. It is not clear either why the replacement of hornblende by biotite, which normally takes place during alkali-enrichment of amphibolite (Turner and Verhoogen, 1960, p. 569), has been superseded, but reactions similar to those just outlined have been recorded from other localities. Ogura (1958) noted that in the progressive granitization of basic rocks in the Abukuma plateau, Japan, the hornblende gained Al, Fe''', Fe'' and Na, and lost Si and Mg, so that the amphibole in the most highly granitized amphibolite is hastingsite. Buddington and Leonard (1953) have reported a broadly similar correlation from granite-gneisses in the Adirondack Mountains.

Because of inadequate data, very little can be said about the metamorphic history. The textures of several rocks tend to suggest that the main metamorphism and the regional alkali metasomatism post-dated the phase of maximum folding, but it is impossible to be more precise, and regional variations in the time relationships between folding and metamorphic events are almost certain to have occurred. It is deduced from the succession of deformed rocks south of Kay Nunatak that the main thrusting took place after the metamorphism had effectively ceased.

VI. INTRUSIVE ROCKS

1. *Metagabbros*

A basic hornblende-rich mass of limited extent occurs on the west flank of Maitland Glacier, and it appears to be intruded by a contaminated quartz-diorite although the precise nature of the contact is obscure. For the most part, the metagabbro has a poorly defined foliation, but in certain localized zones particularly at the margin of the intrusion strong shearing stress has created a finely gneissose structure. No other metagabbro intrusions were encountered within the area mapped. Fresh hypersthene-gabbros were recorded on the northern flank of Lammers Glacier west of the Mercator Ice Piedmont.

Microscopically, the typical specimens consist of fresh though highly twisted and fractured crystals of bytownite ($Ab_{25}An_{75}$) set in a confused aggregate matrix of amphibole containing patches of pale brown biotite, and sparse grains of rutile and iron ore (Plate VIIIf). The general texture is blastoporphyritic; however, the former ophitic texture is still discernible in places. Secondary twinning is developed extensively in the plagioclase but zoning is either weak or absent. A few of the larger crystals possess a faint zoning in which a core of almost colourless and non-pleochroic actinolite grades into a rim of pale green faintly pleochroic (?) ferro-actinolite. The latter has a slightly lower birefringence and extinction angle than the colourless amphibole and it may be close to hornblende in composition.

It is very difficult to ascertain the time relations between the metagabbro and the metamorphic schists and gneisses exposed in adjacent areas since no contacts were observed. However, hornblendic dykes intrude the gneisses to the north at station E.1670 and, if (as seems probable) these dykes are apophyses of the main metagabbro mass, the latter must clearly post-date the development of the foliation. Also, the unaltered bytownite rules out complete recrystallization under amphibolite-facies metamorphism, although the general texture definitely indicates shearing stress. Since a significant proportion of the amphibole appears to be of a primary origin, the metagabbro might be classed as a syntectonic intrusion (Gates, 1967) and its structural position would therefore be quite different from that of the granodiorites and granites which are post-kinematic high-level intrusions.

The amphibolite dykes cutting the gneisses at station E.1670 have irregular and highly contaminated margins. A typical dyke rock is a coarse-textured biotite-amphibolite (E.1670.5) with accessory calcite, sphene, apatite and iron ore. The larger euhedral to subhedral crystals of amphibole display sharp discontinuous zoning with a core of brownish green hornblende surrounded by a broad rim of normal green hornblende. In a few crystals there is three-fold zoning in which the zone of green hornblende gives way marginally to a very pale green or colourless actinolite. Oscillatory zoning was noted in some crystals. Pegmatitic facies in the dykes have large interlocking hornblendes accompanied by altered acid oligoclase. The presence of volatiles is shown by large euhedral apatites, epidote, sphene, calcite and chlorite. The latter two phases actively replace some of the hornblende. The marked variations in composition in a single crystal of amphibole associated with considerable activity of volatiles indicate that the former may be related to variations in the vapour pressure (Bowes and others, 1964).

A foliated (?) dyke recorded in the *para*schists and *para*gneisses at station E.1667 may also be related to the same metagabbro intrusion, although its distinctly metamorphic texture possibly implies an earlier age, and it may therefore have more affinities with the metabasites (p. 43). The texture is mainly granoblastic and the essential minerals include pale green poikilitic actinolite grading into hornblende, biotite, quartz and relatively large relict crystals of altered andesine. An important and abundant mineral is meionitic scapolite; this has grown late at the expense of all the earlier mineral phases, especially quartz which usually forms poikilitic inclusions within it. As with the scapolite occurring locally in the metagabbro intrusion to the west, the presence of this mineral is probably the result of localized intense activity of CO_2-rich solutions along shear zones such as is found in several of the basic dykes in the north-west Highlands of Scotland (Tarney, 1963). Granular epidote, sphene and calcite are prominent.

2. *Granodiorites*

Granodiorite, including related rock types such as tonalite and quartz-diorite, accounts for the bulk of the intrusive rocks in this area. In mineral composition and texture, the granodiorites bear a number of striking similarities to the biotite- and hornblende-biotite-gneisses but they are sharply distinguished by the almost complete absence of foliation, by conspicuous zoning (especially of the oscillatory type) in the plagioclase, and in some cases by the presence of primary zeolite. Modal analyses of some intrusive rocks are given in Table VIII.

A tonalite from the south-east corner of Hogmanay Pass (E.1658.2) has a hypidiomorphic-granular texture and consists of abundant andesine ($Ab_{60}An_{40}$), untwinned potassium feldspar and interstitial pools of strained quartz together with hornblende and biotite clusters. Epidote and titaniferous iron ore are the main accessory minerals. A late origin for at least some of the potassium feldspar is indicated not only by its very sporadic distribution but also by its insinuation round quartz and plagioclase, and its active replacement of the latter. Well-developed myrmekite has invariably formed where the potassium feldspar reacted with the plagioclase. Optically, the hornblende appears to contain small but significant amounts of the hastingsite molecule. A little muscovite replaces the andesine.

Another intrusion on the south-west flank of Hogmanay Pass (E.1651.1) is a coarser-grained and more quartz-rich variety of the previous one. The only other difference is the presence of allanite and zeolite. In spite of its small quantity, the zeolite is important because its occurrence in intergranular pockets demonstrates that it crystallized from a residual liquid and that it is not secondary after plagioclase. It is difficult to identify it partly because of its paucity and partly because the optical properties determined do not fit exactly any single described zeolite. However, apart from the fact that it appears to be almost uniaxial, stilbite is the most probable identification, and this is supported by the complex aggregate or cockscomb structure exhibited in several crystals.

Granodiorite intrusions were recorded from the large nunatak at the confluence of Grimley and Casey Glaciers (E.1648), on the west flank of Maitland Glacier (E.1676) and on a nunatak on the southern margin of the Mercator Ice Piedmont (E.1632). The main rock types from these three intrusions are closely similar

TABLE VIII

MODAL ANALYSES OF INTRUSIVE ROCKS

	E.1658.2	E.1651.1	E.1648.2	E.1632.1	E.1646.1
Quartz	14·8	24·3	33·4	34·5	36·5
Microcline	4·3	7·9	14·7	16·4	33·0
Plagioclase†	53·5	52·0	43·5	40·6	25·7
Myrmekite	2·3	1·3	1·5	4·0	0·4
Hornblende	12·9	6·1	0·2	*	—
Muscovite	0·6	—	—	0·2	—
Biotite	9·4	5·3	5·1	3·4	3·0
Chlorite	—			—	—
Iron ore	0·8	0·6	0·4	*	1·1
Sphene	0·4	0·5	0·3	—	0·1
Epidote	0·7	1·5	0·4	0·3	—
Allanite	—	*	0·2	*	0·2
Apatite	0·3	0·4	0·3	0·1	—
Zeolite	—	0·1	*	0·5	—
Average plagioclase composition	An_{40}	An_{40}	An_{30}	An_{30}	An_{20}

*Present but not recorded.
†Includes alteration products.

E.1658.2	Tonalite, Hogmanay Pass.
E.1651.1	Tonalite, Hogmanay Pass.
E.1648.2	Quartz-rich granodiorite, large nunatak at confluence of Casey and Grimley Glaciers.
E.1632.1	Quartz-rich granodiorite, nunatak in southern margin of Mercator Ice Piedmont.
E.1646.1	Granite, southern flank of Grimley Glacier.

to each other in mineralogy and texture, and they are clearly related to the tonalites. Quartz is particularly abundant and, compared with the tonalites, the potassium feldspar (partially twinned microcline) occurs in coherent plate-like crystals as well as in small interlobate masses. The plagioclase has an average composition of approximately $Ab_{70}An_{30}$, although zoning which includes discontinuous normal, oscillatory and irregular patchy types yields extreme values of $Ab_{50}An_{50}$ and $Ab_{82}An_{18}$. Hornblende of the variety present in the tonalites is accessory in most rocks. Small amounts of late primary zeolite which is believed to be stilbite are also present.

Contact phenomena. The contact between the granodiorite and the country-rock *para*schists and *para*-gneisses at station E.1648 is marked by a broad xenolithic zone in which skarn-type rocks have formed. Xenoliths near the margin of the granodiorite have undergone considerable alteration, especially muscovite enrichment, and in the extreme products of skarn-type reaction, the country-rock xenolith has been almost wholly replaced by muscovite, microcline and titaniferous ore (E.1648.10), an assemblage which demonstrates the influx of much potash, alumina and iron from the granodiorite.

A banded xenolith containing sodian augite, from the same locality, is penetrated by a narrow concordant vein of contaminated granodiorite which contains scarce garnet and significant amounts of zeolite. Some of the latter actively replaces the plagioclase. At least two species of zeolite are present and a little analcite occurs in close association. The latter is very slightly birefringent with faint lamellar twinning. As in the granodiorites, the zeolites are difficult to determine optically and their small amount precludes X-ray identification. One zeolite is optically positive and almost uniaxial; this is provisionally identified as chabazite which, according to Walker (1951), is positive if the mean refractive index is less than 1·488. The second zeolite, with a small 2Vα (30–40°), is probably stilbite. The remaining zeolite differs from the previous one in that it possesses no good cleavage and exhibits aggregate structure which may take the form of regular stellate or sector twinning, irregular twinning, cockscomb structure, or delicate feathery intergrowths. The general optical properties are, however, indicative of stilbite, and it is therefore concluded that this mineral occurs in two distinct forms.

3. *Granites*

The only late granite intrusion actually recorded in the metamorphic belt occurs on the south flank of Grimley Glacier (E.1646), although the intrusion which has given rise to the contact hornfelses at station E.1647 on the northern edge of the glacier is believed to be closely related if not part of the same granite. The hand specimen is a typical medium- to coarse-grained granite with flesh-coloured feldspar and slightly smoky quartz predominant. The thin section shows a hypidiomorphic-granular fabric of quartz, microcline-microperthite and oligoclase with scattered flakes or aggregates of partially chloritized biotite. Large grains of allanite are present; other accessory minerals include sphene, epidote, apatite and zircon. The microcline replaces some of the oligoclase but, in contrast to the tonalities and granodiorites, myrmekite is rare in this setting.

4. *Later dykes*

Lamprophyre dykes, which were intruded after the regional metamorphism of the area had completely ceased, probably have a fairly wide distribution although they were observed at only two localities: at station E.1648 where they post-date the granodiorite, and at station E.1661 on the southern margin of Sunfix Glacier where one dyke intrudes migmatitic gneisses. At both localities, the lamprophyre is a typical camptonite with conspicuous phenocrysts of hornblende. The hornblende occurs in two distinct habits: stout prismatic crystals many of which show a perfect idiomorphism, and slender prismatic crystals greatly elongated parallel to c and having poorly formed terminal faces. These two habits persist into the finer grain-sizes. Twinning is especially common in the columnar crystals. The general pleochroism scheme is α = pale brownish to yellowish green, β = light brown and γ = greenish brown or khaki. The larger crystals have a narrow marginal zone with a more intense absorption, and oscillatory zoning is also common. In a few phenocrysts there is a well-rounded core of turbid dark greenish brown hornblende peppered with fine iron ore particles. Phenocrysts of a very pale green augite with $\gamma : c = 32°$ are also present but they are not as distinctly euhedral as the hornblende, and in addition they are replaced in varying degrees by carbonate. Pseudomorphs of large phenocrysts believed to be olivine commonly occur in compact clusters. The nature of the original phenocrysts is indicated not only by their general form but also by the nature of the alteration products. These include fine scaly talc, carbonate (possibly magnesite) and haematite dust. Several of the pseudomorphs have a peripheral zone of small hornblendes of varying habit. Apart from a few microphenocrysts, the plagioclase feldspar (labradorite) is confined to the matrix where it occurs in radiating aggregates accompanied by hornblende, octahedral magnetite and scarce interstitial quartz. Small quartzose xenoliths and xenocrysts are surrounded by a broad zone of turbid carbonate.

VII. STRUCTURAL GEOLOGY

BECAUSE the geological mapping was essentially of a reconnaissance nature, only a limited amount of structural work was undertaken, so that while the general structural pattern seems fairly clear a more detailed analysis must await further work. For descriptive purposes, the structural elements, folding and thrusting, are treated in geographical areas but the faulting is discussed on a wider regional basis. The final section gives a possible structural synthesis related to the metamorphic history.

A. FOLDING AND THRUSTING

1. *Mobiloil Inlet*

On Kay Nunatak, a prominent thrust zone (p. 9) occurs near the contact between the shallow-water sediments and the overlying volcanic rocks. The sediments have been strongly folded and deformed (Plate IVb) especially just below the thrust zone, where asymmetrical folds with associated bedding-plane slip and fracture cleavage have an approximate north-west–south-east trend. However, it is probable that this thrust on the north side of the nunatak is of comparatively minor importance since a major thrust is believed to occur about 2 km. farther south. In the highly deformed and mylonitic rocks adjacent to this thrust, tight zig-zag folding was observed in several finely banded quartzites. A moderately well-developed lineation, resulting from the intersection of bedding with cleavage planes, plunges at 10–15° to the west-north-west, and small monoclinal folds present in some of the mylonitic rocks have axes trending in a similar direction. In general, the cleavage has a gentle or moderate dip to the south-south-west and the other structural data recorded in the cataclastic rocks are consistent with thrusting from this direction. The wide col separating Kay Nunatak from the cliffs on which the cataclastic rocks are exposed either marks a major fault or is the result of deep erosion along the trace of the thrust.

The strongly deformed diorite on the east flank of Aphrodite Glacier probably records the eastward continuation of the thrust zone south of Kay Nunatak, but elsewhere on the south coast of Mobiloil Inlet little evidence of major tectonic activity was found. The purple and black volcanic rocks are either unfolded or exhibit only gentle warping about axes varying between north-west to south-east and west-north-west to east-south-east.

On the ridge south-east of Crabeater Point, it is difficult to elucidate the structure because in many places the bedding cannot be determined with confidence. In those outcrops where the bedding could be measured, the strike is generally east-south-east to west-north-west, i.e. sub-parallel to the trend of the ridge. Near the south-east end of the main outcrop, 3 km. from Crabeater Point, the beds are in normal superposition for the most part and have an average dip of 45° to the south. Towards the north-west the dip progressively steepens and at Crabeater Point the beds are slightly overturned. The quartzite-shale sequence on the south-west side of the ridge 13 km. from Crabeater Point dips at about 60° to the north. The cleavage strike appears to parallel the ridge a little more closely than the bedding and its dip is invariably steep or vertical. The only definite major structure observed is a recumbent fold which occurs on the edge of a prominent cirque at the south-east extremity of the exposure. The fold is more easily discerned from a distance than at close range and its relationship to the overlying and underlying unfolded sediments is obscure. Numerous fragments of breccia in nearby scree material may indicate that the structure is closely associated with thrusting, but this is doubtful since the consistently high cleavage angle is not readily reconciled with low-angle thrusting.

2. *Mount Argus*

This is a critical locality concerning the structural history of the area south of Mobiloil Inlet. However, it is extremely difficult to establish the true structural relations, partly because many important contacts could not be investigated and partly because the stratigraphical succession is uncertain. Although volcanic rocks occur at different and distinct levels in the Mount Argus sections, it is difficult to ascertain whether these represent more than one phase of volcanicity interrupted by relatively long periods of sedimentation or whether the repetition is wholly of tectonic origin. There appear to be equally valid grounds for supporting either alternative. The fact that, on lithological, petrographic and chemical grounds, lavas from the lower and upper volcanic rocks at Mount Argus can be convincingly matched with each other, and with those occurring at different levels in the apparently continuous sequence in Mobiloil Inlet, points to one period of major volcanicity only. However, the absence of a strong interpenetrative deformation throughout the uppermost volcanic rocks in the summit area seems to preclude thrusting on the considerable scale implied in the first alternative. Furthermore, volcanic rocks which are almost certainly younger than those underlying the green and purple arkoses at Mount Argus are known to occur farther east at Cape Mayo.

At present it is impossible to come to a firm conclusion concerning the Mount Argus succession but the following points are relevant. First, the lavas at Cape Mayo possess significant though not fundamental differences compared with those on the summit of Mount Argus (p. 33). Secondly, thrusting has clearly affected the uppermost volcanic rocks (Plate IIc), and the strongly deformed and highly cleaved arkoses just below these volcanic rocks could justify the view that the thrusting was on a major scale. Consequently, it is tentatively suggested that all of the volcanic rocks in the Mount Argus succession belong to one period of volcanic activity and that the repetition is of tectonic origin. The general absence of intense deformation in the volcanic rocks may be partly explained by the fact that the major translational movements were taken up by the relatively incompetent adjacent sediments. It is noteworthy, however, that strongly schistose lavas were recorded just south-east of the summit (p. 10).

As far as can be ascertained no overturning has occurred in the succession at Mount Argus and consequently, if there has been only one volcanic phase, the repeated sequences shown in Figs. 4 and 5 must have been produced by a series of fracture thrusts. Thrusting of this kind is particularly well displayed on the north-eastern scarp edge (Plate IVc) where the complex relationships between the various rock groups are believed to have resulted from the sequence of events illustrated in Fig. 9a–d. A schuppen

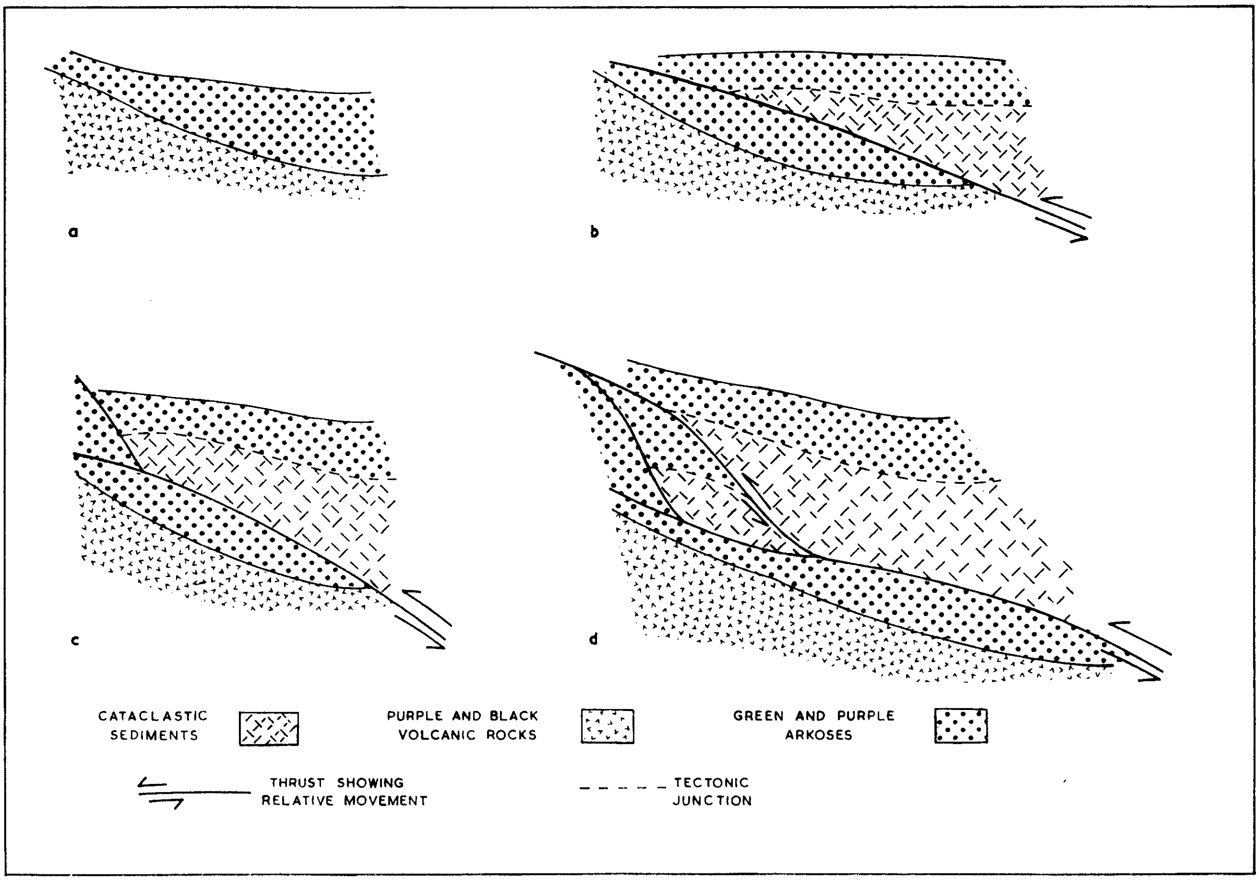


FIGURE 9

A series of diagrams to illustrate the suggested structural evolution of Mount Argus (cf. Fig. 5).

zone with associated intense brecciation occurs in the arkoses immediately below the main (lower) thrust; the very irregular nature of the contact between these arkoses and the underlying black volcanic rocks indicates that translational movement along the plane of unconformity was considerable. The evolution of thrust wedges provides a possible explanation for the abrupt changes in thickness which characterize most of the rock sequences on Mount Argus, particularly the green and purple arkoses. However, some of the irregular contacts may have resulted from pre-thrust faulting. Since the thrusting is not apparently associated with major folding, the comparatively incompetent cataclastic sediments were almost certainly folded and deformed prior to the thrusting.

In the highly fissile and deformed arkoses immediately below the uppermost volcanic rocks on the north wall of Mount Argus, the cleavage strikes in a direction 115° mag. and dips steeply to the south-west, and the cleavage in the cataclastic sediments 3 km. to the north-west dips at between 20° and 40° in the same direction. The direction of the thrust movements indicated by these measurements is fully consistent with the general pattern of structures in the Mount Argus massif.

3. *Northern Wilkins Coast*

Evidence for folding or thrusting is completely lacking at Cape Mayo. Farther south, at Miller Point, no major thrust was recorded but the shales and conglomerates are cut by cleavage and minor shear zones, both of which dip at a low angle to the south. At Cape Hinks, the volcanic rocks are affected by numerous small-scale thrusts striking in a direction 264° mag. and dipping at 22° to the south; in places this shearing has reduced the lavas to hydrothermally altered and pyritized schists. Low-grade metasediments west of Cape Hinks apparently overlie the volcanic rocks, the contact being marked by well-banded or bedded rocks followed upwards by a light buff-coloured band at least 50 m. thick, containing angular fragments and lenticular blocks which have an estimated maximum diameter of over 6 m. This breccia band is provisionally interpreted as marking the trace of a major thrust.

4. *Inland areas*

No large folds were observed in the lowest-grade metamorphic rocks west of Cape Hinks, but tight minor folds plunging gently to the north or north-north-west are common. Disjunctive folds occur in tightly folded sediments which consist of alternating quartzo-feldspathic and semi-pelitic bands of greatly differing competency. Both strain-slip and slaty cleavage have developed during folding, the latter being restricted to the more argillaceous bands. The combined effect of cleavage and frost-shattering has been to reduce many of the outcrops to cleavage blocks, none of which is in place. In the *para*gneisses and *para*schists farther inland towards the plateau, the pattern of folding is broadly similar to that just described except that a few major structures were also recorded. Also, complete recrystallization has increased the competency of the more argillaceous layers so that disruption of individual bands is much less common; instead, quartzo-feldspathic material has tended to migrate to the fold crests. The *ortho*gneisses present in the metamorphic complex are not so conspicuously folded as the *para*gneisses. The dominant fold axis over the entire complex trends north-north-west to south-south-east but later folding about a west-north-west to east-south-east axis is also present. This second generation of folding appears to have modified the metamorphic rocks only locally and only to a minor degree.

B. FAULTING

In general, faults are difficult to locate and examine in the Mobiloil Inlet area, since the fault zones are almost invariably planes of weakness which offer little resistance to erosion and are thus occupied by glaciers or form snow-covered cols between mountain blocks. Well-defined valleys or troughs cutting across the general grain of the peninsula and bearing no apparent relation to the drainage pattern are regarded as probable fault zones but other troughs are considered to represent normal coastward drainage unless there is good geological and/or morphological evidence to indicate otherwise.

Major faults which can be readily proved in this area occur on the south-east margin of Mobiloil Inlet at the base of Kenyon Peninsula (Fig. 3). The prominent straight north-east edge of Mount Argus is a fine example of a fault scarp, and it is this fault which is reponsible for the great morphological contrast between the gently rounded, low-lying Kenyon Peninsula and the mountainous area to the south-west (Plate IVd). The downthrow to the north-east is at least 1,300 m., although some horizontal component may also have been involved in the faulting. Calypso Cliffs are approximately colinear with the Mount Argus scarp and they almost certainly mark the north-westerly continuation of the same fault zone. It is uncertain whether the prominent col between Kay Nunatak and the high cliffs to the south is a further expression of this fault or whether it has been caused by erosion along a major thrust.

Another important fault zone trending west-north-west to east-south-east occurs along Poseidon Pass. This fault accounts for the different successions at Cape Mayo and Cape Keeler, and on the basis of recorded dips in both successions the downthrow to the north-east is believed to be of the order of several hundred metres. The fault zone is clearly complex since Poseidon Pass is not a linear feature. Also, it is probable that this fault consists of a series of closely spaced step faults rather than a single plane of movement. However, there is no evidence to suggest that the ridges and troughs in the Kenyon Peninsula area are horst and graben structures as proposed by Knowles (1945); in fact, all of the evidence is to the contrary.

These major fault systems contribute substantially to the narrowing of the Antarctic Peninsula in the Mobiloil Inlet area and they also explain the preservation of the Cretaceous sediments at Crabeater Point and Cape Keeler. The nearest known occurrence of fossiliferous sediments of comparable age on this east coast is at Cape Marsh on Robertson Island, 440 km. to the north-north-east (Fleet, 1966).

Faults, which cannot be conclusively proved, but for which the evidence is strong, occur on the northern Wilkins Coast and along Gibbs Glacier north of the Mercator Ice Piedmont. In the former locality, the steep coastal cliffs at Cape Walcott and Cape Hinks are believed to be fault scarps associated with block-faulting and the widely developed surfaces of slickensiding with a steep plunge to the east at Cape Hinks provide additional support for this fault. It is possible, as Knowles (1945) has suggested, that the offshore islands farther south owe their existence to a continuation of this block-faulting parallel to the coast. Gibbs Glacier is part of an exceptionally regular trough linking Neny Fjord on the west coast with the Mercator

Ice Piedmont and Mobiloil Inlet. Although this feature lies outside the area described in this report, it is mentioned here since it is clearly of fundamental structural significance. The geology on either side of the trough is so little known that it is impossible to state whether the structure is a graben, a normal fault or a wrench fault.

Structural discontinuities, which have a more speculative basis, coincide with such features as Weyerhaeuser Glacier and the well-defined east–west gap from Mobiloil Inlet through the Mercator Ice Piedmont, the Traffic Circle, Lammers Glacier and Windy Valley to the west coast. Weyerhaeuser Glacier is a deep regular trough which may represent the southerly continuation of Gibbs Glacier.

C. STRUCTURAL EVOLUTION

Two periods of folding have been recognized in the area south of Mobiloil Inlet. As far as can be determined on the available evidence, the earlier generation of folds along axes trending north-north-west to south-south-east has only affected rocks within the metamorphic complex, whereas the second generation of folding along approximately west-north-west to east-south-east axes has involved virtually all of the rocks, although it is only prominent in a few localities. The orientation of folds and related structures in Mobiloil Inlet, and especially at Kay Nunatak, strongly suggests that the second generation of folding is co-genetic with the thrusting movements. The highly deformed rocks on the cliffs south of Kay Nunatak are thought to have been brought into their present position by thrusting. Since the mylonitic bands in this sequence of cataclastic rocks are strongly folded in a manner suggesting that the rocks behaved plastically during deformation, it is evident that these rocks were formed at depth and are not the product of high-level thrusting and brittle fracture.

Excluding true Basement Complex rocks in the area, the tentative structural history of the area south of Mobiloil Inlet began with the deep burial and folding of psammitic and semi-pelitic sediments about north-north-west to south-south-east axes. During deep burial, the sediments were regionally metamorphosed, the grade of metamorphism being very low in the north-east and increasing steadily in a general south-westerly direction. This metamorphism with associated metasomatism, migmatization and synkinematic intrusion was either broadly co-eval with, or subsequent to, the folding movements, and by analogy with other orogenic belts the folding and metamorphism may have been spread over a long period of time. The highly deformed and mylonitic rocks south of Kay Nunatak are thought to be the result of intense sliding along movement zones at considerable depth at the outward margin of the mountain belt.

The next important tectonic event resulted in large-scale thrusting from south-south-west to north-north-east. Although this thrust zone is depicted in Fig. 3 as a single line, in detail the zone must be extremely complex, consisting of numerous thrust planes of greatly varying magnitude, since there are considerable differences in degree of deformation and metamorphism of rocks brought up to the present level of erosion. Thus, south of Kay Nunatak, the thrust approximately coincides with a much earlier plane of movement along which intense deformation of the metamorphic rocks took place at depth, whereas at Mount Argus the thrust has carried virtually unmetamorphosed though deformed sediments into their present position. The thrusting produced local but marked folding along west-north-west to east-south-east axes, as at Kay Nunatak where volcanic rocks have been thrust over sediments. It is possible, however, that some folding along this axis also occurred before the main translational movements.

The final orogenic phase is represented by major block-faulting, which appears to have developed with remarkable consistency just outside the outward margin of the thrust zone along the south side of Mobiloil Inlet and the northern Wilkins Coast. Compressional forces associated with this faulting are believed to have caused the surprisingly high degree of deformation and cleavage development in the Cretaceous sediments at Crabeater Point.

VIII. REGIONAL CORRELATIONS AND GENERAL CONCLUSIONS

UP till now, the geology of the area south of Mobiloil Inlet has been described without detailed reference to the general stratigraphy and geological history of the Antarctic Peninsula, summaries of which have been given by Adie (1957*b*, 1958).The main purpose of this section is to attempt the correlation of major lithological groups and significant tectonic events between the Mobiloil Inlet area and other parts of the same orogenic belt so that the geological evolution of the area can be considered in a wider regional context. In the almost complete absence of faunal evidence and isotopic ages, this is the only way in which a time scale can be suggested for the sequence of events.

One of the most extensive and important rock types in this area is represented by the cataclastic sediments and their presumed metamorphic equivalents, which are exposed along a broad belt to the south and west of the coast. Mainly on petrographic grounds (p. 18), the sediments at Kay Nunatak and Miller Point are believed to be the shallow-water equivalents of the cataclastic sediments, although they are considerably less deformed than the latter. The key to the present stratigraphical interpretation is the correlation of these cataclastic sediments with the Trinity Penisula Series, a pre-orogenic sedimentary succession which has been firmly established as by far the most important in Graham Land (Adie, 1957*a*; Aitkenhead, 1965; Elliot, 1965, 1966). Whereas the sediments of the Trinity Peninsula Series of northern Graham Land tend to be highly feldspathic (Adie, 1957*a*; Aitkenhead, 1965; Elliot, 1965), those south of Mobiloil Inlet are feldspar-poor. Nevertheless, the correlation is supported by gross lithological similarities, including the presence of intercalated metabasites (Aitkenhead, 1965) and similarities in the environment of deposition as shown by the sedimentary structures. On the basis of fragmentary plant remains, the Trinity Peninsula Series of northern Graham Land is known to be Carboniferous in age.

According to Aitkenhead (1965), these sediments are eugeosynclinal deposits laid down in a turbidite environment in an active tectonic basin, sedimentation being brought abruptly to a close by major orogenic events which resulted in folding and strong deformation. Two periods of folding have been recognized: the first and main phase gave a regional strike sub-parallel to the axis of the peninsula; the second acted at right angles to this and produced marked deflections in the regional trend. During folding the sediments were regionally metamorphosed but, despite a perceptible increase in metamorphism from north-east to south-west, the grade is everywhere low in Trinity Peninsula, never attaining more than the lower part of the greenschist facies (Aitkenhead, 1965; Elliot, 1966).

In areas farther south, such as in the Nordenskjöld Coast (Elliot, 1966) and the northern part of the Oscar II Coast (Fleet, 1968), the regional metamorphism of the Trinity Peninsula Series is so low that there is little or no evidence to suggest that the gradual increase in metamorphism noted in Trinity Peninsula is maintained southward along the Antarctic Peninsula at least to lat. 65° S. At one locality, Elliot (1966, p. 33) found unequivocal evidence of two phases of folding and it seems therefore that cross-folding of the Trinity Peninsula Series occurred on a regional scale, although its effects might only be recognizable locally.

Between the Oscar II Coast and Mobiloil Inlet, sediments which definitely belong to the Trinity Peninsula Series have not been recorded except at Three Slice Nunatak, where Adie (1957*a*) found "highly fissile slates". In the Cabinet Inlet area, there is what A. F. Marsh (personal communication) has described as a metamorphic complex, part of which comprises *para*gneisses with a metamorphic grade corresponding to the amphibolite facies. If these *para*gneisses are part of the Trinity Peninsula Series, they would be the first positive indication of a significant increase in metamorphic grade to the south; however, there is at present no evidence concerning their age. Thus, with the possible exception of this metamorphic complex, the present evidence suggests that north of Mobiloil Inlet the Trinity Peninsula Series has not been regionally metamorphosed to a high grade; indeed, for the most part the metamorphism is predominantly of a cataclastic type (Adie, 1957*a*). The strong contrast provided by the progressive metamorphism and high-grade rocks of sedimentary origin in the area south of Mobiloil Inlet means either that the sediments are considerably older than the Trinity Peninsula Series or that during orogenesis they were subjected to conditions different from those prevailing farther north. The second alternative is more probable; the differences in metamorphism can be readily explained in terms of the major fault systems in Mobiloil Inlet. These faults, which are responsible for the marked narrowing of the Antarctic Peninsula at that latitude have a downthrow to the north-east, thus bringing deeper structural levels to the surface farther south. Thus, the metamorphism, metasomatism and migmatization of the Trinity Peninsula Series exposed at the present level of erosion south of Mobiloil Inlet correspond to what is present at depth in the northern part of the Antarctic Peninsula. The absence of synkinematic intrusions in the latter region is fully consistent with this interpretation.

The regional metamorphism of the Trinity Peninsula Series is definitely pre-Jurassic (Adie, 1957*a*, p. 5) and an upper Triassic–Lower Jurassic age (*c*. 185 m. yr.) has been postulated by Miller (1960) following radiometric age determinations on micas from the Basement Complex of the South Orkney Islands.

The metamorphism of the Trinity Peninsula Series south of Mobiloil Inlet is considered to be of an age comparable to that in the north and it is either broadly contemporaneous with or subsequent to the main folding movements. Whether all of the rocks in the metamorphic belt are referable to this one metamorphic event or whether much older rocks are also present is uncertain. Since a Basement Complex of possible Lower Palaeozoic or Precambrian age is known to occur in Marguerite Bay farther to the north-west, it may well be that segments of this basement are present in the metamorphic complex. Alternatively, the Basement Complex of west Graham Land is entirely of a Lower Mesozoic age but in the light of the present information this hypothesis is very doubtful. However, it is interesting to note that the general regional strike of the foliation in the Basement Complex of the Neny Fjord area is north-west to south-east (Hoskins, 1963).

The position of the keratophyres and related volcanic rocks in the stratigraphical succession is uncertain and the problem is complicated by the fact that more than one phase of volcanicity has occurred, although there is considerable doubt about the extent of the later activity. Lavas, tuffs and porphyries of a predominantly rhyolitic composition, which are assigned on good evidence to the Upper Jurassic, are extremely widespread along the east coast of the Antarctic Peninsula north of Mobiloil Inlet (Adie, 1953; Elliot, 1965, 1966; Fleet, 1968), and it is not unreasonable to suppose that volcanic activity on such a major scale also extended to south of Mobiloil Inlet. Correlation is seemingly justified by broad similarities in chemical composition, secondary activity such as silicification and the re-distribution of alkalis, and in some cases by similarities in texture. However, the distinctive purple or brown colour which characterizes much of the volcanic succession in the Mobiloil Inlet area is not typical of the Upper Jurassic volcanic rocks; purple haematite-rich crystal tuffs have been described from Churchill Peninsula (Adie, 1953) but these seem to be exceptional in this respect. The volcanic rocks farther north are also different in that quartz phenocrysts are common and usually predominate, and they also lack the rounded pools of bright green chlorite. More important differences are shown by the subaqueous eruption of at least some of the lavas south of Mobiloil Inlet and by the semi-plutonic post-depositional (-eruptive) conditions to which they were all subjected. Furthermore, the Upper Jurassic volcanic rocks of northern Graham Land are clearly post-orogenic, whereas these seem to be an integral part of the geosynclinal environment in which the Trinity Peninsula Series was deposited. This is inferred not only by the possible upward transition of the sediments at Kay Nunatak but also by the arcuate distribution of the volcanic rocks which strongly suggests deposition along a volcanic island arc. Finally, it is difficult to equate the keratophyres with the Upper Jurassic rocks, since there are too many major geological events to squeeze in between their initial eruption and the deposition of the Cretaceous sediments at Crabeater Point. Consequently, the volcanic rocks south of Mobiloil Inlet are believed to be mainly Carboniferous in age, the Cape Mayo lavas being regarded as appreciably younger in view of their relationship to the green and purple arkoses. Although no volcanic rocks have been found *in situ* in the Trinity Peninsula Series of northern Graham Land, there is abundant evidence of contemporaneous activity in the form of numerous lithic fragments of acid lavas and tuffs in the greywacke sandstone and intraformational conglomerates (Aitkenhead, 1965; Elliot, 1965). The differences between the Upper Jurassic volcanic rocks and the older ones are believed to be more a function of differences in environment and post-depositional history than in initial composition, and it is therefore probable that the same magma source was tapped at different times during the evolution of the orogenic belt.

The green and purple arkoses, together with their supposed equivalents, the Mount Argus sediments, are locally derived sediments rich in volcanic material which are not comparable with sedimentary rocks described from farther north. It is therefore difficult to establish their age other than that they are post-Carboniferous and pre-Cretaceous. On Mount Argus, the arkoses rest with a marked unconformity on the volcanic rocks, suggesting a major time interval during which orogenesis occurred, although the unconformity has probably been exaggerated by later thrusting. The distinctive spongy growth of prehnite present in the Mount Argus sediments is closely comparable with that in the Cumberland Bay Series of South Georgia (Trendall, 1953) and in the Yahgan Formation of Navarino Island (Watters, 1965), both of which are believed to be Lower Cretaceous in age, but it would be hazardous to attempt any correlation on this basis; the prehnitization is obviously more closely linked with the type of volcanic debris present in the sediments than any age factor. In any case, a Cretaceous age is almost certainly ruled out by the considerable changes in palaeogeography and geological setting which clearly occurred between the deposition of the arkoses and the Crabeater Point sediments. It is therefore believed that the green and purple arkoses are Jurassic in age and their deposition followed soon after the major folding of the Trinity Peninsula Series.

The earth movements responsible for the large-scale thrusting south of Mobiloil Inlet represent a tectonic event of major proportions which is bracketed in age by the green and purple arkoses and the Cretaceous Crabeater Point sediments, assuming that the structural pattern of the latter has been correctly interpreted (p. 49). Although thrusting has been recorded in the Trinity Peninsula Series of northern Graham Land (Aitkenhead, 1965), no age has been attached to it because of inadequate evidence. G. M. Stubbs (personal communication) has mapped a probable thrust zone in Joerg Peninsula, just to the north of Mobiloil Inlet, but here again there is no means of dating the event. However, in Alexander Island, about 300 km. south-west of the Mobiloil Inlet area, thrusting has been well documented by several workers (Adie, 1964; Taylor, 1966; Horne, 1967*a*; personal communication from M. R. A. Thomson), and not only have the movements occurred in a similar sense in the two areas, i.e. from a general west to east direction, but the age is almost certainly comparable. The thrusting in Alexander Island is definitely known to be post-Aptian which fits in well with the proposed chronology of the Mobiloil Inlet area.

Plutonic igneous activity is known along the whole length of the Antarctic Peninsula and in several areas intrusive rocks greatly predominate. As far as Graham Land (that part of the Antarctic Peninsula north of Mobiloil Inlet) is concerned, much of this plutonism was concentrated in late Cretaceous–early Tertiary times and the intrusions are referred to as the Andean Intrusive Suite (Adie, 1955). Undoubtedly, several of the granites and granodiorites south of Mobiloil Inlet, in particular those which are high-level plutons, belong to this intrusive suite (*sensu stricto*). Variations in the type of contact together with differences in structure and texture indicate a wider span of time than that generally implied for the Andean Intrusive Suite, although recent radiometric dating has given increasing evidence of older intrusive rocks (Rex, 1967). Consequently, the intrusion of igneous rocks (Table IX) occurred over an extended time range, the later rocks being emplaced at progressively higher structural levels in accordance with the granite series of Read (1957). Indeed, the earliest phase of plutonic activity could well be represented by the synkinematic intrusions and *ortho*gneisses along the axis of the metamorphic belt.

The last major geological event in the Mobiloil Inlet area was large-scale faulting. As suggested on p. 10, the fault zones may have been initiated much earlier in the geological history of this area, but there is no doubt that as far as the present geomorphological features are concerned, the main movements took place comparatively recently in geological time. Nichols (1960) believed that the plateau of the Antarctic Peninsula is a Middle or late Tertiary surface and Linton (1964) provisionally assigned the uplift of the peninsula to late Tertiary times. Since the uplift was not accomplished by folding, the margins of the peninsula must be strongly faulted, and the faults along the northern Wilkins Coast and along the southern margin of Mobiloil Inlet are assumed to be related to the uplift of the Antarctic Peninsula.

The preceding discussion demonstrates that from the Upper Palaeozoic onward the general pattern of geological activity in the Mobiloil Inlet area was closely comparable with what has been established from many other parts of the Antarctic Peninsula. As to the earlier geological history, there is little or no positive evidence and there is clearly much scope for further research on this topic.

Excluding the possible presence of basement rocks, the geological history begins with geosynclinal sedimentation in a deep trough aligned in a general north-west to south-east direction. On the north-eastern margin of the sedimentary basin there appears to have been a geanticlinal zone, on which relatively shallow-water facies sediments were deposited, and on which volcanic activity was located periodically to give a volcanic island arc. The difficulties in establishing a stratigraphical succession and correlating in this zone may not only be due to later thrusting but also to the complex regime of sedimentation likely to have prevailed in such a zone. The source area is unknown but the general geological framework of this area suggests that the sediments may have been derived from the east. The Trinity Peninsula Series of northern Graham Land is also thought to have been derived from an easterly quarter (Adie, 1964).

This prolonged sedimentation culminated in orogenesis which was marked by deep burial of the sediments, compressive folding and metamorphism. Whereas in its initial stages the latter may have been more or less isochemical, regional soda metasomatism followed by potash metasomatism is clearly imprinted in nearly all of the metamorphic rocks. In the highest-grade rocks, migmatization and *lit-par-lit* injection occurred with the closely associated intrusion of granitic gneisses. The metagabbro of the Maitland Glacier area may belong to the last stages of this folding and metamorphism. The sediments and volcanic rocks along the geanticlinal zone do not appear to have been strongly deformed during this

TABLE IX
GENERALIZED STRATIGRAPHY OF THE AREA SOUTH OF MOBILOIL INLET

Age	*Tectonic and metamorphic history*	*General stratigraphy*	*Remarks*
Tertiary	Block faulting	Granite Granodiorite	Andean Intrusive Suite
Cretaceous	Folding (?)	Crabeater Point sediments	Folding in the Crabeater Point sediments almost certainly local and may be associated with block faulting
	Thrusting		Responsible for occurrence of cataclastic sediments of the Trinity Peninsula Series at Mount Argus and for the succession of mylonites and cataclastic gneisses on cliffs south of Kay Nunatak
		Diorite	Highly deformed intrusion on coastal buttress between Aphrodite and Pan Glaciers. Almost certainly belongs to the Andean Intrusive Suite
Jurassic		〰〰〰 Metagabbro	Possibly earliest phase of Andean Intrusive Suite
		Green and purple arkoses	Mount Argus sediments probably facies variation but of somewhat younger age. Volcanicity at Cape Mayo believed to indicate different location of volcanic arc at this time
	Folding, metamorphism and migmatization	*Ortho*gneisses 〰〰〰	Synkinematic intrusions
Triassic			
Carboniferous		Purple and black volcanic rocks	Only definitely known in coastal areas where they appear to occur in volcanic arcs
		〰〰〰 (?)	If present, the hiatus is only a minor one
		Trinity Peninsula Series	Shallow-water facies at Kay Nunatak and Miller Point
(?) Precambrian (Basement Complex)	Metamorphism and orogeny (?)	(?) *Ortho*gneisses Amphibolite and mica-schist	No evidence for age. Provisionally interpreted as slices of Basement in the later metamorphic complex

period of folding. However, the deposition of the green and purple arkoses probably stems from associated movements. The arkoses were laid down during vigorous sedimentation in narrow zones at the margin of the newly formed mountain belt, much of the material being contributed by the volcanic rocks. It is probable that the Cape Mayo succession represents a later position of the geanticlinal zone with a similar sequence of sedimentation→volcanicity→sedimentation. Volcanic activity may also have been renewed in the Mount Argus area at this time but this has not been established.

The events following the deposition of the arkoses and the Mount Argus sediments cannot be easily deciphered. While intrusion of igneous rocks continued in the central part of the mountain belt, both the sedimentary and the volcanic rocks of the supposed geanticlinal zone appear to have been relatively deeply buried so that major changes must have occurred in the general tectonic setting. Thrusting from the south-west, involving considerable translational movements, marked the next stage in the orogenic cycle. It appears that no great elevation resulted from this thrusting since the Crabeater Point sediments were clearly deposited in a relatively quiet-water environment. The present outcrop of these Cretaceous sediments is controlled by faults, but even so, the pre-faulting distribution is unlikely to have been extensive.

The final event in the evolution of the orogenic belt is represented by block-faulting, the intrusion of high-level granites in the metamorphic belt presumably being associated with this differential uplift. These essentially vertically directed movements, which are of the order of 1,500 m. or more, determined the pre-glacial landscape not only of the Mobiloil Inlet area but also of much of the Antarctic Peninsula and resulted in a well-defined peninsular block with steep margins. Many workers (e.g. Linton, 1964) have demonstrated beyond all doubt that subsequent glaciation exerted a profound influence in modifying the morphology of this uplifted landmass.

IX. ACKNOWLEDGEMENTS

WE wish to thank Professor F. W. Shotton for providing all the necessary facilities for laboratory work in the Department of Geology, University of Birmingham, and Dr. R. J. Adie who constantly guided the course of the work and assisted in the preparation of the manuscript. We are particularly grateful to Dr. M. R. A. Thomson for providing vital information and material from the Cape Mayo area. Many members of the British Antarctic Survey Geology Section and the staff of the Department of Geology gave invaluable help during discussion and this is gratefully acknowledged. Mr. L. W. Vaughan kindly assisted with the preparation of the plates. One of the authors (A.G.F.) was responsible for arranging and writing the manuscript, and he wishes to acknowledge his wife's assistance in correcting and checking the final manuscript and the proofs.

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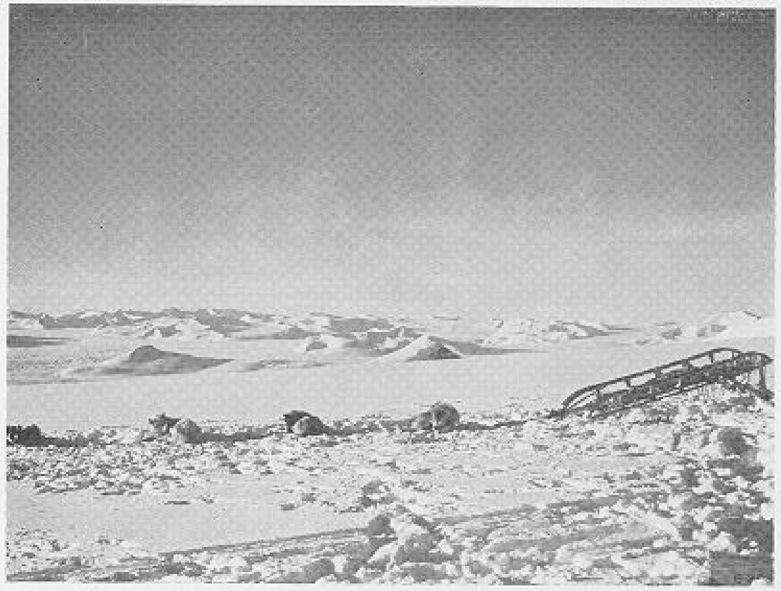
PLATE I

a. Tributaries of Casey Glacier descending with a fairly uniform gradient from the plateau ice cap.

b. The middle and upper reaches of Casey Glacier with Fin Nunatak approximately midway across the ice stream.

c. The middle and lower reaches of Casey Glacier showing its great width (*c.* 8 km.) and its heavily crevassed nature.

d. Kay Nunatak viewed from the north.



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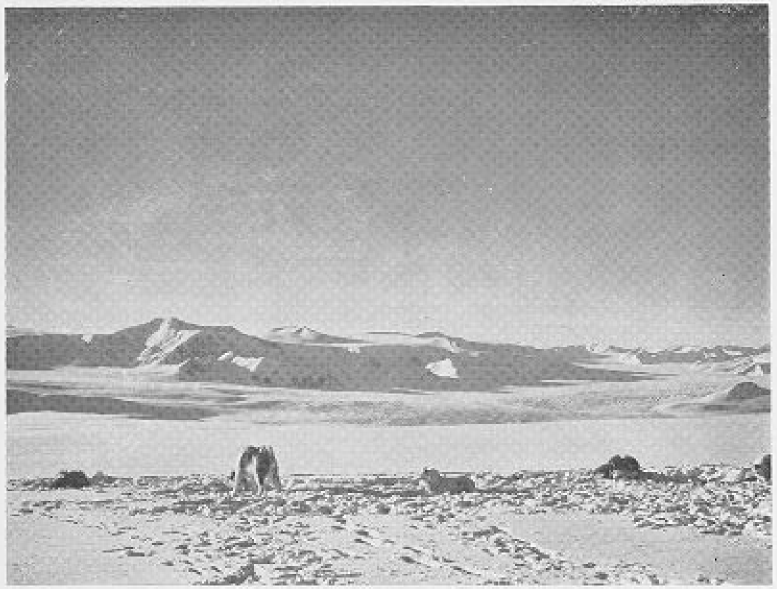

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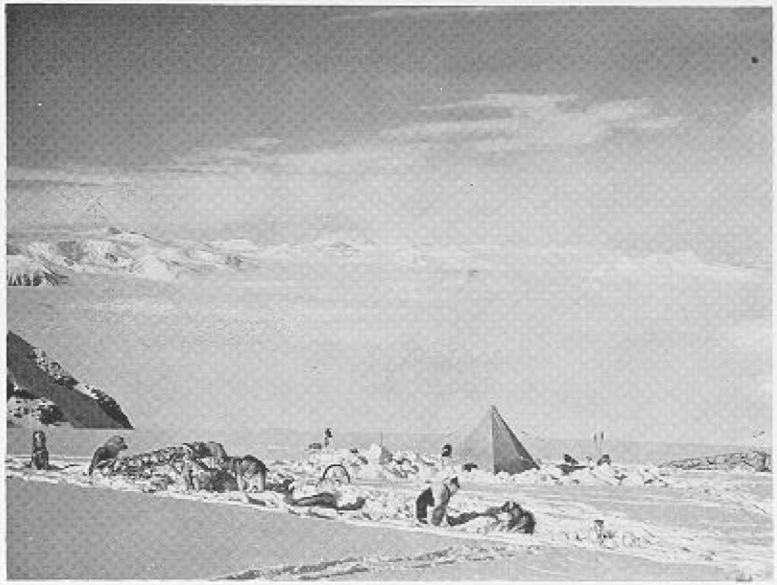

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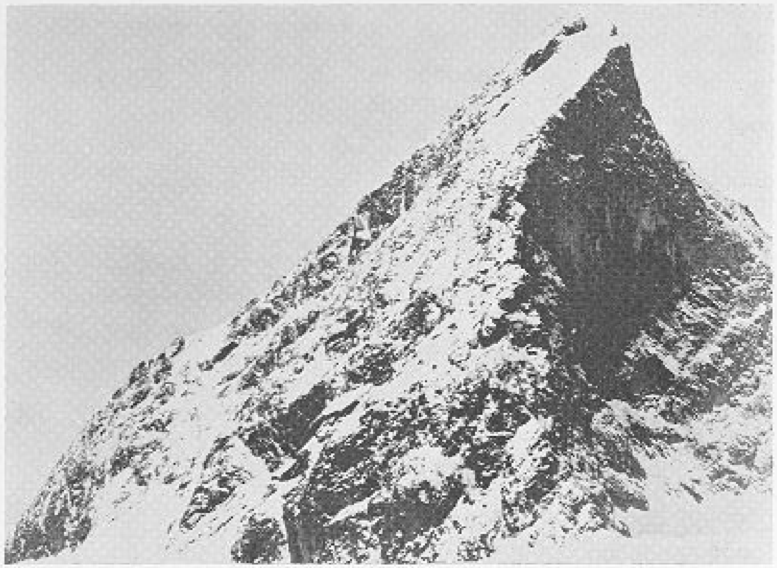

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PLATE I

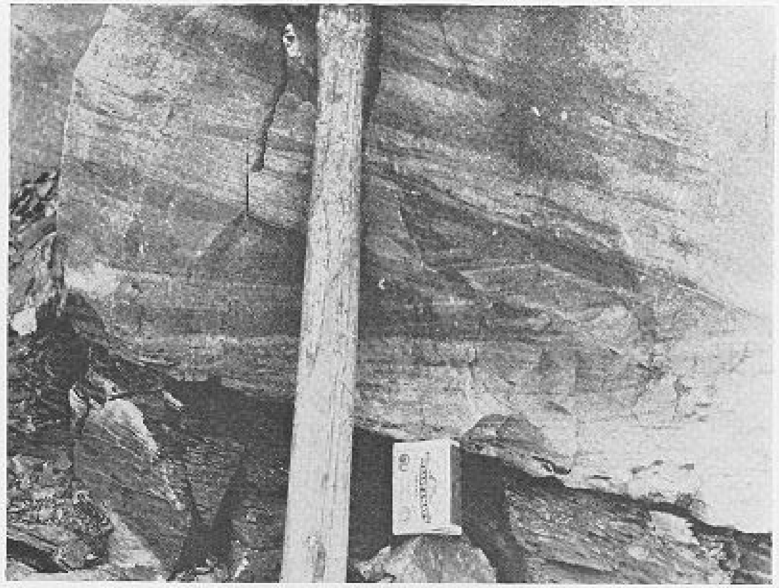
PLATE II

a. False bedding in the Kay Nunatak sediments; Kay Nunatak.

b. Calypso Cliffs, Victory Nunatak and (just to the right of Victory Nunatak) Kay Nunatak, viewed from the south-east.

c. The Mount Argus massif viewed from Poseidon Pass.

d. Mount Argus, showing part of the north-eastern scarp in the foreground and the three summit peaks behind.



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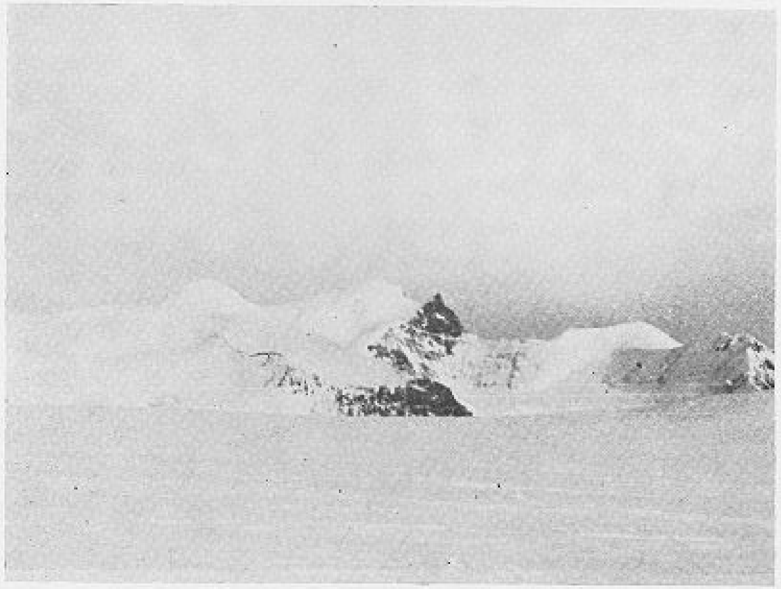

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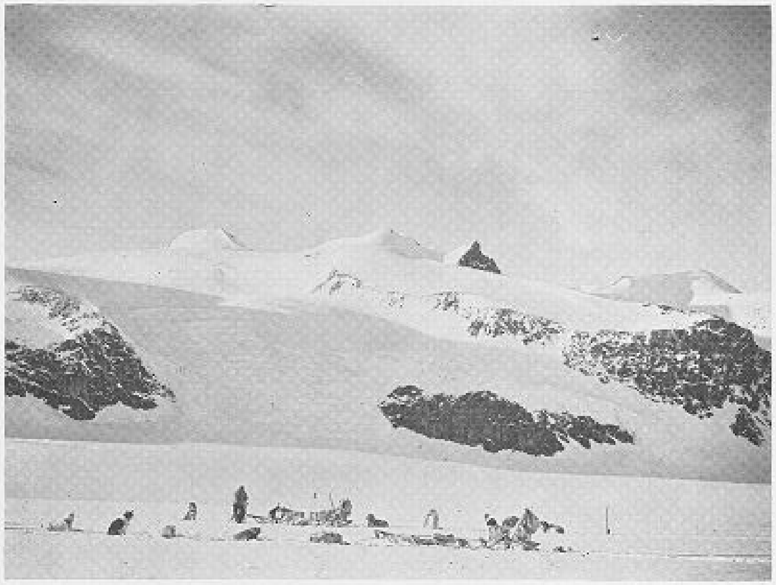

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PLATE II

PLATE III

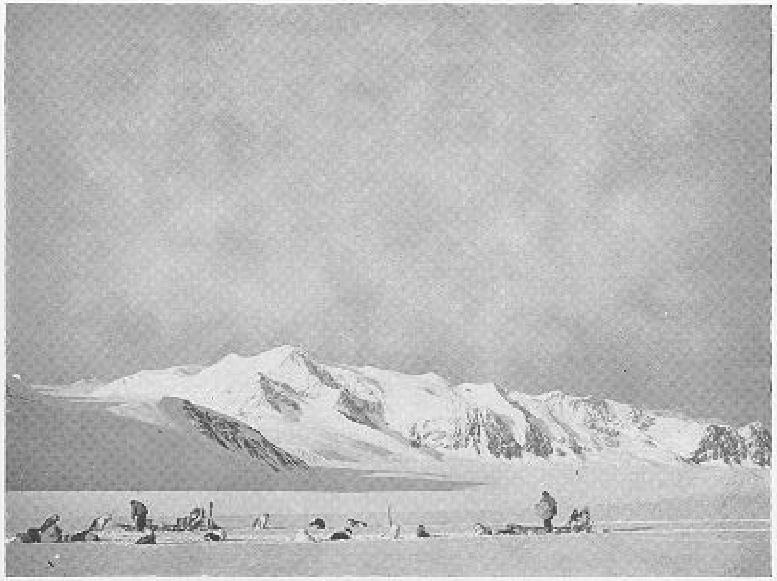
a. Part of the cliff face near Cape Mayo. The contact between the dark volcanic rocks and the underlying sediments is clearly visible.

b. The mountainous area immediately south of Mobiloil Inlet. The small buttress to the left of centre marks the north-western tip of Mount Argus.

c. The mountainous area south of Mobiloil Inlet viewed from Mount Argus.

d. Well-banded cataclastic rocks on the northern margin of Hitchcock Heights.

a



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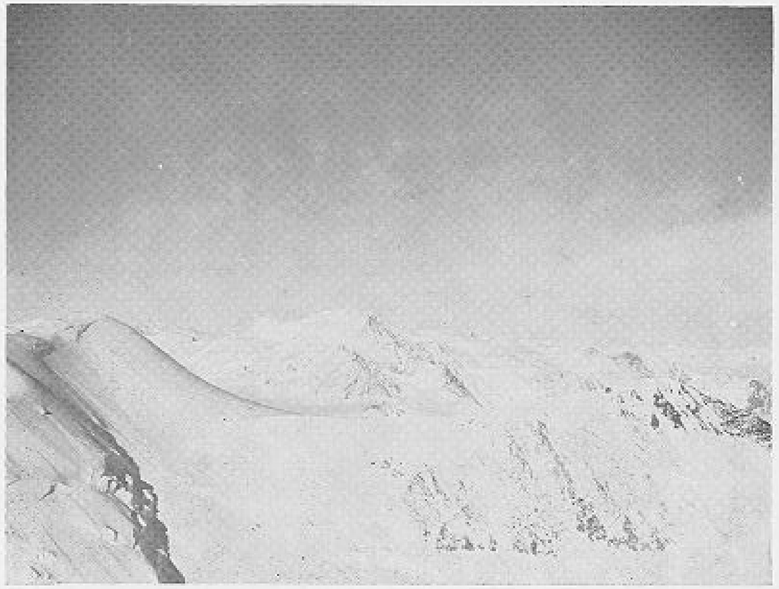

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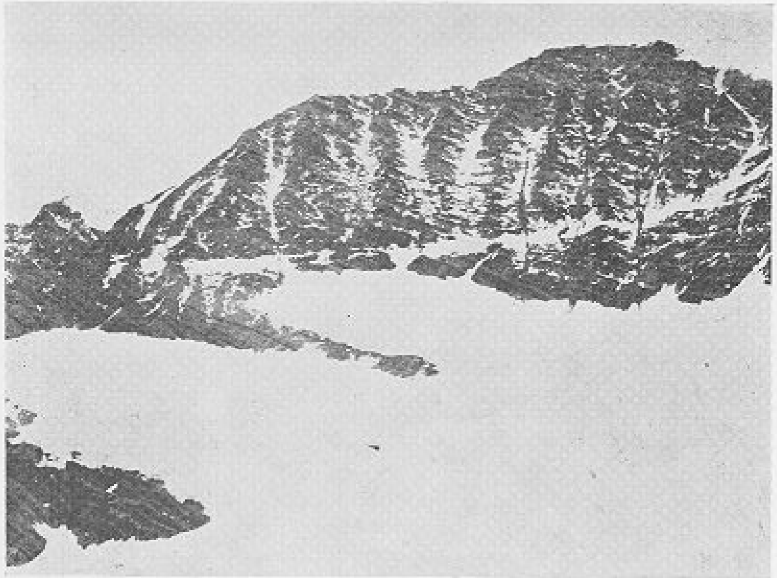

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PLATE III

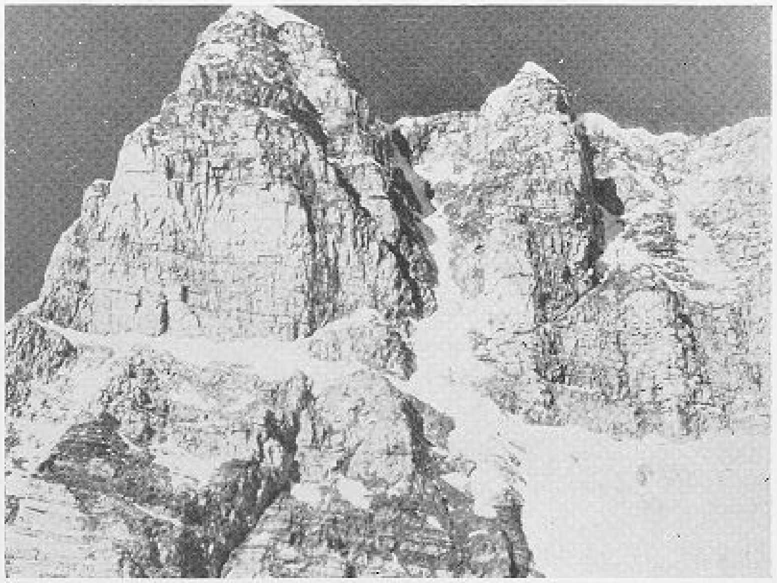
PLATE IV

a. Strongly banded quartzo-feldspathic gneisses; Mount Blunt.

b. Asymmetric tight folding in the Kay Nunatak sediments; Kay Nunatak.

c. Part of the Mount Argus scarp. The main (lower) thrust is visible on the top right of the triangular buttress (cf. Fig. 5).

d. Mobiloil Inlet viewed from Mount Argus. The ridge trending south-eastwards from Crabeater Point is on the right.



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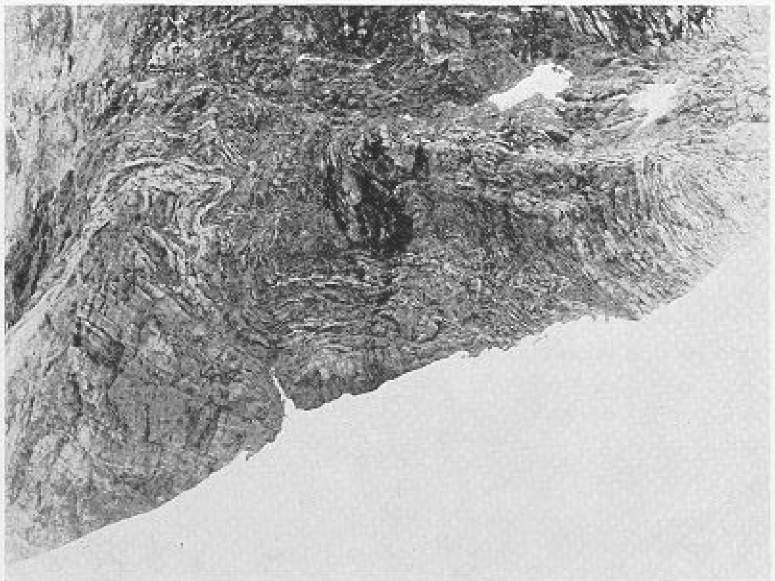

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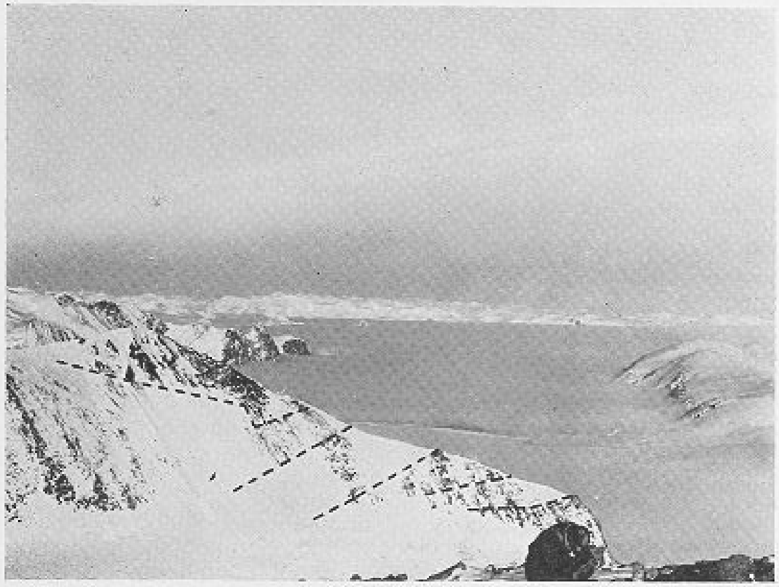

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PLATE IV

PLATE V

a. Poorly sorted muddy sandstone; Kay Nunatak (E.1602.6; ordinary light; × 50).

b. Authigenic albite in the volcanic-rich matrix of an arkose; Mount Argus (E.2140.4; X-nicols; × 110).

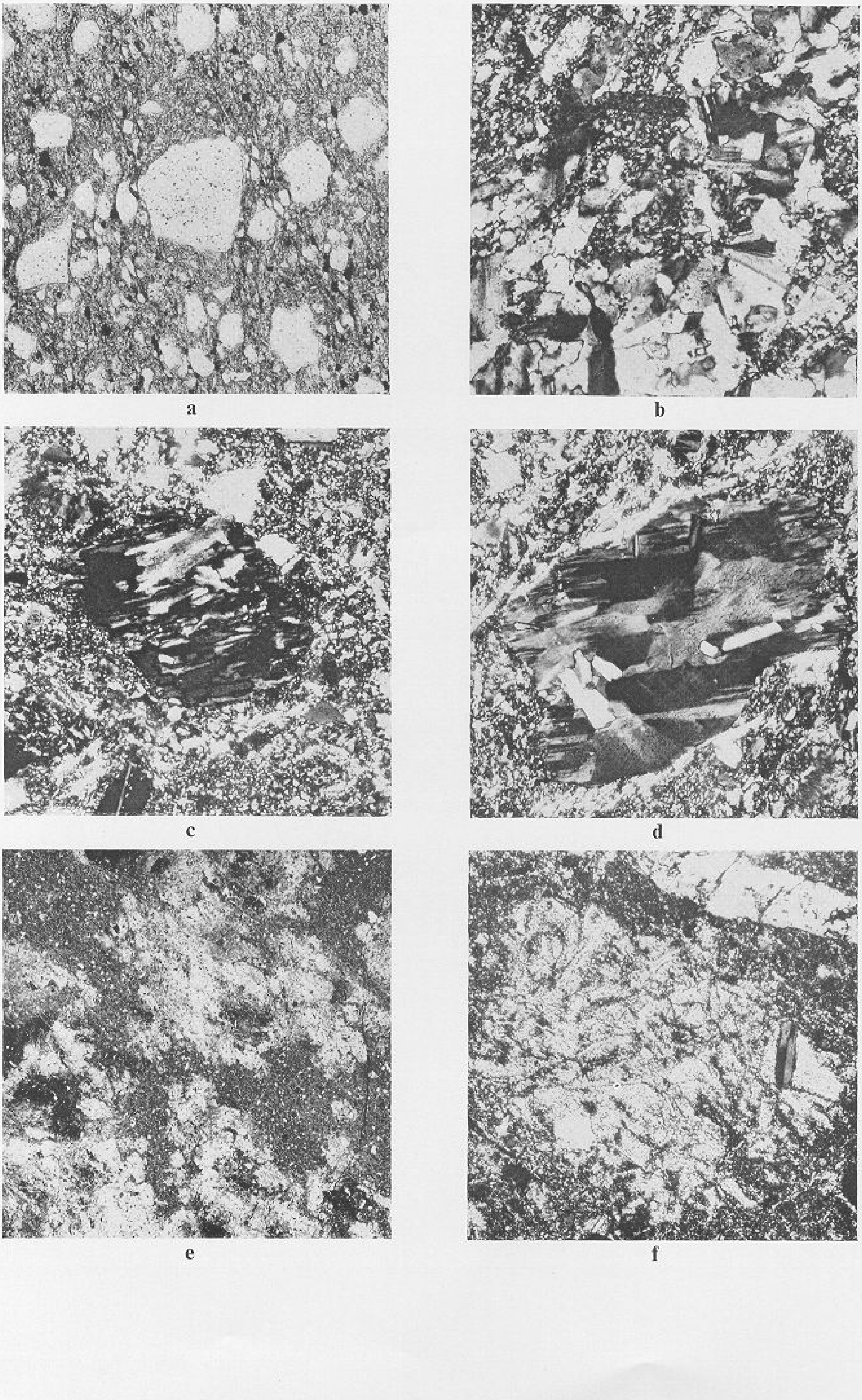
c. Rounded clot of albite containing several disorientated laths; green and purple arkoses, Mount Argus (E.2135.2; X-nicols; × 135).

d. A very similar example to Plate Vc (E.2135.3; X-nicols; × 125).

e. Spongy growth of prehnite in Mount Argus sediments illustrating variation in extinction; Mount Argus (E.2134.2; X-nicols; × 8).

f. Prehnite showing typical aggregate structure; Mount Argus sediments, Mount Argus (E.2134.5; X-nicols; × 135).

PLATE V



a b c d e f

PLATE VI

a. Prehnite aggregate containing numerous shard pseudomorphs; Mount Argus sediments, Mount Argus (E.2134.2; X-nicols; × 100).

b. Similar to Plate VIa (E.2134.5; X-nicols; × 100).

c. Authigenic fluorite in a volcanic sediment, showing its "pseudo-pebble" form; Mount Argus sediments, Mount Argus (E.2139.1; X-nicols; × 9).

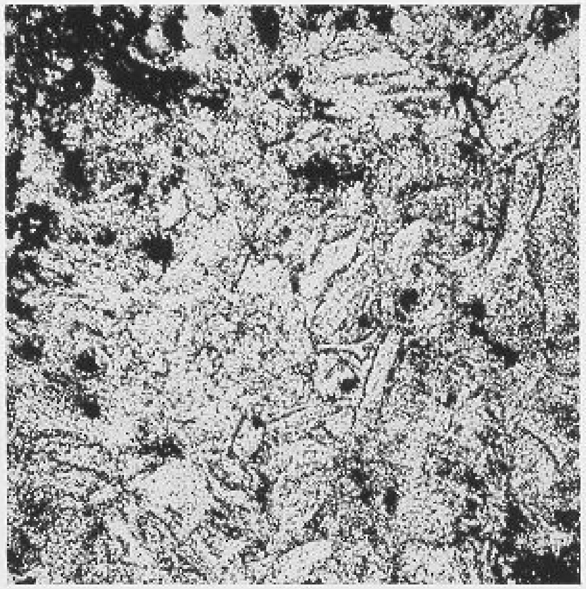
d. Haematite inclusions in a devitrified volcanic glass; Mount Argus (E.2132.2; ordinary light; × 135).

e. Plexus of quartz in a micropoikilitic keratophyre; Calypso Cliffs (E.1609.2; X-nicols; × 135).

f. Highly magnified part of the quartz plexus shown in Plate VIe, illustrating changes in optical orientation along single quartz rods (E.1609.2; X-nicols; × 355).

PLATE VI


a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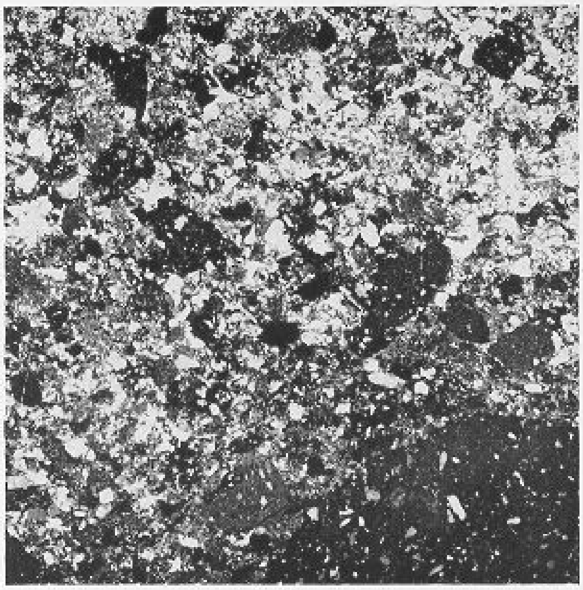
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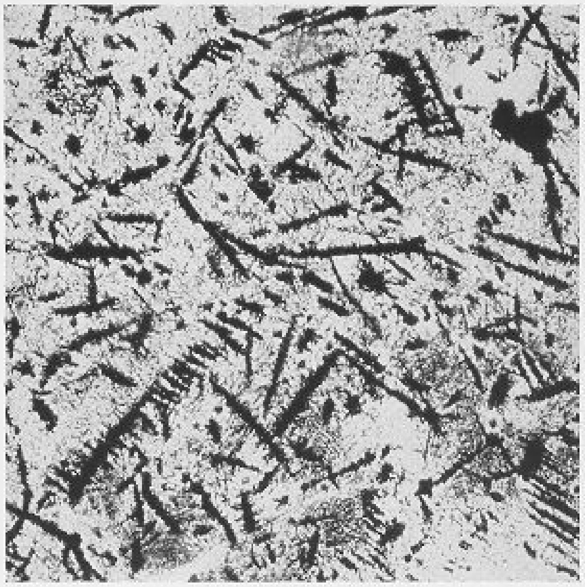
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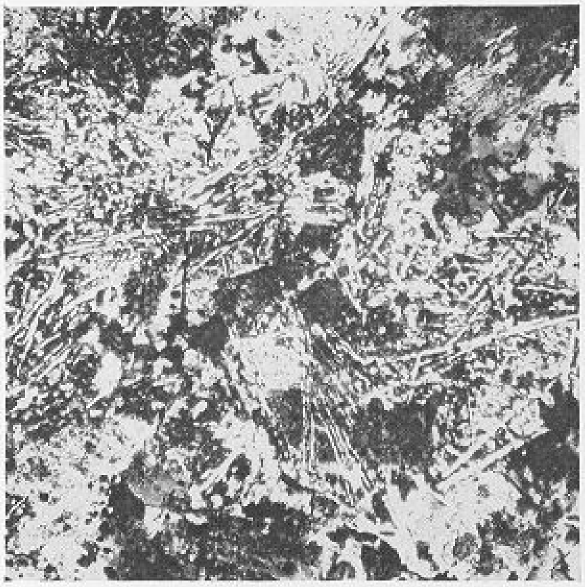
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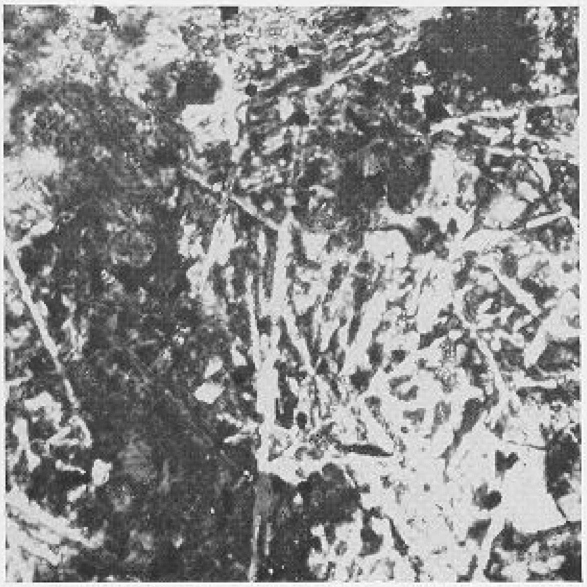
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PLATE VII

a. Development of polycrystalline quartz pools in a devitrified lava showing incipient growth of chequer-board albite from the cryptocrystalline groundmass (E.1609.2; X-nicols; × 135).

b. Similar to Plate VIIa with the newly formed albite tending to show stronger crystal outlines in places (E.1609.2; X-nicols; × 135).

c. More extensive development of chequer-board albite in a quartz pool. The albite is intergrown with orthoclase (E.1609.2; X-nicols; × 135).

d. The crystal of albite at the top illustrates further growth of chequer-board albite (E.1609. 2; X-nicols; × 135).

e. Altered lava with its original texture defined by the arrangement of secondary minerals; Cape Mayo (E.1618.1; ordinary light; × 65).

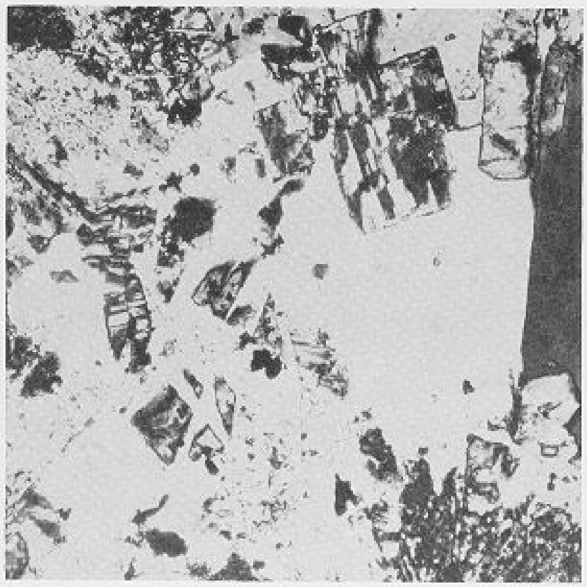
f. The same field of view as in Plate VIIe but under X-nicols showing the quartz mosaic resulting from silicification (E.1618.1; X-nicols; × 65).

PLATE VII

a

b

c



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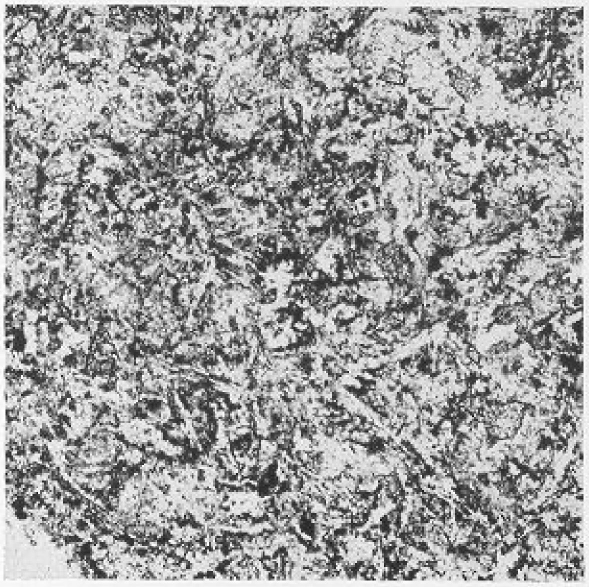

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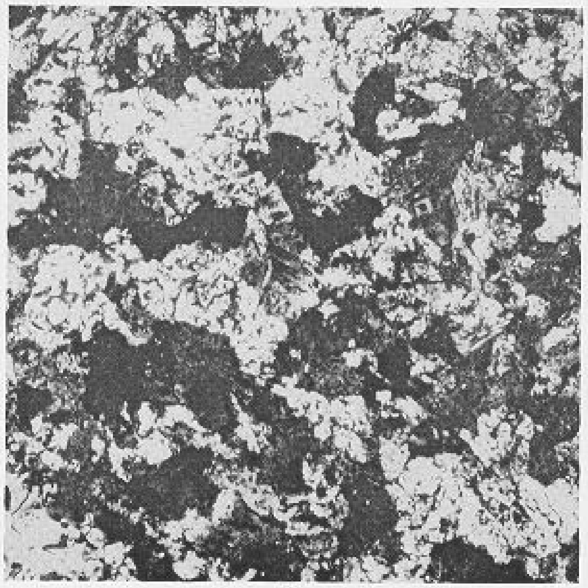

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PLATE VIII

a. Slightly deformed perlitic texture preserved in chlorite in an altered lava; Mount Argus (E.2143.4; X-nicols; × 11).

b. Incipient oligoclase porphyroblasts in a quartz-biotite-hornblende-schist; Scripps Heights (E.1649.4; X-nicols; × 60).

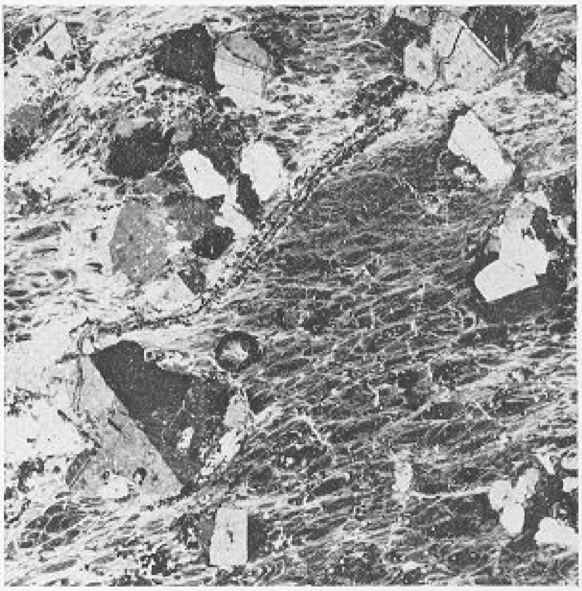
c. Oligoclase porphyroblast containing numerous vermicular and rounded inclusions of quartz (E.1649.4; X-nicols; × 60).

d. Leptite-gneiss; Mount Blunt (E.1643.9; X-nicols; × 65).

e. Highly deformed acid gneiss; cliffs south of Kay Nunatak (E.1671.1; X-nicols; × 60).

f. Twisted crystals of bytownite accompanied by xenomorphic hornblende in metagabbro; near Maitland Glacier (E.1668.1; X-nicols; × 50).

PLATE VIII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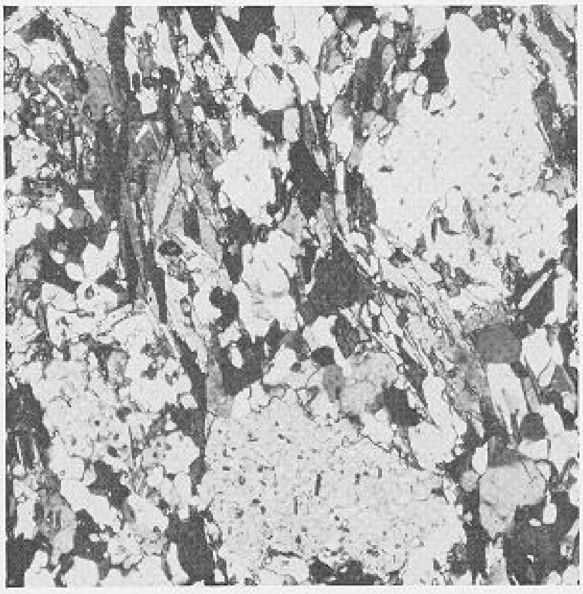
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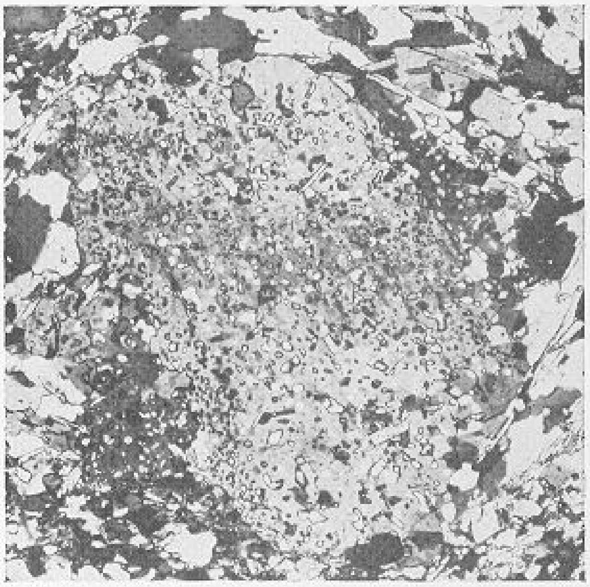
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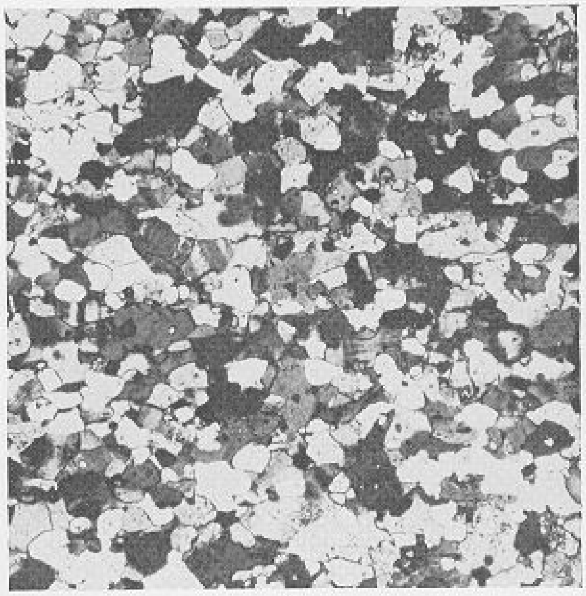
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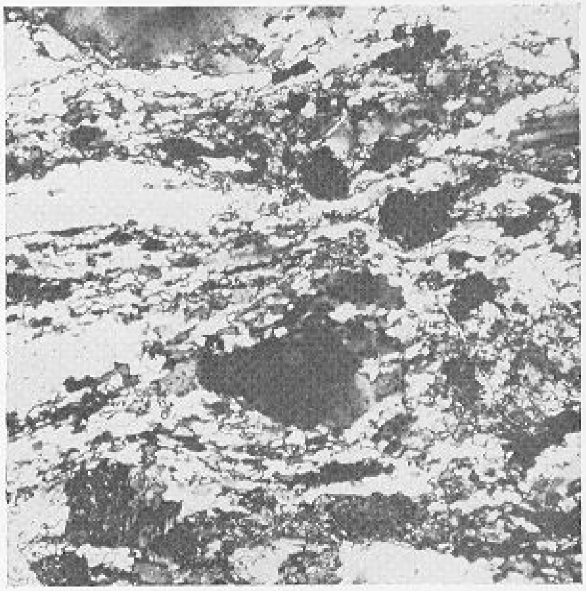
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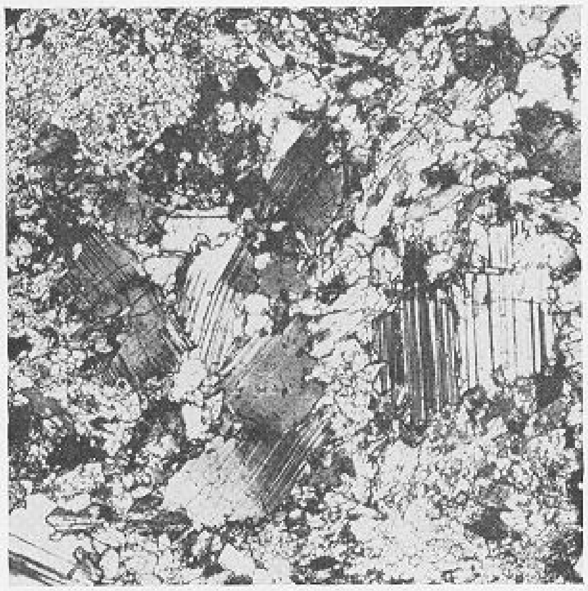
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