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THE GEOLOGY OF ADELAIDE ISLAND

By

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and

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ABSTRACT

SOME aspects of the geology of Adelaide Island and adjacent islands are described and discussed. A flat-lying succession of volcanic, sedimentary and mixed strata has been intruded by many superstructure plutons of the Andean Intrusive Suite, and mafic dykes have been intruded both before and after the Andean plutons. In the stratified rocks, which are probably of Upper Jurassic age, a succession of lavas separates two successions of volcaniclastic and sedimentary rocks; about 10,000 ft. (3,050 m.) of the stratified rocks are exposed on Adelaide Island. The lavas are spilitic in parts. A succession of devitrified rhyolites is exposed in north-eastern Square Peninsula but similar rocks have not been found elsewhere. Some conglomerates in a sedimentary succession contain boulders of ancient plutonic and metamorphic rocks which have not been found *in situ* in the Adelaide Island area.

The Andean intrusive rocks, which range from olivine-gabbro to adamellite and appear to have been intruded strictly in that order, have not forcibly displaced the stratified rocks. Although the effects of thermal metamorphism are not noticeable in the field, recrystallization and some redistribution of minerals have taken place in the country rocks near Andean plutons. A number of these plutons are heterogeneous and are composed of rocks ranging from gabbros to granodiorites, although there are no contacts within them. These rocks are not otherwise abnormal, because geochemical investigations have shown that they follow the variation trends which are typical of the Andean Intrusive Suite. Assimilation may have been an important process in the emplacement of these heterogeneous plutons. Analyses of four dark gabbros from the Adelaide Island area show that they, like other gabbros from the Antarctic Peninsula, have crystallized from two contrasting magmas; three have crystallized from a parental magma which has been enriched in cumulative olivine and the other one from a magma from which cumulative plagioclase has been removed.

Three separate post-Andean phases of mafic dyke intrusion have been distinguished on Jenny Island, where also an unusual hypabyssal intrusion of a low-temperature suspension of lithic fragments has been emplaced at the contacts between two Andean gabbros and the stratified country rocks. Another unusual hypabyssal complex on Square Peninsula contains both tholeiitic and alkaline basalts; the latter is the earlier and it contains pyroxenite inclusions. The two basalts are separated by harrisitic layers.

In southern Square Peninsula restricted exposures are of sedimentary and volcaniclastic rocks which are rich in introduced magnetite. Block-faulting has had an important structural influence in the Adelaide Island area, and the most prominent faults strike parallel to the local trend of the Antarctic Peninsula. Joints, common to both the Andean intrusive rocks and the Jurassic stratified rocks, have formed on the removal of overburden.

CONTENTS

		PAGE
I.	Introduction	3
II.	Stratigraphy	5
III.	Stratified volcanic and sedimentary rocks	5
	A. Stratigraphic succession	10
	B. Sloman Glacier succession	11
	1. West of Sloman Glacier	12
	2. Western Mount Bouvier	12
	3. Cape Alexandra and Fitton Rock	15
	4. Eastern Mount Barré, Mount Liotard and Mount Mangin	16
	5. Square Peninsula and the Ryder Bay area	16
	C. Mount Liotard succession	18
	1. Southern Mount Liotard, northern and eastern Mount Ditte, and Jenny Island	18
	2. Western and southern Mount Bouvier	19
	3. Mount Barré and Mount Mangin	21
	4. Northern Square Peninsula and Shambles Glacier	22
	D. Geochemistry of some rocks of the Mount Liotard succession	23
	1. Quench-breccias and associated basalt	23
	2. Devitrified rhyolite	24
	3. Nature of the parent magma	25
	E. Mount Bouvier summit succession	26
	F. Down-faulted conglomeratic successions and other uncorrelated rocks	26
	1. Down-faulted conglomeratic successions	26
	2. Eastern Mount Bouvier and Mount Reeves	27
	3. Mount Vélain and Visser Hill	29
	4. Exposures around south-western Adelaide Island	30
IV.	Andean Intrusive Suite	30
	A. Dark gabbros of homogeneous intrusions	31
	1. Léonie Island	31
	2. Jenny Island	31
	3. Mikkelsen Islands	32
	4. South-western Mount Gaudry	32
	5. McCallum Pass	32
	6. Webb Island	32
	7. Islands off south-western Adelaide Island	32
	B. Flow-banded dark gabbros	33
	1. Brockhamp Islands	33
	2. Coast of Square Peninsula south of Webb Island	35
	3. Discussion	36
	C. Heterogeneous intrusions	36
	1. Islands and coast of western Laubeuf Fjord	37
	2. Northern Mount Mangin	40
	3. South-western Mount Bouvier	40
	4. Blümcke Knoll	41
	5. Western Mount Gaudry and Mount Barré	41
	6. Mount Vélain	41
	D. Homogeneous tonalites and granodiorites	41
	1. Mount Reeves and western Mount Bouvier	42
	2. Western Mount Liotard	42
	3. Leucogranodiorite of Square Peninsula	42
	4. Augite-granophyres south-west of Sighing Peak	43
	5. Eastern Mount Liotard	43
	6. Islands off south-western Adelaide Island	44
	E. Late-stage silicic differentiates	44
	1. Adamellite of League Rock	44
	2. Late-stage veins	44
	F. Geochemistry	44
	1. General comparison of Andean rocks from Adelaide Island with those from other areas	45
	2. Geographical distribution of major elements in the rocks of McCallum Pass	47
	3. Variation in heterogeneous intrusions	50
	4. Comparison of the dark gabbro of McCallum Pass with those from other areas	50
	G. Discussion on the heterogeneous intrusions	52
V.	Mafic hypabyssal rocks	53
	A. Pre-Andean	53
	B. Post-Andean	53
	1. Typical post-Andean dykes of Jenny Island	53
	2. Hypabyssal complex of central Square Peninsula	54
	3. Post-Andean modification of contacts of Andean intrusive rocks	57
	4. Veins in a probable fault zone	59
	5. Solus Island	59
VI.	Structure	59
VII.	Conclusions	62
VIII.	Acknowledgements	65
IX.	References	65

I. INTRODUCTION

Adelaide Island, which has an area of approximately 1,400 sq. miles (3,625 km.^{2}), is the second largest of the many islands off the west coast of the Antarctic Peninsula (Fig. 1). It is about 85 miles (137 km.) long and at most 25 miles (40 km.) wide, and extends approximately between lat. 67°45′ and 69°40′S., and between long. 67°40′ and 69°00′W. The island is elongated parallel to the local trend of the Antarctic Peninsula, from which it is separated by a narrow steep-walled channel (The Gullet) connecting Hanusse Bay and Laubeuf Fjord. The topography and glacierization of this area have been described elsewhere (Dewar, 1967).

The first geological work carried out in this area was by Gourdon (1917), who published analyses and descriptions of an "ample collection" of rocks examined and collected during the visit of the Deuxième Expédition Antarctique Française, 1908–10, to Laubeuf Fjord and eastern Adelaide Island in 1909 (Charcot, 1910). This expedition was the first to visit Adelaide Island after its discovery in 1832 by Biscoe (Murray, 1901, p. 305–35), apart from the visits of Evensen in 1832 and de Gerlache in 1898, neither of whom published important descriptions. Gourdon found that Jenny Island, which is 3 miles (4·8 km.) east of Adelaide Island, is composed of grey mesocratic gabbro (quartz-gabbro) traversed by numerous, often thick, dykes of basalt (in some cases ophitic) and of less calcic andesites ranging to one "of trachytic facies". Gabbros from Léonie and Webb Islands, which are closer to Adelaide Island than Jenny Island, were found to be more calcic though more leucocratic than that of Jenny Island. Three gabbro and seven dyke specimens were analysed (Gourdon, 1917); although the dykes range widely in composition, their field relationships were not discussed.

Information collected by the Deuxième Expédition Antarctique Française was used by Holtedahl (1929) in a description of the physiographical evolution of Graham Land. Barth and Holmsen (1939) examined the analyses given by Gourdon in a discussion of the regional relationships and origin of the Antarctic Peninsula, but they followed Burri (1926) in mistakenly considering the fine-grained dark rocks from Jenny Island as lavas, though Gourdon positively stated that they were collected from dykes. Stewart (1956), in re-presenting these analyses for comparison with others from Antarctica, has perpetuated Burri's error. Specimens dredged by R.R.S. *Discovery II* in lat. 67°08′S., long. 69°06·5′W. (close to the central western coast of Adelaide Island) have been described by Tyrrell (1945): of the 46 specimens mentioned, five were andesitic breccias, five flow lavas (including rhyolite, dacite and andesite), 14 quartz-porphyries and similar rocks (some of which had undergone cataclasis), three dioritic lamprophyres, eight quartz-diorites and one quartz-gabbro; ten were more silicic plutonic rocks which included "ordinary granite".

Laubeuf Fjord and Adelaide Island were visited by the British Graham Land Expedition, 1934–37 (Fleming and others, 1938; Rymill, 1938; Fleming, 1940; Stephenson, 1940; Stephenson and Fleming, 1940), but their investigations and those of subsequent American (Nichols, 1955) and British expeditions were concentrated in Marguerite Bay south of Adelaide Island (Adie, 1955). Adie (1953), discussing the stratigraphy of the volcanic country rocks of Marguerite Bay, described the volcanic rocks of Adelaide Island as augite-andesites and trachytic andesites. Although Falkland Islands Dependencies Survey geologists have continued to work in Marguerite Bay since then, it was not until 1957 that geological work was carried out during a visit to Adelaide Island (Procter, 1959). Goldring (1962), working in Hanusse Bay, was unable to land on northern Adelaide Island but he made distant observations on what were apparently exposures of plutonic rocks but which included poorly stratified volcanic rocks.

The rock types described by Procter (1959) include stratified volcanic rocks intruded by plutonic rocks predominantly of light mesocratic appearance. These plutonic rocks have been displaced locally by more silicic rocks of granitic appearance. Unusual features of the intrusive rocks include the widespread formation of intrusion breccias and the presence of unusually coarse-grained mesocratic rocks in which flow-banding is very well displayed. Procter found good exposures of stratified rocks which had been affected by iron mineralization. Unfortunately, he was apparently misled by flat-lying stratified rocks on the mountain walls west of the area he was able to examine. Because of the high dips he recorded near the coast, he suggested that the flat-lying strata were unconformable on the tilted strata and plutonic rocks. This hypothesis is no longer tenable, because the country rocks which Procter examined in a disturbed area are in other localities characteristically horizontally stratified.

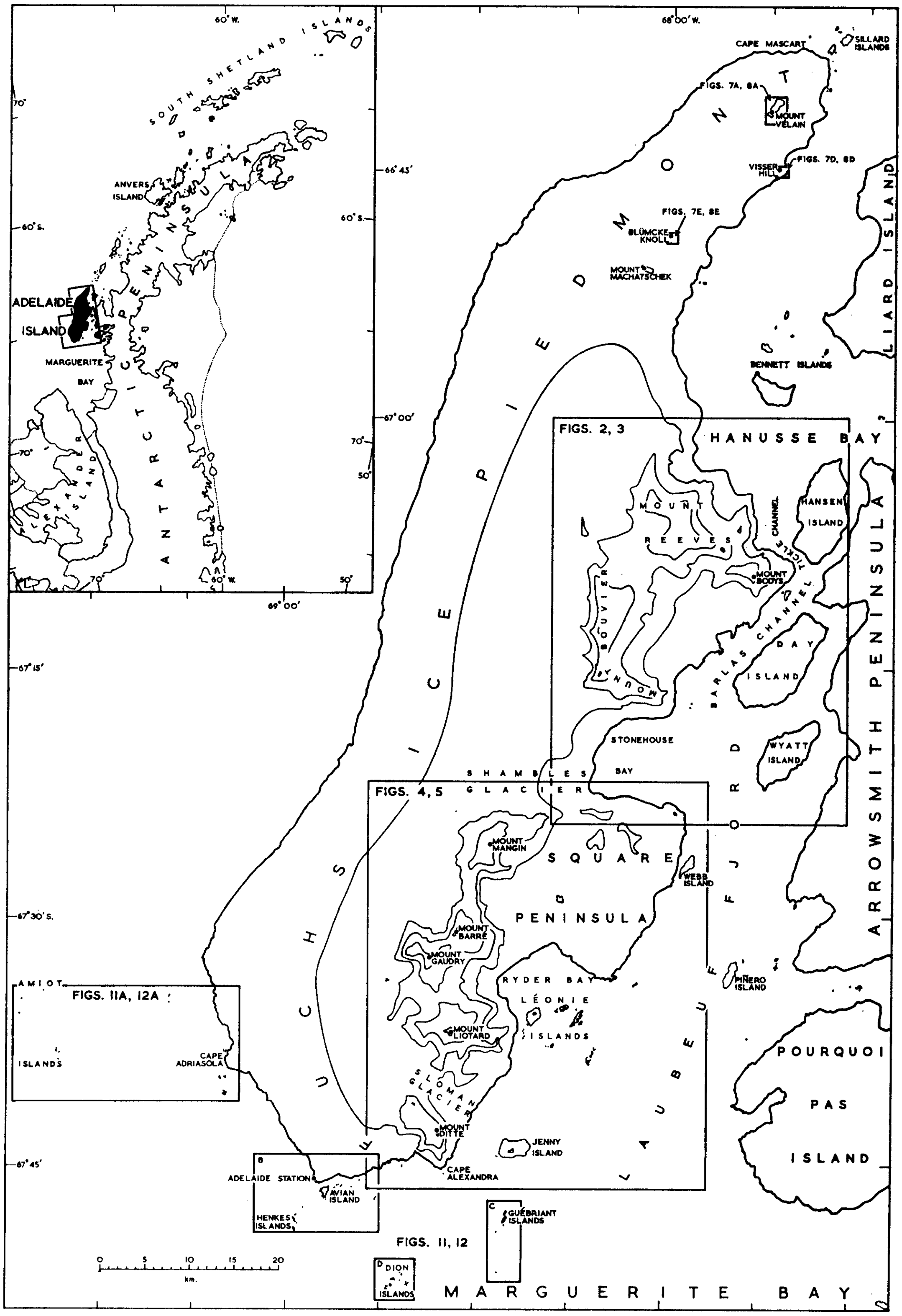

FIGURE 1

Sketch map of Adelaide Island and adjacent islands showing the positions of detailed maps appearing elsewhere in this report. The contour interval is 500 m.

II. STRATIGRAPHY

Rocks which are exposed in the Adelaide Island area have been grouped in stratigraphic units (Table I), the relative order of which is known but which have not yet been dated by radioactive methods.

In a thick unfossiliferous succession of lavas, pyroclastic materials and sediments, most pyroclastic beds have been re-worked by sedimentary processes. Similar rocks have been reported from the Fallières and Loubet Coasts and islands east of Adelaide Island, and they have been referred to as Upper Jurassic in age (Adie, 1953; Procter, 1959; Hoskins, 1960; Goldring, 1962). These country rocks have been displaced by large and small plutons of intrusive rocks which seem to belong to a single cycle of magmatic intrusion, because contacts between any two of these rock types show that the more calcic one is displaced by the more alkalic. Thin-section evidence seems to indicate that silicic and alkalic material was admixed to previously intruded gabbroic magma in the formation of heterogeneous intrusions. Such a possible evolution of the plutonic rocks is reflected in their title of Andean Intrusive Suite (Adie, 1955).

The remaining stratigraphic units are of only local importance. Rocks correlated with a metamorphic Basement Complex and with ancient but unmetamorphosed plutonic rocks are not exposed *in situ* in the Adelaide Island area, but they are found as boulders in conglomeratic country rocks. Though boulders of the plutonic rocks are common, ones of gneissose material of Basement Complex provenance are rare. Ancient unmetamorphosed plutonic rocks and a metamorphic Basement Complex, which crop out in eastern Marguerite Bay as far north as the latitude of southern Adelaide Island, have been referred to as early Palaeozoic and Precambrian (Adie, 1954; Hoskins, 1963).

The oldest identifiable mafic dykes were emplaced before the Andean intrusive rocks, and this is demonstrated in the Adelaide Island area by a single dyke intruded into the volcanic and sedimentary country rocks and itself cut by an Andean intrusive aplitic vein. Probably many of the mafic dykes which have intruded the country rocks are of this early phase, but they are not demonstrably so because they are not visibly cut by Andean intrusive rocks. These early dykes may have been the source of higher beds of the volcanic succession. Mafic dykes of the last phase or phases of intrusion affecting this area have been emplaced along fissures which follow joint directions in the Andean intrusive rocks and the stratified rocks alike.

Table I

STRATIGRAPHY OF ADELAIDE ISLAND

Recent Pleistocene		*Raised beaches* *Glacierization*
Upper Tertiary (?) Tertiary Lower Tertiary	Andean Intrusive Suite	{ *Block faulting* { *Extensive planation* Mafic dykes { Adamellite { Granodiorite { Gabbro
Middle Cretaceous		
(?) Upper Jurassic	Stratified volcanic and sedimentary rocks	Mafic dykes Lavas, tuffs; re-worked volcaniclastic rocks; conglomerates, siltstones
(?) Early Palaeozoic	Older intrusive rocks	Granodiorites, tonalites
(?) Precambrian	Basement Complex	Silicic gneisses

III. STRATIFIED VOLCANIC AND SEDIMENTARY ROCKS

Stratified rocks of sedimentary, volcanic and mixed origins are exposed in many places in the Adelaide Island area; the most extensive and easily correlated outcrops are on the high walls of the main mountain masses (Figs. 2–5). The main exposures are mostly of flat-lying rocks, and the rocks of smaller exposures where dips exceed 25° have probably been disturbed by faulting. Even the main mountain-wall exposures

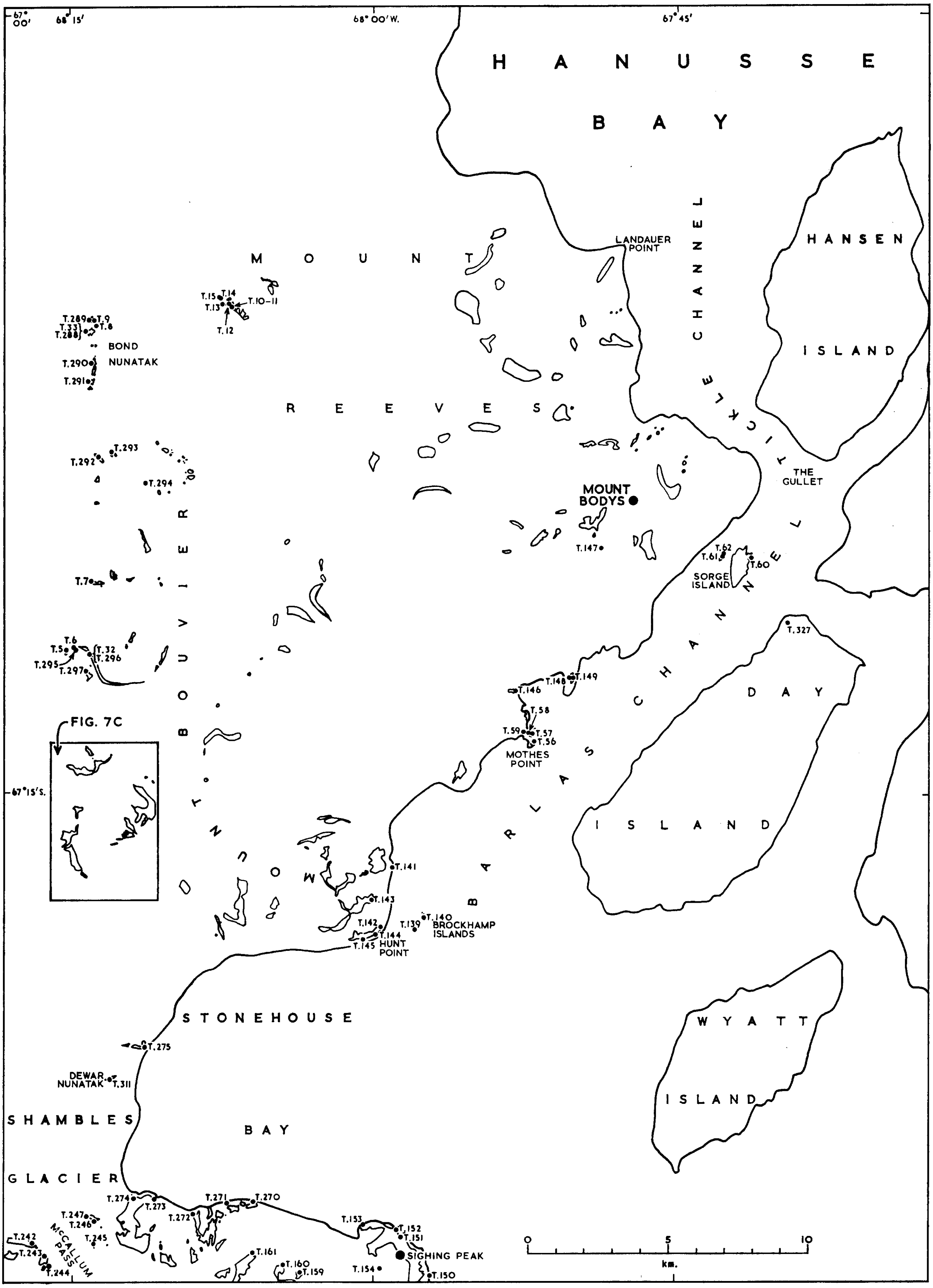

FIGURE 2

Sketch map of central eastern Adelaide Island and northern Laubeuf Fjord showing exposures and the positions of geological stations. The position of Fig. 7C is indicated.

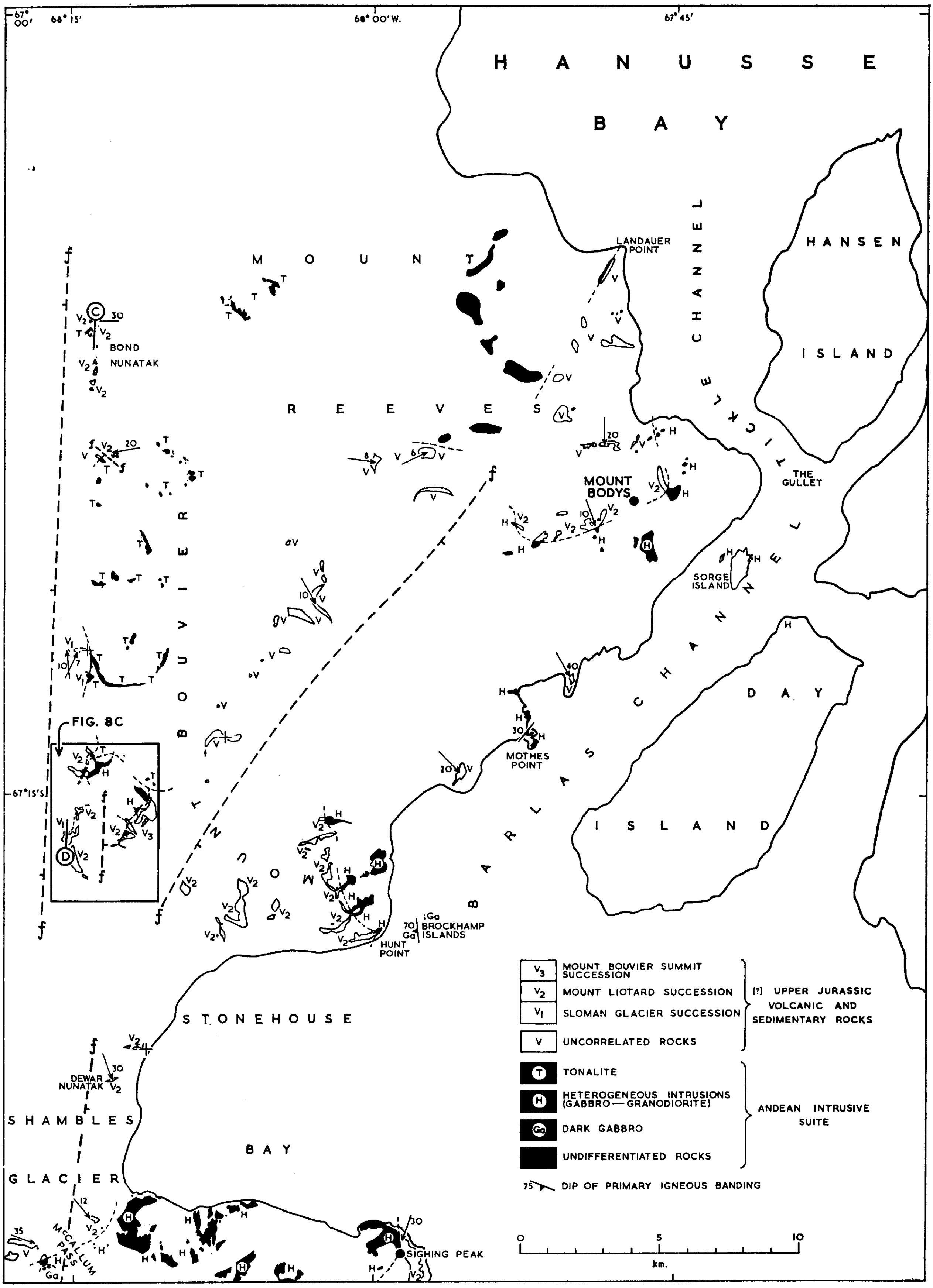

FIGURE 3

Geological sketch map of central eastern Adelaide Island and northern Laubeuf Fjord. The positions of Figs. 6 (C–D) and 8C are indicated.

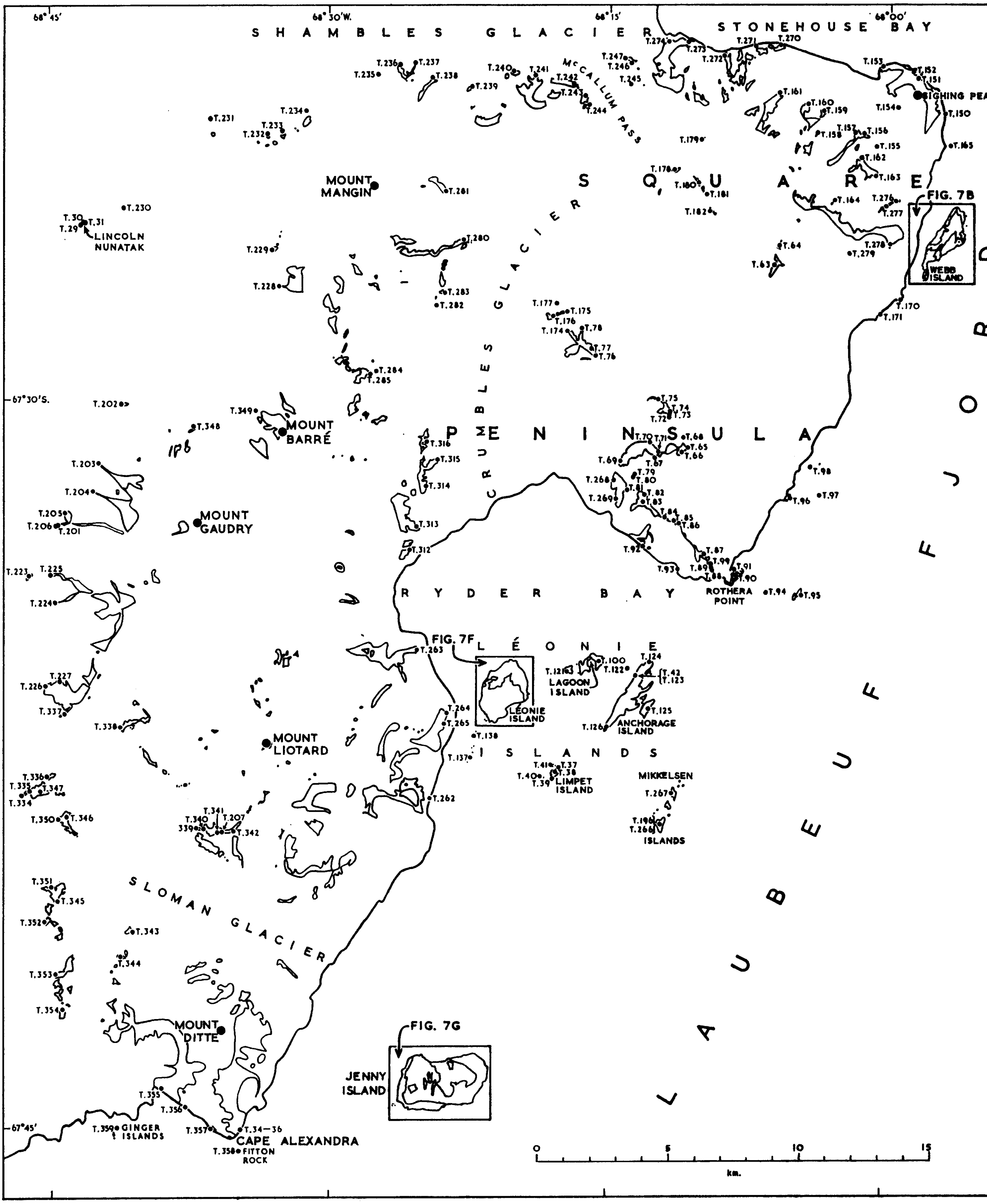

FIGURE 4

Sketch map of south-eastern Adelaide Island and southern Laubeuf Fjord showing exposures and the positions of geological stations. The positions of Figs. 7B, F and G are indicated.

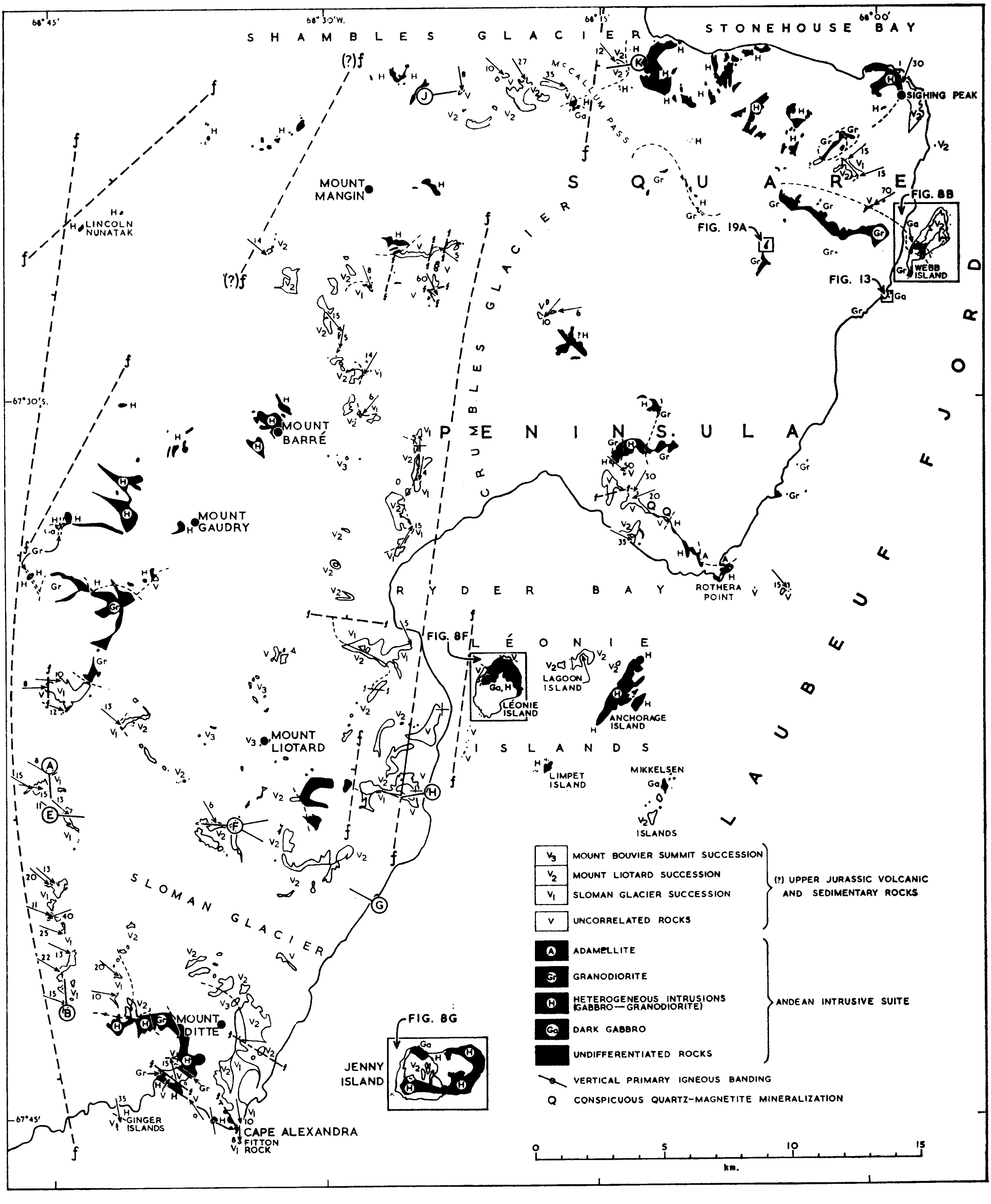

FIGURE 5

Geological sketch map of south-eastern Adelaide Island and southern Laubeuf Fjord. The positions of Figs. 6 (A–B, E–F, F–G, F–H and J–K), 8B, F, G, 13 and 19A are indicated.

have been affected by large-scale block-faulting, which has brought to the same levels rocks of completely differing appearances and is marked in places by drag-folding (Plate Ia). Fault lines have been difficult to examine because movement has been distributed across shatter zones. The faulting has made the preparation of a detailed stratigraphic succession difficult, particularly because marker horizons are of neither regional extent nor accessibility. The stratified rocks are usually thoroughly indurated and, since their frequently similar fragmental appearances have been produced in different ways, they have been difficult to identify and classify.

Lavas. The only lavas recognizable in the field are glassy flow-lined porphyritic rhyolites (p. 22); other exposures of unbrecciated lava are rare. The largest other exposure of unbrecciated lava is of porphyritic basalt, which crops out among fragmental lavas of similar appearance and mineralogy. Such fragmental lavas are very common in this area. They characteristically contain lithic fragments which are usually cognate, often accidental-cognate, and occasionally foreign; in some rocks they predominate to the exclusion of a definite matrix. The fragments may be surprisingly well rounded (Plate Ib). The matrix rock may be an unmodified lava, or one which has been totally (auto)brecciated to fragments of all sizes; amygdales are common in the matrix, in the lithic inclusions or in both. Agglutinates may be present but they have not been identified, because in rocks containing many lithic inclusions, the inclusions have been distorted and fit together closely as a result of compaction and induration.

Because the origin of these fragmental lavas is not well understood, their classification is difficult. They crop out predominantly but not solely in a thick massive stratum (Mount Liotard succession) which is formed of rocks of only this type. The rocks at different horizons in this succession differ, however, in their content of amygdales and lithic inclusions, and slight coloration differences suggest that the stratum may be internally bedded. Lack of definite bedding suggests that the rocks are not pyroclastic, and the presence of amygdales suggests that they were possibly deposited under water. It is believed that the fragmental lavas were extruded under water, granulated on cooling and flowed from the eruptive centres as a mass of lithic fragments which incorporated cognate and foreign lithic material from the country rocks in the same way as subaerial *Agglomeratlaven* (Wentworth and Williams, 1932, p. 26). Fiske (1963) has called rocks produced in this way "subaqueous pyroclastic flows", although the two adjectives appear to be mutually exclusive (Wentworth and Williams, 1932, p. 25). In the belief that these rocks "flowed" as semi-coherent masses after eruption, they have been termed "quench-breccias". No sign of central volcanic activity has been found in Marguerite Bay (Adie, 1953), the Loubet Coast (Goldring, 1962) or Adelaide Island, and these rocks were probably erupted through fissures.

Epiclastic rocks. In appearance the quench-breccias grade to lighter-coloured fragmental rocks with higher contents of accessory-cognate and foreign lithic inclusions. These rocks are composed of clastic or re-worked pyroclastic debris, as is shown by the following general characteristics:

i. Persistent thick and thin bedding with slight or considerable colour differences between adjacent beds.
ii. Fairly good sorting into the size grades of different beds.
iii. Current- and graded-bedding in fine-grained beds.
iv. Imbricated boulders in conglomerates and volcanic conglomerates.
v. Though rounding of macroscopic cognate and accessory-cognate lithic fragments is very poor in some beds, it is never completely absent, and all have been modified by transportation.
vi. Rounding of macroscopic foreign lithic inclusions is always very pronounced (Plate Ic).
vii. The matrices of rocks containing coarse lithic fragments are of well-sorted small volcanic rock fragments.

Since both the matrix and inclusions in most rocks are of volcanic origin though modified by transportation, the word "volcanic" has been used in such terms as "volcanic gravelstone". The only sediments which are regarded as being non-volcanic are conglomerates in which an epiclastic volcanic aggregate contains abundant boulders of plutonic rocks; according to Geikie's (1893) definition these rocks are not volcanic conglomerates. These sedimentary conglomerates have all been faulted into place and their stratigraphic position is not completely certain (p. 26).

A. Stratigraphic Succession

Because of the lack of identifiable marker horizons in the stratified rocks, the stratigraphic succession which is 10,000 ft. (3,050 m.) thick (Table II) shows only units of contrasting lithologies whose relationships are visible on the mountain walls. Since this stratigraphic succession is founded on field identifications, it is discussed in conjunction with the petrology of these rocks. The rocks of exposures distant from the mountains are not all positively correlated with the stratigraphic succession. Many such exposures are of rocks whose characters are those of the Mount Liotard succession, and this suggests that coastal areas have been faulted down relative to the mountains (Dewar, 1967). Although the rocks of the Adelaide Island stratigraphic succession are typically sedimentary, the succession might be loosely compared with the lower part of that proposed for volcanic rocks exposed in the Marguerite Bay area (Adie, 1953).

TABLE II

STRATIGRAPHY OF THE VOLCANIC AND SEDIMENTARY ROCKS OF ADELAIDE ISLAND

Adelaide Island			*Marguerite Bay* (Adie, 1953)
Unit	*Thickness* (ft.) (m.)	*Lithology*	
			Interstratified trachytic andesites, rhyodacites, rhyolites (Mushroom Island)
			Interstratified agglomerates, dacites, tuffs and lavas (Lagotellerie Island)
Mount Bouvier summit succession	*Top not seen* 2,000 610	Well-bedded clastic and volcaniclastic rocks	Stratified agglomerates, tuffs and lavas (Lagotellerie Island)
Mount Liotard succession	5,000 1,525 maximum	Massive, unbedded fragmental (quench-brecciated) lavas	Trachytic augite-andesites and agglomerates (Pourquoi Pas Island)
			Coarse agglomerates, breccias and tuffs (Millerand Island—Laubeuf Fjord)
Sloman Glacier succession	3,450 1,050 *Bottom not seen*	Well-bedded clastic and volcaniclastic rocks	"Volcanic conglomerate" (Pourquoi Pas Island)

Table II shows that two successions of well-stratified sediments and sedimentary volcanic rocks are separated by a succession of massive lavas which are not well bedded. The higher succession of sediments (Mount Bouvier summit succession; p. 26) has not been examined in localities where it is seen to overlie the lavas (Mount Liotard succession; p. 18) except on southern Mount Bouvier where the lowest sedimentary strata are accessible. The lower sedimentary succession (Sloman Glacier succession; see below) is accessible in several areas where it passes upwards into the Mount Liotard succession.

Conglomerates containing very many boulders of plutonic rocks have not been seen in any exposure of the Sloman Glacier succession, where it passes upwards to the Mount Liotard succession. The stratigraphic position for such conglomerates (p. 26), which have been faulted into place in at least four accessible localities on the mountain walls, is therefore uncertain. They are thought to belong to the Mount Bouvier summit succession and to have been down-faulted into place. It is significant that on southern Mount Bouvier talus fallen from exposures of the Mount Bouvier summit succession contains blocks of sedimentary conglomerate in which boulders of plutonic rocks are present. It is believed that block-faults, which trend along the mountain walls and were instrumental in the formation of the mountains by raising them relatively to the surrounding terrain (Dewar, 1967), are the ones along which the conglomerates have been faulted down into place.

B. SLOMAN GLACIER SUCCESSION

The Sloman Glacier succession is composed of pale-coloured, fine- and coarse-grained sedimentary and volcaniclastic rocks, each unit of which is generally much thinner than 100 ft. (30·5 m.). 3,450 ft. (1,050 m.) of this succession are visible on the scarp west of Sloman Glacier.

1. *West of Sloman Glacier*

A scarp 8 miles (12·9 km.) long, west of Sloman Glacier (Figs. 4 and 5), is the most extensive accessible exposure of the Sloman Glacier succession, which is thinly stratified and dips generally at 15° towards 100° mag. in this locality. The lowest visible beds (T.334; Fig. 6 (A–B); Table III) are dark blue-green

TABLE III

SLOMAN GLACIER SUCCESSION EXPOSED ON THE SCARP WEST OF SLOMAN GLACIER (FIG. 6 (A—B))

Thickness (ft.)	(m.)	*Lithology*	*Grain-size*	*Roundness*	*Colour*	*Stations*
		Mount Liotard succession			↑	T.338, 345
300	90	Poorly bedded dark tuffites, rare thin tuffaceous gravelstones	↑	↑		T.345
500	150	Well-washed tuffaceous gravel breccias	—Becomes finer→	—Decreases→	—Darkens→	T.346
1,100	330	Well-washed interbedded tuffites, volcanic gravels and volcanic cobble breccias; volcanic conglomerates near base ↑				T.227, 337, 347, 351, 352 T.350
800	240	Washed pebble and gravel breccias, and tuffite beds (←Occasional aphanitic (?) ash beds→)	↑	↑	↑	T.336
750	230	Blue-green tuffs; occasional pebble beds *Bottom not seen*	—Coarsens→	—Increases→	—Lightens→	T.334, 335

tuffs, but lighter colours indicative of an aerobic depositional environment are visible above them, particularly in the volcanic conglomerates. Dark colours re-appear in the highest beds on the scarp (T.345); these are coarse andesitic tuffites with an abundant dark tuffaceous sandy matrix. These tuffites also crop out to the east at station T.338 on southern Mount Liotard, and they represent the top of the Sloman Glacier succession, because bedding is not present above their horizon (Fig. 6 (A–B, E–F)).

Uncorrelated sediments and volcaniclastic rocks crop out at both ends of the scarp. Fairly well-bedded, dark fine-grained tuffites and interstratified pebble- and cobble-breccia beds are exposed on the northernmost nunatak (T.227, 337) and they are tentatively correlated with tuffaceous sediments to the south (T.347, etc.; Table III). Uncorrelated beds exposed at the western end of the nunatak (T.226) have been faulted into place and they are discussed on p. 26.

No marker horizons are exposed on the southernmost nunatak of the scarp (T.353, 354). Massive grey-green washed tuffites alternate with paler finely bedded units, which are composed of fine-grained lithic tuffites, crystal and lithic-crystal tuffites and well-washed sandy volcanic gravelstones. These alternations are generally about 50 ft. (15·2 m.) thick, and they cannot be positively identified with any strata cropping out to the north.

2. *Western Mount Bouvier*

On the high buttress of south-western Mount Bouvier (Figs. 6 (C–D), 7C, 8C; Table IV), accessible water-laid epiclastic strata of the Sloman Glacier succession dip gently east but they have been locally disturbed by block-faulting. The lowest visible beds (T.2, 310) contain lithic fragments up to cobble size

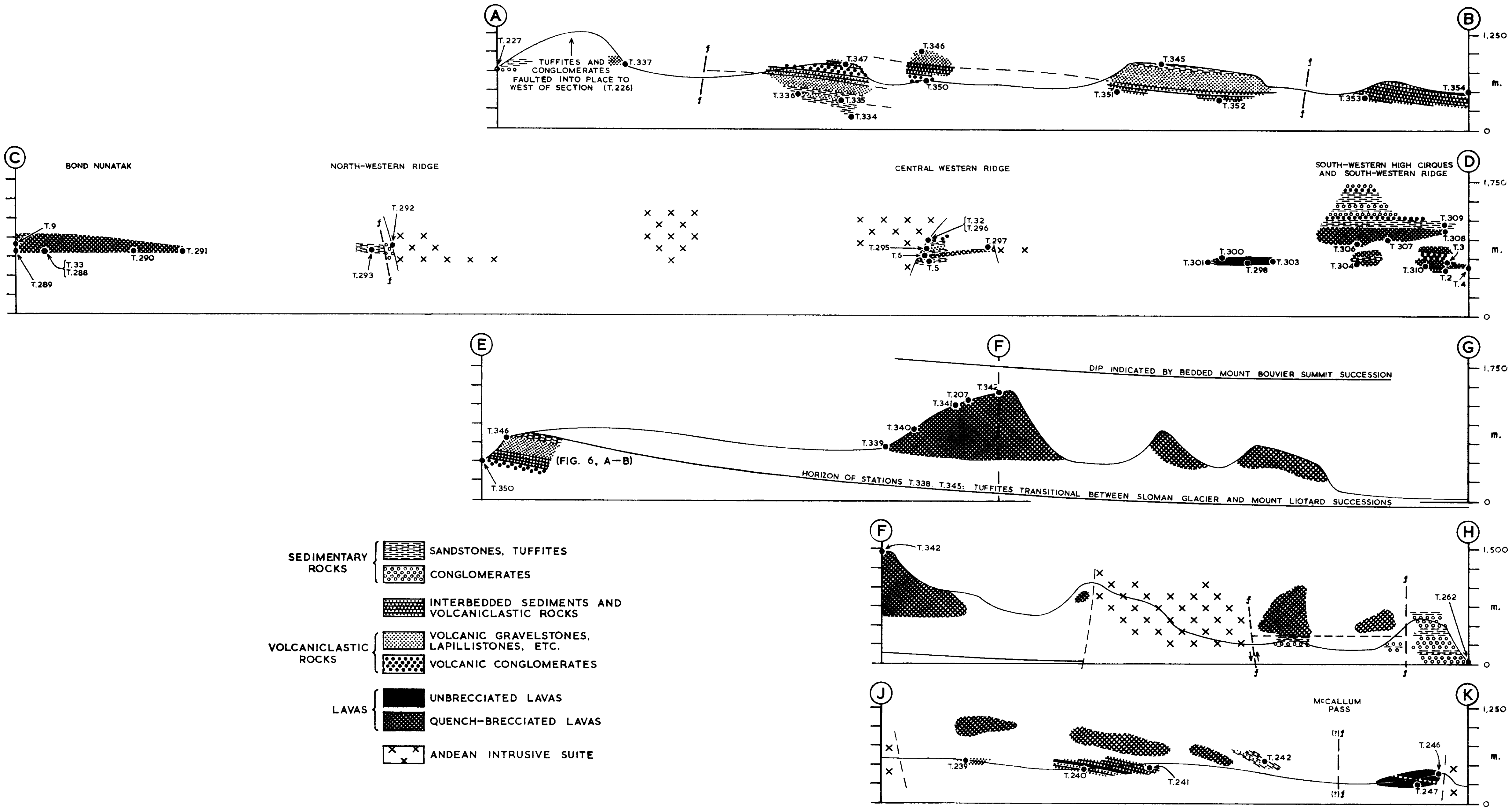

FIGURE 6

Cross-sections based on cliff sections exposed on Adelaide Island and showing the relationships of the stratified successions.

A–B. Along 156° mag. between stations T.227 and 354, west of Sloman Glacier (Fig. 5; Table III).

C–D. Along 163° mag. between stations T.9 and 4, western Mount Bouvier (Fig. 3; Table IV).

E–F. Along 074° mag. between stations T.350 and 342, southern Mount Liotard (Fig. 5). The Sloman Glacier succession dips eastwards below the Mount Liotard succession.

F–G. Along 099° mag. between station T.342 and Laubeuf Fjord, southern Mount Liotard (Fig. 5). Conglomeratic strata are not exposed near the Laubeuf Fjord coast, and one of the important faults displacing strata farther north (cross-section F—H) does not cross the line of section.

F–H. Along 080° mag. between stations T.342 and 262, southern Mount Liotard (Fig. 5). A thick succession of conglomerates exposed on eastern Mount Liotard has been faulted against the Mount Liotard succession. Because it is not certain whether the conglomerates belong to the Sloman Glacier succession or to the Mount Bouvier summit succession, the direction of the faulting is not shown. The conglomerates are believed to have been faulted down from the higher sediments.

J–K. Along 062° mag. through stations T.239 and 246, north-eastern Mount Mangin (Fig. 5; Table VI).

TABLE IV

STRATIGRAPHIC SUCCESSIONS IN VOLCANIC AND SEDIMENTARY ROCKS ON WESTERN MOUNT BOUVIER (FIG. 6 (C—D))

	Bond Nunatak	*Mount Bouvier*				
		Northern ridge	*Central ridge*	*Southern central ridge*	*Northern exposures on southern ridge*	*Southern high cirques and ridge*
Mount Bouvier summit succession		300 ft. (90 m.) massive lapilli brecciastone cementing conglomerate. (*Top and bottom not seen*) fault				*Top not seen* ~2,000 ft. (610 m.) thickly and thinly bedded epiclastic and sedimentary rocks grading into:
Mount Liotard succession	700 ft. (210 m.) massive mafic quench-breccia, thermally metamorphosed in places. (*Top and bottom not seen*)	180 ft. (55 m.) flag- to block-bedded mafic tuffites. (*Top and bottom not seen*)	*Top not seen*	400 ft. (120 m.) basalts with cryptic bedding. (*Top and bottom not seen*)	*Top not seen* ~270 ft. (80 m.) massive mafic quench-brecciated lava (*not examined*)	>750 ft. (230 m.) massive mafic quench-brecciated lava (?) fault: *interval not exposed* ~350 ft. (105 m.) massive mafic quench-brecciated lava (*not examined*)
Sloman Glacier succession		fault	140 ft. (45 m.) conglomerates passing down to sandstones, grading into: 130 ft. (40 m.) sandy volcanic gravel breccias 100 ft. (30 m.) mottled crystal tuffs 170 ft. (50 m.) massive fragmental lava, fragments becoming finer upwards 100 ft. (30 m.) laminated to block-bedded andesitic tuffs, tuffites *Bottom not seen*		210 ft. (65 m.) slab-bedded intermediate (?) tuffites 50 ft. (15 m.) massive mafic tuffaceous lava-breccia *Bottom not seen*	140 ft. (45 m.) (volcanic) conglomerates (*not examined*) 360 ft. (110 m.) quench-brecciated lava with cryptic very thick bedding 240 ft. (75 m.) laminated to thickly bedded well-sorted impure sandstones, granulestones and washed gravel breccias *Bottom not seen*

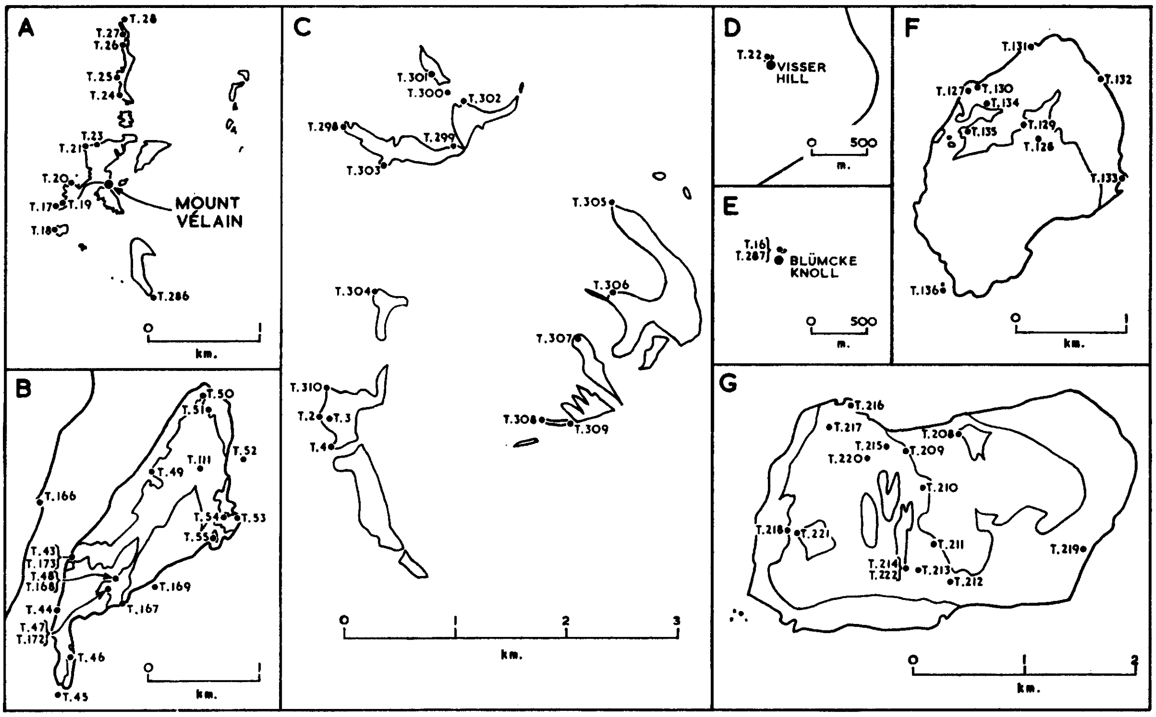

FIGURE 7

Detailed sketch maps showing exposures and the positions of geological stations (see Figs. 1, 2 and 4).

A. Mount Vélain (Fig. 1).
B. Webb Island (Fig. 4).
C. South-western Mount Bouvier (Fig. 2).
D. Visser Hill (Fig. 1).
E. Blümcke Knoll (Fig. 1).
F. Léonie Island (Fig. 4).
G. Jenny Island (Fig. 4).

but they are stratified very thinly in the finest-grained units; some laminae in the tuffite horizons are 0·3 cm. thick. The overlying 360 ft. (110 m.) of poorly stratified quench-brecciated lavas (T.3) are dark grey-green, weathering to dark brown-green, and they are mottled by sparse angular accessory-cognate lithic inclusions up to 2 ft. (0·6 m.) across, which are finer in grain than the matrix. A rock of similar appearance but of finer fragment size (up to 1·5 in. (3·8 cm.) across) is interbedded in the lower clastic rocks (T.2). About 140 ft. (43 m.) of inaccessible well-bedded conglomerates crop out above these lavas and below the Mount Liotard succession. They are packed with markedly well-rounded small pale lithic inclusions, probably the same as those found to the north in conglomerates exposed on the central west ridge of Mount Bouvier (Fig. 6 (C–D); Table IV). On the northern face of the south-western buttress of Mount Bouvier the succession differs from that on the main faces, because below the Mount Liotard succession 210 ft. (64 m.) of fairly well-bedded (?) tuffites are exposed. These rocks have not been examined but they appear to be stratigraphically equivalent to the cobble-conglomerates exposed to the south. A small thickness of inclusion-filled lava is exposed below the (?) tuffites (T.304) and it is similar to that present at station T.3 to the south, although the lithic fragments contained in it are very much smaller.

On the central western ridge of Mount Bouvier, strata vary in attitude from horizontal to dipping at 10° towards 340° mag. The lowest visible beds (T.5) are 100 ft. (30·5 m.) of thinly bedded tuffites which in places display small-scale graded- and false-bedding; their dark fine-grained matrices contain up to 40 per cent (estimated) of plagioclase porphyroclasts up to 2 mm. in length and also sparse small lithic inclusions. 170 ft. (52 m.) of massive dark blocky lava which overlies these tuffites (T.6, 297) contains well-rounded (Plate Ib) accessory-cognate lithic fragments up to 2 ft. (0·6 m.) across. The lowest 50 ft. (15·2 m.) of the lava are amygdaloidal and pipe amygdales are visible at their base. Water-laid clastic rocks cropping out above the lava coarsen upwards from tuffites to cobble-breccias (T.295). Above a sandstone intercalation, the highest visible beds (T.32, 296) are conglomerates in which sand forms the sparse matrix between well-rounded pebbles and cobbles, which are up to 3 in. (7·6 cm.) but are generally

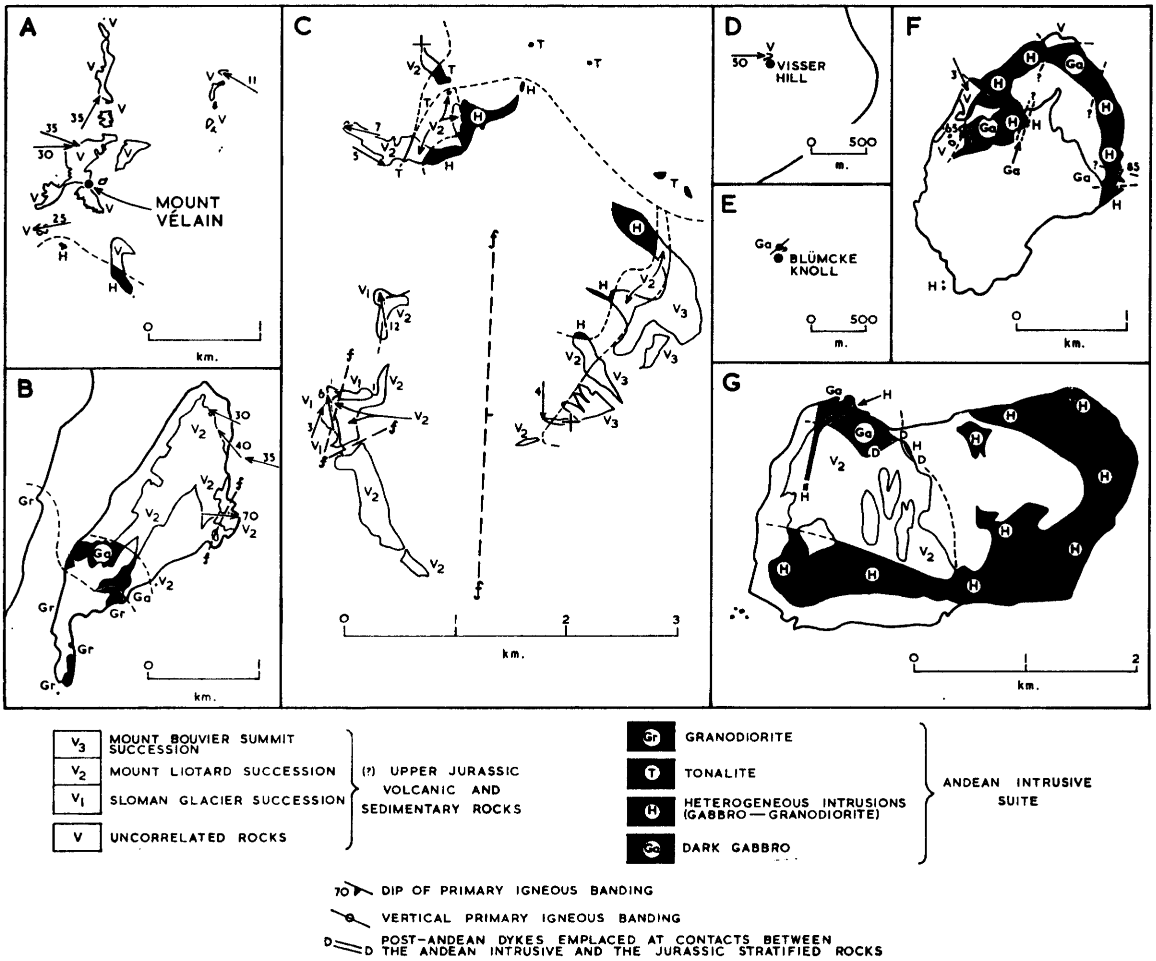

FIGURE 8

Detailed geological sketch maps of the areas shown in Fig. 7 (see Figs. 1, 3 and 5).

A. Mount Vélain (Fig. 1).
B. Webb Island (Fig. 5).
C. South-western Mount Bouvier (Fig. 3).
D. Visser Hill (Fig. 1).
E. Blümcke Knoll (Fig. 1).
F. Léonie Island (Fig. 5).
G. Jenny Island (Fig. 5).

1 to 1·5 in. (2·5 to 4·8 cm.) in diameter. Most of the pebbles weather white but a few are grey and some are similar in appearance to the lower dark lava. The thickness of the conglomerates is unknown because younger tonalite is exposed on the upper part of the ridge.

A uniform stratum of medium- to fine-grained clasolite (T.310.4; Plate Id) in the Sloman Glacier succession on south-western Mount Bouvier is composed principally of well-sorted but poorly rounded cryptocrystalline and microlitic lapilli of closely related types (Plate IVa). Sparse trachytic or intersertal lithic fragments of coarser grain-size contain prisms of epidote and laths of oligoclase, which in some cases surround amorphous inclusions dusted with limonite. In some fragments, up to 50 per cent (estimated) of the rock is formed by fine-grained felsic material between interlocked relatively large epidote crystals. The most altered lithic inclusions are now composed of calcite and epidote, or isotropic chlorite with accessory epidote, limonite, feldspaıs, calcite and pennine. Andesine ($Ab_{62}An_{38}$) forms phenocrysts and porphyroclastic crystals.

Lithic inclusions in the massive fragmental lava (T.3.1) overlying these clastic horizons differ from the matrix in their colour index and contents of amygdales and plagioclase laths. The matrix is of altered glass and ragged andesine ($Ab_{67}An_{33}$) laths up to 0·3 mm. in length; it encloses squat euhedral andesine phenocrysts of the same composition which are up to 4 mm. in length. The amygdales are usually 0·3 mm. across but the largest are 1 mm. in diameter. The amygdales are filled by antigorite, cloudy potassium feldspar in the smaller examples, and epidote, in some cases rimmed by the antigorite or the feldspar, in the larger ones. The lava (T.2.1) in the clastic beds below has a similar texture (Plate IVb).

The lava (T.5.9) below the sediments exposed on central western Mount Bouvier has recrystallized. Its groundmass is formed by fibro-acicular amphibole, subsidiary plagioclase microlites and iron ore granules; it contains euhedral flow-aligned phenocrysts of andesine ($Ab_{61}An_{39}$) up to 3 mm. in length which have been rendered cloudy by their high content of tiny amphibole needles. These needles are a pale-coloured hornblende which also forms rare euhedral phenocrysts up to 1·5 mm. across. A few probable altered lithic inclusions are composed of small plagioclase and iron ore crystals. The amydgales in this rock have a fibrous or crystalline central filling of the groundmass hornblende, surrounded by an outer rim of small equidimensional andesine crystals. Some amygdales lack rims or cores. One amygdale is of andesine tabulae, interstitial pale-coloured amphibole and a little epidote, surrounded by a narrow selvage of radiating fibrous amphibole outside of which there is locally a narrow rim of plagioclase. A narrow vein traversing the rock has been filled by small andesine crystals which enclose amphibole needles. Some granular iron ore and fibrous amphibole masses are present in the vein, near which the host rock has been slightly enriched in hornblende.

The pebbles and the matrix of the volcanic conglomerates (T.32.7; Plate IVc) of western central Mount Bouvier have been thermally metamorphosed by the adjacent tonalite. The holocrystalline fine-grained poeciloblastic matrix has a colour index of 30, varying to 50 in parts surrounding the leucocratic pebbles. It is an allotriomorphic mosaic with an estimated composition of 20 per cent quartz, 10 per cent potassium feldspar, 30 per cent andesine ($Ab_{58}An_{42}$), 20 per cent hypersthene and 10 per cent biotite, with magnetite and pyrite. The hypersthene is poeciloblastic, especially towards biotite, and its concentration varies inversely with that of chlorite which is concentrated in some parts of the rock. Of four pebbles which have been sectioned, three are fine-grained and appear to be recrystallized sandstones in which plagioclase has intergrown with quartz. Small iron ore crystals have aggregated into clusters, occasional irregular crystals are of the ferromagnesian minerals of the matrix, and rare zircon crystals are present. The fourth pebble was originally (?) porphyroclastic; its complex groundmass is composed of irregular small quartz crystals and a felsic cloudy network of slightly higher relief, and it contains rounded plagioclase (?) porphyroclasts which have been altered to sericite and chlorite. Quartz, cloudy potassium feldspar and iron ore are present as other large crystals.

3. *Cape Alexandra and Fitton Rock*

On the well-stratified cliffs of Cape Alexandra (Figs. 4 and 5; Plate Ia), the accessible strata are thinly bedded tuffites and thicker (10 ft.; 3 m.) coarser-grained volcaniclastic rocks. Similar but more massively bedded tuffites crop out on Fitton Rock nearby. The Cape Alexandra beds extend north on the inaccessible eastern walls of Mount Ditte, where they have been disturbed by vertical faults which have brought down to their level the massive Mount Liotard succession.

The dark epiclastic rocks range from the finest tuffaceous silts to sandy lapillistones and rare gravelstones containing moderately well-rounded cognate and accessory-cognate lithic inclusions. Pyritous traces of fragmented leaves and wood have been found in a 4 in. (10 cm.) tuffaceous shale bed (T.34). Rounded inclusions in typical dark beds are similar to the rocks of light green or cream-coloured beds up to 1 ft. (0·3 m.) thick. The inclusions vary in shape from spherical masses up to 8 in. (20 cm.) across to sausage-shaped outlines up to several feet in length in the plane of the bedding. Their grain-size diminishes outwards from fine-grained to aphanitic through concentric bands. Different colours occur at different horizons but in any one horizon the colour remains uniform. These bodies may have originated as volcanic bombs, the largest of which broke up on entering water, while some of the smaller ones remained intact. The continuous beds of the light-coloured rock are thought to be of tuff ejected so rapidly that clastic contamination did not occur. Another possibility is that these bodies are parts of attenuated submarine flows which broke up into small pillows.

The centre of a typical example of the concentrically layered fine-grained inclusions in the Cape Alexandra strata is much coarser in grain-size than the outer shells. The enclosing sediment is composed of fragments of micro-trachytic lava and porphyroclasts of bytownite. The character of this rock is progressively modified on the passage inwards through the outer 15 mm. of the inclusion, where a groundmass of calcite, quartz, plagioclase and unidentifiable material contains lithic fragments and crystals of epidote, clinozoisite, bytownite and tremolite or pale-coloured hornblende. In the 6 mm. around the central core, the content of clinozoisite increases and irregular aggregates of crystals of pale amphibole are present. In the centre of the body, a groundmass predominantly of anhedral calcite, quartz and labradorite ($Ab_{39}An_{61}$) contains colourless to very slightly pink subhedral crystals of (?) grossular (Plate IVd) up to 1 mm. across which have a patchy low birefringence similar to disrupted zoning.

4. *Eastern Mount Barré, Mount Liotard and Mount Mangin*

At the foot of high faces on the generally inaccessible eastern side of Mount Barré (T.284, 285, 312–316), sub-horizontally bedded epiclastic rocks include all size grades from volcanic conglomerates to tuffaceous silts. In strata of the Sloman Glacier succession, which crop out below the Mount Liotard succession, boulders of the coarsest grades are more than 1 ft. (0·3 m.) across. The top 50 ft. (15·2 m.) of the Sloman Glacier succession (T.285) consists of well-bedded alternations of pale-weathering, rather coarse-grained crystal tuffite and relatively dark aphanitic tuffite, which display very conspicuous current- and graded-bedding (Plate IIa). Current directions were towards the south. Strata of an even more sedimentary facies are exposed at the end of the main eastern ridge of Mount Mangin (T.280), on the eastern walls of Mount Liotard (T.262–265) and on the Léonie Islands (T.127–138), where flat-lying conglomerates contain many foreign boulders of plutonic rocks. These conglomerates have been faulted into place and are discussed elsewhere (p. 27).

Very small shows of molybdenite have been found within and near a narrow silicic band in silty lapillistones interbedded with massive tuffaceous granulestones on eastern Mount Barré (T.313). These beds have been sheared and the more incompetent ones pinch and swell slightly. The shear fractures have been filled by epidote, quartz and molybdenite, which is slightly magnetic and probably contains appreciable amounts of iron. The silicic band with which the mineralization is associated may be a narrow sill.

5. *Square Peninsula and the Ryder Bay area*

Fragmental rocks underlie the inaccessible Mount Liotard succession on the north side of the ridge south of Sighing Peak (T.155, 162, 163; Fig. 4). Poorly sorted volcanic conglomerates, gravelstones, and tuffaceous shales and sandstones contain lithic material ranging in size from the small angular fragments of the matrices to boulders which are all well-rounded.

Faulting in southern Square Peninsula has hindered the correlation of the stratified rocks exposed there and in the Ryder Bay area (Figs. 4 and 5). Some of these rocks are of only slightly varying massive volcanic facies, but others are well-bedded sedimentary or volcaniclastic rocks. Typical of this area is a massive dark grey quench-brecciated lava containing barely discernable, slightly rounded cognate inclusions and, usually, porphyritic feldspar crystals. On the best exposures (Lagoon Island; T.120–122), an obscure horizontal contact separates massive and bedded facies of what is probably Adie's (1953) porphyritic augite-andesite of the small islands of Laubeuf Fjord. Very dark fine-grained lava which contains no feldspar phenocrysts is exposed on the southern Mikkelsen Islands (T.196, 266). Conglomerates which crop out on the Léonie Islands are described on p. 27.

A stratum, at least 400 ft. (122 m.) thick, of rock of similar appearance to the Lagoon Island brecciated rock forms part of a succession (Table V) exposed on a ridge close to the southern coast of Square Peninsula. The quench-brecciated lava (T.81) is overlain by progressively more sedimentary rocks, of which the highest visible units (T.83) include sandy gravelstones and sandy volcanic gravelstones containing pale-weathering lithic fragments that are only moderately rounded. Volcanic gravelstones identical to those at station T.83 crop out on the larger island off Rothera Point (T.95); on the smaller island (T.94), midway between the larger one and the point, are exposed fine-grained green volcanic rocks traversed by feldspathic and epidotic veins and containing tiny phenocrysts of plagioclase and ferromagnesian minerals. The succession thought to underlie the quench-brecciated lava at station T.81 is exposed near the southern Square Peninsula coast east of the snout of Crumbles Glacier (T.79, 268, 269). At station T.269, an estimated 300 ft. (91·4 m.) of massive pale green and limonitic orange rock, possibly an indurated fine-grained sandstone, have been faulted up against the brecciated lava and the rocks which underlie it.

On remote small exposures east of central Crumbles Glacier (T.175–177), a conglomerate bed 15 ft. (4·6 m.) thick contains fine-grained accessory-cognate cobbles, some of which are of banded lavas (Plate Ic). A few clasts are of silicic intrusive rocks. This bed, which is intercalated in a pale-weathering

TABLE V

STRATIGRAPHIC SUCCESSION OF THE VOLCANIC AND SEDIMENTARY ROCKS OF SOUTHERN SQUARE PENINSULA

Thickness (ft.)	(m.)	*Main area*		Correlated areas
		Top not seen		
100	30	Sandstones, tuffites, gravelstones and volcanic gravelstones (T.83)		(?) = Sediments of larger island off Rothera Point
~150	~45	Tuffites, volcanic gravelstones and gravelstones; some interbedded banded lavas (T.82)		
400	120	Massive dark grey fine-grained porphyritic fragmental lava (T.81)		(?) = Lava of Lagoon Island
		—*Interval not known*—		
			fault	
Thickness uncertain		Pale non-porphyritic brecciated lavas with thin glassy brecciated flow-banded lavas (T.79)	Indurated fine-grained sandstone (T.269)	
~150	~45	Massive volcanic gravelstone (T.268)		
			fault	
		Bottom not seen		

crystal tuff overlying an exposure of 250 ft. (76 m.) of dark andesitic lava, grades upwards to a lapilliferous gravelstone.

Some of the sediments in the succession exposed on southern Square Peninsula, and described above, are conspicuously stained red by limonite. This staining is particularly intense towards the south-east, where the stratified rocks have been displaced by gabbros (T.86), and the rocks most conspicuously modified are the sediments of finest grain-size. At stations T.85 and 86, rocks near the gabbro contact have been stained to a bright blood-red colour not seen elsewhere on Adelaide Island, and they noticeably affect a magnetic compass (Procter, 1959, p. 14). Thick quartz-magnetite veins intrude these rocks and swarms of quartz-pyrite veins intrude the stratified rocks up to 1 mile (1·6 km.) from the gabbro contact. 0·5 miles (0·8 km.) from it, a typical swarm about 10 yd. (9·1 m.) wide crops out at the centre of a zone of rocks, 40 yd. (36·6 m.) wide, which have been intensely stained by limonite but do not deflect a compass needle (T.84). The staining diminishes rapidly in intensity from near these veins to the margin of the stained zone. At its contact near the stratified rocks the quartz-gabbro has not weathered to red colours, but a few silicic veins containing druses of specular haematite have been intruded into it.

In the volcanic sediments of northern Square Peninsula, a sparse ashy mudstone matrix is probably a product of abrasion during transportation, and it is so closely similar to most lithic fragments that it makes them barely distinguishable in section. Most of the matrix of a typical poorly sorted gravelstone (T.155.1) is formed by antigorite which has replaced ferromagnesian minerals, but tiny crystals of epidote, felsic minerals and iron ores are present. The groundmasses of the lithic inclusions are less altered and contain phenocrysts of andesine ($Ab_{52}An_{48}$) up to 3 mm. in length which are not present in the matrix. The phenocrysts have shadowy twinning and they are altered to calcite in places. The textures of the lithic inclusions range from glassy through felted and intersertal to holocrystalline, the coarsest rock being largely of equigranular andesine and chlorite. Cavities throughout are filled by pennine and calcite.

On southern Square Peninsula, even the stratified rocks which have been least affected by quartz-magnetite mineralization contain metamorphic minerals including andalusite and muscovite. Although the original mineralogical compositions of these rocks are uncertain, most of them appear to have been fine-grained sediments and sedimentary volcanic rocks, and interbedded coarser-grained sediments are still easily recognizable in the hand specimen. The volcanic gravelstones of the stratigraphically highest exposures of southern Square Peninsula (T.83.1) contain flow-banded lithic inclusions which have re-crystallized to a fine-grained quartz mosaic. The fine-grained matrix containing them is composed of quartz, porphyroblastic potassium feldspar, dispersed colourless to slightly pink andalusite crystals, some accessory haematite and muscovite in both coarse-grained lenses and disseminated crystals. In volcanic gravelstones with a similar mineralogy cropping out slightly lower in the succession (T.82), lithic inclusions are more easily distinguishable, although their margins are very ragged in detail. The pronounced limonitic staining of this horizon is reflected in the high content of pyrite in both the inclusions and the matrix. In the unit thought to be the lowest exposed in the local succession (T.269.1), a very fine-grained quartz mosaic contains tabular porphyroblasts of albite up to 1 mm. in length (estimated as 10 per cent of the rock), and potassium feldspar anhedra which have been replaced centrally by radiating prismatic epidote crystals. Epidote-rich spherulites are concentrated in sharply demarcated subhedral patches which have been stained an intense brown by limonite in places. The whole rock is traversed by silicic veins in which crystals of epidote, chlorite and pyrite are locally present.

In limonite-stained rock from the quartz-pyrite mineralized zone at station T.84, a very fine-grained mosaic of quartz and (?) sanidine, concentrated in ill-defined anastomosing veins, has permeated into the host rock so that these two minerals are present throughout. Relatively large crystals in the host rock are of andesine. Andalusite, muscovite and biotite have crystallized in irregularly distributed anhedral clusters and veinings, and pyrite is disseminated throughout the rock. Stratified rocks near the contact of the gabbro, where the red staining is most intense (T.85) have been considerably altered, and they consist of coarse-grained equigranular mosaics of quartz and slightly subordinate magnetite in equidimensional crystals. The magnetite is not distributed evenly throughout the rock but it is concentrated in irregular veins. In thin section it appears that the magnetite has preferentially replaced the former matrix of a fine-grained volcaniclastic rock and the quartz has replaced the former lithic inclusions. One of the thick quartz veins (T.85.3) traversing the magnetite-rich rock contains magnetite which has in places coarsely intergrown with the quartz in florescent masses. Pale-coloured biotite which has altered to epidote is a very rare accessory mineral in the vein.

The mineralization of the stratified rocks in southern Square Peninsula is attributed to the action of hydrothermal solutions which were rich in silica, iron oxide and potash. Where the mineralization has been most intense, quartz and magnetite are the only minerals present in other than negligible quantities, but farther from the most affected area there has been a concentration of andalusite, muscovite, potassium feldspar and pyrite. It is thought that the finest-grained volcaniclastic rocks have been most affected by the mineralization, because they offered the easiest penetration for the mineralizing solutions. They may, on the other hand, have contained more of the minerals suitable for stabilization of the circulating fluids, so that minerals formed from the solutions have been most concentrated in these beds. The source of the hydrothermal solutions was probably the pluton of pink granodiorite to the north, although it is not exposed close to the mineralized rocks. There has been only slight mineralization of the gabbro near the magnetite-rich stratified rocks, although the gabbro was intruded before the granodiorite. Not even incipient mineralization has been found at other exposed contacts of the quartz-gabbro, at contacts of the granodiorite, or even close to any other Andean intrusive rocks exposed on Adelaide Island.

C. Mount Liotard Succession

The typically massive dark grey Mount Liotard succession is composed of quench-brecciated (p. 10) eruptive rocks which contain angular cognate lithic inclusions and, usually, small plagioclase phenocrysts. A few exposures are of unbrecciated lava; the most calcic of these lavas is a basalt but the plagioclase of other rocks is andesine or even oligoclase. About 5,000 ft. (1,525 m.) are exposed on southern Mount Liotard, 3,000 ft. (914 m.) are visible but inaccessible on eastern Mount Barré, and 1,200 ft. (366 m.) crop out on northern Mount Mangin and south-western Mount Bouvier. In the last two localities some thicknesses are believed to have been faulted out.

1. *Southern Mount Liotard, northern and eastern Mount Ditte, and Jenny Island*

On a southern peak of Mount Liotard, 2,500 ft. (762 m.) of the Mount Liotard succession have been examined between stations T.339 and 345 (Figs. 4, 5, 6 (E–F)); the horizon at station T.339 is 1,500 ft. (457 m.) above the base of the formation (T.338, 345; p. 12). To the south, inaccessible exposures on northern and eastern Mount Ditte show the succession passing upwards to the well-stratified Mount Bouvier summit succession, which is also visible on upper Mount Liotard. The high bedding shows that the easterly dip of these rocks gradually decreases towards the east from a general 15° (p. 12) to horizontal on the east coast of Adelaide Island (Fig. 6 (F–G, F–H)).

A typical rock from southern Mount Liotard (T.341.1) contains dark subangular inclusions in a slightly coarser-grained grey porphyritic matrix. The plagioclase of many of the phenocrysts has been epidotized to a light green colour and the rock is traversed by ill-defined irregular epidotic veins. Specimens from stations T.339 and 340 are very amygdaloidal and even more fragmental; the content of plagioclase phenocrysts and lithic fragments varies locally.

The country rock of Jenny Island (Figs. 7G and 8G) is completely massive and has the same hand-specimen appearance as the rock at station T.341.

The hemicrystalline lava matrix of a typical rock from southern Mount Liotard (T.341.1) contains two generations of unorientated plagioclase laths, both of albite-oligoclase. The phenocrysts, which are up to 3·5 mm. in length, are cloudy because they have been altered, mainly to epidote. Lithic inclusions are of dark cloudy glass surrounding small plagioclase laths which are also of albite-oligoclase. Small very irregular amygdales are filled by anhedral epidote. In highly altered rocks from lower in the succession, phenocrysts are of labradorite (T.340.1) and oligoclase (T.339.2; Plate IVe).

A specimen from the country rock of Jenny Island is a slightly metamorphosed, poorly sorted tuffite (T.210.1). Fragments of volcanic rocks and the rather felsic, very fine-grained matrix show signs of having recrystallized. Both contain aggregates of small pale-coloured hornblende crystals and smaller amounts of iron ore and pale biotite. The original sedimentary texture is most clearly seen in the plagioclase porphyroclasts, which have no preferred orientation, are often marginally rounded and may be fractured across well-marked zoning (Plate IVf).

2. *Western and southern Mount Bouvier*

On one of the western ridges of Mount Bouvier near the southern end of the mountain (Figs. 7C and 8C) unbrecciated porphyritic basalt (T.298) extends upwards for at least 400 ft. (122 m.) and it displays a barely distinguishable wide banding, the attitude of which is variable but never far from horizontal. Less than 1 mile (1·6 km.) south of station T.298, the Mount Liotard succession crops out on the south-western buttress of Mount Bouvier (Figs. 6 (C–D), 7C, 8C; Table IV) and has a similar field appearance to the basalts. This appearance is common to all exposures of quench-brecciated lavas in the Adelaide Island area.

Massive brecciated lavas are exposed on the lower parts of the main faces of southern Mount Bouvier (T.306–309), which are separated by snow cover from the exposures described above. Many examined exposures of the massive brecciated lava on the higher faces have been affected by a quartz-gabbro intrusion, which has caused porphyroblastic brown biotite to crystallize locally (T.306). Above station T.308 the massive formation passes within 250 ft. (76 m.) into sediments (Table IV; p. 26).

On the 700 ft. (213 m.) steep western face of Bond Nunatak, exposures of fragmental re-worked effusive rocks display nearly indistinguishable wide bedding which strikes generally north–south. At the disturbed northern end of the nunatak, dips up to 30° in various directions have been recorded. The fragmental rock contains a few feldspar laths up to 0·5 mm. in length and numerous barely distinguishable cognate lithic fragments. Low down at the southern end of the faces (T.291), lithic inclusions up to 3·5 cm. across are exactly comparable to those normally found, except that some have weathered noticeably paler than the matrix; at the extreme northern end of the nunatak (T.289), the lowest rocks are light green breccias containing cognate and accessory-cognate lithic fragments ranging in colour from white to olive-green. Many silicic dykes traverse the volcanic rocks near the northern end of the nunatak.

Dark fine-grained tuffites crop out 2 miles (3·2 km.) south of Bond Nunatak at small exposures on the north-western ridge of Mount Bouvier (T.293). Rather obscure colour banding, 2 ft. (0·6 m.) wide and over, is paralleled in places by silicic intrusive veins. The veins have been intruded from the tonalite (p. 42), which crops out on adjacent exposures and which is seen in contact with conglomerate (p. 26) on the largest exposure on the ridge (T.292).

No bedding whatsoever is visible in the Mount Liotard succession exposed on the southern side of Mount Bouvier on high inaccessible faces. The stratum falls to the west, probably because of faulting. At Hunt Point, the rock has the usual massive fragmental appearance but it is traversed by micro-veins from a nearby younger quartz-gabbro intrusion.

The unbrecciated basalt at station T.298 (Plate Va) has a fine-grained slightly trachytic groundmass, in which labradorite ($Ab_{45}An_{55}$) laths up to 0·1 mm. in length form an estimated 45 per cent of the rock. Interstitial hornblende has replaced pyroxene. Some of the amphibole has altered to a mixture of olive-green chlorite and semi-opaque limonite, and other crystals have altered to finely felted fibrous and lamellar chlorite. Irregular cracks and small amygdales are filled by antigorite crystals. Phenocrysts of labradorite, most of which have rounded margins, are identical in composition to the laths of the groundmass and they form an estimated 30 per cent of the rock; all have been partially altered along irregular cracks and patches. The principal alteration product is a chlorite. Although the plagioclase crystals are not zoned, the alteration is in several cases concentrated in the crystal cores. A few hornblende phenocrysts are more intensely coloured than the groundmass amphibole. Pennine forms a few coarse lenses of alteration product.

The quench-breccias of south-western Mount Bouvier were originally effusive in spite of their clastic appearance. A rock from station T.308 is an intersertal porphyritic fragmental lava with a colour index of 30 which is mostly derived from dustings and minute crystals of iron ores. The phenocrysts are of sodic plagioclase ($\sim Ab_{90}An_{10}$) and neutral to pale yellow clinopyroxene, which are respectively estimated as forming 50 and 5 per cent of the rock. The clinopyroxene crystals are never more than 1 mm. in length but the plagioclase crystals are larger and have in places concentrated into aggregates up to 4 mm. across. The groundmass of this rock is composed of albite-oligoclase (estimated at 25 per cent of the rock), interstitial iron ore crystals, pyroxene similar to that of the phenocrysts, and chrysotile which fills amygdales and has replaced small ferromagnesian crystals.

The typical rock from Bond Nunatak contains a greater proportion of clastic fragments. In a specimen containing white-weathering inclusions (T.291.1), angular to rounded lithic fragments are packed densely together in a fine-grained holocrystalline porphyritic matrix. The estimated colour indices of the lithic fragments range from 25 to 60; the more leucocratic ones are the white-weathering types in which a mosaic of quartz crystals up to 0·4 mm. across encloses randomly orientated acicular crystallites of hornblende and sparse iron ore crystals up to 0·2 mm. across. A few lithic inclusions are of coarser grain and they contain unorientated oligoclase laths up to 0·3 mm. in length and rather ragged subhedral andesine phenocrysts up to 1 mm. in length. The colour indices of the lithic inclusions depend on their content of ragged fresh hornblende phenocrysts up to 0·4 mm. across. The rock is interpreted as one originally comparable to specimen T.308.1, but metamorphosed to amphibole grade with introduction of silica.

A specimen from the breccias that crop out at the northern end of the nunatak is a clasolite in which matrix and lithic inclusions are both fine-grained and contain very fine-grained interstitial material (T.289.1; Plate Vb). The matrix is melanocratic but the lithic inclusions are mostly leucocratic or light-mesocratic. Some of the clasts are trachytic. The estimated composition of the matrix is 10 per cent of quartz, 85 per cent of clinopyroxene and a probable 5 per cent of potassium feldspar. One part of the matrix is formed of clinopyroxene only. The rock has recrystallized so that the lithic inclusions have no clearly marked margins and their textures are equigranular, although many are believed to have been originally trachytic or intersertal. The lithic inclusions are composed mainly of quartz (? introduced), potassium feldspar and clinopyroxene; in some fragments potassium feldspar is absent and a quartz mosaic contains aggregated clinopyroxene crystals. In one lithic inclusion, squat euhedral phenocrysts are labradorite ($Ab_{48}An_{52}$) and smaller crystals are andesine ($Ab_{60}An_{40}$). Nearby, to the south at station T.288, many silicic dykes intrude the massive rock which has been metamorphosed in the same way. The rock here is less obviously clastic and former lithic inclusions are less well marked in thin sections.

With clinopyroxene crystallizing strongly against other minerals, the rocks from stations T.288 and 289 are granulites, representing a higher stage in the metamorphism observed in the granulite at station T.291. In the latter, the white inclusions, differing in some slight detail from the matrix, are believed to have been bleached by the migration from them of the constituents of ferromagnesian minerals and the introduction of quartz. Lithic fragments in the rocks of higher grade were probably affected in the same way before the grade rose to that of pyroxene. The metamorphism is believed to have been caused by the nearby presence of a silicic intrusion which fed the dykes visible at station T.288.

At Hunt Point (T.144, 145), the only accessible exposure on southern Mount Bouvier, micro-veins traversing the fragmental rock contain small phenocrysts of felsic minerals (plagioclase; ? quartz) and less common crystallites of pyroxene and small crystals of iron ore. The rock between the veins contains an estimated 50 per cent of labradorite ($Ab_{48}An_{52}$) laths up to 0·3 mm. in length. Colourless clinopyroxene crystals (estimated at 40 per cent of the rock), a few small crystals of brown biotite and small subhedral iron ore crystals are interstitial. Anhedral andesine ($Ab_{52}An_{48}$) phenocrysts up to 1·5 mm. across are rare. In some disturbed parts of the rock, thin veins and the rock surrounding them are rich in aegirine-augite crystals and a mineral, probably talc, which locally forms the groundmass enclosing the pyroxene.

3. *Mount Barré and Mount Mangin*

The Mount Liotard succession crops out on high walls on the eastern side of Mount Barré, but only the lowest rocks are accessible at the well-marked contact against the underlying Sloman Glacier succession (T.285; p. 16). The contact rises towards the south, partially through faulting on eastern Mount Liotard (Fig. 5). Over 3,000 ft. (914 m.) of the succession are exposed on these faces; the accessible lowest part is not eruptive rock but it is a volcanic cobble-conglomerate. The matrix of this rock, a very dark sandy lapillistone or volcanic gravelstone, encloses well-rounded cobbles of dark aphanite which contains sparse small porphyritic feldspar crystals. The top of the conglomerate has not been seen. An obscure banding is visible in places in the typically massive stratum of the Mount Liotard succession on eastern Mount Barré, but the banding is not related in attitude to the dip of the stratum. Barely discernible colour differences are visible in bands perhaps 10 ft. (3 m.) wide which trace out irregular festoons and may represent the paths of internal currents in a thick lava flow.

Over 1,500 ft. (457 m.) of dark massive rocks, similar in appearance to those cropping out on southern Mount Liotard (p. 18), are exposed on intermittent outcrops on western Mount Mangin (Figs. 4 and 5). The westernmost exposure (T.228), however, is of volcanic conglomerates interbedded with blocky brecciated lavas which are similar in appearance to the unbedded rocks of the main exposures. True bedding planes are absent, for the conglomerates grade into the lavas; planar inclusions in the conglomerate beds preferentially dip at 14° towards 109° mag. The matrix of the cobble-conglomerate appears to be formed of washed lava debris and it encloses well-rounded accessory-cognate lithic inclusions which are up to 1 ft. (0·3 m.) in greatest diameter. The conglomerates have probably been faulted into place.

Extensive exposures of the Mount Liotard succession are visible on the north side of the north-eastern spur of Mount Mangin (Figs. 4 and 5), but they are not accessible. Poorly bedded volcanic and volcaniclastic strata underlie them (T.239–241) and they probably belong to the upper part of the Sloman Glacier succession. About 1,200 ft. (366 m.) of the massive stratum are present (Fig. 6 (J–K); Table VI). Bedded strata examined at station T.242 are believed to overlie the massive rocks. Exposures (T.246, 247) east

TABLE VI

STRATIGRAPHIC SUCCESSION OF THE VOLCANIC AND SEDIMENTARY ROCKS OF THE McCALLUM PASS AREA (FIG. 6 (J—K))

West of McCallum Pass				*East of McCallum Pass*
Station	*Interval* (ft.)	(m.)		
			(?) fault	
T.242			*Top not seen* Well-bedded tuffites; occasional thin lapilli-breccia beds	
	1,750	533	Includes 1,200 ft. (366 m.) of massive unbedded (?) lavas	T.246, 247; 700 ft. (213 m.) massive fine-grained lavas containing small plagioclase phenocrysts; rare thin lapillistone beds. Probably of Mount Liotard succession
T.241 T.240	650	198	Sandy / Lapilli / Breccias — Finely banded thin lavas	
T.239	*Small interval*		Dark fragmental tuffaceous granulestones *Bottom not seen*	
			(?) fault	

of McCallum Pass are of rocks of the Mount Liotard succession which appear to have been faulted up relative to those to the west, and McCallum Pass is the natural line for such a fault.

4. *Northern Square Peninsula and Shambles Glacier*

The re-worked dark volcanic rocks of eastern McCallum Pass are comparable to some of those that crop out to the north across Shambles Glacier (Figs. 2 and 3). On nunataks (T.275) near sea-level on the western coast of Stonehouse Bay, a horizontally bedded, almost completely massive clasolite contains large cognate lithic fragments. This rock extends upwards to just below the summit of Dewar Nunatak (T.311; 1,500 ft. (457 m.) a.s.l.), where crystal lithic tuffites, derived in part from the lower horizons, are relatively well-bedded. These horizons are thought to have been faulted down relative to those on south-western Mount Bouvier (p. 19).

Stratified rocks exposed on Sighing Peak and Webb Island (Figs. 7B and 8B) are mostly dark fragmental lavas, which are completely massive and contain numerous plagioclase phenocrysts and small fine-grained lithic lapilli. In contrast the lowest rocks exposed in these areas are devitrified rhyolites not encountered elsewhere. These lavas are characterized by pale flow lines or thin banding in black or pale green, and they usually contain squat plagioclase phenocrysts up to 3 mm. in length, of which the estimated proportions vary from 0 to 30 per cent in different specimens. Wide colour banding is visible near the top of these lavas on eastern Webb Island (T.51), where tuff and breccia beds are intercalated, although lithic inclusions are otherwise uncommon in the lavas.

Near the coast of Square Peninsula west of Webb Island, very coarse fragmental lavas dip at 70° towards 220° mag. and hence they must have moved well out of place. Very occasional intercalations of thinly bedded tuffs indicate the attitude of this otherwise massive exposure. Farther west, on the ridge south of Sighing Peak, the Mount Liotard succession crops out above bedded sediments (p. 16).

The massive rock of the lowest exposure on the north side of Shambles Glacier (T.275.1) is a fragmental lava which differs from most already described (p. 19, 20) in that it possesses labradorite ($Ab_{49}An_{51}$) porphyroclasts which are often fractured. Lithic fragments contain small flow-orientated laths ($Ab_{64}An_{36}$). The irresolvable fine-grained matrix is darker than the lithic fragments, which contain amygdales up to 1 mm. across filled by epidote and hornblende. Small iron ore crystals are ubiquitous in the matrix.

The only identifiable original mineral present in the finest-grained detrital rocks of upper Dewar Nunatak (T.311.1) is labradorite ($Ab_{44}An_{56}$). These rocks are interbedded with indurated lapillistones with sparse matrices in which lithic fragments are of fragmental lavas similar to those of the lower nunataks.

i. The darkest lithic inclusions predominate. They contain a groundmass of unorientated oligoclase ($Ab_{71}An_{29}$) crystals, rare small quartz crystals and phenocrysts of labradorite ($Ab_{42}An_{58}$).

ii. Some inclusions differ in that they contain amygdales up to 0·1–0·4 mm. in diameter. The amygdales are filled with antigorite and many have narrow margins of epidote. They are streaked out in a crude flow structure. The groundmass surrounding these amygdaloidal inclusions is composed of andesine ($Ab_{55}An_{45}$) laths up to 0·4 mm. in length and crystals of quartz, chlorite and epidote. The epidote appears to have replaced small (?) pyroxene crystals. Some fresh labradorite ($Ab_{35}An_{65}$) phenocrysts up to 2 mm. in length are euhedral but others are appreciably rounded.

iii. A few inclusions are trachytic and they contain no phenocrysts. Laths of labradorite ($Ab_{47}An_{53}$) up to 0·2 mm. in length are present in a groundmass of crystals of epidote, chlorite and sparse iron ore.

The glassy matrix of a typical fragmental lava from Webb Island resembles that of the typical rock of southern Mount Liotard (p. 19), but it is a darker brownish green in colour. An estimated 10 per cent of the rock is formed by totally altered ferromagnesian phenocrysts which are often euhedral and may have been pyroxene originally. Leucoxene is associated with dustings and phenocrysts (up to 4 mm. across) of iron ore. Marginally embayed lithic inclusions characteristically contain closely set but very rounded small felsic crystals (? quartz) in a matrix of chlorite, and these enclose irregular rounded blebs of glassy material which is liberally dusted with tiny iron ore crystals.

A specimen of flow rhyolite (T.51.1) has a devitrified glassy groundmass which contains phenocrysts of iron ore, embayed plagioclase and altered pyroxene (Plate Vc). Very small ferromagnesian crystallites vary in concentration in different flow bands in the felsic matrix, in which iron ores (up to 0·3 mm. across) have crystallized out. An estimated 20 per cent of the rock is composed of albite-oligoclase

Table VII

CHEMICAL ANALYSES OF ROCKS FROM THE MOUNT LIOTARD SUCCESSION COMPARED WITH ANALYSES FROM OTHER LOCALITIES

	T.341.1	T.298.1	T.308.1	T.275.1	T.51.1	1	2	3	4	5	6	
SiO_2	52·35	52·99	53·92	58·21	69·16	54·25	48·50	51·22	52·21	69·36	70·41	SiO_2
TiO_2	0·99	0·82	0·66	1·60	0·85	1·76	2·00	3·32	1·16	tr	1·55	TiO_2
Al_2O_3	14·34	15·39	14·55	12·57	11·39	13·78	13·56	13·66	18·13	10·53	11·44	Al_2O_3
Fe_2O_3	5·34	2·82	4·31	2·99	2·03	3·27	6·59	2·84	3·60	2·99	2·45	Fe_2O_3
FeO	3·98	6·32	4·94	6·10	2·76	6·69	7·08	9·20	5·49	3·03	2·37	FeO
MnO	0·67	0·74	0·42	0·67	tr	0·74	n.d.	0·25	0·16	n.d.	n.d.	MnO
MgO	4·46	5·02	5·23	3·71	0·75	4·06	5·15	4·55	4·02	0·90	0·72	MgO
CaO	8·03	10·75	7·72	7·60	4·11	8·32	9·24	6·89	8·28	3·57	3·02	CaO
Na_2O	3·85	2·67	5·00	4·26	4·04	4·67	2·69	4·93	3·76	3·56	3·74	Na_2O
K_2O	1·44	0·75	0·69	0·51	3·12	0·56	0·89	0·75	0·91	3·15	2·88	K_2O
H_2O+	3·48	1·41	1·76	1·18	1·53	1·29	3·21	1·88	1·69	1·46	1·00	H_2O+
H_2O-	0·19	0·05	0·09	0·07	0·08	0·08	n.d.	n.d.	0·09	n.d.	0·31	H_2O-
P_2O_5	0·50	0·31	0·28	0·32	0·16	0·35	0·49	0·29	0·44	0·22	0·39	P_2O_5
CO_2	0·58	0·19	0·27	0·16	0·21	0·18	0·63	0·94	0·13	2·07	n.d.	CO_2
TOTAL	100·20	100·23	99·84	99·95	100·19	100·00	100·03	100·72	100·07	100·84	100·28	TOTAL
					ANALYSES LESS TOTAL WATER (Recalculated to 100)							
SiO_2	54·23	53·65	55·03	58·98	70·16	55·00	50·09	51·82	53·12	69·79	71·14	SiO_2
TiO_2	1·03	0·83	0·67	1·62	0·86	1·78	2·07	3·36	1·18	—	1·57	TiO_2
Al_2O_3	14·86	15·58	14·85	12·73	11·55	13·97	14·00	13·82	18·45	10·60	11·56	Al_2O_3
Fe_2O_3	5·53	2·86	4·40	3·03	2·06	3·32	6·81	2·87	3·66	3·01	2·48	Fe_2O_3
FeO	4·12	6·40	5·04	6·18	2·80	6·78	7·31	9·31	5·59	3·05	2·39	FeO
MnO	0·69	0·75	0·43	0·68	—	0·75	—	0·25	0·16	—	—	MnO
MgO	4·62	5·08	5·34	3·76	0·76	4·12	5·32	4·60	4·09	0·91	0·73	MgO
CaO	8·32	10·89	7·88	7·70	4·17	8·44	9·54	6·97	8·42	3·59	3·05	CaO
Na_2O	3·99	2·70	5·10	4·32	4·10	4·73	2·78	4·99	3·82	3·58	3·78	Na_2O
K_2O	1·49	0·76	0·70	0·52	3·17	0·57	0·92	0·76	0·93	3·17	2·91	K_2O
P_2O_5	0·52	0·31	0·29	0·32	0·16	0·36	0·51	0·30	0·45	0·22	0·39	P_2O_5
CO_2	0·60	0·19	0·27	0·16	0·21	0·18	0·65	0·95	0·13	2·08	—	CO_2
						NORMS						
Q	5·96	6·13	1·28	12·31	27·36	3·87	7·11	0·07	3·91	32·67	32·92	Q
or	8·81	4·49	4·14	3·07	18·73	3·37	5·44	4·49	5·50	18·73	17·16	or
ab	33·76	22·85	43·16	36·56	34·69	40·03	23·52	42·23	32·33	30·29	31·99	ab
an	18·24	28·15	15·56	13·81	3·75	15·20	23·01	13·07	30·45	3·22	5·98	an
di	12·61	18·56	16·04	17·48	7·88	19·04	13·50	11·15	6·14	—	3·92	di
wo	—	—	—	—	2·11	—	—	—	—	—	0·65	wo
hy	8·10	12·96	10·89	8·20	—	9·07	10·71	15·61	12·79	5·38	—	hy
mt	8·02	4·15	6·38	4·39	2·99	4·81	10·71	4·16	5·31	4·36	3·15	mt
il	1·96	1·58	1·27	3·07	1·63	3·38	3·93	6·38	2·24	—	2·98	il
hm	—	—	—	—	—	—	—	—	—	—	0·31	hm
ap	1·23	0·78	0·73	0·80	0·40	0·90	1·21	0·75	1·13	0·52	0·98	ap
cc	1·36	0·43	0·61	0·36	0·48	0·41	1·48	2·16	0·30	4·73	—	cc
C	—	—	—	—	—	—	—	—	—	0·09	—	C
					CATION PERCENTAGES							
Si^{+4}	25·35	25·08	25·72	27·57	32·80	25·71	23·42	24·22	24·83	32·62	33·26	Si^{+4}
Al^{+3}	7·86	8·25	7·86	6·74	6·11	7·39	7·41	7·31	9·76	5·61	6·12	Al^{+3}
Fe^{+3}	3·87	2·00	3·08	2·12	1·44	2·32	4·76	2·01	2·56	2·11	1·73	Fe^{+3}
Mg^{+2}	2·79	3·06	3·22	2·27	0·46	2·49	3·21	2·77	2·47	0·55	0·44	Mg^{+2}
Fe^{+2}	3·20	4·97	3·92	4·80	2·18	5·27	5·68	7·24	4·35	2·37	1·86	Fe^{+2}
Na^{+1}	2·96	2·00	3·78	3·20	3·04	3·51	2·06	3·70	2·83	2·66	2·80	Na^{+1}
Ca^{+2}	5·95	7·78	5·63	5·50	2·98	6·03	6·82	4·98	6·02	2·57	2·18	Ca^{+2}
K^{+1}	1·24	0·63	0·58	0·43	2·63	0·47	0·76	0·63	0·77	2·63	2·42	K^{+1}
Ti^{+4}	0·62	0·50	0·40	0·97	0·52	1·07	1·24	2·01	0·71	—	0·94	Ti^{+4}
Mn^{+2}	0·53	0·58	0·33	0·53	—	0·58	—	0·19	0·12	—	—	Mn^{+2}
P^{+5}	0·23	0·14	0·13	0·14	0·07	0·16	0·22	0·13	0·20	0·10	0·17	P^{+5}
O^{-2}	45·40	45·01	45·35	45·73	47·77	45·00	44·42	44·81	45·38	48·78	48·08	O^{-2}
Position $[(\frac{1}{3}Si+K)-(Ca+Mg)]$	+0·95	−1·85	+0·30	+1·85	+10·12	+0·52	−1·46	+0·95	+0·56	+10·38	+10·89	Position $[(\frac{1}{3}Si+K)-(Ca+Mg)]$
{ Fe	71·7	69·5	68·5	75·3	88·7	75·3	76·5	77·0	73·7	89·1	89·1	{ Fe
{ Mg	28·3	30·5	31·5	24·7	11·3	24·7	23·5	23·0	26·3	10·9	10·9	{ Mg
{ Fe	50·3	55·0	48·0	54·0	37·1	54·0	63·4	56·6	53·3	43·4	38·8	{ Fe
{ Mg	19·8	24·2	22·1	17·7	4·7	17·7	19·5	16·9	19·0	5·3	4·8	{ Mg
{ Alk	29·9	20·8	29·9	28·3	58·2	28·3	17·1	26·5	27·7	51·3	56·4	{ Alk
{ Ca	58·6	74·7	56·4	60·2	34·5	60·2	70·7	53·5	62·6	32·7	29·5	{ Ca
{ Na	29·2	19·2	37·8	35·1	35·1	35·1	21·4	39·7	29·4	33·8	37·8	{ Na
{ K	12·2	6·1	5·8	4·7	30·4	4·7	7·9	6·8	8·0	33·5	32·7	{ K

T.341.1 Andesite with many essential lithic inclusions, southern Mount Liotard, Adelaide Island (anal. G. J. Dewar).
T.298.1 Basalt, south-western Mount Bouvier, Adelaide Island (anal. G. J. Dewar).
T.308.1 Albitized quench-breccia, upper southern Mount Bouvier, Adelaide Island (anal. G. J. Dewar).
T.275.1 Quench-breccia, western coast of Stonehouse Bay, Adelaide Island (anal. G. J. Dewar).
T.51.1 Devitrified rhyolite, Webb Island (anal. G. J. Dewar).
1 Analysis of specimen T.275.1 recalculated to give a silica percentage similar to that of other fragmental rocks from the Mount Liotard succession (T.298.1, 308.1, 341.1).
2 Quartz-dolerite, Hound Point, Dalmeny, Scotland (Day, 1928).
3 Average of 19 analyses of spilites (Sundius, 1930).
4 Average of three analyses of post-Andean microdiorite dykes, Argentine Islands (Elliot, 1964).
5 Segregation vein in quartz-dolerite (Day, 1928).
6 Spherulitic rhyolite (flow lava), Antsenavolo, Madagascar (Lacroix, 1913).

phenocrysts which are flecked by epidote, rare calcite, (?) potassium feldspar and iron ore crystals. Free iron ore phenocrysts (up to 1 mm. across) have been partially altered to haematite. Very small lithic fragments comprise an estimated 5 per cent of the rock; most of them are of green or brown glass, though some have devitrified to ferromagnesian microlites and tiny feldspar laths. Other lithic fragments are very finely trachytic and they contain oligoclase microlites in a glassy groundmass speckled by extremely fine-grained ferromagnesian segregations.

D. Geochemistry of Some Rocks of the Mount Liotard Succession

The dark colours and the high ferromagnesian mineral content of the fragmental rocks of the Mount Liotard succession are more typical of calcic rocks than of ones containing sodic plagioclase. Many of them contain oligoclase or albite (p. 18, 20). The textures of the quench-brecciated lavas (p. 10) seem to show that they were erupted under water, although structures definitely recognizable as pillows have not been found. The presence of sodic plagioclase suggests that their eruption was submarine and this has been confirmed by the chemical analyses of specimens of fragmental lava. In all, five specimens of rocks from the Mount Liotard succession have been chemically analysed (Table VII).

1. *Quench-breccias and associated basalt*

Although no completely fresh specimens were taken from the dark brecciated lavas of the Mount Liotard succession, three have been analysed for comparison with the unbrecciated basalt of station T.298 (p. 20). The basalt, modally the most calcic of the rocks in this succession, should most closely resemble the parent magma from which these rocks were derived. For comparison, the average of three analyses of microdiorite dykes from the Argentine Islands (Elliot, 1964) is given in Table VII (analysis 1). These dykes intrude volcanic rocks assigned to the Upper Jurassic period (as are the volcanic rocks of Adelaide Island), and they are thought to have been feeders of higher strata in the succession of volcanic rocks. They are considered to be of a composition close to that of the parental magma of the volcanic rocks (Adie, 1964).

The basalt at station T.298 is more calcic than the average microdiorite of the Argentine Islands. It contains normative labradorite ($Ab_{45}An_{55}$) and less potassium feldspar than this average microdiorite, which contains normative andesine ($Ab_{51}An_{49}$). When plotted on triangular variation diagrams ($Fe''+Fe'''$)—Mg—Alk and Ca—Na—K (Fig. 9), the basalt is close to the distribution curves of the Upper Jurassic Volcanic Group of Graham Land (Adie, 1964). The basalt may be even closer than the average microdiorite of the Argentine Islands to the parent magma of these extrusive rocks, because the average microdiorite is relatively distant from the Ca—Na—K distribution curve.

Of the quench-breccias which have been analysed, specimen T.341.1 (a lava containing lithic fragments and sodic plagioclase; p. 19) is normatively andesitic and is close to the distribution curves of the Upper Jurassic Volcanic Group of Graham Land. It could be a normal product of differentiation of the basalt. Specimens T.275.1 and 308.1 (quench-breccias containing modal labradorite and albite-oligoclase respectively; p. 22, 20) plot close together on triangular variation diagrams (Fig. 9) and, although they plot close to the average microdiorite of the Argentine Islands on the ($Fe''+Fe'''$)—Mg—Alk diagram, they are well on the Na side of the distribution curve typical of the Upper Jurassic volcanic rocks on the Ca—Na—K diagram. These two rocks have spilitic affinities and plot close to the position of the average world spilite (Sundius, 1930; Table VII, analysis 2). They are well within the field of differentiation of the calcic spilites (Battey, 1956) in the Ca—Na—K diagram and they plot close to the spilitic distribution curve (Battey, 1956) in the ($Fe''+Fe'''$)—Mg—Alk diagram. This curve is approximately coincident with that typical of the Upper Jurassic Volcanic Group (Fig. 9).

The two analyses of spilitic rocks from Adelaide Island differ in detail from those of typical spilites. Sundius (1930) emphasized that a high Fe''/Fe''' ratio and a comparatively high content of titania are characteristic of spilites, but neither is noticeable in the rocks from Adelaide Island. The absence of these characters is shown by several analyses of spilites from other areas, e.g. Tasmania (Scott, 1951) and Oregon (Gilluly, 1935*a*, *b*), where the spilites are, however, undersaturated. Both characters are shown to a certain extent by the average microdiorite of the Argentine Islands and this rock plots only just outside the field of the calcic spilites (Battey, 1956) in the Ca—Na—K triangular variation diagram (Fig. 9).

The silica contents of the breccias and the basalt are very similar (between 53 and 55 per cent) except for specimen T.275.1, in which nearly 59 per cent of silica is present. (These figures are taken from the water-free analyses recalculated to 100 per cent (Table VII).) In specimen T.275.1 most other constituents are correspondingly low, and after recalculation to 100 per cent with silica reduced to 55 per cent the analysis (Table VII, analysis 3) corresponds closely to that of the other analysed spilite (T.308.1). Specimen T.275.1 is believed to contain additional silica, which may have been introduced metasomatically, as in the quartz-clinopyroxene-granulites of Bond Nunatak (p. 20) and Mount Vélain (p. 30), or it may represent detrital quartz grains incorporated during the "sedimentary" deposition of the quench-breccia.

The spilitic character of two analysed quench-breccias from Adelaide Island is believed to show clearly that they were extruded in a submarine environment. This is consistent with the origin postulated on the evidence of their field occurrences, textures and mineral contents (p. 10). The conglomeratic sediments which crop out above and below the Mount Liotard succession (Table II) are therefore probably of a shallow-water marine facies.

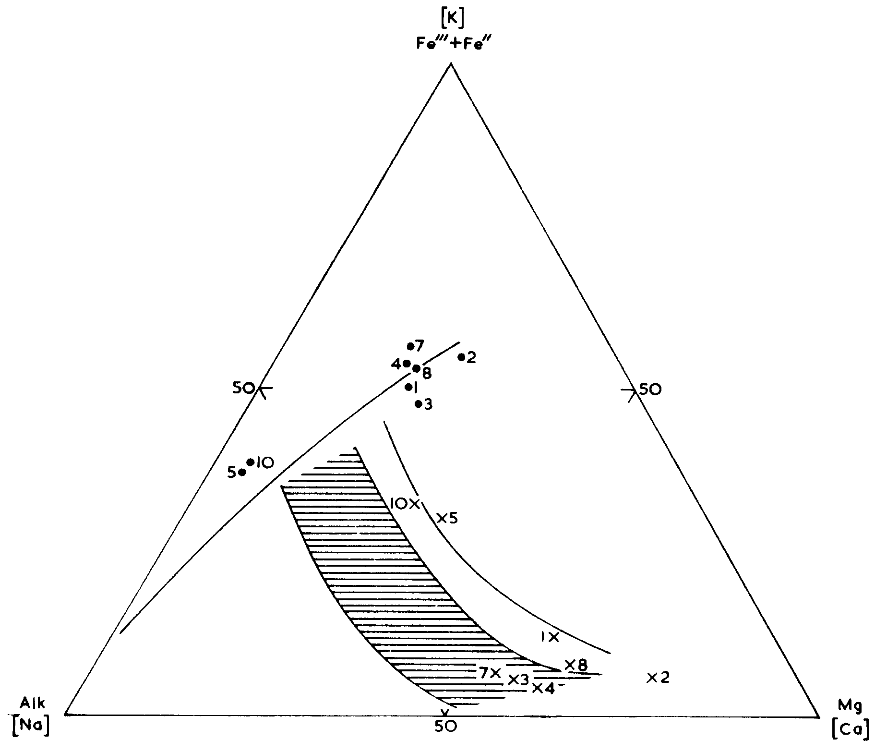

FIGURE 9

Triangular variation diagrams for chemical analyses (Table VII) plotted on the co-ordinates (Fe″+Fe‴)—Mg—Alk (●) and Ca—Na—K (×). The variation curves are those suggested by Adie (1964, fig. 2) as typical of the Upper Jurassic Volcanic Group of Graham Land. The shaded field is that of the calcic spilites on the Ca—Na—K diagram (Battey, 1956, fig. 3).

1. Andesite with many essential lithic inclusions (T.341.1; Table VII).
2. Basalt (T.298.1; Table VII).
3. Albitized quench-breccia (T. 308.1; Table VII).
4. Quench-breccia (T.275.1; Table VII).
5. Devitrified rhyolite (T.51.1; Table VII).
7. Average of 19 analyses of spilites (Table VII, analysis 3).
8. Average of three analyses of post-Andean microdiorite dykes (Table VII, analysis 4).
10. Spherulitic rhyolite (Table VII, analysis 6).

2. *Devitrified rhyolite*

A specimen (T.51.1) from the devitrified rhyolites of Sighing Peak and Webb Island (p. 22) differs noticeably in composition from the other analysed rocks of the Mount Liotard succession (Table VII). It contains normative albite-oligoclase. Lavas of a similar composition are not common but a rhyolitic lava flow from Madagascar (Table VII, analysis 4) is nearly identical.

This rhyolite may be a product of extreme differentiation of the basaltic parent magma of the extrusive rocks of the Upper Jurassic Volcanic Group. Its composition resembles those of typical tholeiitic pegmatoid segregations (Kennedy, 1933) of the type found as veins and pockets in the upper parts of minor and major basaltic intrusions. These pegmatoid segregations have been shown to be extreme differentiates of the calcic host rock (see references in, for instance, McDougall (1962)). The analyses of a quartz-dolerite sill and an enclosed segregation from Hound Point, Dalmeny (Day, 1928) are given in Table VII (analyses 5 and 6) for comparison. There is a marked similarity between the segregation and the Adelaide Island rhyolite. The similarity between the Dalmeny tholeiite and the basalt from station T.298 is less well marked in the analyses, but it is clear from their positions on the triangular variation diagrams (Fe″ + Fe‴)—Mg—Alk and Ca—Na—K (Fig. 10). The tie-lines between the two rocks from Dalmeny are sub-parallel to those joining the Adelaide Island rhyolite and the basalt, which is believed (p. 23) to be close in composition to the parent magma of the Adelaide Island volcanic rocks. It is suggested that the rhyolite was derived from a magma similar to the basalt from station T.298 by magmatic differentiation analogous to that shown to have occurred in the rocks of Dalmeny (Day, 1928).

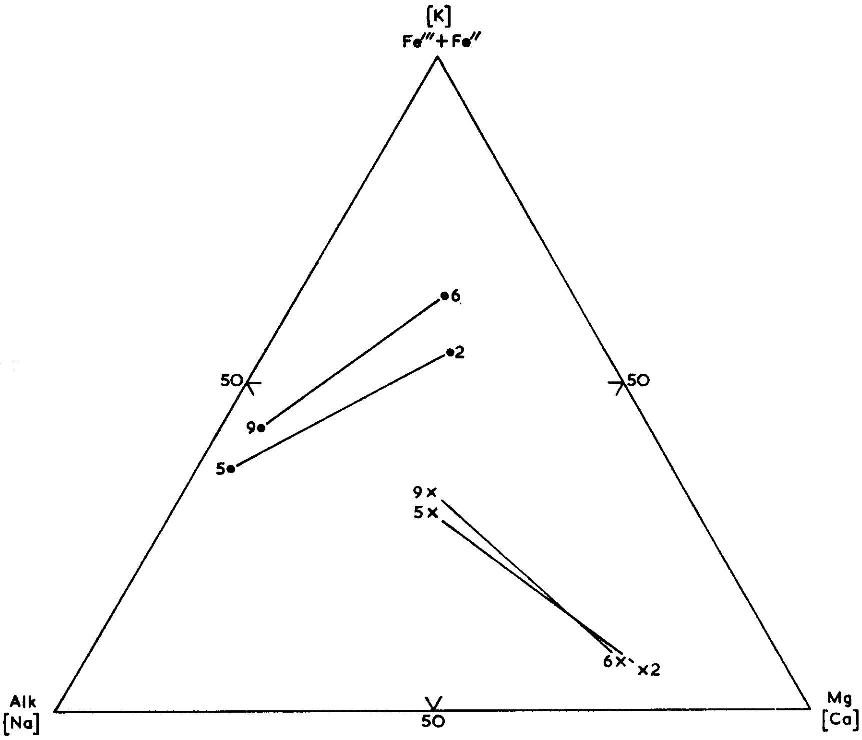

FIGURE 10

Triangular variation diagrams for chemical analyses (Table VII) plotted on the co-ordinates (Fe″+Fe‴)—Mg—Alk (●) and Ca—Na—K (×).

2. Basalt (T.298.1; Table VII).
5. Devitrified rhyolite (T.51.1; Table VII).
6. Quartz-dolerite of Dalmeny (Table VII, analysis 2).
9. Segregation vein in quartz-dolerite of Dalmeny (Table VII, analysis 5).

Tie-lines joining rocks from the same area are sub-parallel, suggesting that the two silicic rocks may have similar origins.

3. *Nature of the parent magma*

The parental magma of the volcanic rocks of Adelaide Island is thought to have been a tholeiitic basalt. Turner and Verhoogen (1960) have considered that rocks of the spilite—keratophyre association may be derived from a basaltic magma by any of a number of petrogenetic processes; these include magmatic differentiation, assimilation of sodium-rich rocks and the action of sodium-rich liquids. These liquids may be late magmatic differentiates, derived from juvenile or connate sources, or derived from sea-water. Battey (1956) has shown that the differentiation trends of the spilite—keratophyre suite differ only slightly and in a predictable fashion from those of the tholeiitic rocks, and he believed that the spilite—keratophyre differentiation series is genetically connected with the tholeiites. The highly silicic nature of the rhyolite from station T.51 indicates (Kennedy, 1933) that it was derived from a tholeiitic magma.

E. Mount Bouvier Summit Succession

The Mount Bouvier summit succession is well stratified and it is predominantly composed of sedimentary rocks like the Sloman Glacier succession. Only the bottom of the succession has been examined, on southern Mount Bouvier (Figs. 7C and 8C) where about 2,000 ft. (610 m.) are exposed. There is a gradual transition upwards from the dark massive rocks of the Mount Liotard succession (T.308; p. 19) through about 250 ft. (76 m.) to clastic materials (T.309). At station T.309, horizontal well-stratified andesitic tuffites, in which individual well-sorted beds may be as thin as 1 in. (2·5 cm.), vary from tuffaceous sandstones to lapilli-tuffs. The overlying strata have not been examined directly but talus blocks which have fallen from higher exposures are mostly of sedimentary rocks. Many of these boulders are volcanic conglomerates and conglomerates which have a high content of boulders of plutonic rocks. Conglomerates containing many plutonic rocks have not been found in the Sloman Glacier succession and it is thought that such conglomerates found at lower levels have been down-faulted into place from the Mount Bouvier summit succession. Similarly stratified rocks crop out above the Mount Liotard succession high on southern Mount Liotard and northern Mount Ditte (p. 18). Sediments which may overlie the Mount Liotard succession have been examined at McCallum Pass (T.242; p. 21) but this area has probably been faulted and the stratigraphy is not completely clear.

F. Down-faulted Conglomeratic Successions and Other Uncorrelated Rocks

1. *Down-faulted conglomeratic successions*

Conglomerates exposed in four accessible localities on the mountain walls contain an abundance of boulders of plutonic rocks, usually in a matrix of smaller volcanic rock fragments. The rocks in all four localities must have been faulted into place, because rocks of quite different appearances crop out on adjacent exposures. These conglomerates have not been found in the Sloman Glacier succession, and the rocks of the examined exposures are believed to have been faulted down from the Mount Bouvier summit succession by the block-faults which trend along the mountain walls and which are thought to have elevated the mountains relative to the surrounding terrain (Dewar, 1967). Though the Mount Bouvier summit succession has not been thoroughly examined because it is usually inaccessible, it is known to include beds of conglomerate which contain boulders of plutonic rocks since such conglomerate has been found in talus blocks below exposures of the succession (see above). The four localities where these conglomerates have been examined are:

i. North-western Mount Bouvier (T.292; Figs. 2 and 3).
ii. Eastern Mount Mangin (T.280; Figs. 4 and 5).
iii. South-western Mount Liotard (T.226; Figs. 4 and 5).
iv. Eastern Mount Liotard (T.262–265) and the Léonie Islands (T.127–138; Figs. 4 and 5).

Inclusions of plutonic rocks are rare and small in the volcanic conglomerates of the Sloman Glacier succession. In the conglomerates of the down-faulted localities, they are very common, large and well rounded. The largest boulder found in the down-faulted conglomerates was 6 ft. (1·8 m.) across (T.262). Boulders of granodiorite, tonalite and diorite are common and a few are of gabbroic and metamorphic rocks.

The two exposures of these conglomerates on the western side of the mountains are small. Tuffites of the Mount Liotard succession crop out at small exposures on the north-western ridge of Mount Bouvier (p. 19) but on the largest of the group of outcrops about 300 ft. (91·4 m.) of conglomerate intruded by tonalite are exposed (T.292; Fig. 6 (C–D)). The very coarse conglomerate, in which no bedding is visible, contains perfectly rounded boulders of granodiorite (Plate IIb) up to 4 ft. (1·2 m.) across. The matrix of the conglomerate is a dark crystal-tuff breccia containing small, rather angular fragments of volcanic rocks. On south-western Mount Liotard, the Sloman Glacier succession crops out below the Mount Liotard formation and it includes some volcanic conglomerates (p. 12), but the exposure at station T.226 is formed by conglomerates containing plutonic rock boulders which are not found in the conglomerates of the Sloman Glacier succession (Fig. 6 (A–B)). The fault which has brought the foreign conglomerates into position dips at 80° towards 250° mag. and it is well exposed; a post-Andean mafic dyke has been intruded along it. The conglomerates containing boulders of plutonic rocks are the predominant strata in a succession (about 350 ft. (107 m.) of which are exposed) in which there are also dark thin-bedded tuffites and pale crystal tuffites.

The largest exposures of the down-faulted conglomerates are on eastern Mount Mangin and eastern Mount Liotard, where rocks that have not been faulted include volcanic conglomerates of the Sloman Glacier succession. The foreign conglomerates crop out at the eastern end of the main eastern ridge of Mount Mangin, on the easternmost buttress of Mount Liotard, and on some of the Léonie Islands. About 1,850 ft. (565 m.) of the faulted strata are exposed on the steep cliffs of eastern Mount Liotard, where thick beds of the conglomerates containing numerous boulders of plutonic rocks are interstratified with finer-grained sedimentary and volcaniclastic rocks, the finest of which are siltstones. The faults which have moved these rocks into position are not well exposed on eastern Mount Mangin, where the down-faulted conglomerates are exposed next to the equally well-bedded Sloman Glacier succession, but they have been accurately identified on eastern Mount Liotard where the adjacent outcrops are rocks of the Mount Liotard succession (Fig. 6 (F–H)).

In contrast to the well-bedded conglomerates and other sediments exposed at low levels on the eastern walls of Mount Liotard, the conglomerates exposed on many of the Léonie Islands are massive and unbedded. The apparent lack of bedding may be caused by the small stratigraphic thicknesses exposed; the beds are horizontal and most of the islands are not high, though stratified rocks crop out on Léonie Island up to 320 ft. (97·5 m.) a.s.l. (Figs. 7F and 8F). At station T.137, on one of the southernmost islands of the group, a conglomerate is cemented by pilotaxitic andesite. This cementation of a conglomerate by a flow lava is unusual in the Adelaide Island area but it has been described by Adie (1953) from Pourquoi Pas Island, eastern Laubeuf Fjord, where sedimentary conglomerates have not been found. Because the conglomerates of the Léonie Islands appear to belong to a different horizon from those cropping out at sea-level on eastern Mount Liotard, a fault is believed to be present between the Léonie Islands and Adelaide Island (Fig. 5).

An example (T.137.1) of the rare schistose silicic boulders found in the sedimentary conglomerates contains wisps and lenticular patches of plicated biotite concentrated along schistosity planes (Plate Vd). Most of the rock is a mosaic of round crystals of unstrained quartz up to 1·8 mm. across set in a groundmass of potassium feldspar crystals of similar size or, very rarely, in a groundmass of sericitized andesine ($Ab_{55}An_{45}$) crystals. This rock appears to be a biotite-schist which has been granitized or feldspathized by a process which destroyed signs of strain in the quartz crystals and introduced the potassium feldspar.

The tonalite which forms one of the boulders (T.137.4) has an interstitial texture. The quartz (28·7 per cent) is slightly strained, has a purple tinge in the hand specimen and a tendency to crystallize in aggregates. Concentric trails of tiny inclusions in andesine ($Ab_{68}An_{32}$) phenocrysts emphasize their zoning to peripheral albite-oligoclase. Some plagioclase is myrmekitic and other crystals contain microperthitic potassium feldspar. Relatively insignificant interstitial potassium feldspar has corroded the sutures between quartz and plagioclase crystals. The rock contains 44·9 per cent of plagioclase and 3·9 per cent of potassium feldspar. Rare crystals of biotite (6 per cent) are liberally dusted with iron ore and have cleavages which are rather plicated. 7·7 per cent of iron ore is present, the remaining minerals being chloritic alteration products. The same minerals are present in darker-coloured plutonic boulders of rather finer grain-size in the same specimen.

2. *Eastern Mount Bouvier and Mount Reeves*

Stratified rocks crop out along the eastern main walls of Mount Bouvier in a belt trending north–south, between Andean plutons on western Mount Bouvier and Barlas Channel (Figs. 2 and 3). At 3,000–3,500 ft. (914–1,066 m.) a.s.l. (aircraft altimeter), the fairly thick well-marked beds include some conglomerates, washed volcanic breccias and tuffites; the dip overall is very low and towards the south-east. North of east central Mount Bouvier, this belt trends north-east to south-west over the divide between Mount Reeves and Mount Bodys; it is 2 miles (3·2 km.) wide at its narrowest. The dips increase northwards. The western contact of the belt crosses the coast at Landauer Point but the stratified rocks do not crop out as far north as northern Hansen Island (Goldring, 1962, p. 39). The stratified rocks exposed on Mount Bodys appear to belong the the Mount Liotard succession. Stratified rocks are exposed on two isolated coastal nunataks north and south of Mothes Point, but their stratigraphic relationships are rather obscure.

i. On the southern nunatak, thick conglomerate beds contain conspicuous pale-weathering rounded lithic fragments. They have not been directly examined.

ii. Andesitic lavas crop out on the peninsula north of Mothes Point (T.148, 149). Some contain sub-rounded cognate or accessory-cognate lithic fragments and also unusually large plagioclase phenocrysts up to 8 mm. in length. Relatively thin black tuffaceous breccia beds are up to 2 ft. (0·6 m.) thick. Epidote has been deposited along shatter zones which follow joints dipping at 70° towards 340° mag.

It is thought that the disturbed rocks at these two nunataks are roof pendants or rafts of stratified rocks in the surrounding heterogeneous intrusion, which is exposed at Hunt Point, Mothes Point and on southern Mount Bodys (p. 38).

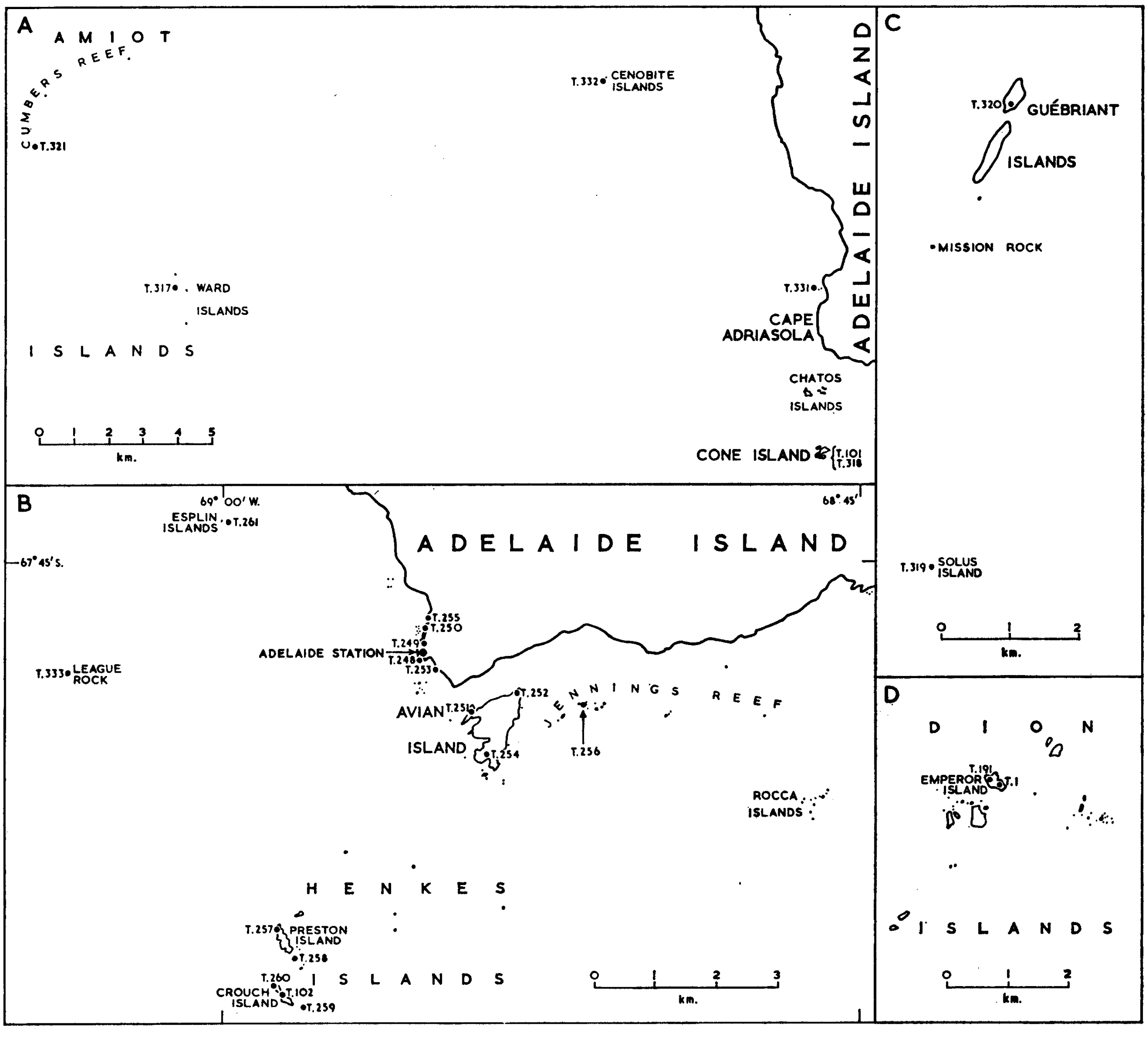

FIGURE 11

Detailed sketch maps showing the positions of geological stations on islands and exposures near the south-western coast of Adelaide Island (see Fig. 1).

A. Cape Adriasola and nearby islands.
B. Adelaide scientific station and nearby islands.
C. Guébriant Islands and Solus Island.
D. Dion Islands.

3. *Mount Vélain and Visser Hill*

Massive thickly bedded stratified rocks crop out on the western side of Mount Vélain (Figs. 7A and 8A). Massive dark andesitic lava is the sole rock exposed at the northern end of the mountain (T.24–28), but towards the south similar lavas which tend to be brecciated are interbedded with thick beds of sandy lapillistones, more coarsely porphyritic lavas and rare thin fine-grained beds (T.17–23). Massive bedding in inaccessible dark rocks on the eastern side of the mountain is visible only in the north-east (p. 3). Many of these exposures are conspicuously stained by limonite. At stations T.19 and 20, pale-weathering silicic dykes have permeated into and metamorphosed the country rocks, altering the fragmental lavas until lithic inclusions are a pale cream colour and the matrix is light green (cf. northern Bond Nunatak; p. 19). The alteration is concentrated around the faces of joints, which are covered in places by magnetite with a superficial coating of haematite. Druses of specular haematite are present in one of the dykes (T.19.3). On small exposures at Visser Hill (T.22; Figs. 7D and 8D), grey-weathering fine-grained beds alternate

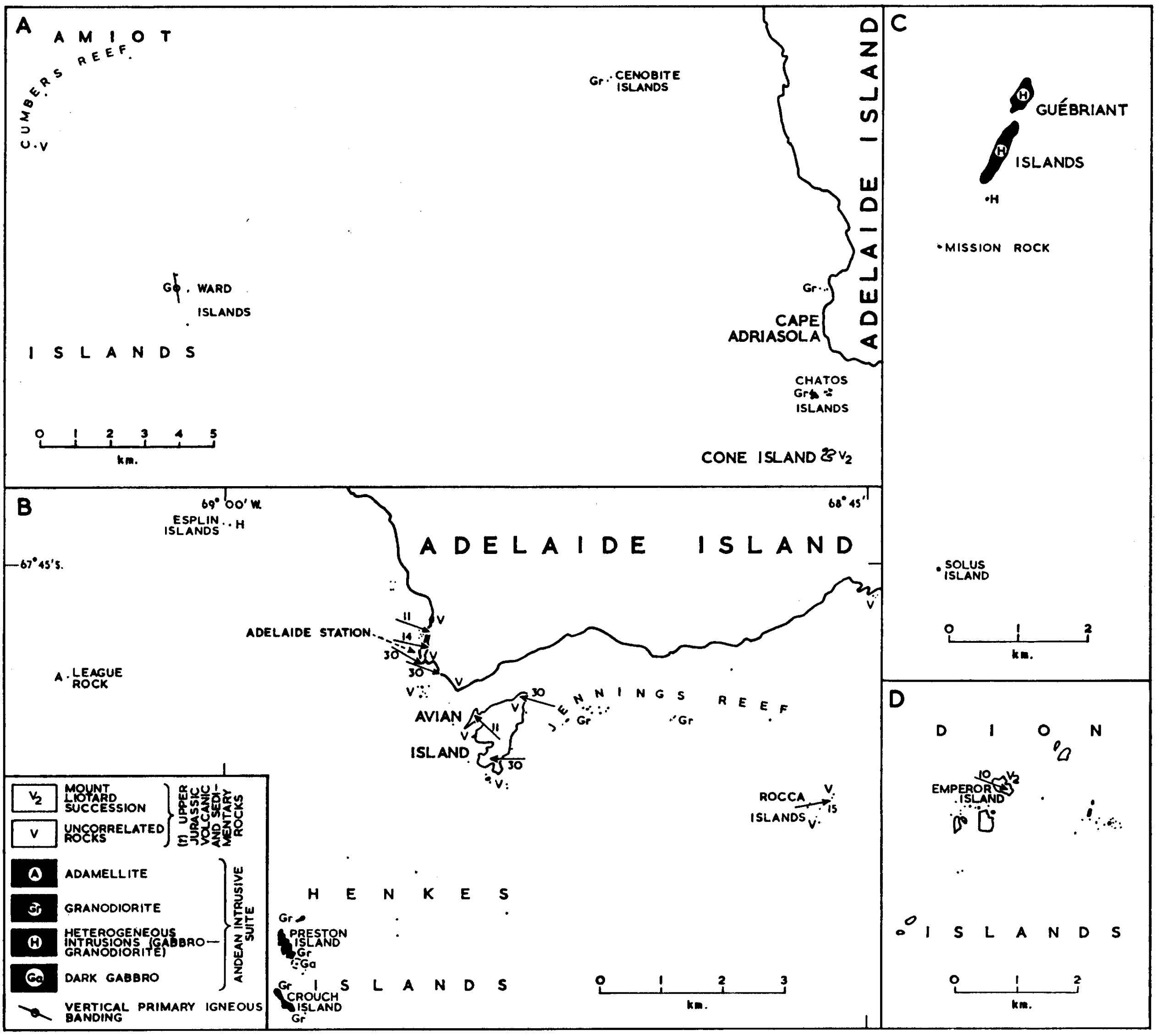

FIGURE 12

Detailed geological sketch maps of the areas shown in Fig. 11 (see Fig. 1).

A. Cape Adriasola and nearby islands.
B. Adelaide scientific station and nearby islands.
C. Guébriant Islands and Solus Island.
D. Dion Islands.

with sandy volcanic cobble-conglomerates and gravelstones. These alternations are up to 20 ft. (6·1 m.) thick.

An irresolvable groundmass encloses very small sparse flow-orientated laths of oligoclase in a rock from northern Mount Vélain (T.28·1); vesicles and cracks contain chloritized (?) biotite, often within an outer rim of quartz. Silicic dykes intruding fragmental lavas of the normal type (cf. Mount Liotard type; p. 19) have altered them to holocrystalline quartz-epidote-granulites, in which former lithic fragments have been altered to quartzites containing relatively coarse andesine crystals (cf. pyroxene-granulites; p. 20); the epidote has probably replaced porphyroblastic amphibole or pyroxene.

4. *Exposures around south-western Adelaide Island*

Cone Island (T.318; Figs. 11A and 12A) is composed of a dark rock of the Mount Liotard succession. The massive andesitic rock which crops out at the summit, 147 ft. (44·8 m.) a.s.l., is the matrix surrounding rounded accessory-cognate lithic fragments near sea-level. The islet of the hydrographic survey station on Cumbers Reef (T.321; Figs. 11A and 12A) is composed of pale green, finely banded, very fine-grained (?) lava. At the Adelaide scientific station (T.248–250, 253, 255; Figs. 11B and 12B), feldspathic tuffaceous gravelstones are similar to the massive porphyritic lava of Lagoon Island (p. 16). They are obscurely colour-banded, because different horizons contain different amounts of angular, dark fine-grained inclusions. Fine-grained beds have more easily distinguishable banding and are water-laid tuffs. This assemblage, dipping at 20° towards 090° mag., forms a synclinal structure with similar rocks exposed on Avian Island (T.251, 252, 254) to the south-east, where the average dip is 20° towards 270° mag. On the Rocca Islands (Figs. 11B and 12B) and the Ginger Islands (T.359; Figs. 2 and 3), dark volcanic rocks are more massive than those of the nearest correlated exposures (Cape Alexandra; p. 15). Though conspicuous narrow bedding is visible on the largest of the Ginger Islands, nearby islets are composed of completely massive rock. Massive breccias and interbedded thin tuffites crop out on the Rocca Islands. Dark lava cropping out on Emperor Island (T.1, 191; Figs. 11D and 12D), the largest of the Dion Islands, is indistinguishable from the lava of the Mikkelsen Islands (p. 16).

IV. ANDEAN INTRUSIVE SUITE

THOUGH there are numerous exposures in the Adelaide Island area of the stratified volcanic and sedimentary rocks, there are at least as many of plutonic rocks which have intruded the stratified rocks. These plutonic rocks range from olivine-bearing gabbros to adamellites. The intrusions are of all sizes from masses over 20 miles (32 km.) in length to dykes and veins a few inches in width. These rocks belong to the Andean Intrusive Suite (Adie, 1955). Some plutons appear to be homogeneous, but in heterogeneous intrusions without overt internal contacts the rocks vary considerably in both hand specimen and the minerals they contain. Where intrusions of these rocks are in contact with one another the transgressing rock is always the more silicic. All facies of the plutonic rocks appear to have been intruded very gently into the country rocks, which are often no more than slightly thermally metamorphosed at the contacts that are almost always very sharp. Only the most mafic plutonic rocks exhibit small-scale internal variations such as banding and orbicular structure. The commonest of the intrusions are of the heterogeneous type described above. Diorites are not common and this is unusual in Graham Land (Adie, 1955). All the rocks which contain essential potassium feldspar also contain essential quartz. Many of the specimens examined are granodiorites which contain gabbroic minerals such as labradorite and pyroxenes, and these rocks are typical of the heterogeneous intrusions.

Xenoliths of stratified rocks have been observed in all facies of the Andean intrusive rocks, but they appear to be rare in the dark gabbros in which the typically dark though fine-grained inclusions are probably often masked by the dark colours of the rocks. Most of the xenoliths have sharp margins even where they have been rounded by assimilation. Intrusion breccias, in which over 50 per cent of the rock is xenolithic, are common especially in the heterogeneous intrusions, not only close to pluton margins but also where no contact is nearby. Where one plutonic rock has been intruded by another, the later rock only rarely contains xenoliths of the earlier, though it may locally be filled with inclusions of the stratified country rocks.

Adie (1955) estimated the age of the Andean Intrusive Suite of Graham Land by comparing it with similar rocks in Patagonia. Because the Patagonian plutons displace Upper Cretaceous but not Tertiary

Table VIII

MODAL ANALYSES OF ANDEAN INTRUSIVE ROCKS

	Dark gabbros					*Rocks of heterogeneous intrusions*																			*Quartz-diorites, granodiorites and adamellites*										
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Quartz	—	—	—	0·3	—	—	17·2	17·7	7·4	7·4	9·5	7·6	—	—	14·6	9·9	12·3	10·7	—	19·6	1·2	7·6	11·5	9·6	19·9	31·0	26·3	20·9	17·6	21·9	10·1	30·6	28·3	23·2	25·
Potassium feldspar	—	—	—	—	—	—	—	11·2	2·1	3·0	4·1	1·1	—	—	5·7	9·3	9·7	3·1	—	13·6	—	1·2	17·1	4·4	3·0	4·1	21·3	7·6	14·1	36·1	8·4	22·7‡	33·6‡	10·8	38·
Plagioclase	33·9	72·7	98·9	76·1	54·3	63·7	63·9	48·4	68·0	67·5	55·8	67·3	71·6	71·0	57·3	55·2	59·4	68·1	63·6	52·6	71·7	65·8	55·9	60·5	53·1	51·1	47·6	58·4	47·7	32·9	64·9	45·2	36·8	52·1	32·
Clinopyroxene	3·4†	23·6	0·1	7·3	8·6	10·1	—	—	3·8	1·8	8·4	0·4	21·4	7·9	—	1·4	1·2	—	5·2	0·7	5·7	2·9	1·4	1·4	—	—	—	—	1·3	—	5·4	—	—	—	—
Hypersthene	—	—	—	4·0	11·4	—	—	—	2·7	1·4	2·9	—	3·1	—	—	—	—	—	4·1	—	3·2	3·6	—	—	—	—	—	—	—	—	—	—	—	—	—
Amphiboles	47·6†	0·7	0·3	4·1	5·1	14·4	5·0	6·4	7·6	9·3	7·9	14·4	—	10·1	5·8	15·2	10·5	3·7	23·3	6·1	8·8	7·7	6·9	9·8	14·0	1·3	—	7·4	10·0	4·8	2·1	—	—	7·9	1·
Olivine	5·6†	*	0·6	—	1·3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Biotite	—	—	—	3·2	4·8	—	—	—	5·2	3·2	7·5	4·6	0·2	—	—	7·3	2·1	—	0·8	4·7	2·2	8·0	4·6	12·5	3·7	—	—	3·4	0·8	1·9	—	—	0·2	4·1	1·
Iron ores	3·1	1·1	0·1	4·1	4·2	10·1	2·8	1·1	1·3	2·3	2·7	1·8	1·1	1·3	2·5	1·4	2·9	2·6	2·3	1·3	3·6	2·2	—	1·6	2·2	1·1	0·8	1·4	2·2	0·7	2·4	0·8	0·7	1·2	0·
Apatite	—	—	—	—	—	*	—	0·4	1·0	0·2	0·4	0·6	—	0·1	0·1	0·2	0·2	0·9	0·1	0·1	0·2	0·7	0·6	0·1	*	*	—	0·1	0·1	*	*	—	*	*	*
Sphene	—	—	—	—	—	—	—	—	0·1	—	—	—	—	—	—	—	0·2	—	—	—	—	—	—	0·1	0·1	—	—	—	—	—	—	—	—	—	—
Epidote	—	—	—	—	—	—	0·8	1·5	0·2	0·3	—	0·4	0·2	0·2	—	—	—	0·9	—	0·3	—	—	—	—	1·1	1·0	0·3	0·4	1·2	1·1	—	0·1	—	—	*
Chlorite	6·4	1·9	—	—	6·0	1·7	10·2	9·8	0·5	3·5	0·7	1·8	2·3	9·3	7·1	—	1·5	8·3	0·5	1·0	3·3	0·3	—	—	2·8	10·0	3·7	0·6	4·8	0·7	6·7	0·6	0·2	0·8	0·
Calcite	—	—	—	—	—	—	—	3·6	—	—	—	—	—	—	6·9	—	—	1·5	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Accessory minerals	—	—	—	0·7	4·3‖	—	—	—	0·1§	—	0·1§	—	—	—	—	—	—	—	—	*	*	—	0·4	—	0·1	0·3	*	—	0·3	—	—	—	0·2§	—	0·
Plagioclase composition — *Groundmass* — *Core*	An_{66}	An_{88}	An_{88}	An_{57}	An_{79}	An_{66}	An_{50}	An_{64}	An_{37}	An_{49}	An_{55}	An_{49}	An_{68}	An_{64}	An_{58}	An_{51}	An_{58}	An_{52}	An_{65}	An_{40}	An_{58}	An_{52}	An_{54}	An_{55}	An_{33}	An_{48}	An_{30}	An_{46}	An_{35}	An_{40}	An_{59}	An_{33}	An_{34}	An_{40}	An_{2}
Plagioclase composition — *Groundmass* — *Rim*	An_{66}	An_{88}	An_{88}	An_{40}	An_{58}	An_{63}	An_{40}	An_{20}	An_{20}	An_{20}	An_{20}	An_{43}	An_{20}	An_{49}	An_{20}	An_{23}	An_{20}	An_{20}	An_{53}	An_{20}	An_{54}	An_{43}	An_{20}	An_{30}	An_{20}	An_{14}	An_{14}	An_{18}	An_{19}	An_{20}	An_{20}	An_{10}	An_{20}	An_{20}	An_{1}
Plagioclase composition — *Groundmass* — *Zoning*	—	—	—	n	n	o	o	o	o	n	n	n	o	n	o	n	n	o	n	n	o	o	n	o	o	o	o	o	n	n	n	o	o	o	n
Plagioclase composition — *Phenocrysts* — *Core*						An_{88}				An_{59}	An_{55}				An_{58}			An_{65}		An_{56}	An_{62}								An_{48}		An_{65}				
Plagioclase composition — *Phenocrysts* — *Rim*						An_{63}				An_{20}	An_{20}				An_{20}			An_{20}		An_{20}	An_{54}								An_{12}		An_{20}				
Plagioclase composition — *Phenocrysts* — *Zoning*						o				o	n				o			o		n	o								o		o				

* Present.
† Partially altered to chlorite.
‡ Perthitic.
§ Schorlite.
‖ Predominantly talc.
n Normal zoning.
o Oscillatory zoning.

1. T.129.1 Dark gabbro, Léonie Island.
2. T.139.1A Gabbro (main phase), Brockhamp Islands.
3. T.139.1B Felsic band in gabbro, Brockhamp Islands.
4. T.216.1 Dark gabbro, Jenny Island.
5. T.244.1 Dark gabbro, west of McCallum Pass.
6. T.16.1 Gabbro, Blümcke Knoll.
7. T.37.1 Tonalite, Limpet Island.
8. T.56.1 Granodiorite, Mothes Point.
9. T.60.1 Diorite, islet east of Sorge Island.
10. T.61.1 Diorite, islet west of Sorge Island.
11. T.62.1 Tonalite, islet west of Sorge Island.
12. T.125.1 Diorite, Anchorage Island.
13. T.130.1 Gabbro (coarse-grained phase), Léonie Island.
14. T.130.2 Gabbro (medium-grained phase), Léonie Island.
15. T.147.1 Tonalite, southern Mount Bodys.
16. T.202.1 Granodiorite, north-western Mount Gaudry.
17. T.212.1 Granodiorite, Jenny Island.
18. T.214.1 Tonalite (local contact phase of granodiorite), Jenny Island.
19. T.223.1 Microgabbro, south-western Mount Gaudry.
20. T.281.1 Granodiorite (matrix to granodiorite xenoliths), eastern Mount Mangin.
21. T.305.1 Gabbro, southern Mount Bouvier.
22. T.327.4 Gabbro, Day Island.
23. T.348.1 Granodiorite, northern Mount Gaudry.
24. T.355.1 Tonalite, south-western Mount Ditte.
25. T.13.1 Brown-weathering tonalite, western Mount Reeves.
26. T.32.1 Brown-weathering tonalite, western Mount Bouvier.
27. T.63.1 Red-weathering leucogranodiorite, central Square Peninsula.
28. T.76.1 Grey-weathering tonalite (? part of a heterogeneous intrusion), east of Crumbles Glacier.
29. T.89.1 Dark fine-grained granodiorite (altered gabbro wall rock near adamellite), west of Rothera Point.
30. T.89.2 Adamellite (contact phase of leucogranodiorite), west of Rothera Point.
31. T.157.2A Augite-granophyre, south of Sighing Peak.
32. T.164.1 Red-weathering leucogranodiorite (main phase), south of Sighing Peak.
33. T.164.2 Dark red-weathering leuco-adamellite (upper phase), south of Sighing Peak.
34. T.224.1 Brown-weathering granodiorite, western Mount Liotard.
35. T.333.1 Leuco-adamellite, League Rock.

[*facing page*

strata (Hauthal, 1898), he concluded that the Andean intrusive rocks are of late Cretaceous to early Tertiary age. The age of the Patagonian intrusions has recently been more accurately estimated as Aptian (Adie, 1962). K/Ar and Pb_{α} ages of Andean intrusive rocks from the Antarctic Peninsula range from 100 ($\pm$20) to 45 ($\pm$5) m. yr. (Halpern, 1964; Scott, 1965).

A. Dark Gabbros of Homogeneous Intrusions

Undersaturated or saturated very dark coarse-grained gabbros in which flow-banding is not present crop out in seven strictly limited areas. A few gabbros included in this section contain traces of quartz; in these rocks the dark colour is usually produced by the remarkably dark colour of the plagioclase (e.g. Jenny Island; see below). Textures are hypidiomorphic granular to subophitic.

1. *Léonie Island*

On three sides of Léonie Island (T.131, 133–135; Figs. 7F and 8F), enough of the steeply dipping contact of dark gabbro against stratified rocks is visible to show that the former was emplaced as a sub-circular boss, about 1 mile (1·6 km.) in diameter which is roughly coincident with the island in position. Much of the dark gabbro boss has been displaced by the paler-coloured gabbros of a younger heterogeneous intrusion (p. 37).

The mafic gabbro (T.129.1; Table VIII) is inequigranular because of degradation of the ferromagnesian minerals it contains. The only felsic crystals present are tabulae of labradorite up to 3·5 mm. in length which have in many cases been sericitized. Finely pilose matted talc encloses small iron ore crystals and relatively strongly crystallizing fibrous anthophyllite (Plate Ve). The pale yellow fibrous aggregates of this mineral have a high positive relief, parallel extinction, birefringence $= 0{\cdot}025$ and $2V\alpha > 80°$. Talc, iron ore and the anthophyllite are present in rounded masses up to 3·5 mm. across which probably represent former olivine or pyroxene crystals; some of them were almost certainly originally of pyroxene, because the flakes and crystals of iron ore they enclose are distributed along very regular (?) cleavage lines. A narrow zone surrounding these masses is rich in iron ore crystals, and outside of it there is a substantial but irregular border of hornblende crystals. Some parts of the brown hornblende are very pale in colour so that they appear to have been bleached in places. Rare crystals of a dark green amphibole appear to be an alteration stage of hornblende to green isotropic chlorite, which is one of the alteration products common in large fibrous or disrupted chloritic masses. This rock, of which the colour index is 66, is the most mafic of the Andean intrusive rocks found on Adelaide Island, and it is thought to have originally been a typical metaluminous olivine-gabbro. An analysis given by Gourdon (1917, p. 10; Table X, analysis 1) is thought to be of this rock.

2. *Jenny Island*

On the north-western cape of Jenny Island (Figs. 7G and 8G), the planar contact of a very dark gabbro against the massive country rock (p. 19) dips at 50° towards 350° mag. (T.215, 217) and it is truncated in the east by an intrusion of heterogeneous granodiorite (T.209; p. 37). A post-Andean mafic dyke (p. 57), which in hand-specimen appearance is identical to the country rock, has been intruded along parts of the contact and it contains blocks of dark gabbro (cf. p. 37), so that the order of intrusion is locally apparently reversed (T.215).

The dark gabbro of Jenny Island (T.216.1; Table VIII) is composed mostly of large disorientated labradorite laths which are an unusually dark waxy grey in the hand specimen. A little quartz is graphically intergrown with the plagioclase, which is ophitically enclosed by anhedral clinopyroxene crystals; some of the clinopyroxene has altered to pale hornblende. Some crystals up to 5 mm. across are both rhombic and monoclinic pyroxenes in coarse symplectic intergrowth as plates with common *c*-axes. The orthopyroxene shows slight hypersthene pleochroism in places. Clinopyroxene, not intergrown, fringes large crystal aggregates (former (?) olivine crystals) consisting principally of medium-grained to minute distributed iron ore crystals, small crystals of orthopyroxene and rarer biotite flakes. Small euhedral platy crystals of pale brown to dark russet biotite and relatively large iron ore crystals surround, but have not replaced, the clinopyroxene which has altered to talc, iron ore and biotite. A *cheval-de-frise* of tiny (?) apatite needles, set in minute anhedral colourless crystals of a mineral with low negative relief, birefringence = 0·012 and 2Vα = 80°, is quite common on the outer side of the micaceous zone. This rock is thought to be the one described by Gourdon (1917, p. 8; Table X, analysis 3).

3. *Mikkelsen Islands*

Material almost exactly comparable to the dark gabbro of Jenny Island crops out over the northern end of the Mikkelsen Islands (T.267; Figs. 4 and 5). The rock is less coarse in grain than the usual rocks of this type and it is distinguishable only with difficulty from the dark massive volcanic rocks of the southern islands of the group.

The grain-size of the dark gabbro of the Mikkelsen Islands (T.267.1) is finer than that of the dark gabbro of Jenny Island, but both rocks are ophitic in contrast to the equigranular gabbro of Léonie Island. Anhedral clinopyroxene crystals up to 1·2 cm. across ophitically enclose narrow plagioclase laths up to 5 mm. in length, of which the shadowy extinctions suggest that they were once more calcic than andesine. Actinolite has replaced the margins of pyroxene crystals, and many tiny needles and blebs of it are enclosed in the plagioclase crystals. There are local granular or well-formed skeletal aggregates up to 5 mm. in length of iron ore intergrown with plagioclase and actinolite, which may be the result of recrystallization or may represent altered crystals of a ferromagnesian mineral.

4. *South-western Mount Gaudry*

The southern tip of the south-western ridge of Mount Gaudry (T.201, 206; Figs. 4 and 5) is composed of dark gabbro, which extends for about 200 yd. (183 m.) up the ridge. It is in contact to the north and east with younger granodiorites of heterogeneous and homogeneous intrusions, but otherwise its margins are not known.

5. *McCallum Pass*

A dark but not very coarse-grained gabbro crops out on the small terminal buttress of the north-eastern ridge of Mount Mangin (T.244; Figs. 4 and 5). This buttress forms the western wall of McCallum Pass. Other outcrops nearby are of stratified rocks (T.239–242; p. 21) intruded by diorites of a heterogeneous intrusion which is exposed to the east and west of the dark gabbro buttress at stations T.243 and 245. The field evidence does not show whether the dark rock is a (marginal) facies of the heterogeneous pluton (p. 38) or an earlier intrusion, because none of its contacts is exposed. The dark gabbro is now considered to be an earlier intrusion, because no undersaturated rocks have been found in heterogeneous plutons.

The dark gabbro (T.244.1; Tables VIII and X) is the freshest dark gabbro examined. It is also the finest in grain-size and it contains subophitically enclosed laths and tabulae of bytownite which have wide rims of labradorite. Magnesium-rich olivine ($2V \simeq 90°$) is believed to have formed about 10 per cent of the rock before its partial alteration to talc, green fibrous tremolite-actinolite, chlorites and small granular opaque crystals. Very pale brown augite anhedra up to 4 mm. across and smaller hypersthene anhedra enclose the olivine and the plagioclase (cf. Plate Vf); both pyroxenes have altered to hornblende which is unusually pale-coloured in parts and which grades into tremolite-actinolite. Some crystals of sparse biotite are also unusually pale in parts.

6. *Webb Island*

A rather fine-grained dark gabbro crops out on eastern Webb Island (T.48, 168). It is intruded into the volcanic rocks of northern Webb Island (p. 22) and it is in turn intruded by a younger leucogranodiorite in the south. The contact against the volcanic rocks is obscure but it is thought to trend westwards across the low central col of the island, and the contact against the granodiorite is exposed only on the east (T.47, 167, 172). The gabbro cropping out at stations T.48 and 168 contains no xenoliths but on the western side of Webb Island a rock believed to be part of the same mass is full of inclusions of stratified rocks (T.43, 173). The analysis of the gabbro is the one given by Gourdon (1917; Table X, analysis 2).

7. *Islands off south-western Adelaide Island*

Coarse-grained dark gabbro is exposed on the highest island of the Henkes Islands group (T.258), between Crouch Island and Preston Island (Figs. 11B and 12B). Lighter-coloured granodiorite is exposed on the lower islands (T.257, 259, 260). Dark rock of similar appearance crops out on the Esplin Islands to the north (T.261).

The dark gabbro (T.258.1) is similar in the hand specimen to that of Jenny Island (p. 31). Zoned and cracked groundmass crystals and a few phenocrysts which may be as large as 1·6 cm. across are bytownite ($Ab_{28}An_{72}$). An estimated 20 per cent of the rock is composed of pale-coloured hornblende which has replaced ophitic pyroxene. Rounded patches of iron ore and the amphibole are enclosed by larger masses of poecilitic hornblende and are believed to represent altered olivine crystals. Small amounts of biotite and apatite are present, and fibro-lamellar antigorite has replaced parts of the hornblende.

The coarse-grained dark rock of the Esplin Islands (T.261.1) shows every sign of being a hybrid rock. In it, quartz and potassium feldspar are interstitial to andesine ($Ab_{62}An_{38}$) tabulae which are slightly zoned. Coarse augite prisms are associated with large iron ore crystals and they enclose rounded titanaugite crystals which appear to have replaced olivine, although no trace of the olivine remains. Small amounts of hornblende and biotite have replaced clinopyroxene. Unusually large apatite crystals are common. This rock is thought to be a gabbro modified by the introduction of silicic material into it.

B. Flow-banded Dark Gabbros

Undersaturated very coarse-grained banded gabbros are not very common in the Adelaide Island area. Their contacts are not well exposed but they are associated with relatively fine-grained gabbro which has been involved in the banding.

1. *Brockhamp Islands*

A very coarse-grained gabbro is exposed on the eastern sides of both of the Brockhamp Islands (T.139, 140; Figs. 2 and 3). Its western contact against the fine-grained gabbro of Hunt Point is a gradational zone, 1–5 yd. (0·9–4·6 m.) wide, in which the two rocks are sub-vertically interbanded. The fine-grained gabbro appears to have been intruded after the coarse-grained rock, because it has fed veins up to 8 in. (20 cm.) wide which cross the contact at a high angle and pass into the dark gabbro. In contrast, remobilization of the coarser rock is indicated by its presence in diffusely margined veins and schlieren in the fine-grained gabbro close to the contact. The gabbro over about 6 sq. ft. (0·6 m.^{2}) of the exposure is packed with round or elliptical orbicules (Plate IIc) up to about 5 in. (12·7 cm.) across, in which it is usual for a single, relatively dark, fine-grained marginal zone to surround a coarse-grained centre of which the composition is similar to that of the host rock. The cores of some orbicules are more feldspathic or ferromagnesian than the host rock. In a few unzoned orbicules coarse crystals are radially arranged, a structure which has been reported in gabbros cropping out on the Bennett Islands in Hanusse Bay, not very far north of the Brockhamp Islands (Goldring, 1962, p. 31). The orbicular gabbro seems to have been contained completely within the normal rock, into which it passes very rapidly.

A specimen of the coarse gabbro from the eastern side of the larger of the Brockhamp Islands (T.139.3; Table VIII) is very coarse-grained, but it is not as coarse as the rock close to the contact on the western side. Marginally cracked crystals of bytownite, normally 4 mm. but up to 7 mm. across (estimated at 50 per cent of the rock) are in some cases ophitically enclosed by coloured minerals. Colourless rounded anhedra of magnesian olivine ($2V \simeq 90°$; estimated at 20 per cent) up to 3 mm. across and of plagioclase are enclosed in very pale hypersthene and less common clinopyroxene (Plate Vf). Rare crystals of biotite, and hornblende which has replaced the pyroxenes, are pale coloured in places. The content of iron ore is not as high as might be expected in a rock of this type. There are radial cracks in the rock around many of the olivine crystals, particularly those which have altered most extensively to pale yellow or colourless chlorites. The radial cracks have probably been pıoduced by the increase in volume involved in some reactions which take place during the degradation of olivine; similar expansion cracks are illustrated in a troctolite by Hatch and others (1949, p. 286).

The coarse-grained rock which is commonest in the banded contact zone (T.139.1A; Table VIII) contains bytownite which is slightly more calcic than that of specimen T.139.3. Rounded crystals of very pale brown clinopyroxene up to 2 mm. across have aggregated into groups, and rounded colourless relicts of olivine are present in the centres of the largest clinopyroxene clusters. The pyroxene has altered in the same way as in specimen T.139.3. A hololeucocratic layer (T.139.1B; Table VIII) from the banded zone is composed essentially of flow-orientated laths of the same bytownite ($Ab_{88}An_{12}$) as is present in specimen T.139.1A. The margin of this band is very sharp but locally irregular.

A typical orbicule (T.139.6) has a core which is texturally similar to the host rock (T.139.3) but it has a smaller clinopyroxene content. The harrisitic dark fine-grained margin of the orbicule is composed of radially disposed anhedral olivine aciculae and interstititial bytownite laths (Plate VIa). The olivine crystals may be up to 8 mm. in length, but few are more than 0·1 mm. wide. Aggregated tiny iron ore crystals are arranged in zones at intervals across the harrisitic zone. While the outer margin of the zone is microscopically sharp, its inner side is more gradational because small equidimensional olivine crystals are concentrated around the margin of the feldspathic core. Olivine does not appear to be commonly found in orbicular rocks, which are mostly dioritic and may contain quartz; the ferromagnesian mineral which occurs in most of them is hornblende (Mourant, 1932; Hatch and others, 1949; Leveson, 1963; other references are cited in these papers). Hornblende and plagioclase are the minerals present in the enclosing shells of the orbicules described from the Bennett Islands (Goldring, 1962, p. 31) in which the structure is coarser than in those of the Brockhamp Islands. The hornblende is an alteration product of augite and olivine (Goldring, 1962, p. 32) and the orbicules of the Bennett Islands may have been similar in some respects to those described above before they were partially altered.

The harrisitic texture of the margins of these orbicules indicates that the margin was formed under conditions of "moderate undercooling" as described by Taubeneck and Poldervaart (1960), because the margins appear to be a very local form of the rhythmic banding of Willow Lake type which they explained. The orbicules are believed to have originated as wholly cognate xenoliths suspended in the gabbro magma. Although all the cores of the orbicles are rounded, they are not all spherical, and this is believed to show that the cores were completely crystalline bodies before the mafic rim crystallized around them. Because they are not all spherical, the orbicules are not likely to be segregations which originated in such a process as unmixing of the gabbroic magma. If it is assumed that the rims were formed in conditions of moderate undercooling, then to produce this effect the cores were cooler than the magma in which they were suspended, because it seems certain that the orbicules formed before the rock which encloses them. (The reverse relationship involves many equal-sized rounded pockets of magma undercooled against their enclosing walls which is unlikely because the orbicules are found in such a restricted part of the large exposure.) It is believed that the cores of the orbicules represent parts of the gabbro pluton which had crystallized and therefore cooled, probably at the margin of the intrusion, and had then been brecciated to fragments of tennis-ball size. The brecciated fragments may then have been transferred to that part of the intrusion which had not crystallized and which still contained only liquid magma. Transportation of these fragments may not in fact have taken place, because their density must have been similar to that of the enclosing liquid and they may have remained suspended at the point where they broke from the crystallized gabbro. They were not wholly re-dissolved in the magma but were rounded as their margins were re-melted by the liquid magma. That the magma which surrounded the cores was wholly liquid is shown by the very regular widths of the mafic rims, which enclose no coarse crystalline material such as would be expected to interfere with their growth in a partially crystallized magmatic mush. It is under these conditions that the harrisitic rims are believed to have grown, and after the rims had crystallized the magma crystallized to the gabbro around the orbicules. The history of crystallization of the orbicules is summarized in the following stages:

i. Intrusion of undersaturated gabbro magma into a deep-seated chamber.
ii. Crystallization of part of the magma around the chamber walls.
iii. Local brecciation of part of the crystallized gabbro.
iv. The gabbro fragments remained in close association or collected in one place. They are believed merely to have remained in suspension near the gabbro wall rock and not to have drifted apart to a great extent.
v. The liquid magma surrounding the brecciated fragments resorbed parts of their margins and effectively rounded them.
vi. The magma became "moderately undercooled" *only* against the rounded fragments and not against the wall rock. The reason for this selective undercooling is not known.
vii. Harrisitic olivine crystallized around the rounded gabbro fragments because of the undercooling.

viii. After conditions of moderate undercooling had prevailed for a time sufficient for the radially crystallizing olivine crystals to become very long, the magma surrounding the orbicules cooled to a temperature at which it crystallized to a homogeneous coarse-grained gabbro enclosing them.

2. *Coast of Square Peninsula south of Webb Island*

Flow-banded dark gabbros crop out on the eastern coast of Square Peninsula south of Webb Island, on an exposure about 350 yd. (320 m.) long and 10–50 yd. (9·1–45·7 m.) wide (T.170; Fig. 13). A vertical contact trends irregularly north–south (mag.) and separates two main olivine-gabbro facies:

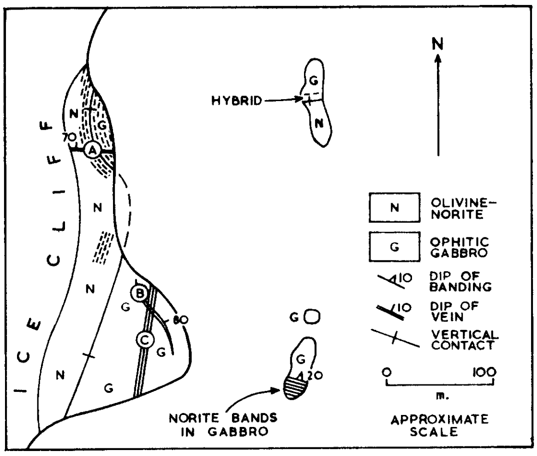

FIGURE 13

Detailed geological sketch map of an exposure on the coast of Adelaide Island south of Webb Island (T.170; Figs. 4 and 5).
A. Vertical contact between olivine-norite and ophitic gabbro.
B. Fine-grained quartz-gabbro vein intruding ophitic gabbro.
C. Coarse-grained olivine-norite veins intruding ophitic gabbro.

i. West of the contact: coarse plagioclase facies (olivine-norite). This rock (T.170.5) is very similar in the hand specimen to the main rock of the Brockhamp Islands (T.139.3). Even-grained squat euhedra of plagioclase up to 4 cm. across are contained in a groundmass of only slightly smaller hypidiomorphic granular ferromagnesian and plagioclase crystals. Conspicuous banding is present only along the contact, although a broad colour banding has been distinguished with difficulty in a small area at a distance from the contact.

ii. East of contact: darker (ophitic) facies. East of the contact, an apparently darker rock (T.170.1) contains mutually interfering ophitic pyroxene crystals up to 4 cm. across, which enclose relatively small plagioclase crystals. This facies is most noticeably banded near its contacts.

In the south the contact between the two rocks is sharp, but in the north the two types are roughly interbanded in units about 1 ft. (0·3 m.) wide parallel to the contact. Thinner bands of finer-grained gabbro are relatively finely laminated and sometimes display false-bedding festoons which may be truncated by the thick bands of coarse rock (Plate IId). Interbanding of the norite in bands up to 4 ft. (1·2 m.) thick and of the gabbro in thinner bands dips at 20° towards 010° mag. on the southern islets near this exposure. On the northern islets, a sharp vertical contact striking close to 250° mag. separates the dark facies in the north from the norite in the south. Occasional large plagioclase crystals are present in the dark gabbro near the contact which also contains orbicules up to 4 cm. across. These orbicules are of fibrous radiating ferromagnesian material around a leucocratic granular core, and they are similar to those reported by Goldring (1962, p. 31) from the Bennett Islands.

Because these rocks are very coarse in grain-size, their exact mineral contents are not known. The rock that crops out west of the contact (the coarse plagioclase facies; T.170.5) appears to be slightly more melanocratic than the one on the east; it is also much less ophitic. The plagioclase of both matrix crystals (up to 8 mm. across) and of the euhedra (up to 4 cm. across) which are characteristic of this rock is bytownite ($Ab_{27}An_{73}$). A few large crystals of hypersthene enclose anhedral olivine crystals ($Fo_{80}Fa_{20}$) and some of the smaller plagioclase crystals. The hypersthene has altered to a brown hornblende. Sparse crystals of red biotite are probably primary. Iron ore crystals up to 1 mm. across are associated with these ferromagnesian minerals. The olivine-gabbro east of the contact is strongly ophitic. An attenuated "matrix" of clinopyroxene and hypersthene contains crystals of bytownite ($Ab_{19}An_{81}$; estimated at 80 per cent of the rock) and olivine (estimated at 5 per cent). The olivine is the same as in the coarse plagioclase facies. Although the ophitic pyroxenes once formed crystals up to 4 cm. across, the pyroxene content before alteration to bleached brown hornblende is estimated at only about 15 per cent.

3. *Discussion*

The most characteristic feature of the dark gabbros of the Adelaide Island area is the banding, which is found in no other rock types in this area. The banding is almost invariably vertical but irregular in direction (Fig. 13) and this attitude is unusual in banded intrusive rocks. So intense is the banding that it is identifiable even on the smallest exposures, and indeed none of the exposures of these rocks in the Adelaide Island area are large ones. Banded gabbros have been found in other parts of the Antarctic Peninsula and a number of detailed descriptions of them are available (Adie, 1955; Curtis, 1966; Goldring, 1962; Hooper, 1962; Fraser, 1964). The banding is close to vertical in all the localities described.

As Fraser (1964, p. 32) has pointed out from his work on banded gabbros in the Anagram Islands, it is clear that the banding is a primary igneous structure. The unusual attitude is difficult to explain. He has suggested that the banding has resulted from the repeated intrusion of a crystal mush in which crystalline material was greatly in excess of liquid fractions. A very heterogeneous magma source has been suggested by Hooper (1962, p. 37) as the single provenance of the several interbanded rocks in any one locality. Fraser believed that the banding is most intense near contacts, because the intruded heterogeneous gabbro magma suffered the greatest differential movement close to the wall rock, where the velocity gradient would be greatest. The higher velocity gradient caused more pronounced streaking of the heterogeneous magma into bands. If this were the case, it seems likely that at a distance from the contact, where the velocity gradient would be very small, a number of rock types would be present in the rock intruded in one pulse, but they would not be drawn out into bands. Some of these rock types would be monomineralic, because some of the bands which Fraser has suggested have been drawn out from discrete magma types in the heterogeneous magma are monomineralic. With the exception of gabbro autoliths, rocks of contrasting composition are not present at any distance from contacts, however, and Fraser's proposed mechanism may not be the complete explanation of the banding.

Flow in a horizontal sense was postulated by Fraser, because of the orientation of the long axes of plagioclase crystals (parallel to the direction of flow) and because the most pronounced pseudo-sedimentary structures in the banded rocks seemed to show that vertical flow was unimportant. However, long-axis orientations may not be wholly reliable as indicators of the direction of flow (Hooper, 1965). Furthermore, on the flat glaciated Anagram Islands there are very few exposures which show cross-sections of banding but there are many which show it in plan; the result of this is that there is abundant evidence for horizontal flow but that for or against vertical flow (whether up or down) is not easily found. Vertical flow may have been more important than Fraser has suggested. Whatever the direction of flow, it was along contacts with other rocks, i.e. along the walls of the intrusions. The extreme regularity and parallelism of many of these bands must mean that flow was laminar, if magmatic flow was responsible for their formation. Such evidence as has been found in the Adelaide Island area seems to show that, as Fraser (1965) has pointed out, undercooling has not been important in the formation of the banding and it is not rhythmic banding of the Willow Lake type (Taubeneck and Poldervaart, 1960) as Hooper (1965) has suggested.

C. Heterogeneous Intrusions

In the Adelaide Island area, the commonest type of pluton is one in which the rocks are heterogeneous. They have been found to range from gabbros to granodiorites but no internal contacts have been found in these intrusions. Specimens from the same intrusion may differ considerably in appearance and this difference reflects the differences in mineralogical composition. Colour indices vary greatly but they cannot be reliably estimated from hand specimens because of the dark colour of the plagioclase in some rocks; those rocks which contain most potassium feldspar and quartz tend to be relatively coarse in grain-size and lighter in weathering colour. The most extreme variation has been found in a pluton which varies from gabbro to a rock which is nearly adamellitic (p. 38, 39). Most of the rocks in the heterogeneous intrusions contain essential quartz and all are very much lighter in colour than the dark gabbros (p. 31). Small-scale internal banding, associated in places with mafic schlieren, has been found at a few localities near intrusion margins.

1. *Islands and coast of western Laubeuf Fjord*

Rocks of a heterogeneous intrusion are present on intermittent exposures to the north and south of a younger leucogranodiorite pluton on Square Peninsula (Figs. 3 and 4; p. 42). The northern and southern exposures are of rocks of a single pluton divided by the later intrusion.

Typical of the heterogeneous intrusion is tonalite which crops out on Limpet Island (T.37–42). It is homogeneous apart from small fine-grained xenoliths and it is only just coarse in grain-size. Very similar but slightly coarser diorite crops out on Anchorage Island and the nearby islands (T.43, 123–126). The tonalite surrounds and grades into darker coarser-grained rock on the summit of Limpet Island. Relatively fine-grained dark rocks with traces of stratification are exposed in the dark rocks, which have probably absorbed some xenolithic material. The stratification in the xenoliths is contorted.

Rocks of a similar appearance to that of Limpet Island intrude the country rocks and the dark gabbro boss (p. 31) of Léonie Island (T.129–134, 136). Two facies are mixed in irregular patches and inclusions of either are present in the other, but the finer phase has been found as veins cutting the coarser phase (T.130). Displacement of the Léonie Island dark gabbro by the lighter-coloured gabbros has been controlled structurally by vertical planes striking near to 360° mag., and the remaining elongated masses of dark gabbro (T.129, 134) are surrounded by belts of gabbroic intrusion breccia which are 30–40 yd. (27·4–36·6 m.) wide at station T.129. In the intrusion breccias the rounded lithic inclusions, which are up to 1 ft. (0·3 m.) across, have all been derived from the stratified rocks. Possibly many xenoliths of the dark gabbro sank in the intruding magma, and the large independent masses of dark gabbro are the traces of roof pendants in the later intrusion.

The heterogeneous intrusion is exposed on Rothera Point and on the ridge extending north-west from it (T.86–91, 99). Its vertical contact against iron-mineralized country rocks (T.86; p. 17) is very poorly exposed. On nunataks west of these country rocks (T.67, 69–71, 74, 75), similar rocks are rather darker in appearance and some of them are intrusion breccias. The rather sparse matrix of the breccias is a quartz-microgabbro containing plagioclase phenocrysts up to 3 mm. in length. Few other minerals in the matrix are fresh. The predominantly rounded lithic inclusions are mostly of stratified rocks, although there are some of finer-grained, darker-coloured intrusive rocks (T.69; Plate IIIa). Parts of the intrusion breccias have been re-brecciated by the intrusion of younger granodiorite. This intrusion may be exposed on the large nunatak (T.76–78, 174) immediately east of Crumbles Glacier, where a tonalite is homogeneous apart from its content of angular inclusions of stratified rocks. The tonalite is much coarser in grain-size than other rocks of the heterogeneous intrusion in the Ryder Bay area, and it may be an independent intrusion or a marginal facies of the leucogranodiorite exposed to the north (p. 42). Only its western contact has been found; it has intruded stratified rocks which are exposed on scattered exposures near Crumbles Glacier (p. 17).

The heterogeneous intrusion also occurs on Jenny Island (Figs. 7G and 8G), where variable granodiorite is slightly coarser in grain-size than the rock of Limpet Island. Its contact against the massive country rock (p. 19) has been modified near the north-western cape of the island by the intrusion of a post-Andean mafic dyke (T.209; Plate IIIb) along it. The granodiorite grades to a comparatively pale-coloured tonalite at the contact against country rock on the col west of the summit of the island (T.214, 222). Quartz-gabbro which has weathered to a similar pale colour crops out on the Guébriant Islands (T.320; Figs. 11C and 12C). Dark, rather variable tonalite which crops out on the western side of Mount Ditte (T.355; Figs. 4 and 5) is probably connected at depth with this intrusion. It is believed to extend westwards at least as far as the Ginger Islands (T.359), where similar rocks are in contact with stratified rocks (p. 30). The roof contact of this part of the intrusion is visible at about 1,500 ft. (457 m.) a.s.l. north-west of Cape Alexandra on cliffs above station T.355, and elsewhere, some of the contacts of this part of the intrusion are faulted (Plate Ia). At station T.359 this rock contains dark rounded inclusions and at station T.355 a fine-grained dark facies is internally banded.

The northern part of the heterogeneous intrusion extends from northern Square Peninsula to Sorge

Island (Figs. 2 and 3). It crops out over the western end of Sighing Peak (T.151–154) and has an intrusion-brecciated contact against volcanic rocks to the east (T.151). It extends eastwards as far as north-eastern Mount Mangin and it is exposed nearly continuously on the cliffs of northern Square Peninsula. Though no internal contacts are present on these exposures, the rocks vary considerably. Besides the local (50 ft. (15·2 m.) wide) marginal intrusion breccia zones, there are concentrations of xenoliths in some of the rocks, especially at station T.270. The darkest rocks of the intrusion crop out south-west of Sighing Peak (T.158), where it is free of xenoliths but very fine-grained. This tonalite grades westwards into paler coarser granodiorite (T.274) before a relatively rapid transition to intrusion breccias at McCallum Pass (T.243) and on an isolated nunatak south-east of the pass (T.179). Near the pluton margin (T.243), where diorites are intruded into country rocks exposed just west of the pass (p. 21), dark gabbro crops out at station T.244; although this gabbro was at one time believed to be part of the heterogeneous intrusion, it is now thought to have been intruded before it (p. 32, 47).

In the Barlas Channel area, the irregular contact between the heterogeneous intrusion and the stratified rocks to the west crosses the coast at Hunt Point (T.144) and it passes to the west on the north side of the main south-western ridge of Mount Bouvier. Tonalite crops out low on Mount Bodys (T.147) below clearly stratified rocks which form the summit of the mountain. Light-weathering exposures of gabbro on Day Island (T.327) are like the inaccessible ones on eastern Mount Bodys and on Hansen Island. The variable rocks of Mothes Point (T.56–59, 146) include quartz-gabbro, cut by coarse-grained ramifying white veins, and granodiorite. Diorite and tonalite have been found on islets near Sorge Island (T.60–62).

The tonalite of Limpet Island (T.37.1; Table VIII) is holocrystalline, fine- to medium-grained and generally equigranular. Crystals of quartz have in places intergrown with the predominating plagioclase. Colourless to greenish antigorite has replaced most of the ferromagnesian minerals. In the fresher diorite of Anchorage Island (T.125.1; Table VIII; Plate VIb) a ferromagnesian clot in the section examined probably represents a partially resorbed xenolith. Large xenocrysts which have probably been derived from such xenoliths are composed of andesine-labradorite, as are the smaller groundmass plagioclase crystals. Interstitial quartz appears to have been introduced. The clinopyroxene has almost completely altered to hornblende and tremolite. The hornblende encloses small plagioclase crystals. Biotite, both primary and derived from the amphibole, has in places altered to pennine.

Both of the quartz-gabbro phases of Léonie Island are rather ophitic and they contain plagioclase tabulae which range in size. In the coarser, first-intruded rock (T.130.1; Table VIII), subhedral tabulae of labradorite are up to 4 mm. in length, and smaller plagioclase crystals may be enclosed by larger ones or by pyroxene. Hypersthene forms crystals up to 4 mm. across which are seamed by iron ore-studded antigorite trails and surrounded by antigoritic corrosion borders. Colourless or very pale brown subhedra of clinopyroxene, 2·5 to 3·5 mm. across, are in some cases schillerized, and others are polysynthetically twinned or symplectically intergrown with the orthopyroxene. A trace of brown platy biotite is primary. The finer-grained Léonie Island gabbro phase (T.130.2; Table VIII) is more equigranular and it contains diopside instead of hypersthene. The diopside ophitically encloses small labradorite crystals and it has altered to pale green hornblende which is also present in radial cracks surrounding the altered crystals.

The tonalite of the nunatak east of Crumbles Glacier (T.76.1; Table VIII) contains irregular quartz crystals up to 1 mm. across, some of which are intergrown with the interstitial cloudy potassium feldspar. The quartz crystals tend to form lines or crystal chains which have no regular margins. The rock is modally similar to the granodiorite of eastern Mount Mangin (T.281.1; p. 40), but it contains less potassium feldspar.

A typical specimen from the granodiorite of Jenny Island (T.212.1; Table VIII) has an unusual texture. Phenocrysts of labradorite up to 4·5 mm. but usually 2 mm. in length are contained in a fine-grained, coarsely graphic groundmass of quartz, potassium feldspar, coloured minerals and smaller labradorite crystals. Sparse phenocrysts up to 2·5 mm. across are of clinopyroxene which has altered to a pale hornblende. The coloured minerals in the groundmass include this hornblende, biotite, sphene and ores. The texture of this rock suggests that a coarse plagioclase-pyroxene crystal mush has been invaded by an alkalic and silicic mesostasis. The paler coarser-grained tonalite (T.214.1; Table VIII), which is the contact phase of this granodiorite in one locality, contains the same minerals; it contains labradorite xenocrysts up to 4 mm. in length which are zoned, cracked and disrupted (Plate VIc). A similar pale rock from the Guébriant Islands contains no potassium feldspar at all and it is more mafic; over 15 per cent of

TABLE IX

MODAL ANALYSES OF ROCKS FROM ADJACENT HETEROGENEOUS INTRUSIONS ON MOUNT MANGIN AND SQUARE PENINSULA

		Northern and north-western Mount Mangin									McCallum Pass and northern Square Peninsula				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Quartz		12·5	5·3	13·5	22·1	25·4	10·6	15·6	11·3	9·5	5·7	11·5	7·1	26·2	18·2
Potassium feldspar		8·1	3·5	1·3	13·2	11·9	9·9	25·9†	7·3	9·5	*	—	1·3	19·5	5·6
Plagioclase		62·4	69·1	62·4	50·2	49·3	60·8	43·2	52·9	56·5	60·8	57·8	58·1	43·6	57·6
Clinopyroxene		1·0	7·5	6·5	—	—	—	0·7	4·1	4·6	12·3	3·1	0·8	2·9	2·4
Hypersthene		—	2·1	0·3	—	—	—	—	—	0·1	1·0	—	—	—	—
Amphiboles		7·4	3·9	4·4	7·2	—	9·2	8·5	2·6	8·7	5·2	15·3	24·8	2·2	7·2
Biotite		7·0	6·0	9·2	3·9	—	0·3	2·4	8·2	2·7	1·3	—	0·4	1·1	6·3
Iron ores		1·0	2·3	1·6	1·0	0·4	1·1	2·3	1·4	2·1	7·8	2·4	5·1	1·8	1·5
Apatite		*	—	0·6	*	—	0·2	0·3	0·5	0·1	0·7	0·1	0·3	*	*
Epidote		—	—	—	0·3	4·0	0·7	—	0·2	—	0·2	—	0·4	—	0·1
Chlorites		0·2	0·3	0·2	1·1	7·5	6·9	0·9	2·8	6·1	5·0	7·4	1·4	2·6	1·1
Sericite		—	—	—	—	—	—	—	8·6	—	—	2·8	—	—	—
Accessory minerals		0·2	—	—	0·1	1·6	0·2	0·3	—	*	—	—	0·4	*	*
Plagioclase compositions — Groundmass	*Core*	An_{64}	An_{50}	An_{51}	An_{36}	An_{40}	An_{46}	An_{60}	An_{53}	An_{54}	An_{32}	An_{62}	An_{43}	An_{36}	An_{55}
	Rim	An_{28}	An_{20}	An_{35}	An_{20}	An_{20}	An_{20}	An_{20}	An_{31}	An_{34}	An_{32}	An_{26}	An_{43}	An_{27}	An_{36}
	Zoning	n	o	o	o	n	o	n	n	n	—	n	—	o	n
Plagioclase compositions — Phenocrysts	*Core*	An_{64}	An_{50}		An_{36}	An_{40}	An_{54}	An_{60}		An_{54}	An_{41}		An_{50}		
	Rim	An_{28}	An_{20}		An_{20}	An_{20}	An_{20}	An_{20}		An_{34}	An_{32}		An_{43}		
	Zoning	o	o		o	n	o	n		n	o		n		

* Present. n Normal zoning.
† Perthitic. o Oscillatory zoning.

1. T.29.1 Tonalite, Lincoln Nunatak.
2. T.230.1 Diorite, scarp peak north of Lincoln Nunatak.
3. T.231.1 Tonalite, north-western exposures of scarp north-west of Mount Mangin.
4. T.232.1 Granodiorite, scarp north-west of Mount Mangin.
5. T.234.1 Granodiorite, scarp north-west of Mount Mangin.
6. T.235.1 Granodiorite, north-west Mount Mangin.
7. T.236.1 Granodiorite, northern Mount Mangin.
8. T.237.1 Tonalite, northern Mount Mangin.
9. T.238.1 Granodiorite, northern Mount Mangin.
10. T.243.2 Recrystallized andesite (wall rock), west of McCallum Pass.
11. T.243.1 Microtonalite (contact phase of heterogeneous intrusion), west of McCallum Pass.
12. T.245.2 Microdiorite, east of McCallum Pass.
13. T.274.1 Granodiorite, coastal cliffs of south-western Stonehouse Bay.
14. T.158.1 Tonalite, south of Sighing Peak.

(The modal analyses are set out in their order of field occurrence.)

clinopyroxene is thought to have been present in this rock before its partial alteration to amphibole. This hornblende is more intensely coloured than any in the Jenny Island granodiorites, with α' = very pale brown, β' = green and γ' = olive-green.

A rock from western Mount Ditte (T.355.1; Table VIII) is rather inequigranular, because it contains labradorite (zoned to oligoclase-andesine) phenocrysts up to 4 mm. in length which show some parallel alignment. Interstitial quartz is concentrated near mafic inclusions, and potassium feldspar, also interstitial, contains perthitic shreds of plagioclase. The texture is not nearly so inequigranular as in the Jenny Island granodiorite. The colourless clinopyroxene forming subhedra up to 1 mm. across has altered to actinolite mantled by hornblende. Brown biotite crystals up to 2·5 mm. across contain crystals of iron ore minerals and apatite. A fine-grained decussate inclusion contains the same minerals with the exception of the plagioclase, which is andesine.

Of the rocks forming the northern part of this intrusion, the one on the ridge south of Sighing Peak (T.158.1; Table IX) is a tonalite. It is medium-grained apart from its content of coarse labradorite tabulae which are zoned to andesine and have been corroded by interstitial potassium feldspar and abundant quartz. Alteration of clinopyroxene to hornblende has produced a sieve texture, and biotite has altered to chlorite.

The granodiorite of north-western Square Peninsula (T.274.1; Tables IX, X) and rocks of exposures between it and the pluton margin (T.243) have been chemically analysed in a study of these typical heterogeneous rocks (p. 44). The granodiorite is coarse-grained but noticeably inequigranular; there is some fine-grained interstitial material, parts of the rock are thought to be altered xenoliths and some coarse crystals are poecilitic. Potassium feldspar forms cloudy anhedra up to 2 mm. across and it irregularly mantles and veins the other constituents; it has corroded larger quartz crystals and once euhedral andesine tabulae which have a weak oscillatory zoning. Relatively fine-grained crystal aggregates (Plate VId) contain crystals of colourless to neutral clinopyroxene, colourless to pale green tremolite and sparse hornblende, and they may be altered xenoliths. Biotite is absent from them, although it is present in the matrix rock. The coloured minerals of these aggregates are also present as larger free crystals. Some of the larger plagioclase crystals have unusually calcic cores, around which either a wide or narrow rim of more sodic plagioclase has crystallized; though the crystal with its rim is euhedral, the calcic cores are rounded and anhedral. The cores may be xenocrystic (p. 51). Some of them contain many very small globular crystals of clinopyroxene, iron ore and hypersthene (Fig. VIe).

On exposures west of station T.274, microdiorite crops out (T.245.2; Tables IX, X). In it, quartz and potassium feldspar are usually interstitial to andesine laths up to 1·2 mm. in length, but quartz also occurs in larger anhedral "pools" or oikocrysts from which plagioclase has been largely expelled. Occasional subhedral tabular phenocrysts of andesine-labradorite are conspicuously zoned. Ophitic clinopyroxene, originally up to 1 mm. across, has altered to hornblende; some larger crystals of hornblende are primary. Biotite is only locally present; iron ores and apatite are accessory, and secondary chlorites, actinolite and epidote are present in places. The dark gabbro (T.244.1) that crops out west of this microdiorite has already been described (p. 32). Specimen T.243.1, from a wide vein in the marginal intrusion breccias of the pluton, is a microtonalite which is very similar to the diorite at station T.245, except that its plagioclase is more calcic and more quartz is present (Tables IX, X). A specimen (T.243.2; Tables IX, X) from the intrusion-brecciated wall rock is even finer in grain-size but it has a texture similar to those in the nearby intrusive rocks. Oikocrysts of quartz are very prominent. Andesine is the main mineral of a fine-grained mosaic. Both clinopyroxene and relatively uncommon hypersthene are fresh; biotite forms occasional poecilitic patches up to 1 mm. across. Finely granular iron ores are common and apatite is present in places.

All the other minerals, including quartz up to 1·5 mm. across, are idiomorphic towards interstitial potassium feldspar in the tonalite of southern Mount Bodys (T. 147.1; Table VIII). Plagioclase occurs in two poorly differentiated generations. Crystals of it and some of the potassium feldspar have been fractured and they are traversed by irregular veins of oligoclase. Clusters of ragged anhedral to subhedral crystals of hornblende up to 1 mm. across have been replaced by fibro-lamellar chrysotile aggregates and rare pennine crystals. The apparent history of this rock is that of a gabbroic magma which cooled to an advanced stage of crystallization and was disrupted (as shown by cracked feldspar crystals) by an alkaline leucocratic magma or hydrothermal solution which introduced the quartz, potassium feldspar and oligoclase.

At Mothes Point, the porphyritic granodiorite (T.56.1; Table VIII) has a similar texture to the tonalite of Mount Bodys. A gabbro which also crops out on Mothes Point contains no potassium feldspar but interstitial quartz is present. A coarse-grained vein traversing the gabbro is less mafic than the host rock but it contains the same minerals. The coloured minerals in this rock have all altered to fibrous green amphibole but relicts of biotite have survived. Apatite is a very common accessory. The alteration to amphibole has affected the ferromagnesian minerals of the host rock close to the vein. A very leucocratic vein (T.59.1; colour index estimated at 10) is composed predominantly of labradorite ($Ab_{44}An_{56}$), zoned to andesine ($Ab_{64}An_{36}$), and interstitial quartz (estimated at 15 per cent of the rock).

One of the three exposures on islets near Sorge Island is a tonalite (T.62.1; Table VIII). In it, potassium feldspar mantles and replaces plagioclase, and abundant quartz has corroded other minerals. Hypersthene is mantled by schillerized clinopyroxene, which has altered to hornblende. The hornblende has itself altered to tremolite via a pale-coloured stage. A few crystals of schorlite are present. A dark-coloured diorite (T.61.1; Table VIII) contains fewer of the same important coloured minerals, which are present also in a paler coarse-grained diorite (T.60.1; Table VIII) containing sphene and schorlite. The light-weathering gabbro of Day Island (T.327.4; Table VIII) is similar to the tonalite of specimen T.62.1.

2. *Northern Mount Mangin*

Coarse-grained rocks, ranging from diorites to granodiorites, crop out on northern Mount Mangin and on the scarp north-west of the mountain (T.29, 230–232, 234–238; Figs. 4 and 5). The grain-size and colour index vary gradually but considerably in the rocks of this intrusion. At station T.236 the grain-size is greatest and it diminishes steadily towards stations T.29 and 238, and the colour index is lowest at station T.232 (Table IX). Similar variations have been observed in the heterogeneous rocks of northern Square Peninsula to the east (p. 38), and it is believed that the two areas of exposure are of a single pluton which is continuous at no great depth below the stratified rocks west of McCallum Pass (p. 21). An exposure of medium-grained granodiorite on eastern Mount Mangin has been mapped as part of this intrusion; at this outcrop (T.281) a granodiorite contains many well-rounded large xenoliths of a finer-grained, slightly darker plutonic rock, which is also granodioritic.

Zoned tabular labradorite or andesine crystals predominate in these intrusive rocks (Table IX). Some crystals of plagioclase tend to be larger than those typical of these rocks and the cores of these phenocrysts are unusually anorthite-rich. In some rocks, their zoning is oscillatory while that of the typical crystals is normal. They are believed to be xenocrystic in origin. Large crystals of potassium feldspar are common in some rocks and all of these rocks contain interstitial potassium feldspar which is perthitic where it has corroded the plagioclase. Essential interstitial quartz, which has also corroded the plagioclase (Plate VIIa), is relatively constant in its amount. Colourless or locally purplish clinopyroxene crystals are grouped in clusters in which hypersthene crystals are sometimes present. The clinopyroxene in most of these rocks has partially altered to hornblende, but some of the crystals have altered first to actinolite. Biotite mantles clinopyroxene in places (Plate VIIb). Symplectic vermicular crystals of iron ore are in places concentrated in the ferromagnesian clusters and apatite is a common accessory in these rocks. Many tiny clinopyroxene crystals are contained in some of the larger plagioclase crystals and they may be arranged as a zone in the host crystal (T.29.1). This is a modification of a texture found in other rocks of this type, where the cores of large plagioclase crystals may be filled with tiny globular enclaves of clinopyroxene and other ferromagnesian minerals (p. 39; Plate VIe).

The xenolith-rich granodiorite of eastern Mount Mangin (T.281.1; Table VIII) contains anhedral quartz and potassium feldspar. Euhedral andesine laths up to 2 mm. in length are zoned to oligoclase; in some cases they are sericitized and have been noticeably corroded by the potassium feldspar (Plate VIIc). Aggregated clinopyroxene crystals have altered to hornblende as in the rocks described above, and the amphibole has itself altered to biotite which is usually brown but sometimes green. Iron pyrites is associated with the ferromagnesian mineral aggregates.

3. *South-western Mount Bouvier*

A sub-circular heterogeneous pluton 1·75 miles (2·8 km.) across has been intruded into the stratified rocks of south-western Mount Bouvier (p. 19; Figs. 7C and 8C). The rocks of this pluton range widely in appearance. Some are dark and fine-grained, and they contain large phenocrysts of plagioclase (T.301);

a few are dark and coarse-grained (T.299), and relatively pale-coloured and coarse-grained rocks (T.306, 307) are commonest. A part of the dark and fine-grained facies contains inclusions of a rock similar to the dark gabbros (p. 31), and the dark coarse-grained facies at station T.305 is banded by stringers of finer-grained material and schlieren of a very femic coarse-grained rock.

The predominant rock at station T.305 (T.305.1; Table IX) is a gabbro in which hypersthene is only slightly less concentrated than clinopyroxene. The rock is apparently a product of disturbed crystallization. Labradorite is present both as phenocrysts, which are flow-aligned, and the more common crystals of a coarsely trachytic groundmass. The hypersthene is mantled by the clinopyroxene, which has been partially altered to hornblende. The coloured minerals are small and it is believed that many of them have been derived from the assimilation of xenoliths (cf. T.274.1). The coarse-grained rock from near the intrusion margin at station T.307 has a lower colour index and it is slightly more silicic than the rock at station T.305. The equigranular tabulae in it are andesine-labradorite and its pyroxene has totally altered to hornblende.

4. *Blümcke Knoll*

Of the very variable rocks cropping out on a restricted exposure on Blümcke Knoll (T.16, 287; Figs. 7E and 8E), the predominant rock is gabbroic. A very coarse-grained gabbro has been intruded as veins which are parallel to the broad banding in these rocks.

The main rock of this exposure (T.16.1; Table VIII) contains labradorite crystals which range greatly in size; large markedly zoned crystals are probably xenocrysts. Clinopyroxene is either interstitial or it ophitically encloses plagioclase, and it has altered to hornblende and to rarer actinolite. Iron ores are unusually numerous. The only felsic crystals in the coarse veins (T.16.7) in the gabbros are phenocrysts (up to 1·3 cm. in length) of labradorite zoned to andesine. They comprise 65 per cent (estimated) of the rock. Interstitial or aggregated hornblende may poecilitically enclose smaller plagioclase crystals, and euhedral and skeletal iron ores. Chlorite has replaced the hornblende and this is often most noticeable in the centres of the aggregated amphibole masses; in some cases hornblende has re-grown as a fibrous network in the chlorite (Plate VIId). Apatite crystals are rare and small.

5. *Western Mount Gaudry and Mount Barré*

Rather variable rocks cropping out on western Mounts Gaudry and Barré are on all exposures darker than those of the nearby intrusion of northern Mount Mangin (p. 40). The facies exposed on north-western Mount Gaudry (T.202.1; Table VIII) is almost identical in petrography to the rock exposed on western Mount Ditte (T.355.1; p. 39). A rock from south-western Mount Gaudry (T.223.1; Table VIII), close to the contact between the intrusion and a very dark gabbro (p. 32), is similar in appearance and mineralogy to the gabbro of Blümcke Knoll (T.16.1), apart from its smaller ore content and comparative fineness in grain-size. A labradorite-bearing granodiorite from western Mount Barré (T.348.1; Table VIII) is unusually rich in potassium feldspar.

6. *Mount Vélain*

An intrusive rock, similar in the hand specimen to the coarser of the two light-coloured gabbros of Léonie Island (p. 37), is exposed on south-western Mount Vélain (Figs. 7A and 8A). The country rocks have been stained by limonite near its contacts. Well-rounded xenoliths of the country rocks are common in this intrusion (T.286).

D. Homogeneous Tonalites and Granodiorites

Tonalites and granodiorites cropping out in homogeneous intrusions are coarser in grain-size and lighter in weathering colour than most of the rocks of the heterogeneous intrusions. They weather to a characteristic honey-brown colour. The tonalite of the large nunatak east of Crumbles Glacier (T.76–78, 174), which has already been described because it may be part of a heterogeneous intrusion (p. 37), may be either an independent intrusion of this type or a marginal facies of the leucogranodiorite described below (p. 42).

1. *Mount Reeves and western Mount Bouvier*

An apparently homogeneous intrusion is exposed on the western and northern sides of Mount Reeves and it is believed to extend eastwards as far as Landauer Point (p. 27). It is accessible only on south-western Mount Reeves (T.10–15; Figs. 2 and 3), where the rocks are tonalites. A tonalite regarded as distinct from that of Mount Reeves crops out on the western side of Mount Bouvier, from southern Mount Reeves to near the southern end of Mount Bouvier. This rock weathers on all exposures to a noticeably lighter shade than the rock of Mount Reeves; however, snow covers the presumed contact between the two intrusions on the mountain walls east of Bond Nunatak. The steeply dipping western contact of the southern pluton against stratified rocks is visible at the tips of the western ridges of Mount Bouvier (T.32, 296, 297, 301). Its eastern margin against the country rocks exposed on the eastern walls of Mount Bouvier is not visible but it must trend along the mountain crest.

The tonalite of south-western Mount Reeves (T.13.1; Table VIII) contains sparse large clots of aggregated ferromagnesian minerals. Crystals of quartz up to 1 mm. across and of potassium feldspar up to 2·5 mm. across are interstitial to tabular subhedra of andesine, which often display oscillatory zoning. Hornblende forms small aggregated crystals and larger prisms up to 2·5 mm. in length, with which are associated occasional crystals of iron ore and ragged biotite. The tonalite of western Mount Bouvier (T.32.1; Table VIII) is noticeably more silicic and less mafic than that of Mount Reeves. Anhedra of quartz and potassium feldspar are set between euhedral tabular crystals of andesine zoned to oligoclase. Intricate twinning and intergrowths are present in some of the plagioclase crystals. The smaller examples among hornblende crystals up to 2·5 mm. across have in many cases clustered together; the amphibole, which is the same as that found in the intrusion on Mount Reeves, has alteıed to a chlorite with similar colours and to epidote.

2. *Western Mount Liotard*

The brown-weathering granodiorite exposed on the western faces of Mount Liotard (Figs. 4 and 5) is identical in hand-specimen appearance to the rock of south-western Mount Reeves (T.13.1). Only the northern and southern limits of the intrusion are known. Relatively leucocratic dykes have been intruded from the granodiorite into the gabbros exposed on south-western Mount Gaudry (p. 32, 41) and the calcic rocks have been bleached near the dykes. This granodiorite (T.224.1; Table VIII) is nearly identical in composition to the matrix granodiorite of eastern Mount Mangin (T.281.1; p. 40) but it is slightly coarser in grain-size. Though clinopyroxene is absent, there is a corresponding increase in the proportion of aggregated crystals of hornblende, which has partially altered to biotite and chlorite. Quartz crystals, which have been slightly corroded by potassium feldspar, are also concentrated into aggregates.

3. *Leucogranodiorite of Square Peninsula*

A large intrusion of hololeucocratic granodiorite crops out over much of Square Peninsula. The rocks of this pluton vary only near its northern end, where there are exposed in places marginal microgranodiorites and micro-adamellites whose red colours are darker than that of the main phase of the intrusion. On the ridge on Square Peninsula west of Webb Island, such a redder rock overlies the main phase; the contact between the two rock types dips at 11° towards 312° mag. (T.164). Zones of screens have been formed at the north-western and south-western sides of this intrusion, where it is in contact with quartz-gabbros of a heterogeneous intrusion (p. 37, 38). Contacts examined elsewhere are sharp. Large and small inclusions in the zones of screens show little sign of having been assimilated, and there has been little assimilation of the xenoliths nearer the centre of the intrusion. In the south-western zone, which is 250 yd. (229 m.) wide, the screens of quartz-gabbro are parallel to a joint set dipping at 70° towards 070° mag. and separated by wide sheets of the granodiorite. The quartz-gabbro intrusion breccia of the screens and the surrounding quartz-gabbro intrusion-breccia mass have been extensively brecciated by fine-grained veins from the granodiorite. Net-veins of micro-adamellite are prominent in the north-west (Plate IIIc). On a nunatak east of Crumbles Glacier, a belt of intrusive rock 100 yd. (91·4 m.) wide lies between the leucogranodiorite and the heterogeneous rocks which it intrudes. This veneer of coarse-grained light-mesocratic rock, in which feldspar is dark in the hand specimen, contains many xenoliths and it has sharp contacts with the gabbros it intrudes and the leucogranodiorite intruding it.

West of and on Rothera Point, very limited exposures are of adamellite intruding the darker, finer-grained heterogeneous intrusion to the south (p. 37). The adamellite is interpreted as a marginal modification of the leucogranodiorite. The contact between the adamellite and the gabbro (T.89) is peculiar in that it varies from well-defined to gradational. It is easily distinguished in localities where the adamellite is a very coarse intrusion breccia (Plate IIId), in which stratified rocks, not the quartz-gabbro, form the xenoliths. The contact is not easily traced where the penetrating rock contains only sparse inclusions.

Typical leucogranodiorite from a nunatak at the centre of the intrusion (T.63.1; Table VIII) is hypidiomorphic granular tending to xenomorphic granular. Potassium feldspar and subhedral to anhedral quartz containing many inclusions are interstitial to cloudy oligoclase-andesine tabulae, which are zoned to albite-oligoclase. Antigorite has pseudomorphed a mica, probably biotite, which was apparently the only ferromagnesian mineral present. Iron pyrites and occasional associated zircon crystals are scattered through the rock. The dark red fine-grained upper rock of the ridge west of Webb Island is a leuco-adamellite (T.164.2; Table VIII). Quartz has coarsely intergrown with potassium feldspar, which is usually microperthitic, and the rock has a granophyric texture. Coarse-grained andesine zoned to albite-oligoclase is rimmed by perthite, and some tabulae are antiperthitic. Very rare disrupted clots of hornblende crystals have altered via biotite to yellow-green chlorite and epidote. The hornblende is very pale coloured in some parts of the crystals. The paler rock which the micro-adamellite overlies is a granophyric leucogranodiorite (T.164.1; Table VIII).

The more femic adamellite of the south-eastern margin of the pluton (T.89.2; Table VIII) is also crudely granophyric in parts and it contains anhedral quartz crystals in clots up to 6 mm. across. Shreds of quartz are contained by interstitial penetrative potassium feldspar, which has corroded tabulae up to 4 mm. in length of andesine zoned to oligoclase. Iron ores and apatite are contained by hornblende crystals up to 4 mm. across. The rock of the heterogeneous intrusion close to the contact of this adamellite appears to have been modified by mobile quartz and potassium feldspar, because this very dark and fine-grained rock is modally granodioritic (T.89.1; Table VIII). Its composition is very similar to that of the much coarser granodiorite of north-western Square Peninsula (T.274.1; p. 39) except for its rather higher colour index and the presence in it of plagioclase phenocrysts; these are zoned, like the plagioclase of the groundmass, to oligoclase. Ferromagnesian minerals are aggregated. Pale hornblende has been derived from clinopyroxene. A relatively dark fine-grained xenolith in this rock contains the same minerals as the matrix, except for the more calcic plagioclase of both the phenocrysts and the small crystals. The xenolith margin is marked by concentrations of quartz and perthitic potassium feldspar.

4. *Augite-granophyres south-west of Sighing Peak*

Two miles (3·2 km.) south-west of Sighing Peak, a small pluton of pale-coloured rocks (T.156, 157; Figs. 4 and 5) has been intruded into the stratified rocks and into the tonalite of station T.158 (p. 38). Two phases of the intrusion are separated by a sharp vertical contact striking along 100° mag.; to the south of the contact the rock is packed with usually angular inclusions (T.156) but to the north the same matrix contains almost no inclusions (T.157). Among the xenoliths of stratified country rocks are a few of gabbroic plutonic rocks. The inclusion-filled phase is possibly an extensive marginal modification of the pluton, though the sharp junction between the phases is in that case unusual. It is more likely that the inclusion-free phase was intruded soon after the older xenolithic rock and displaced it from parts of the pluton.

Both phases of this intrusion are conspicuously myrmekitic and perthitic (Plate VIIe). Both contain phenocrysts up to 3 mm. across and smaller groundmass crystals which are of labradorite, strongly zoned to oligoclase-andesine. In both of these rocks, colourless euhedral to subhedral clinopyroxene crystals up to 0·8 mm. across have altered to epidote or marginally to chlorites, of which antigorite and pennine are the commonest varieties. Very long apatite needles are prominent in both phases.

5. *Eastern Mount Liotard*

A light-coloured intrusion is emplaced in stratified rocks on the north side of the large inaccessible cirque on the south-western flank of Mount Liotard, north of Sloman Glacier. The homogeneous intrusion weathers to the characteristic honey-brown colour of typical granodiorites. Only the approximate positions of the pluton margins are known.

6. *Islands off south-western Adelaide Island*

Coarse-grained white-weathering granodiorite exposed on Crouch Island, Preston Island and smaller islands nearby (T.102, 257, 259, 260; Figs. 11B and 12B) surrounds an islet on which darker gabbro is exposed (T.258; p. 32). The silicic rock crops out over Jennings Reef, where in places it contains many xenoliths up to 6 in. (15 cm.) across or more (T.256). Farther north, coarse-grained granodiorite, which weathers to a brilliant white, crops out on the Chatos and Cenobite Islands (T.332; Figs. 11A and 12A) and below the ice cliffs of Cape Adriasola (T.331).

A coarse-grained felsic granodiorite exposed on one of the western islets of Jennings Reef (T.256.1) contains andesine tabulae which are zoned to albite-oligoclase. The sodic plagioclase has filled cracks in some of the disrupted tabulae, of which the zoning is very disturbed. Quartz (estimated at 15 per cent of the rock) and potassium feldspar (10 per cent) are interstitial; the potassium feldspar has corroded plagioclase and is in places perthitic. Rather sparse green hornblende and brown biotite have altered extensively to chlorite. Very pale granodiorite which crops out on the Cenobite Islands (T.332.1) contains oligoclase, large crystals of quartz and considerable amounts of interstitial potassium feldspar. Sparse pale green amphibole may be primary. Brown biotite has been generally replaced by platy aggregates of crystals of a dark grey-green biotite, with which are associated anhedra of sphene up to 1·5 mm. across.

E. Late-stage Silicic Differentiates

1. *Adamellite of League Rock*

The most silicic and alkalic rock exposed in the Adelaide Island area is a leuco-adamellite, which crops out on League Rock (T.333; Figs. 11B and 12B). This pink rock is homogeneous apart from its content of rounded grey xenoliths up to 3 in. (7·6 cm.) across. In this equigranular rock (T.333.1; Table VIII), abundant potassium feldspar has corroded and probably extensively replaced oligoclase tabulae up to 4 mm. across. The plagioclase is slightly zoned and it has shadowy, disturbed polysynthetic twinning. The rock contains very sparse ferromagnesian minerals, including hornblende, biotite, sphene, orthite, iron ore and epidote.

2. *Late-stage veins*

Systems of fine- to coarse-grained felsic veins ranging from inches to several feet in width intrude all other Andean intrusive rocks and rocks of previous ages. They tend to be intruded parallel to the joint directions. Small deposits of quartz, aragonite, pyrite, magnetite (p. 17) and copper ores are associated with such veins in different places. Many of the vein systems originate in the granodiorite and tonalite intrusions (e.g. at stations T.201, 223, 301). Where these veins traverse the leucogranodiorite of Square Peninsula (p. 42), their margins may be sharp or diffuse. The veins are in places composite and they have a relatively femic centre between pink feldspathic borders. The central parts of such composite veins may contain unusually large crystals; for instance, on Léonie Island (T.233) crystals of amphibole replaced by chlorite are up to 5 in. (13 cm.) long in the centre of one such vein.

White veins traverse the gabbros and related rocks of exposures on the western coast and islands of Laubeuf Fjord (p. 37). Two felsic veins, described on p. 40, are mineralogically similar to the gabbros they intrude but they lack the dark minerals of the gabbros. These thin vein systems are in many cases very constant in attitude, although they do not always follow the directions of the joints which can still be distinguished.

F. Geochemistry

Five new chemical analyses (Table X) have been carried out in the course of investigations into the heterogeneous intrusions of Adelaide Island. They are of rocks taken from exposures near McCallum Pass (Figs. 4 and 5) where the rocks of a heterogeneous intrusion differ considerably in appearance and composition (p. 38, 39). Three of the analysed specimens (T.243.1, 245.2, 274.1) are from the heterogeneous intrusion and one (T.243.2) is of the wall rock exposed near specimen T.243.1 at the pluton margin.

Table X

NEW AND PREVIOUS ANALYSES OF ANDEAN INTRUSIVE ROCKS FROM THE ADELAIDE ISLAND AREA

	T.243.2	T.243.1	T.244.1	T.245.2	T.274.1	1	2	3	4	
SiO_2	54·56	53·43	47·24	55·39	66·96	47·51	48·11	48·50	52·50	SiO_2
TiO_2	1·15	0·76	0·41	1·49	0·49	0·38	0·33	1·32	0·62	TiO_2
Al_2O_3	16·18	16·50	16·28	15·64	14·07	23·03	23·08	19·26	16·02	Al_2O_3
Fe_2O_3	4·26	2·51	3·16	3·30	0·62	1·08	2·29	4·24	1·70	Fe_2O_3
FeO	4·75	4·67	5·98	4·92	2·87	4·00	3·28	5·26	6·58	FeO
MnO	0·19	0·11	0·13	0·13	0·04	n.d.	n.d.	n.d.	0·15	MnO
MgO	4·54	5·81	11·70	4·62	2·80	6·69	5·55	4·63	8·70	MgO
CaO	8·47	9·27	10·40	8·29	3·85	15·08	14·53	12·86	10·18	CaO
Na_2O	4·47	3·56	2·03	3·95	4·07	1·41	1·81	2·02	2·34	Na_2O
K_2O	0·42	0·99	0·14	1·18	3·10	0·22	0·23	1·06	1·08	K_2O
H_2O+	0·71	1·86	2·22	1·18	0·85	0·98	0·88	0·50	0·19	H_2O+
H_2O-	0·07	0·09	0·09	0·07	0·07	n.d.	n.d.	n.d.	n.d.	H_2O-
P_2O_5	0·22	0·14	0·05	0·16	0·08	0·00	0·06	0·19	0·11	P_2O_5
CO_2	0·17	0·31	0·21	0·12	0·22	n.d.	n.d.	n.d.	0·00	CO_2
TOTAL	100·16	100·01	100·04	100·04	100·09	100·38	100·15	99·84	100·17	TOTAL
				ANALYSES LESS TOTAL WATER (Recalculated to 100)						
SiO_2	54·90	54·49	48·34	56·07	67·52	47·80	48·46	48·82	52·51	SiO_2
TiO_2	1·16	0·78	0·42	1·10	0·50	0·38	0·33	1·33	0·62	TiO_2
Al_2O_3	16·28	16·83	16·66	15·83	14·19	23·17	23·25	19·39	16·03	Al_2O_3
Fe_2O_3	4·29	2·56	3·23	3·34	0·63	1·09	2·31	4·27	1·70	Fe_2O_3
FeO	4·78	4·76	6·12	4·98	2·89	4·02	3·31	5·29	6·58	FeO
MnO	0·19	0·11	0·13	0·13	0·04	—	—	—	0·15	MnO
MgO	4·57	5·92	11·97	4·68	2·82	6·73	5·59	4·66	8·70	MgO
CaO	8·52	9·45	10·64	8·39	3·88	15·17	14·64	12·95	10·18	CaO
Na_2O	4·50	3·63	2·08	4·00	4·10	1·42	1·82	2·03	2·34	Na_2O
K_2O	0·42	1·01	0·14	1·20	3·13	0·22	0·23	1·07	1·08	K_2O
P_2O_5	0·22	0·14	0·05	0·16	0·08	—	0·06	0·19	0·11	P_2O_5
CO_2	0·17	0·32	0·22	0·12	0·22	—	—	—	—	CO_2
					NORMS					
Q	5·08	2·92	—	5·76	19·51	—	—	1·77	0·03	Q
or	2·48	5·97	0·83	7·09	18·50	1·30	1·36	6·32	6·38	or
ab	38·08	30·72	17·60	33·85	34·69	12·02	15·40	17·18	19·80	ab
an	22·98	26·65	35·71	21·70	11·06	56·20	54·59	40·64	30·05	an
di	13·43	13·89	12·25	14·60	5·09	15·29	14·06	17·94	15·94	di
hy	8·62	13·61	15·98	9·44	8·58	6·76	9·50	7·00	23·90	hy
ol	—	—	11·53	—	—	6·15	0·96	—	—	ol
mt	6·22	3·71	4·68	4·84	0·91	1·58	3·35	6·19	2·46	mt
il	2·20	1·48	0·80	2·09	0·95	0·72	0·63	2·53	1·18	il
ap	0·52	0·33	0·12	0·38	0·19	—	0·14	0·45	0·26	ap
cc	0·39	0·73	0·50	0·27	0·50	—	—	—	—	cc
					CATION PERCENTAGES					
Si^{+4}	25·66	25·47	22·60	26·21	31·56	22·34	22·65	22·82	24·55	Si^{+4}
Al^{+3}	8·62	8·91	8·82	8·38	7·51	12·26	12·30	10·26	8·48	Al^{+3}
Fe^{+3}	3·00	1·79	2·26	2·34	0·44	0·76	1·62	2·99	1·19	Fe^{+3}
Mg^{+2}	2·76	3·57	7·22	2·82	1·70	4·06	3·37	2·81	5·25	Mg^{+2}
Fe^{+2}	3·72	3·70	4·76	3·87	2·25	3·12	2·57	4·11	5·11	Fe^{+2}
Na^{+1}	3·34	2·69	1·54	2·97	3·04	1·05	1·35	1·51	1·74	Na^{+1}
Ca^{+2}	6·09	6·75	7·60	6·00	2·77	10·84	10·46	9·26	7·28	Ca^{+2}
K^{+1}	0·35	0·84	0·12	1·00	2·60	0·18	0·19	0·89	0·90	K^{+1}
Ti^{+4}	0·70	0·47	0·25	0·66	0·30	0·23	0·20	0·80	0·37	Ti^{+4}
Mn^{+2}	0·15	0·09	0·10	0·10	0·03	—	—	—	0·12	Mn^{+2}
P^{+5}	0·10	0·06	0·02	0·07	0·03	—	0·03	0·08	0·05	P^{+5}
O^{-2}	45·51	45·66	44·71	45·58	47·77	45·16	45·26	44·47	44·96	O^{-2}
Position $[(\frac{1}{3}Si+K)-(Ca+Mg)]$	+0·05	−0·99	−7·17	+0·92	+8·65	−7·27	−6·09	−3·57	−3·45	Position $[(\frac{1}{3}Si+K)-(Ca+Mg)]$
{ Fe	70·9	60·6	49·3	68·8	61·3	48·9	55·4	71·6	54·5	{ Fe
{ Mg	29·1	39·4	50·7	31·2	38·7	51·1	44·6	28·4	45·5	{ Mg
{ Fe	51·0	43·6	44·2	47·8	26·8	42·3	46·0	57·7	44·4	{ Fe
{ Mg	21·0	28·4	45·4	21·7	17·0	44·3	37·1	22·8	37·0	{ Mg
{ Alk	28·0	28·0	10·4	30·5	56·2	13·4	16·9	19·5	18·6	{ Alk
{ Ca	62·3	65·6	82·1	60·2	32·9	89·8	87·2	79·4	73·4	{ Ca
{ Na	34·1	26·2	16·6	29·8	36·2	8·7	11·2	13·0	17·5	{ Na
{ K	3·6	8·2	1·3	10·0	30·9	1·5	1·6	7·6	9·1	{ K

T.243.2 Recrystallized andesite at western contact of heterogeneous intrusion; west of McCallum Pass, Adelaide Island (anal. G. J. Dewar).
T.243.1 Microtonalite (contact phase of heterogeneous intrusion), west of McCallum Pass, Adelaide Island (anal. G. J. Dewar).
T.244.1 Dark gabbro, western wall of McCallum Pass, Adelaide Island (anal. G. J. Dewar).
T.245.2 Microdiorite, eastern wall of McCallum Pass, Adelaide Island (anal. G. J. Dewar).
T.274.1 Granodiorite, coastal cliffs of south-western Stonehouse Bay, Adelaide Island (anal. G. J. Dewar).
1 Gabbro, Léonie Island (Gourdon, 1917).
2 Gabbro, Webb Island (Gourdon, 1917).
3 Gabbro, Jenny Island (Gourdon, 1917).
4 Bronzite-orthoclase-gabbro, Cerro Payne, Patagonia (Quensel, 1912).
(The analyses of rocks from McCallum Pass are set out in their order of field occurrence as found during a traverse from the margin to the centre of the heterogeneous intrusion.)

TABLE XI

PARTIAL CHEMICAL ANALYSES OF ROCKS FROM THE HETEROGENEOUS INTRUSION OF NORTHERN MOUNT MANGIN (TABLE IX)

	T.29.1	T.230.1	T.231.1	T.232.1	T.235.1	T.237.1	T.238.1
SiO_2	59·63	54·59	56·42	63·90	57·91	56·71	58·44
Na_2O	4·42	3·87	3·95	3·95	4·15	3·82	3·76
K_2O	2·34	1·34	1·71	3·38	2·40	2·28	1·50

T.29.1 Tonalite, Lincoln Nunatak.
T.230.1 Diorite, scarp peak north of Lincoln Nunatak.
T.231.1 Tonalite, north-western exposures of scarp north-west of Mount Mangin.
T.232.1 Granodiorite, scarp north-west of Mount Mangin.
T.235.1 Granodiorite, north-west Mount Mangin.
T.237.1 Tonalite, northern Mount Mangin.
T.238.1 Granodiorite, northern Mount Mangin.

Specimen T.244.1 is a dark gabbro, of which the field relationships are doubtful; it is thought to have been intruded independently before the heterogeneous rocks (p. 32).

Partial analyses have been made of seven specimens from the heterogeneous intrusion of north-west Mount Mangin (Figs. 4 and 5), which is believed to connect at a shallow depth with the heterogeneous rocks of McCallum Pass (p. 40). The exposures (T.29, 230–232, 235, 237, 238) from which the specimens for partial analysis were taken are on roughly the same line as the exposures of the rocks of McCallum Pass. The oxides determined in these rocks were SiO_2, Na_2O and K_2O (Table XI).

Three previous analyses of gabbros from the Adelaide Island area (Gourdon, 1917) are quoted in Table X for comparison. The exposures from which Gourdon took his specimens have not been identified from his descriptions, but it is believed that his specimens from Léonie Island (Table X, analysis 1) and Jenny Island (Table X, analysis 3) are dark gabbros (p. 31). The analysis of the rock from Webb Island (Table X, analysis 2) may be of either unmodified or xenolithic gabbro, both of which crop out there (p. 32).

1. *General comparison of Andean rocks from Adelaide Island with those from other areas*

From many published analyses of rocks of the Andean Intrusive Suite of Graham Land, Adie (1955) has shown that the suite is calc-alkaline. A metasomatic silicic facies has been described by Hooper (1962) from Anvers Island.

The distribution of the major elements in the analysed rocks from McCallum Pass is shown in Table X. In Fig. 14 the weight percentages of the elements have been plotted as ordinates against the abscissal modified Larsen function $[(\frac{1}{3}Si+K)-(Ca+Mg)]$. The variation curves (dashed lines) shown in Fig. 14 are those suggested by Adie (1955, figs. 11–14) as typical of the Andean Intrusive Suite.

Only two (T.245.2, 274.1) of the rocks from McCallum Pass plot within the range of modified Larsen index covered by Adie's variation curves, but another (T.243.1) has a modified Larsen position which is only slightly too low to lie within this range. These three analyses show that the proportions of major elements in the McCallum Pass rocks vary in the same way as in rocks typical of the Andean Intrusive Suite (Fig. 14). Si and Mg tend to be higher and Al lower than in the typical Andean rocks.

In all the analyses of Andean intrusive rocks from the Adelaide Island area, apart from that from Jenny Island, the ratio Mg/(total iron) is unusually high. Fig. 14 shows that in any of the analysed rocks from the Adelaide Island area the high Mg/(total iron) ratio is produced by amounts of Mg or total iron which are respectively higher or lower than is typical of the Andean Intrusive Suite. The typical values are shown by the variation curves characteristic of this suite. Total iron in the analysed rocks from the Adelaide Island area generally conforms to the curve typical of the Andean Intrusive Suite but it is unusually low in the gabbros of Léonie and Webb Islands (Fig. 14, analyses 1 and 2). The opposite relationship occurs in the case of Mg, which tends to be unusually high in the rocks from Adelaide Island, except in these two gabbros and in the gabbro of Jenny Island (Fig. 14, analysis 3). The high Mg/(total iron) ratio in these rocks is also shown in the triangular variation diagram $(Fe''+Fe''')$—Mg—Alk (Fig. 15), on which the rocks plot on the Mg-rich side of variation curves suggested by Adie (1955, fig. 10) for the Andean

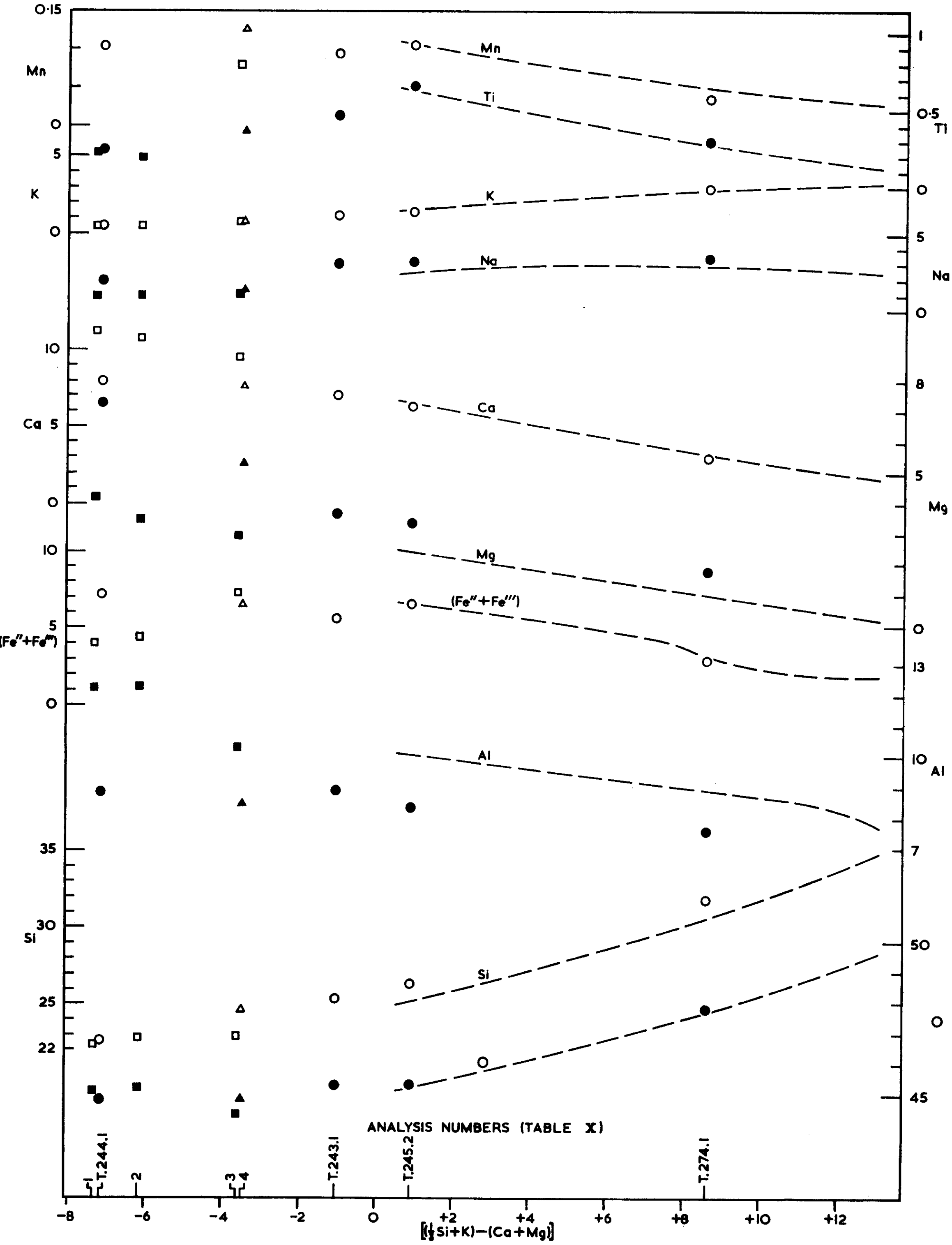

FIGURE 14

Diagram showing variation of the major elements (see chemical analyses in Table X) of the Andean intrusive rocks of the Adelaide Island area. Element percentages have been plotted as ordinates against the abscissal modified Larsen function [(⅓Si+K)–(Ca+Mg)]. The curves are those typical of the Andean Intrusive Suite (Adie, 1955, figs. 11–14). The points (●, ○) refer to rocks from the McCallum Pass area, those (■, □) refer to other analysed rocks from the Adelaide Island area, and those (▲, △) are of a gabbro from Patagonia in which the element distribution is similar to that of the rocks of McCallum Pass.

T.243.1 Microtonalite at a contact with wall rock (Table X).
T.244.1 Dark gabbro (Table X).
T.245.2 Microdiorite (Table X).
T.274.1 Granodiorite (Table X).
1. Gabbro (Table X, analysis 1).
2. Gabbro (Table X, analysis 2).
3. Gabbro (Table X, analysis 3).
4. Bronzite-orthoclase-gabbro (Table X, analysis 4).

Intrusive Suite. Rocks from Anvers Island (Hooper, 1962, p. 59) are also characteristically rich in Mg but they are not as markedly so as the rocks of Adelaide Island. The rocks from McCallum Pass contain more Na than is usual in rocks of the Andean Intrusive Suite (Fig. 14); in the triangular variation diagram Ca—Na—K (Fig. 15) these analyses plot on the Na-rich side of the characteristic curve (Adie, 1955) for the Andean Intrusive Suite. This effect is believed to have been at least partially produced by the Na-rich spilitic rocks into which the plutonic rocks have been intruded (p. 23).

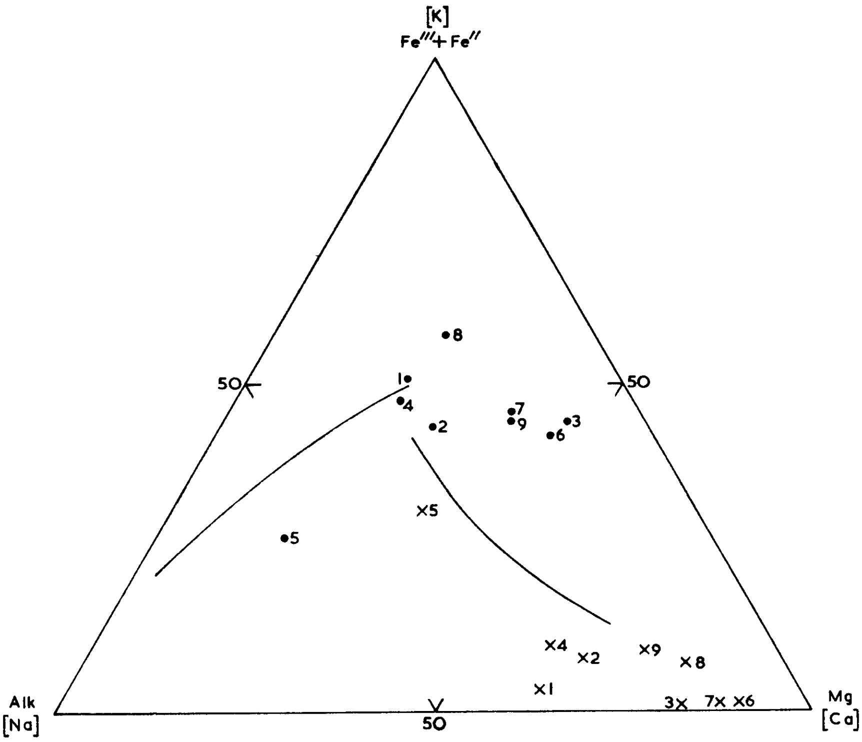

FIGURE 15

Triangular variation diagrams for chemical analyses (Table X) plotted on the co-ordinates (Fe″+Fe‴)—Mg—Alk (●) and Ca—Na—K (×). The variation curves are those suggested by Adie (1955, fig. 10) as typical of the Andean Intrusive Suite of Graham Land.

1. Andesitic wall rock (T.243.2; Table X).
2. Microtonalite at a contact with wall rock (T.243.1; Table X).
3. Dark gabbro (T.244.1; Table X).
4. Microdiorite (T.245.2; Table X).
5. Granodiorite (T.274.1; Table X).
6. Gabbro (Table X, analysis 1).
7. Gabbro (Table X, analysis 2).
8. Gabbro (Table X, analysis 3).
9. Bronzite-orthoclase-gabbro (Table X, analysis 4).

2. *Geographical distribution of major elements in the rocks of McCallum Pass*

The major elements present in the analysed rocks from McCallum Pass have been plotted against their distances from the intrusion margin at station T.243 (Fig. 16). In spite of the small number of analyses, some information can be gained from this diagram:

i. Most of the variation curves of the major elements in Fig. 16 are distant from the positions plotted for elements in the dark gabbro (T.244.1). The two analysed rocks from exposures next to that of the dark gabbro are very similar in composition (T.243.1, 245.2; Table X) and they are probably typical of the margin of the heterogeneous intrusion. Fig. 16 is believed to show that the dark gabbro is not part of the heterogeneous intrusion; the curve which most clearly shows this is that for Mg.

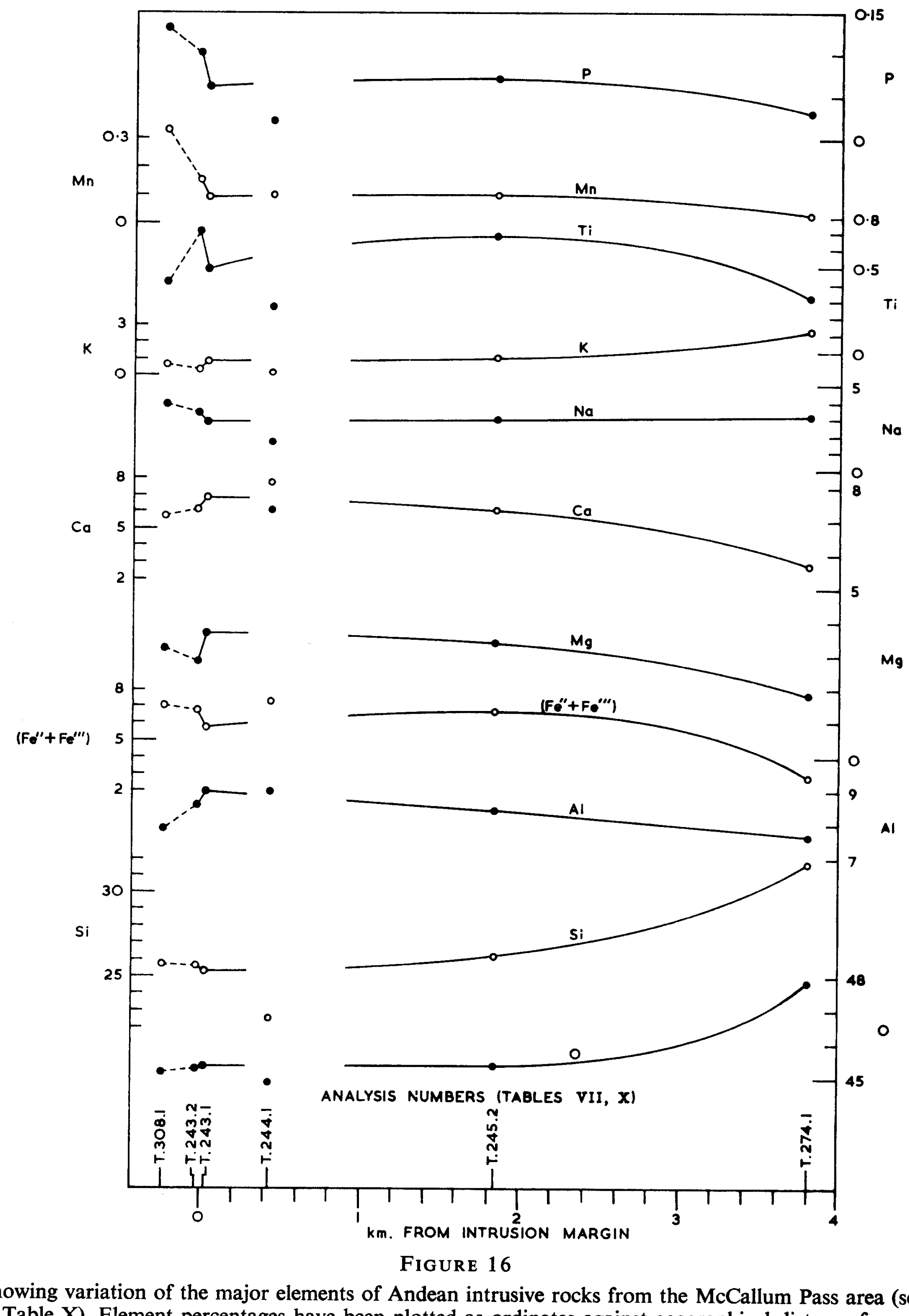

FIGURE 16

Diagram showing variation of the major elements of Andean intrusive rocks from the McCallum Pass area (see chemical analyses in Table X). Element percentages have been plotted as ordinates against geographical distance from the margin of the heterogeneous intrusion from which the analysed specimens were taken. The element distribution of the country rock west of the contact at station T.243 is represented by that of a typical spilite of the Mount Liotard succession (T.308.1; Table VII) plotted at an arbitrary distance from the contact.

T.243.2 Andesitic wall rock (Table X).
T.243.1 Microtonalite at a contact with wall rock (Table X).
T.244.1 Dark gabbro (Table X).
T.245.2 Microdiorite (Table X).
T.274.1 Granodiorite (Table X).
T.308.1 Quench-brecciated lava (Table VII).

ii. The wall rock (T.243.2) has a composition similar to those of spilitic rocks from the Mount Liotard succession (Table VII). The spilitic nature of the wall rock is shown most clearly by its position on the triangular variation diagram Ca—Na—K (Fig. 15; cf. Fig. 9). The alumina content in the wall rock is slightly higher than that of the typical spilites of the Mount Liotard succession. Assuming that the average country rock of McCallum Pass is similar to specimen T.308.1, the analysis of specimen T.308.1 has been plotted in Fig. 16 at an arbitrary distance from the contact.

Specimen T.243.1 is richer in O, Al, Ca and K than the spilite thought to be typical of the country rocks (T.308.1) and the country rocks at the contact (T.243.2). There appear to be Al, Ca and Mg fronts at the contact, because these elements are more concentrated in the contact phase of the intrusion than in the country rocks at the contact and in the intrusion distant from the contact. Na, P and Mn have been extracted from the country rocks by the intrusion. The behaviour of total iron and Ti at the contact is anomalous; Ti reaches a maximum in the contact phase of the country rocks and total iron has its lowest value in the contact phase of the intrusion.

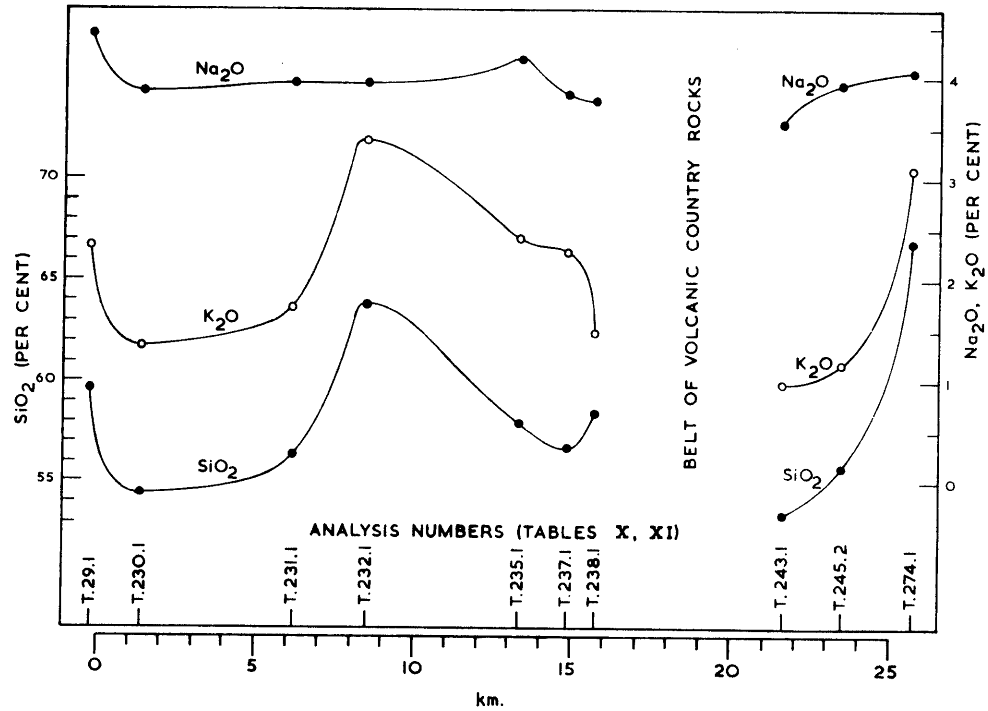

FIGURE 17

Diagram showing the variation of SiO_2, Na_2O and K_2O in rocks from neighbouring heterogeneous intrusions exposed on northern Mount Mangin and Square Peninsula (see chemical analyses in Tables X and XI). Element percentages have been plotted as ordinates against the geographical distance between exposures from which the analysed specimens were taken (Figs. 4 and 5).

T.243.1 Microtonalite at a contact with andesitic wall rock (Table X).
T.245.2 Microdiorite (Table X).
T.274.1 Granodiorite (Table X).
T.29.1 Tonalite (Table XI).
T.230.1 Diorite (Table XI).
T.231.1 Tonalite (Table XI).
T.232.1 Granodiorite (Table XI).
T.235.1 Granodiorite (Table XI).
T.237.1 Tonalite (Table XI).
T.238.1 Granodiorite (Table XI).

iii. Relative to the marginal diorites of the heterogeneous intrusion, the granodiorite at station T.274 contains smaller amounts of Mg and Al, even more noticeably reduced amounts of Ca and total iron, and higher quantities of O, Si and K. This rock has a composition which is unusual for a member of the Andean Intrusive Suite and this is shown most clearly on the triangular variation diagrams (Fig. 15). Its most noticeable deviation from the typical Andean intrusive granodiorites is its high content of Mg, which is almost as pronounced as its high content of Na. Both of these characteristics are typical of the rocks of the heterogeneous intrusion at McCallum Pass; although the high Mg content of specimen T.245.2 is not readily apparent in Fig. 15, it is quite clear in Fig. 14. The consistently high content of Na in these rocks has already been discussed (p. 47). It is difficult to explain the tendency for the rocks of this heterogeneous intrusion to be rich in Mg but it is possible that there has been widespread assimilation of material which is unusually magnesium-rich. An obvious source of such material is the dark gabbro of station T.244, which was intruded before the heterogeneous rocks. Such assimilation, however, cannot be conclusively shown to have taken place.

3. *Variation in heterogeneous intrusions*

In typical rocks from the heterogeneous intrusions of Adelaide Island, quartz and potassium feldspar are noticeably interstitial (p. 36–41). The textures of these rocks suggest that these two minerals, which were clearly the last to crystallize, might have been introduced after crystallization had otherwise virtually been completed. In an attempt to discover whether metasomatism had occurred, the percentages of SiO_2, K_2O and Na_2O for rocks from the heterogeneous intrusions of northern Mount Mangin and McCallum Pass have been plotted against distance (Fig. 17). Fig. 17 shows that SiO_2 and K_2O vary with absolute sympathy in these rocks, except near a contact with the country rocks (T.238). The relatively slight variation in Na_2O is irregular and it is not proportional to those of SiO_2 and K_2O. Such distributions of silica and alkalies, though initially suggesting that Si and K have been introduced, are typical of the differentiation of calc-alkaline magmas (Nockolds and Allen, 1953, figs. 13a–g), and therefore the rocks of the heterogeneous plutons cannot be regarded as abnormal members of the calc-alkaline Andean Intrusive Suite.

4. *Comparison of the dark gabbro of McCallum Pass with those from other areas*

Adie (1955, p. 33) has suggested that the most calcic rocks of the Andean Intrusive Suite are cumulates from a parental magma. He has pointed out that if these rocks, which can be considered as those in which $(Fe''+Fe'''+Mg) : Alk > 3 : 1$, are plotted on the triangular variation diagrams $(Fe''+Fe''')$—Mg—Alk and Ca—Na—K, the points are scattered and are not in agreement with the smooth curves near which more silicic rocks are positioned. Scattering appears to be random on the Ca—Na—K diagram. On the $(Fe''+Fe''')$—Mg—Alk diagram, however, the calcic rocks plot in two distinct groups (Fig. 18) representing two facies:

i. In the rocks of the more randomly distributed group, the ratio $(Fe''+Fe''') : Mg$ is between 24 : 76 and 42 : 58, and the rocks plot along a linear band from the $(Fe''+Fe''')$—Mg side of the triangular diagram towards the Alk apex, generally on the $(Fe''+Fe''')$ side of the distribution curve.
ii. The second group plots on the Mg side of the distribution curve and it shows a trend of rapidly decreasing Mg and correspondingly increasing $(Fe''+Fe''')$ with very little increase in Alk.

Fig. 18 shows that the cumulates are of two distinct facies, which converge to a position $[(Fe''+Fe''') = 54, Alk = 26, Mg = 20]$ at the calcic end of the variation curve for the Andean Intrusive Suite. This is likely to be the position of the proposed parental magma of the Andean Intrusive Suite (Adie, 1955, p. 33).

The distinction between the two facies is clear in Fig. 14, which shows that the element weight percentages of the most calcic rocks of Adelaide Island are not as regular as those of the more silicic rocks of the Andean Intrusive Suite. Variation is most pronounced in the proportions of Ca, Al and especially Mg. The differences between the two facies are expressed in three ways:

i. Ca varies antipathetically with Mg.
ii. With a decrease in the modified Larsen function, Fe may or may not decrease while Mg increases.
iii. Al varies sympathetically with Ca.

It is likely that the rocks of facies (i) have crystallized from a parental magma from which plagioclase had previously precipitated. If cumulative plagioclase (in effect, Alk) had been removed from this magma, the resulting magmas would plot in the same way as the rocks of facies (i), collinear with the parental magma and the Alk apex but near the (Fe''+Fe''')—Mg line. Rocks containing plagioclase precipitated in this way would plot nearer the Alk apex than the parental magma position. It would be almost impossible to distinguish them from rocks crystallized from normal magmas of the Andean Intrusive Suite, because the variation curve which is typical of the Andean Intrusive Suite trends nearly directly from the position of the parental magma to the Alk apex. The scattering of points representing typical Andean intrusive rocks around the typical variation curve (Adie, 1955, figs. 9, 10) is probably partially caused by the incorporation of cumulative plagioclase. Such plagioclase may well be represented in the rocks of Adelaide Island by the xenocrysts or phenocrysts in the heterogeneous intrusions (p. 39); these crystals have relatively calcic cores which are surrounded by more sodic rims. The rocks of facies (ii), in which Mg and (Fe''+Fe''') vary while Alk remains comparatively constant, were probably derived from a parental magma containing cumulative magnesian olivine.

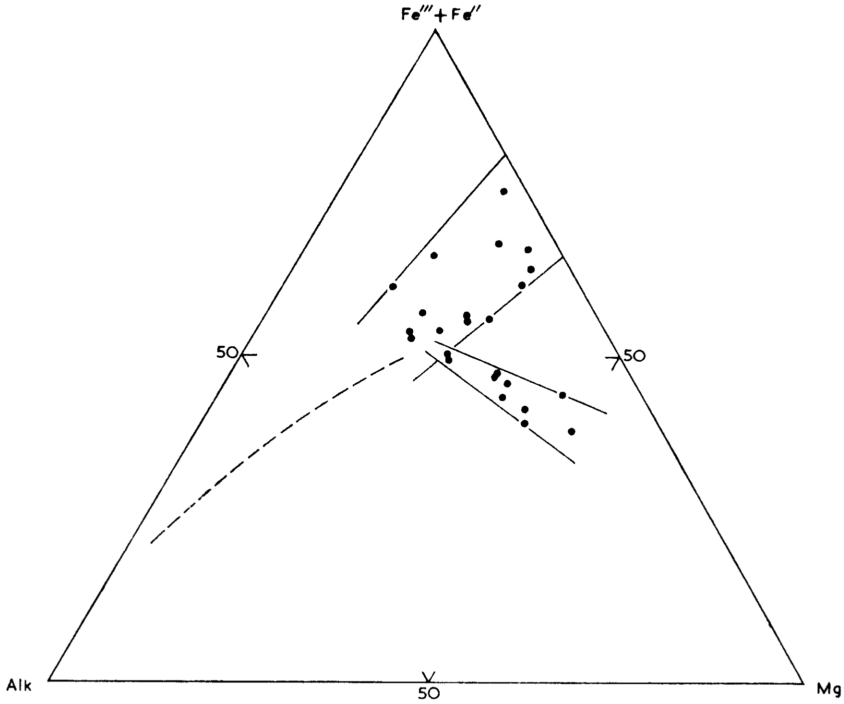

FIGURE 18

Triangular variation diagram plotted on the co-ordinates (Fe''+Fe''')—Mg—Alk, showing positions plotted for the most calcic analysed rocks of the Andean Intrusive Suite (T.244.1; Adie, 1955, fig. 9; Hooper, 1962, fig. 21). The rocks plot into two groups characterized by differences in the distribution of Mg and total iron, and each group has been indicated by lateral lines. The distribution curve representing more silicic members of the Andean Intrusive Suite (Adie, 1955) is also shown (dashed line).

The sub-division into these two facies is shown by the most calcic of the analysed rocks of Adelaide Island. Of the rock analyses given by Gourdon (1917), those from Léonie and Webb Islands (Table X, analyses 1 and 2) are rich in magnesia and belong to facies (ii), whereas that from Jenny Island (Table X, analysis 3) is comparatively rich in iron and belongs to facies (i). The dark gabbro from McCallum Pass is rich in magnesia and belongs to facies (ii) (Table X; Fig. 15).

The dark gabbro from McCallum Pass (T.244.1) has a composition which cannot be matched by other analyses of Andean intrusive rocks from Graham Land. In it, the amount of silica is very high for a rock containing so much lime and magnesia, and alumina is very low (Table X). These characteristics are also shown by a less calcic gabbro from Patagonia (Quensel, 1912) which is included in Table X and Figs. 14 and 15 for comparison. The dark gabbro from McCallum Pass plots close to the gabbros of Léonie and Webb Islands on both the (Fe''+Fe''')—Mg—Alk and Ca—Na—K triangular variation diagrams (Fig. 15), but it is considerably richer in Na, though poorer in Ca, than they are (Fig. 14). It is believed that this dark gabbro is a metasomatic derivative of a rock containing cumulative olivine which was similar to but even more magnesian and calcic than the rock from Léonie Island. Its unusual composition is thought to be due to the introduction of silica and soda from the heterogeneous rocks surrounding the dark gabbro exposure. Potassium has not been introduced, although the younger rocks contain appreciable amounts of interstitial potassium feldspar (p. 39). The introduction of silica and soda after complete or almost complete crystallization of the dark gabbro is shown by the zoning in its fresh plagioclase crystals. Typical gabbros of the Andean Intrusive Suite contain plagioclase which is seldom zoned (Adie, 1955, p. 16), and it is believed that the zonation is not primary. The conversion of bytownite to labradorite in the outer zones of the plagioclase crystals is thought to have caused the apparent deficiencies in Al and Ca in this rock, because both are displaced during this alteration process.

G. Discussion on the Heterogeneous Intrusions

The variations in rock type found in the heterogeneous intrusions of Adelaide Island (p. 36) are clearly visible in the field and they can be demonstrated by petrographical and analytical work (p. 38, 44). These variations are important because the heterogeneous intrusions are those most frequently exposed in this area. It is clear that the rocks found in these intrusions have not had simple magmatic histories, because any of the following characteristics may occur in them:

i. There may be considerable variation in grain-size between the rocks of each intrusion, although no contacts are present in them.
ii. The colour indices may vary as extensively but as gradually as the grain-size.
iii. These rocks may be very inequigranular, because coarse crystals are surrounded by a fine-grained or graphic groundmass. The finer-grained minerals are those crystallizing at lower temperatures.
iv. Xenoliths are very common in these rocks and intrusion breccias containing over 50 per cent of xenolithic material are not rare. Many xenoliths are very rounded in outline (Plate IIIa).
v. Large xenocrysts of plagioclase have been found near xenoliths containing equally large phenocrysts or porphyroblasts. They are believed to have been derived from the xenoliths on the break-up and assimilation of the finer-grained xenolithic material.
vi. The calcic cores of the plagioclase phenocrysts or xenocrysts may have crystallographic orientations which differ from those of the relatively albite-rich rims (Plate VIc). The cores may be either euhedral or rounded. They often contain small rounded crystals of clinopyroxene and iron ores (Plate VIe).
vii. Many of these rocks contain fine-grained anhedral ferromagnesian minerals in aggregates which are likely to be recrystallized xenoliths. These aggregates may be compact or semi-dispersed.
viii. Large crystals of apatite and sphene are locally abundant.
ix. In many of these rocks plagioclase has been corroded by quartz (Plate VIIa) and potassium feldspar (Plate VIIc).
x. Clinopyroxene may be mantled by biotite and hornblende, and it may be replaced by them (Plate VIIb).

It seems likely that all of the heterogeneous intrusions have had similar magmatic histories, although this cannot be definitely demonstrated. The unusual petrographic characters listed above seem to show that a magma originally intruded into the heterogeneous plutons has been modified by foreign material, and it seems likely that this modification has taken place in either of two ways:

i. The magma intruded was granodioritic and has been modified in those parts of the intrusions in which the rock is not a granodiorite. The modification took place when the magma assimilated xenolithic material, the degree of modification depending on the nature of the xenoliths and the amount of foreign material assimilated. That such assimilation may have taken place is shown especially by the characteristics (iv), (v) and (vii) given above.
ii. The magma intruded was gabbroic and it has been modified in those parts of the intrusions in which the rock is not a gabbro. This modification took place when the magma was invaded, after partial crystallization, by a late-stage low-temperature fraction rich in silica and alkalis. The degree of modification depended on the amount of low-temperature liquid available and the stage of crystallization of the original magma at the time of intrusion. That such a metasomatic process may have taken place is shown especially by the characteristics (iii) and (ix) given above.

Curtis (1966), who studied the rocks of the Graham Coast, recorded heterogeneous intrusions in which these features were also present. He interpreted the heterogeneity as being a result of assimilation, and he suggested that an original granodiorite magma had been modified by process (i). The scope of the present study is insufficient to show whether Curtis's suggested process is wholly the cause of the heterogeneity, but several of the rocks studied (p. 38, 40) seem to show that low-temperature material has been introduced, and process (ii) may have been important. It is notable that there are plutons of homogeneous granodiorite and tonalite; if some of the granodiorite plutons were modified by assimilation of calcic material, it might be questioned whether any of them would crystallize without such modification taking place. There are no plutons of homogeneous gabbro, except for the very coarse-grained dark rocks (p. 31), which are believed to be quite distinct from the heterogeneous plutons. One coarse gabbro (T.261.1; p. 32) is believed to have been modified by foreign low-temperature liquids, but its appearance is quite unlike any rock found in a heterogeneous intrusion.

Some of the geochemical results of the present study support Curtis's (1966) suggestion to some extent. The rocks of the heterogeneous intrusion of McCallum Pass are richer in Na than the typical rocks of the Andean Intrusive Suite, and it has been suggested (p. 47) that this is because spilitic country rocks had been assimilated when they were intruded. The process tentatively suggested (p. 50) to explain the unusually high content of Mg in these rocks is that appreciable quantities of magnesium-rich gabbro had been assimilated. Neither of the suggested processes has been conclusively demonstrated as causing these peculiarities of composition.

V. MAFIC HYPABYSSAL ROCKS

A. Pre-Andean

A strong mafic dyke set intruded into the conglomerate of the south-westernmost of the Léonie Islands (Figs. 4 and 5) is cut by a pink Andean aplitic vein. The dyke is composed of dark fine-grained material not readily distinguished in the hand specimen from some of the rocks of post-Andean age. The original nature of the dyke rock (T.137.7) has been masked by its large content of xenocrysts and xenoliths derived from the country rock it intrudes. Its felsic irresolvable groundmass, heavily dusted with tiny opaque crystals, surrounds relatively coarse broken felsic crystals and quartzite fragments up to 1·5 mm. across. A few relatively large iron ore crystals up to 0·5 mm. across tend to be skeletal. Included xenocrysts are andesine ($Ab_{60}An_{40}$) tabulae and laths, and quartz crystals. Very fine-grained aggregated pale green amphibole crystals and fragments of plicated biotite are rare.

B. Post-Andean

1. *Typical post-Andean dykes of Jenny Island*

Three types of mafic dyke have been distinguished among the many which have been intruded into the heterogeneous intrusive rocks of Jenny Island (p. 37; Figs. 4 and 5; Gourdon, 1917, p. 8). They are easily distinguished in the hand specimen because of their different contents of coarse-grained inclusions. The two youngest types are ubiquitous in the Adelaide Island area, where many post-Andean dykes have been intruded along joint directions in the Andean intrusive rocks.

a. The oldest dykes are not consistent in their widths and attitudes and they do not follow the joint directions. They may have been intruded while the host rocks retained some heat and plasticity. They are light-coloured and have gradational margins, because they contain many light-coloured xenoliths which increase in size and number near the walls. The cryptocrystalline andesitic matrix has permeated along cracks in the granodiorite wall rock, parts of which have obviously been incorporated by the dyke to form xenoliths. The following types of inclusion have been distinguished:

i. Numerous andesine-labradorite xenocrysts, which are in many cases saussuritized, have been derived from the wall rock. They mask the original content of plagioclase phenocrysts.

ii. Granodiorite xenoliths have been saussuritized and they contain sericite, epidote, prehnite, clinozoisite, calcite and chlorite.

iii. A few xenocrystic quartz crystals are unstrained and they contain no inclusions.

iv. Distinctive quartzite fragments are composed of highly strained crystals which contain very small greenish (?) rutile needles. These inclusions are believed to have been brought up by the dyke from metamorphic basement rocks.

v. A few lithic inclusions are composed of medium-grained altered plagioclase laths set in a subordinate groundmass of quartz.

vi. Uncommon rounded chloritic masses up to 2 mm. across contain fine-grained euhedral re-crystallized actinolite laths, small irregular sphene crystals and very small crystals of iron ore and epidote.

vii. Euhedral sphene xenocrysts up to 0·4 mm. across are rare.

viii. Some of the lithic inclusions are of microtrachytic andesite. In some of them the andesine laths are aligned parallel to the xenolith margins.

b. The dykes which are intermediate in age are of subophitic macroporphyritic basalt. Xenoliths are absent. The following coarse crystals have been identified:

i. Phenocrysts of labradorite ($Ab_{36}An_{64}$) may exceptionally be up to 5 mm. in length. They are flow-aligned in some parts of the rock but they are not present near the dyke walls nor in apophyses.

ii. Fibro-lamellar actinolite aggregates altering to chlorite are thought to represent altered pyroxene crystals.

iii. Sphene crystals are up to 0·4 mm. across.

c. The rock of the youngest dykes is an intergranular macroporphyritic basalt of the Markle type. Coarse crystalline material includes:

i. Phenocrysts of labradorite ($Ab_{38}An_{62}$) up to 12 mm. in length which are flow-aligned near the dyke margins only.

ii. Fibro-lamellar actinolite aggregates up to 2·5 mm. across containing sphene and iron ore crystals. These aggregates have partially altered to chlorite and they are believed to be altered olivine crystals.

2. *Hypabyssal complex of central Square Peninsula*

On a nunatak (T.64) in central Square Peninsula (Figs. 4 and 5), a basalt pipe has been intruded into the local leucogranodiorite (p. 42) and it is at the junction of three dykes (Fig. 19A). This pipe is elliptical

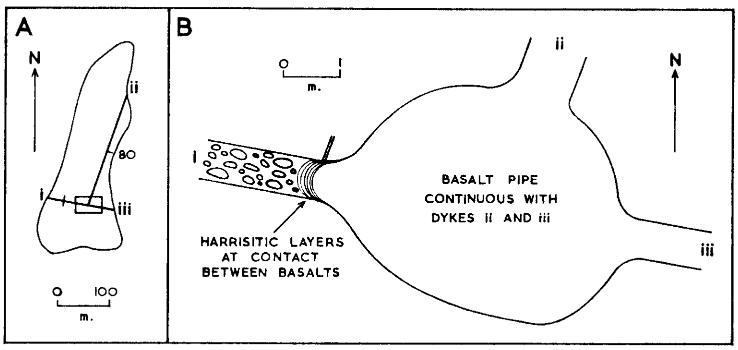

FIGURE 19

A. Detailed sketch map showing dykes (1–3) intruded into granodiorite on a nunatak in central Square Peninsula (T.64; Figs. 4 and 5). The area shown in Fig. 19B is indicated.

B. The junction of the three dykes shown in Fig. 19A. The alkaline basalt of dyke 1 is easily distinguished from the younger basalt of the central pipe and dykes 2 and 3.

in plan and it has a maximum diameter of about 15 ft. (4·6 m.) (Fig. 19B). Of the three dykes which meet at the sub-vertical pipe, one trends northwards from it; this dyke is 3·5 ft. (1·06 m.) wide and dips at 80° towards 090° mag. The other two dykes are 3 ft. (0·9 m.) wide and vertical, and they trend east and west from the pipe, striking at 260° mag. The rocks forming the pipe, the dyke trending northwards and the dyke trending eastwards are all the same, and they form a continuous intrusion, but the dyke trending westwards is separated from the pipe by a series of textural discontinuities and it contains many rounded, coarse-grained lithic inclusions up to 1 ft. (0·3 m.) in diameter. The textural discontinuities roughly follow the sub-circular outline of the pipe, and they have masked the relationship to the complex of a mafic vein, 6 in. (15 cm.) wide, which has been emplaced parallel to the dyke trending northwards. These discontinuities do not occur at any contact between hypabyssal rock and granodiorite country rock. The granodiorite has an unusually dark colour near the intrusion.

The rock forming the pipe (T.64.5) and two of the dykes is an altered inequigranular trachytic basalt, of which the only recognizable remaining mineral is incipiently altered, cloudy brown labradorite ($Ab_{42}An_{58}$). The intersertal groundmass contains fine-grained iron ore crystals and it has altered principally to epidote. Some irregular patches containing smaller amounts of iron ore are a very fine-grained brown-stained mixture of carbonates (probably largely siderite) and chlorites.

Although the matrix rock (T.64.2) of the west-trending dyke is similar in hand-specimen appearance to the rock of the pipe, it is a fresh intersertal olivine-basalt of which the principal minerals are bytownite ($Ab_{28}An_{72}$) as disorientated laths up to 0·9 mm. in length and purple titanaugite in equidimensional euhedral prisms of a similar size. Some of the titanaugite is zoned. Interstitial colourless (?) analcite forms small anhedra and irregular masses. The rarer constituents are fresh euhedral basaltic hornblende crystals up to 4 mm. across, with α'= straw yellow, $\beta' = \gamma'$ = dark russet, $\gamma':c = 18°$, r$<$v and $2V\alpha \simeq 70°$, abundant piliform apatite and chromite up to 0·1 mm. across. Rare small biotite crystals are coloured like the amphibole. Carbonates and greenish yellow chlorites have replaced prismatic euhedral phenocrysts of (?) olivine up to 2 mm. across; the chlorites form a complex box-work of colours. Fibrous chlorites in the amygdales form either botryoidal rims surrounding successive infilling stages of carbonate, or irregular centres enclosed by a fibrous radiating zeolite, probably stilbite. The latter type of amygdale contains the apatite, amphibole, iron ore and biotite of the groundmass, but neither the plagioclase nor the pyroxene. Stilbite and analcite occur as coarser, more easily identified crystals in other parts of the complex. The leucogranodiorite (p. 42) of this area has been severely altered close to this dyke (T.64.7). Analcite has been introduced and it forms an anastomosing coarse mesostasis between parts of the original rock. The relicts are mostly of kaolinized plagioclase, and they rarely show traces of polysynthetic twinning; some relicts of quartz have been divided, embayed and corroded by analcite. Bands of radiating fibres of a zeolite with the optical properties of stilbite mark the margins of the former plagioclase crystals, and they have occasionally replaced the whole crystal.

The coarse-grained mafic lithic inclusions in the west-trending dyke are pyroxenitic (T.64.1–3):

i. The simplest of the inclusions examined is a single black crystal of clinopyroxene, 5 cm. across, which encloses minute flecks of basaltic hornblende; the amphibole is also present along hair-line cracks as an alteration product.

ii. More complex is a pyroxenite in which pink clinopyroxene forms subhedra and anhedra up to 5 mm. across, and rare euhedra, some of which are marginally zoned. Rare interstitial accessory minerals are labradorite, iron ores and a black spinel identified as a picotite forming euhedra up to 4 mm. across. Carbonates and yellow-green chlorite are secondary.

iii. A wehrlitic inclusion contains up to 40 per cent (estimated) of slightly pleochroic very pale brown olivine ($\simeq Fo_{60}Fa_{40}$; $2V\alpha \simeq 80°$) and more common rather pink clinopyroxene; each mineral contains blebs of the other. The clinopyroxene is not as intensely coloured as the titanaugite of the matrix rock.

Around these pyroxenite inclusions is a peripheral zone 1 mm. wide, which is cloudy because it contains many tiny inclusions. Outside this zone, a narrow mantle of the deeply coloured titanaugite of the matrix rock is in optical continuity with the pyroxene of the inclusion.

Five zones (Plate VIIf, a–e) of contrasting texture are present in a specimen (T.64.6) from between the pipe and the west-trending dyke. They contain the same minerals as the dyke (see above) and their textures show that the zone near the dyke (zone (a)) crystallized before the one near the pipe (zone (e)).

a. In the zone nearest the dyke, the interstitial groundmass is composed of slightly poecilitic labradorite-bytownite, yellow-green chlorite, rare small crystals of basaltic hornblende and biotite, iron ore and acicular apatite. Titanaugite forms small pinnate structures, which bifurcate away from the dyke towards the other zones described below. These structures are similar to the larger ones in zone (b).

b. In zone (b), which is 1·5 cm. wide, a groundmass similar to that of zone (a) contains conspicuous pinnate titanaugite crystals. Grossly elongated needles of apatite are common. Simple individual crystals of titanaugite up to 4 mm. in length are simply twinned, well-terminated and show non-oscillatory colour-zoning round parts of their margins. Coarse pinnate clusters grow from, and have similar textures to, the much smaller clusters of zone (a); these clusters are formed of crystals which have the same optical orientation, that may be common to several adjacent clusters. Small independent crystals up to 1 mm. in length, which are zoned but not twinned, may be randomly orientated. Amygdales are common and they are up to 4·5 mm. across, the largest being elongated parallel to the pinnae. They contain chlorites and interfelted (?) epidote, and in some cases they have centres of calcite.

c. The relatively fine-grained zone (c), 2 mm. wide, is composed mainly of titanaugite laths 0·10–0·15 mm. in length. The long axes of these crystals tend to follow the plane of the zonation. Small iron ore, basaltic hornblende, plagioclase and (?) biotite crystals are very subordinate. There are a few coarse pinnate structures of titanaugite. Slightly poecilitic plagioclase anhedra are present and very small irregular amygdales are filled by chlorites.

d. A very sharp margin separates zones (c) and (d). Zone (d), <1 mm. wide, is rich in iron ore and chlorites, and it is relatively poor in plagioclase. Its grain-size is greater than that of zone (c), and it increases away from zone (c). Very rare coarse pyroxene prisms cross this zone.

e. Zone (e) is coarser in grain-size, less rich in iron ore and richer in plagioclase than zone (d). Slightly pinnate pyroxene prisms up to 1 mm. in length tend to be perpendicular to the zonation. In the sparse amygdales, nepheline and (?) stilbite surround chlorite and rare calcite. Although the textures and the grain-size are fairly constant in this relatively wide zone, its composition changes slightly at a distance from zone (d). There is a reduction in its content of pyroxene but labradorite ($Ab_{34}An_{66}$) is more common. The titanaugite is locally organized into "suns" or embryonic pinnae. Sparse rounded olivine ($Fo_{90}Fa_{10}$; $2V \simeq 90°$) crystals are set in a groundmass of plagioclase, titanaugite, rare biotite and basaltic hornblende, chlorites and apatite. Augite has replaced titanaugite only near one of the many amygdales in which nepheline, (?) stilbite and chlorite surround carbonate centres.

It is clear from the texture of the pinnate titanaugite crystals (Plate VIIf) that the west-trending dyke had been intruded and had crystallized while there was still fluid magma in the pipe and other two dykes. It is believed that the magma in the pipe was for some time similar to that which had crystallized in the west-trending dyke; after the formation of the pinnate textures at the contact against the dyke, a different magma replaced the original one in the pipe. The later-intruded magma crystallized to the relatively felsic rock that now occurs in the pipe and in the dykes continuous with it (p. 55).

Wager and others (1960, p. 79) believed that the original harrisites of Rum crystallized upwards during periods of non-deposition of cumulative crystals in a pluton undergoing density differentiation, and Wager and Deer (1939, p. 26, 144) similarly explained "reefs" of "perpendicular feldspar rock" at Skaergaard. Taubeneck and Poldervaart (1960, p. 1316–18) suggested that rocks with such a texture are produced when crystals grow in an environment of "moderate undercooling" at a liquid-solid phase boundary. Where such crystals are growing, differences of composition will arise between the centre and the margin of the intrusion, and migration of material to the crystals is necessary for continued growth. Such migration may occur by:

a. Migration of magma past sites of crystallization, e.g. in convective flow or upwelling of a dyke.
b. Migration of material through the melt, by:
   i. Diffusion.
   ii. Movement of crystals, e.g. dense crystals precipitated from a less dense magma.

Wager and Deer (1939) favoured migration of magma (a) as an explanation for the formation of pinnate textures, but they suggested that diffusion (b, i) may have contributed towards the formation of smaller differentiated bands such as the "perpendicular feldspar rock" of Skaergaard (Wager and Deer, 1939, p. 148). Migration of magma (a) is also favoured by Taubeneck and Poldervaart, but they have suggested that convective magma movement was disturbed by periodic convective overturn which caused the abrupt cessation of pinnate growth or a change in the minerals growing in this way. Gravitational movement of crystals (b, ii) could not affect the growth of pinnate material on a vertical surface such as that studied in the present investigation.

For the textures of the Square Peninsula dyke, an obvious formation mechanism is the slow flow of magma up the pipe while "moderate undercooling" was taking place against the rock already crystallized in the west-trending dyke. However, assuming laminar flow, such magma movement would tend to maintain the same layer of magma in contact with the wall rock, and it would not maintain a supply of titanaugite to all levels of the dyke contact (which is assumed to feature pinnate textures well below and, before erosion, well above the level exposed). Turbulent flow would probably occur only at flow rates at which pinnate crystals would not develop. The possibility that magma flowed transversely across the pipe between the east- and north-trending dykes is not sufficiently general to explain the frequency with which these textures are found in the Willow Lake area (Taubeneck and Poldervaart, 1960, p. 1295). The attitude of the pinnate crystals is perpendicular to the contact and they appear to be only slightly bent in a few places; this seems to suggest that they may not have crystallized from a moving magma. It is believed that the growth of magmatic pinnate crystals in "still magma" conditions would be perpendicular to the contact and parallel to the maximum temperature gradient, but that crystals growing in a moving magma would be bent either towards or against the direction of flow. Since the pinnate crystals in the dyke contact in central Square Peninsula have grown perpendicular to the contact, they are thought to have crystallized from material transported by ionic diffusion during periods when magma was not moving in the pipe. Episodes of magma movement caused pauses in pinnate crystallization and the formation of rock layers of differing textures and compositions. Pyroxene is the only mineral in which the series of layers at the margin of the pipe is noticeably enriched, and the migration of only a selection of the ions of the titanaugite molecule may have been necessary if the others were present throughout the magma in sufficient concentration.

3. *Post-Andean modification of contacts of Andean intrusive rocks*

There are obvious differences between the Andean intrusive rocks and the stratified country rocks, and in most localities the contacts between them are so well defined that the stratigraphic order (Table I) is easily seen. On the north-west cape of Jenny Island (Figs. 7G and 8G), however, there appears to have been a reversal of this normal stratigraphic order, because rounded inclusions of Andean intrusive rocks appear to be contained in the finer-grained country rocks near the margins of plutons of these Andean intrusive rocks (Plate IIIb). One of these plutons is a heterogeneous intrusion (p. 37) and the other is formed of dark gabbro (p. 31). At the rather limited exposure (T.209), which shows the granodiorite of the heterogeneous intrusion apparently intruded by the country rocks, no field evidence could be found to show the reason for the apparent reversal of the intrusion order. On the best exposure (T.215) of the dark gabbro apparently intruded by country rocks, however, evidence has been found which shows that a normal contact has been modified by the intrusion of post-Andean material. This post-Andean rock is closely similar in hand-specimen appearance to the tuffaceous country rock of Jenny Island, but an obscure discontinuity which has been found is believed to be the contact between it and the tuffites. This discontinuity is parallel to the margin of the dark gabbro and the post-Andean rock is believed to be a dyke intruded along the contact with the gabbro. No variation has been found in the country rocks to the south of the discontinuity; between it and the dark gabbro to the north, however, inclusions of coarse-grained dark gabbro are present in the fine-grained rocks and they increase in number and size in the transition to the dark gabbro pluton. Four zones, numbered (i) to (iv) in order from south to north, have been distinguished in the post-Andean rocks between the country rocks and the gabbro (Fig. 20).

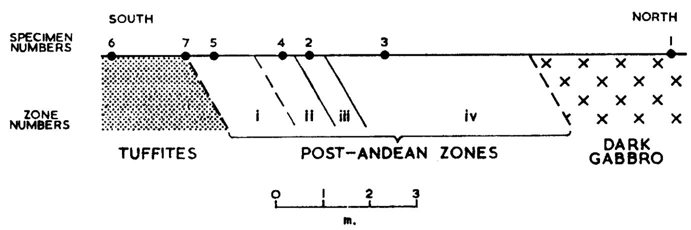

FIGURE 20

Sketch cross-section drawn through the contact between dark gabbro and stratified country rock on Jenny Island (T.215; Figs. 7G and 8G), showing the locations of specimens and zones in the post-Andean rocks described in the text.

The country rock (T.215.6) near the modified contact is a dark fine-grained tuffite or tuffaceous sandstone. It contains no xenoliths of dark gabbro but in zone (i) (T.215.5; Fig. 20), the southernmost part of the contact zone, large and small inclusions of country rock and dark gabbro are present. At the ill-defined discontinuity (T.215.7) between the Jurassic tuffites and the post-Andean rocks, narrow veins of dark fine-grained material have been intruded parallel to the dark gabbro contact, which dips at 60° towards 350° mag. The matrix of specimen T.215.5 is dark and fine-grained like that of the country rock, but it contains large plagioclase crystals which are not present in the tuffites. North of zone (i), zone (ii) (T.215.4), which is 3 ft. (0·9 m.) wide, contains many gabbro xenoliths and large rounded plagioclase crystals. To the north again, there is a comparatively sharp contact against zone (iii) (T.215.2), which is only 2 ft. (0·6 m.) wide and is composed of a pale-coloured, relatively fine-grained material. North of zone (iii), the colour darkens rapidly to that of zone (iv) which has a dark colour similar to that of the gabbro into which it grades; many round inclusions of dark gabbro are present in this zone. The margin of the dark gabbro pluton is more diffuse than that of the quartz-gabbro at its modified contact (Plate IIIb), probably because its dark colour is so like that of the rocks in contact with it.

In thin section, a specimen of the Jurassic country rock (T.215.6) from near the contact zone is similar to a typical tuffite of Jenny Island (T.210.1; p. 19). A petrographic description of the dark gabbro of Jenny Island (T.216.1) is given on p. 31. Thin sections of specimens T.215.3–5, from the contact zone between these two rocks, show that they have sedimentary and porphyroclastic textures. Their scanty, very fine-grained matrices are largely composed of fragments derived from the lithic inclusions and coarse crystals which they contain; these large inclusions, which are from the Andean and Jurassic rocks on either side of the contact zone, have been abraded and rounded.

i. Specimen T.215.5 (from zone (i)), nearest the country rocks (Fig. 20), has the appearance of a well-sorted granulestone. The lithic fragments in this zone are of basaltic rocks, many of which contain small labradorite phenocrysts that are in sub-parallel alignment in some granules. Sparse, rounded large labradorite crystals are without doubt xenocrysts which have been derived from the dark gabbro on the other side of the contact zone. At the ill-defined boundary between zone (i) and the country rocks, the matrix of this zone is almost exactly similar to that of specimen T.215.6 but there is one fundamental difference: rounded lithic fragments and xenocrysts from the gabbro are present in the post-Andean material but not in the Jurassic tuffite. The rounded xenocrysts include many of labradorite ($Ab_{42}An_{58}$) and some of them have a narrow outer rim of oligoclase. Other xenocrysts are of iron ore up to 1 mm. across, slightly pink clinopyroxene crystals up to 1 mm. in length, and rare apatite prisms up to 0·8 mm. across. The clinopyroxene has altered marginally to hornblende and in some cases the remnant clinopyroxene cores have altered to a fibrous tremolite. The contact with the Jurassic rocks has been masked by the intrusion along it of a microtrachytic vein in which microlites of andesine ($Ab_{57}An_{43}$) and finely crystalline iron ore are the only identifiable minerals. A few small volcanic rock inclusions up to 3 mm. across and xenocrysts of labradorite up to 0·6 mm. across are present in this vein.

ii. Zone (i) grades northwards into zone (ii) (T.215.4) which is similar but it contains many large rounded crystals and lithic inclusions from the dark gabbro. The matrix rock of the dyke, unmodified by xenocrysts, is visible in the marginal interstices of the dark gabbro inclusions; it is holocrystalline, very fine-grained, hypidiomorphic granular and composed of (?) labradorite (estimated at 70 per cent of the rock), hornblende (estimated at 20 per cent) and iron ore. The ophitic dark gabbro inclusions are almost unaltered. The minerals in them, labradorite ($Ab_{42}An_{58}$), pale pink clinopyroxene with marginal hornblende, iron ore and apatite, are the same as those of the many rounded xenocrysts also contained in zone (ii).

iii. The pale-weathering rock of specimen T.215.2 (zone (iii); Fig. 20) differs from those of the other zones in being holocrystalline, fine-grained and xenomorphic. An aggregation of ill-sorted fractured anhedral crystals is contained in a groundmass of intermediate plagioclase, amphibole, calcite and chlorite. The larger crystals are probably the recrystallized rounded xenocrysts of the other zones; they have very ragged edges. Clinopyroxene has completely altered to actinolite.

iv. Specimen T.215.3 (zone (iv)) is of rock closely resembling the one of zone (ii), although the proportions of crystals and lithic inclusions from the dark gabbro are much greater.

The texture of most of the rocks in the contact zone between the dark gabbro and the country rock is sedimentary and porphyroclastic, so that they resemble the country rock in texture. The very sparse fine-grained matrix of the contact zone rocks is basaltic (T.215.4) like the tuffaceous country rock; since inclusions of the country rock have been incorporated in the southern zone of the contact, zone (i) is practically indistinguishable from the tuffites. From the evidence available at station T.215, it would be difficult to prove that the Jurassic volcaniclastic rocks of Jenny Island are older than the dark gabbro; the rocks of the contact zone appear to be sedimentary tuff phases modified by the local incorporation of detrital crystals and lithic fragments from the gabbro. Since other contacts nearby show that the tuffites have been intruded by the gabbro, a rock younger than both the gabbro and tuffite must have been intruded between them at station T.215, and this has also happened at station T.209.

The intrusion of hypabyssal material along the contacts between the gabbros and country rocks probably means that the contact was a line of crustal weakness. The mode of intrusion is of interest because there is very little evidence for the intrusion of magma; the rocks now present in the probable fissure are round-fragment breccias containing fragments of the rocks on either side. The contact has not been faulted (Plate IIIb). The sedimentary textures of the post-Andean rocks suggest that they were emplaced by ascending gases or water; whatever the transporting agent, it was not chemically active, because the well-rounded crystals and lithic fragments from the dark gabbro wall rock have not been altered.

No other post-Andean intrusion described so far from the Antarctic Peninsula is composed of fragmental material. The examples on Jenny Island are important because they have caused an apparent reversal of intrusion order. A similar occurrence could cause confusion in an area which was less well exposed.

4. *Veins in a probable fault zone*

The diorites on the western side of Anchorage Island (T.43, 123; p. 37; Figs. 4 and 5) have been extensively modified by veins of post-Andean mafic material intruded into them and which have a preferred orientation of dip 40° towards 095° mag. The strike and perhaps the dip of these veins must be close to that of the nearby contact between the diorites and the volcanic country rocks of an island (T.122) 350 yd. (320 m.) to the north-west. These veins may have been intruded into fractures caused by faulting along the margin of the intrusion; the margins of other Andean intrusive plutons have been faulted (Plate Ia).

5. *Solus Island*

Solus Island (T.319) is composed of homogeneous fine-grained dark basalt, which has not been affected by later veining and is therefore probably of post-Andean age. It is predominantly of euhedral phenocrysts of labradorite ($Ab_{38}An_{62}$) and augite; the latter is very slightly pleochroic in pale green and brown, and some crystals are polysynthetically twinned. Chlorites have completely pseudomorphed other ferromagnesian crystals, which were either biotite or amphibole, or both. Remnants of brown amphibole are visible in the groundmass, in which calcite is common; very small crystals of quartz are in places contained by the calcite.

VI. STRUCTURE

THE predominant structural consideration in the Adelaide Island area is the intrusive relationship between the plutons of the Andean Intrusive Suite and the older stratified rocks. The Andean intrusions are superstructure bodies which have not obviously metamorphosed the country rocks near their sharp contacts, although extensive evidence for thermal metamorphism of the stratified rocks has been found in the laboratory studies (p. 20). Apparently separate plutons of any particular type of Andean intrusive rock probably merge at depth, but the exposed plutons tend to be either sub-circular or elongated in plan. The shapes of the elongated intrusions have clearly been controlled by the regional structure, because their elongation is parallel to the local trend of the Antarctic Peninsula.

Although the stratified rocks are usually flat-lying, dips on some exposures are up to 70° and they may not be constant in direction. No folds have been recorded in the field. Changes of dip and strike appear to take place along vertical or nearly vertical block-fault planes, which are in many places clearly visible from a distance but are difficult to distinguish at close quarters. In each case movement appears to have been dispersed between closely set fault planes in wide shatter zones following the predominant joints. Throws are not large on many typical examined faults and most of them may be described as incipient. The most obvious fault and shatter zones have been observed in the stratified rocks. Possibly, the faults are easily detectable only in the stratified rocks, or it could be that the Andean intrusive rocks have had this detectable dynamic effect on the older rocks. It is believed, however, that much of the faulting is of relatively recent age, because post-Andean dykes may be affected by the movement. One of the most extreme effects of faulting has been found in a vertical post-Andean dyke emplaced in Andean intrusive gabbro on northern Léonie Island (T.131); although flow bands in the dyke show that it originally trended 025° mag., it now strikes 060° mag. This effect has been produced by closely set right-hand tear-faults which cross the dyke. This dyke belongs to the youngest type described on Jenny Island ((c), p. 54) and some important faulting is therefore known to have occurred after the emplacement and consolidation of the youngest known post-Andean rocks of the Adelaide Island area.

Not all of the block-faults are incipient. On Mount Ditte, the positions of many faults with large throws are accurately known (Fig. 5); for instance, the one on the north-eastern side of the mountain has caused the Mount Liotard succession exposed there to crop out at two levels, near the mountain summit in the south and near sea-level in the north. On Cape Alexandra, drag-folds show that the tonalite of western Mount Ditte (p. 38) has been down-faulted relative to the stratified rocks cropping out to the east (Plate Ia). About 2 miles (3·2 km.) north of Cape Alexandra, rocks of this intrusion have been up-faulted relative to the stratified rocks to the east; this is shown especially by the differing heights of the roof of the intrusion on either side of this fault. The drag-folds exposed on Cape Alexandra are the most tangible available evidence showing that faulting has been important on Adelaide Island. The fault with which they are associated is thought to belong to a major fault system, which trends along the western boundary of the southern mountains from Mount Ditte to Mount Mangin (Fig. 5). The position of this fault system is believed to be indicated by the nearly linear scarps and rock walls which are the western limits of the mountains, and for the same reason, a major fault is believed to be present west of Mount Bouvier. On the fault scarp west of Sloman Glacier, dips are generally about 15° to the east, but the strata have been disturbed at one visited locality (T.352) where the rocks dip at 40° towards the west. This is thought to be the result of drag on the up-faulted rocks of the scarp. The northward continuation of this fault scarp is thought to be an isolated flat-topped exposure of gabbro west of Mount Gaudry (T.223). The linear western walls of Mount Gaudry trend north-eastwards from this nunatak and they may mark another fault of the system, but the main fault is believed to strike northwards and to pass west of Lincoln Nunatak. The linear steep western walls of a scarp north of Lincoln Nunatak trend north-eastwards to merge with the straight northern walls of Mount Mangin, and it is believed that a cross-fault may be marked by this line of exposures. If such cross-faults are present, it is likely that the valley of Shambles Glacier is a graben, and that the dip of 30° recorded on Dewar Nunatak (T.311; p. 22) is the result of drag-folding of the generally horizontal rocks by the fault on the north side of the down-thrown block.

Major faults are believed to be present on the eastern sides of the mountains but they are less well-known, because the eastern side of Adelaide Island is relatively inaccessible. At least two major faults trend north–south on eastern Mount Liotard and they have faulted conglomeratic strata against the Mount Liotard succession to the east; the stratigraphic position of these conglomerates is not known but they are assumed to belong to either the Sloman Glacier succession (below the Mount Liotard succession) or to the Mount Bouvier summit succession above it. They are believed to belong to the higher sedimentary succession and to have been down-faulted (p. 26). The rocks of Jenny Island do not appear to have been faulted relative to those nearby on northern Mount Ditte, but the country rocks on Léonie Island are unbedded in contrast to those nearby to the west (p. 27), and another north–south fault is believed to be present between Léonie Island and Adelaide Island. The only other faults of this system that have been distinguished on the eastern side of the mountains are on the main eastern ridge of Mount Mangin, where a number of relatively minor sub-vertical faults have been observed throwing down the strata to the east. Tilted strata at the eastern end of this ridge seem to show that it has been raised relative to the rocks of Square Peninsula to the east. The north–south fault system of the eastern side of the southern mountains may well extend northwards through McCallum Pass (p. 21; Fig. 6 (J–K)); it may control the positions of the western coast of Stonehouse Bay and the eastern walls of Mount Bouvier (Fig. 3).

Curtis (1966) has summarized the available evidence showing that block-faulting has had an important influence on the formation of the Antarctic Peninsula, and that similar earth movements have affected strata in parts of South America. This faulting must be of relatively recent age; in the Adelaide Island area, it is demonstrably post-Andean (Plate Ia) and indeed it is more recent than the youngest type of post-Andean dyke distinguished in the Adelaide Island area (p. 59). These dykes are of a middle or even late Tertiary age (Table I).

The faulting may have displaced parts of planed surfaces; flat-lying surfaces above the scarps west of Mount Bouvier, Mount Mangin and Sloman Glacier may have formed at the level of a planed surface inferred below the Fuchs Ice Piedmont before they were elevated by the faults west of the scarps (Dewar, 1967). The effect of the faulting on planed surfaces on the mountain summits is not known. These high planed surfaces are known not to have been up-faulted from the levels of the lower ones, because the rocks forming the scarp faces can be correlated with those at similar heights on the mountain sides (Fig. 6 (A–B, C–D)). Part of the scarp west of Mount Bouvier (Figs. 5 and 6 (C–D)) has indeed been displaced relative to the mountains but it has been elevated, not depressed; this is thought to be the reason for the apparently reduced thickness of the Mount Liotard succession exposed on south-western Mount Bouvier (p. 18). The scarp west of Mount Mangin is formed by intrusive rocks, and stratigraphic evidence is not available to show whether it has been displaced relative to Mount Mangin, although the topography strongly suggests that there is a fault immediately west of Mount Mangin (Fig. 5). The faulting may thus have taken place after a period of planation. Some of the faulting may have resulted from the unloading of the Pleistocene ice cover, but most of the movement probably took place before or during the most intense glacierization of this area. Curtis (1966) has pointed out that the most accurate estimations of the age of the faulting have been made from evidence available in South America, where large-scale movements have been referred to Miocene, Pliocene and even Quaternary ages. These earth movements in

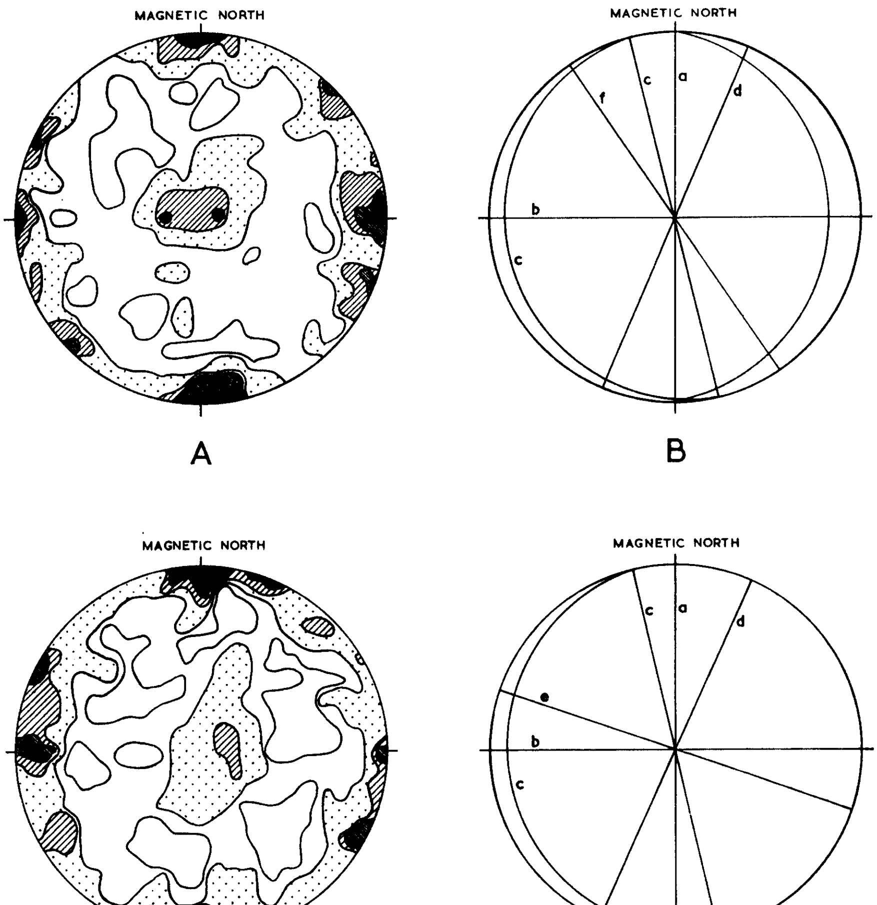

FIGURE 21

A. Orientation diagram for poles to 354 strong joints recorded in the stratified rocks of the Adelaide Island area. Contours are at 0, 1, 2, 3, 4 and 5 per cent.
B. Projection of statistically dominant joint sets (Fig. 21A) developed in the stratified rocks of the Adelaide Island area.
C. Orientation diagram for poles to 312 strong joints recorded in the Andean intrusive rocks of the Adelaide Island area. Contours are at 0, 1, 2, 3, 4 and 5 per cent.
D. Projection of statistically dominant joint sets (Fig. 21C) developed in the Andean intrusive rocks of the Adelaide Island area.

South America have resulted in an uplift of some parts of the Andean Cordillera through heights up to 16,400 ft. (5,000 m.), and Curtis (1966, p. 50) considered that similar movements elevated the Antarctic Peninsula area, the greatest displacements taking place in Pliocene time. Goldring (1962, p. 49) believed that these movements took place before any of the planed surfaces had formed but the evidence quoted by Koerner (1964, p. 5) suggests that planed surfaces were faulted to different levels in north-east Graham Land. King (1964) has suggested that in the Alexander Island and George VI Sound areas a late Cainozoic planed surface was affected by a later episode of block-faulting.

The sub-vertical attitudes of fault-planes and the absence of thrusting and folding in the Adelaide Island area are reflected in the results of statistical analyses of joint attitudes. Joints recorded in both the stratified country rocks (Fig. 21A and B) and the Andean intrusive rocks (Fig. 21C and D) are statistically similar. In both of these rock types, three joint sets (a, b and c; Fig. 21B and D) are at mutual right-angles or nearly so, the two vertical joint sets (a and b) trending north–south and east–west mag., respectively. The vertical joint set trending north–south mag. (a) has been recognized as the dominant one in many localities, and it is significant that it is parallel to the local trend of the Antarctic Peninsula (Procter, 1959, p. 15). The vertical joints striking 023° mag. (d) and the vertical joints nearly at right-angles to them, striking 109° mag. in the Andean intrusive rocks (e), are also nearly at mutual right-angles to the sub-horizontal joint set. An additional vertical common joint system (f), striking 145° mag., is less strongly developed in the Andean intrusive rocks than in the stratified rocks. Because of the similarity of the orientations of joint systems in the stratified rocks and the Andean intrusive rocks of Adelaide Island, the joints in both rock types are thought to have been produced by a single agency. The intrusion of the Andean plutons has not caused the development of additional strong jointing in the country rocks, which shows that the plutons were not forcibly emplaced. The maximum densities of joint attitudes in both of the main rock types are low (just over 5 per cent), and these statistical maxima are believed to represent tension joints which originated by the expansion of rocks subjected to unloading. This relief of load may have been due to removal of the ice cover, but it is more likely to have been caused by erosion of the overlying rocks, because the Andean intrusions now exposed must have been emplaced at some depth.

VII. CONCLUSIONS

In the Adelaide Island area, the rocks which are most abundantly exposed are of two ages. The earlier ones are stratified volcanic and sedimentary rocks which are probably of Upper Jurassic age, whereas the later are the rocks of Andean plutons which intruded the stratified rocks between Middle Cretaceous and Lower Tertiary times. Minor exposures are of hypabyssal rocks of pre- and post-Andean ages.

Fragments of extrusive rocks are contained in most of the strata of the unfossiliferous country rocks. Almost all of these fragments have been re-worked by sedimentary processes, and false- and graded-bedding has been found in many places. Deposition of the epiclastic rocks has been in water which is believed to have been flowing because foreign boulders have been transported from a provenance beyond the area studied, and they have been added to some of the conglomeratic beds. Most of the foreign boulders are of diorite, tonalite and granodiorite which have come from the ancient plutonic rocks of the Antarctic Peninsula, but a few of them are of metamorphic rocks which are of Basement Complex provenance. Many of these boulders are large and all of them are extremely well rounded; from this it is inferred that transportation of the boulders was carried out rapidly over a comparatively short distance. The conglomeratic rocks accumulated at a change in slope, presumably at the foot of a mountain range, and they are believed to be either littoral fanglomerates or coastal sediments. These and the other sediments are thought to be coastal, because alternating well-bedded and well-sorted persistent strata may differ greatly in the sizes of their included lithic fragments. Fragmental lavas which also occur in the stratigraphic succession are spilitic, and this suggests that they were erupted in a marine environment, although it does not prove that this was so. The fragmental lavas (described as quench-breccias) are amygdaloidal and contain many cognate lithic fragments. Their textures and the absence of pillows show that they were not deposited as true lava flows. It is thought that parts of the terrain were exposed to a subaerial environment for some time during the deposition of the succession, because non-fragmental flow basalts have been found at a few exposures.

Not many of the cognate and accessory-cognate lithic fragments in the stratified rocks have been well rounded, and they were therefore probably derived from sources which were much closer to the sites of deposition than the provenances of the foreign boulders. The volcanic rock fragments do not, however, appear to have been extruded through volcanic centres. They may have been erupted through dyke fissures, and this is perhaps indicated to a certain extent by the fact that the mafic dykes are more commonly found passing vertically through the bedded rocks than through the Andean intrusions. However, no example of a dyke feeding a lava flow has been found, and indeed only one dyke in the area has been proved to be of pre-Andean age.

The stratified succession of Adelaide Island is 10,000 ft. (3,050 m.) thick and it has been divided into three units which contrast in lithology. Correlation has been insufficiently detailed to allow further subdivision but the three successions are believed to vary in thickness. The highest and lowest of the three successions are predominantly sedimentary and they contain conspicuously stratified well-sorted beds, but the middle unit is composed of massive quench-brecciated spilites and sporadic unbrecciated tholeiitic basalts and andesites. In one relatively restricted area are exposed devitrified lavas which are normatively rhyolitic; it has been shown that these lavas may be normal differentiates of the tholeiitic basalts.

The Andean intrusive rocks of Adelaide Island range from dark gabbros to rare adamellites, and they appear to have been intruded strictly in order from the most calcic to the most silicic. Those commonest in field occurrence are in the heterogeneous intrusions, in which gabbros and granodiorites may be present, although no contacts have been seen separating them. The discordant plutons, associated with the elevation of the mountainous central spine of the Antarctic Peninsula, belong to the apotectonic phase of the Andean orogeny. In common with other apotectonic superstructure masses, their intrusion poses the spatial problem of the displacement of the country rocks by the invading material, which was not under sufficient pressure to force space for itself. No evidence for forcible displacement of the country rocks is visible near any of the plutons of the intrusive rocks, and magmatic stoping, dissolution, assimilation and granitization may all have taken place during their intrusion. Magmatic stoping has been demonstrated particularly well by the zones of screens at the margin of a leucogranodiorite pluton. There is little direct evidence that granitization has taken place, because the margins of the intrusions are sharp and the country rocks have not been metamorphosed except in a few localities which are not close to the exposed intrusion margins. Although most of the xenoliths in the intrusive rocks have sharp margins, many of them have been well rounded, showing that they have been partially dissolved; they have become coarser in grain-size and enriched in quartz and potassium feldspar. Large, zoned, calcic plagioclase xenocrysts have been found in some of the oversaturated plutonic rocks, and some of them are considered to be remnants of xenoliths of porphyritic and porphyroclastic stratified rocks which have otherwise been totally assimilated. Other similar xenocrysts may have originated in plagioclase cumulates which formed in some of the dark gabbros. Some parts of otherwise typical plutons are formed by intrusion breccias in which xenoliths of displaced Andean intrusive rocks are only infrequently found, even where the adjacent wall rock is an Andean intrusion. The great majority of xenoliths in the intrusion breccias have been derived from the stratified country rocks.

The dark gabbros were the earliest Andean intrusive rocks to be emplaced. The degree of undersaturation of many of the dark gabbros is difficult to estimate, because olivine has been altered in most of the rocks in which it is present. This alteration may have been caused, at least in part, by metasomatism by silica-rich hydrothermal solutions derived from the oversaturated younger rocks of the Andean Intrusive Suite. Some of the dark gabbros are homogeneous but others are flow-banded. They all crop out on small exposures and it is thought that none of the plutons into which they were intruded were large even before their partial displacement by younger intrusive rocks. Very locally, orbicules are present in the flow-layered intrusions, and their best-exposed occurrence has been described in sufficient detail for suggestions to be made as to the sequence of events that caused the formation of the orbicules.

The most calcic of the Andean intrusive rocks of Graham Land are believed to be cumulates (Adie, 1955, p. 33) and it has been suggested that these cumulates are of two types. One type appears to be deficient in calcic (cumulative) plagioclase and the other appears to be enriched in cumulative magnesian olivine. Rocks of each type can be easily distinguished on the triangular variation diagram ($Fe''+Fe'''$)—Mg—Alk. Most of the more calcic gabbros from the Adelaide Island area have been shown to belong to the characteristically Mg-rich group, but a gabbro from Jenny Island is of the other type. A Mg-rich gabbro exposed at McCallum Pass contains amounts of Si and Na which are unusually large for a rock of this type, and it is believed that this rock has been altered by solutions rich in these elements from a heterogeneous intrusion which crops out nearby. The Al content of this dark gabbro is correspondingly low, and it is considered that the predominant metasomatic effect was the marginal sodification of the calcic plagioclase. Plagioclase crystals in this gabbro exhibit a pronounced marginal normal zoning.

The heterogeneous intrusions, which are the most widely exposed on Adelaide Island, are composed of rocks intermediate in composition between the dark gabbros and the homogeneous granodiorites and adamellites, the last of the Andean intrusive rocks to be emplaced in this area. They contain rocks differing greatly in their field appearance but they are not separated by visible contacts; the differing appearances of these rocks are reflected in significant differences in their mineralogical compositions. These rocks range in composition from gabbros to granodiorites and they do not include undersaturated types. Geochemical investigations on the rocks of two adjacent heterogeneous intrusions have shown that these rocks are typically calc-alkaline and that they cannot be regarded as abnormal members of the Andean Intrusive Suite, although they differ in some respects from the typical Andean intrusive rocks. The intrusion which has been examined in most detail is exposed close to the dark gabbro of McCallum Pass, and like the dark gabbro, it is unusually rich in Na and Mg, and poor in Al. The high content of Mg in these rocks is not easy to explain unless some of the dark gabbro has been assimilated by the younger rocks, a process which would be expected to produce other abnormalities of composition as well as the high Mg content. The high content of Na in the rocks of McCallum Pass may be the result of assimilation of the spilitic country rocks into which they have been intruded.

Although it is not known how extensive assimilation was in the history of intrusion of the heterogeneous plutons, it is believed to have been important because the rocks show many signs that it has taken place. It may be the only cause of the heterogeneity, in which case the magma originally intruded to form these plutons was probably granodioritic. The textures of many of these rocks suggest that quartz and potassium feldspar were introduced after crystallization had almost reached completion. These minerals could have been cognate if the original magma was granodioritic, because they would have remained mobile after others had crystallized. Alternatively, they may have been introduced after crystallization had been nearly completed, so that a magma of gabbroic composition may have been modified in the granodioritic parts of the heterogeneous intrusions. The quartz, but not the potassium feldspar, appears to have been introduced into some parts of the stratified country rocks, and this is most clearly seen in the brecciated lavas of the Mount Liotard succession, where it has been affected in this way. The ubiquitous cognate lithic inclusions in this succession are easily visible at localities where metasomatism is dominant, although in most of the lava exposures the inclusions can barely be distinguished. The altered rocks contain considerable introduced quartz and they have recrystallized to augite-granulites. The quartz appears to have been preferentially incorporated in the former lithic inclusions, but it is also present in the former groundmass, which is now composed predominantly of augite.

An intrusion sequence of three post-Andean dykes, which crop out on Jenny Island, has been described. The two types which were intruded last have been found exposed throughout the Adelaide Island area; the earliest type of dyke was intruded very soon after the Andean intrusive granodiorite, which it displaces, and it has not been found elsewhere. Of the atypical post-Andean dykes that have been described, one has modified the contact between an Andean gabbro and the stratified country rocks, so that the pluton appears to be older than the rocks it intrudes; moreover, this dyke is unusual in that it appears to have been intruded as a gas- or water-suspended mixture of fragments of the rocks on either side of the fissure which it filled. Another unusual hypabyssal complex includes a dyke of alkaline basalt in which harrisitic plumose titanaugite crystals have crystallized. The harrisitic texture is developed only at the contact with a basalt of a more usual type, but it shows that the alkaline basalt once occupied the whole complex, crystallized first in the dyke where it is now present, and was replaced in the rest of the complex by the other basalt. The alkaline basalt contains pyroxenite xenoliths which are thought to have been brought up from an ultrabasic basement.

Large-scale block-faulting took place after the emplacement of the Andean intrusive rocks and after the youngest identified type of post-Andean dyke had been intruded. The faulting is believed to have contributed towards the elevation of the mountains to their present height. Folding of the strata is virtually absent. Faults have followed the joint planes, which have been shown to have formed because material was unloaded from above the rocks which are now exposed. The material removed was probably superincumbent rock, but some of it may have been the former ice cover, because it is known that the present ice cover of Adelaide Island is much thinner than it was in the past. The predominant vertical joint set strikes parallel to the local trend of the Antarctic Peninsula, and this is structurally the dominating direction; it appears to have been dominant before the emplacement of the Andean intrusive rocks, because elongated plutons extend only in this direction. The emplacement of the Andean intrusive rocks has impressed no additional joints on the stratified rocks and this shows clearly that the plutons were not forcibly intruded.

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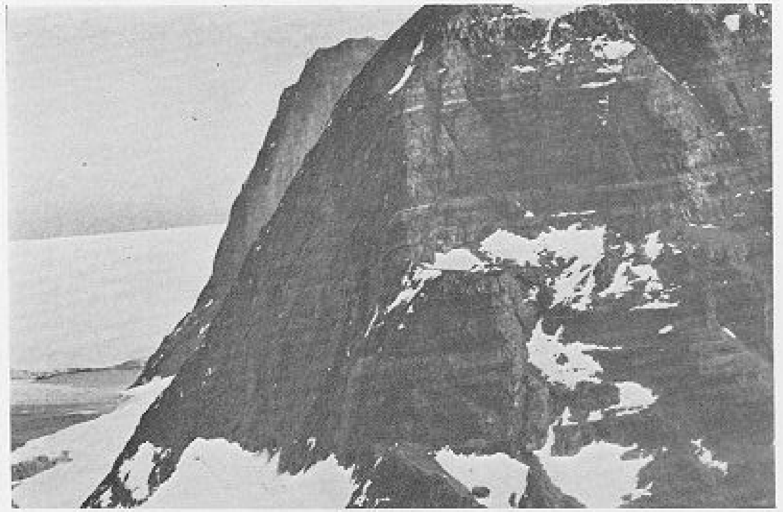
PLATE I

a. Oblique air photograph of the upper part of the cliffs at Cape Alexandra from the south-east. A vertical fault (centre) separates Andean intrusive tonalite (left) and horizontally stratified volcaniclastic rocks. Drag folds in the stratified rocks show that the intrusive rock has been down-thrown by the fault.

b. Quench-brecciated lavas, western Mount Bouvier (T.297). Included fragments of cognate and accessory-cognate lavas are unusually well rounded. The spectacle case is 5 in. (13 cm.) long.

c. Pebbles of intrusive and volcanic rocks in a conglomerate on the nunataks east of Crumbles Glacier (T.176). The matrix is a tuffite. The compass case is 4 in. (10 cm.) long.

d. Indurated lapillistone (T.310.4). Variegated lithic fragments are of closely related extrusive rocks.



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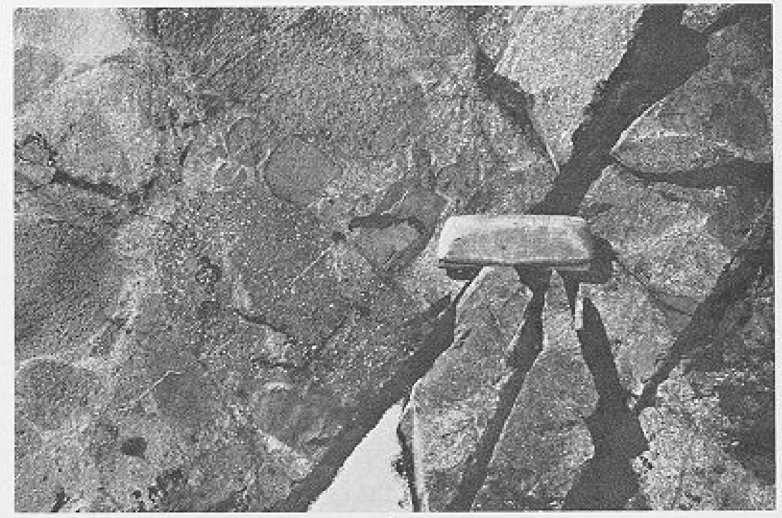

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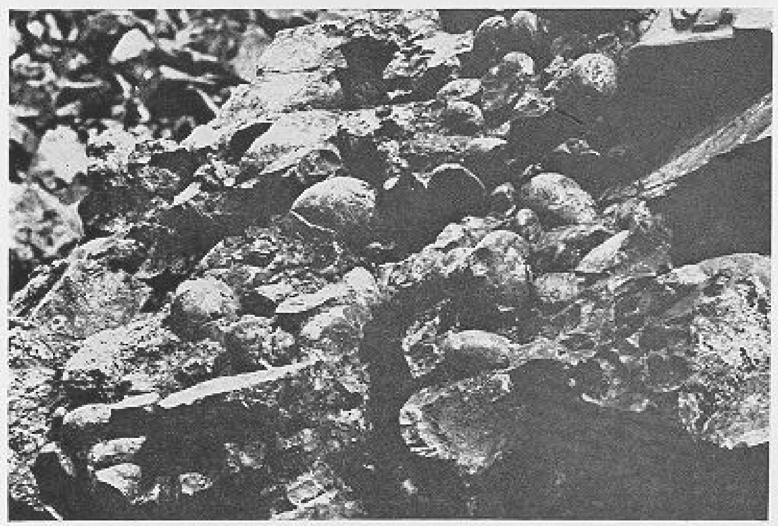

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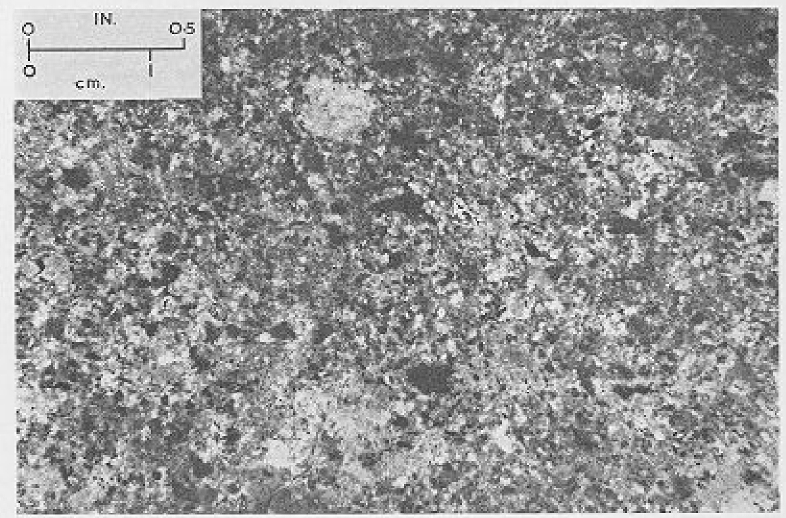

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PLATE I

PLATE II

a. Current- and graded-bedding in crystal and dark aphanitic tuffites at the top of the Sloman Glacier succession on eastern Mount Barré (T.285). The hammer head is 8 in. (20 cm.) long.

b. Conglomerate on north-western Mount Bouvier (T.292). Granodiorite boulders are contained in a tuffaceous, sandy gravel breccia. The hammer shaft is 22 in. (56 cm.) long.

c. Orbicules in gabbro, Brockhamp Islands (T.139). The hammer head is 8 in. (20 cm.) long.

d. Irregular interbanding of olivine-norite with coarse plagioclase crystals (left) and dark gabbro at their contact on the coast of Square Peninsula south of Webb Island (T.170). Some narrow bands are of relatively fine-grained gabbro.

a

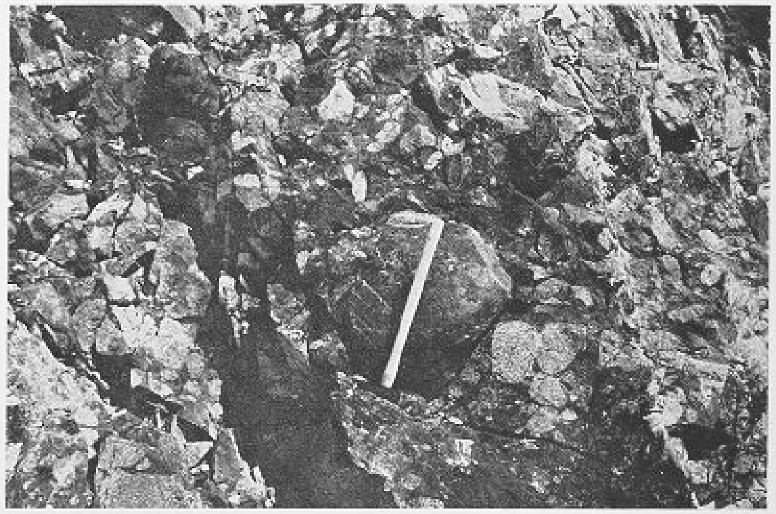

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PLATE II

PLATE III

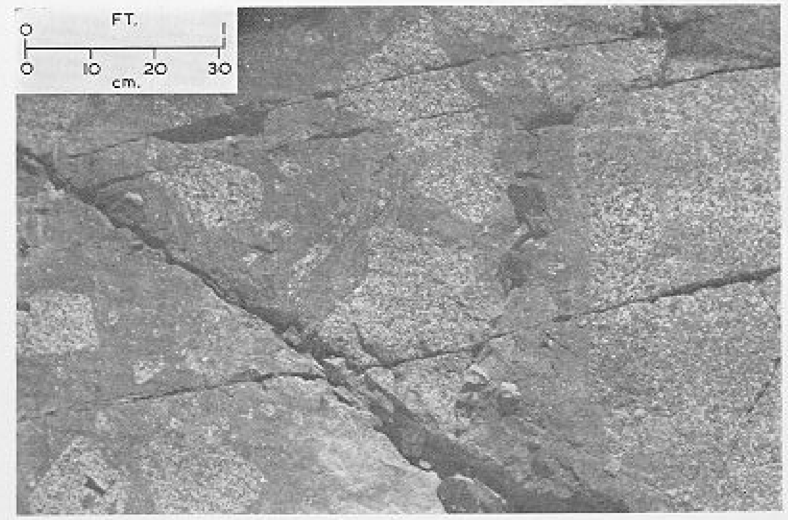
a. A weathered face of gabbroic intrusion breccia on a nunatak east of Crumbles Glacier (T.69). The darker lithic inclusions are of volcanic rocks. The crampon is approximately 12 in. (30·5 cm.) long.

b. The contact of Andean intrusive granodiorite (left) against Jurassic tuffite, modified by the intrusion of massive fine-grained post-Andean material along it; Jenny Island (T.209). The post-Andean rock is similar to the tuffite in appearance but it contains inclusions of the gabbro.

c. Gabbroic intrusion breccia net-veined by micro-adamellite; north-western Square Peninsula (T.180). The hammer head is 8 in. (20 cm.) long.

d. Coarse adamellitic intrusion breccia exposed just west of Rothera Point (T.89). Inclusions are of Jurassic volcanic rocks, not of the gabbro which the adamellite displaces at this contact. The head of the ice-axe is 13 in. (33 cm.) long.

a



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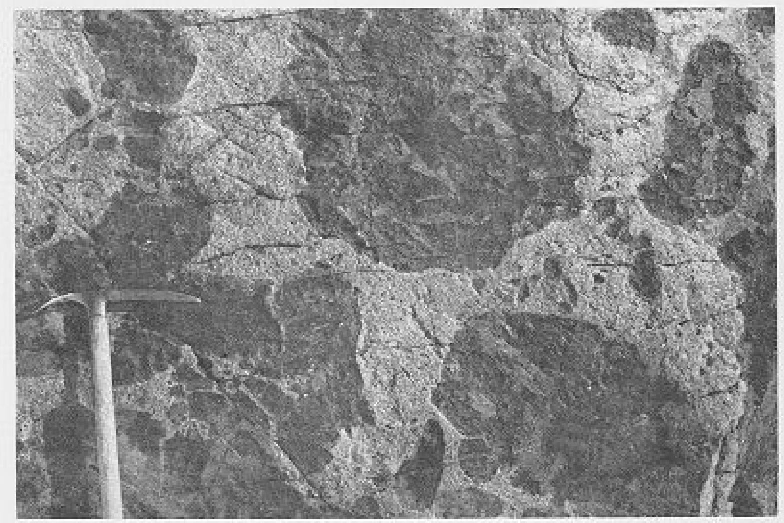

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PLATE III

PLATE IV

a. Indurated lapillistone (Plate Id), in which andesitic lithic fragments display a variety of textures; south-western Mount Bouvier (T.310.4; ordinary light; × 10).

b. Andesitic quench-breccia in which relatively large angular fragments of vesicular andesite are contained in a sparse lava matrix; south-western Mount Bouvier (T.2.1; ordinary light; × 6).

c. The fine-grained quartz mosaic of a pebble (upper left) from a conglomerate, marginally corroded by a narrow biotite-rich zone of the biotite-hypersthene-andesine-hornfels matrix; western Mount Bouvier (T.32.7; X-nicols; × 20).

d. Euhedral crystals of (?) grossular with subordinate quartz, labradorite and calcite at the centre of a specimen believed to be from a disrupted volcanic bomb; Cape Alexandra (T.35.5B; ordinary light; × 45).

e. Typical albitized lava of the Mount Liotard succession. The very fine-grained matrix encloses amygdales and large oligoclase phenocrysts. A cognate lithic inclusion (lower left) is similar to the matrix but it has a relatively high content of small amygdales; southern Mount Liotard (T.339.2; ordinary light; × 5·5).

f. A broken plagioclase phenocryst in fine-grained tuffite. A narrow overgrowth of sodic plagioclase is present around original crystal margins but it is absent on fractured faces; Jenny Island (T.210.1; X-nicols; × 53).

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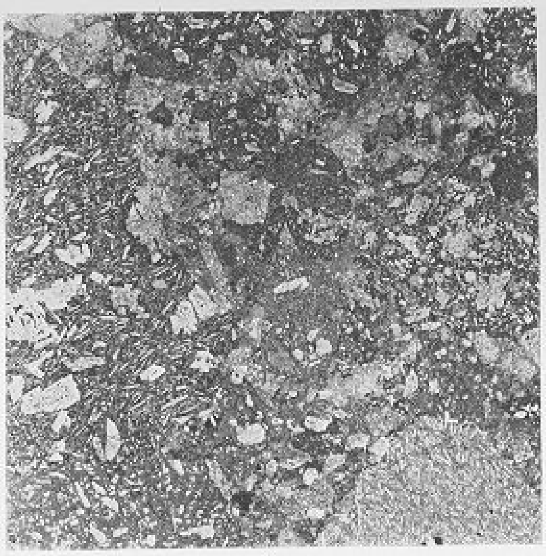

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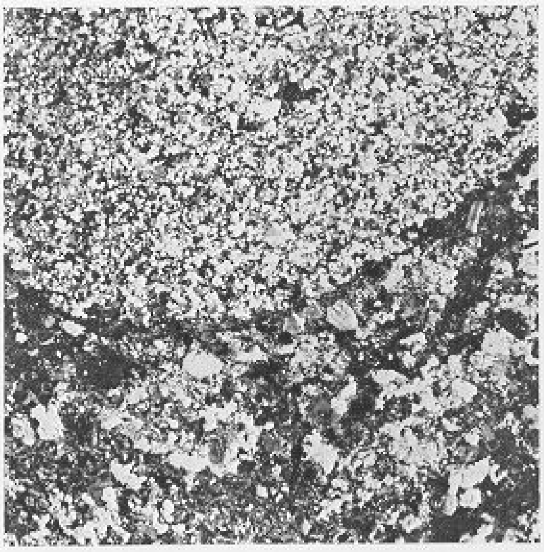

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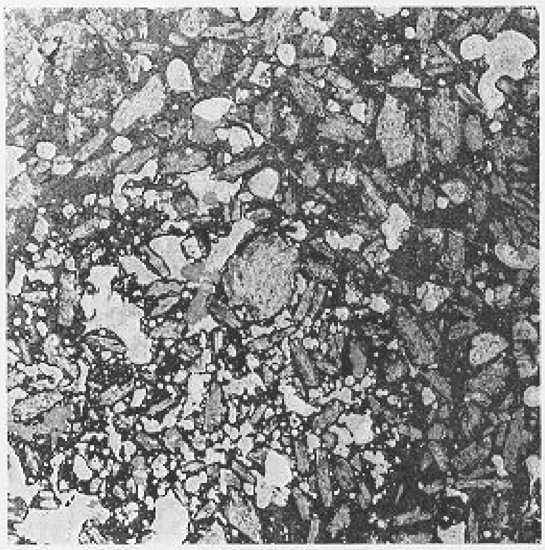

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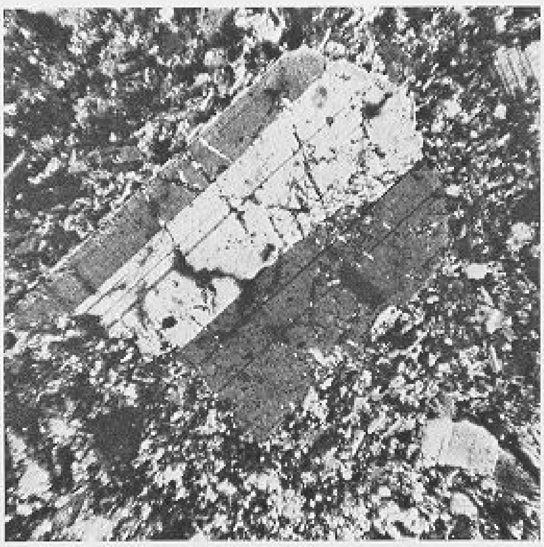

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PLATE V

a. Phenocrysts of hornblende (right) and labradorite (left) in the trachytic groundmass of an unbrecciated basalt; south-western Mount Bouvier (T.298.1; X-nicols; × 26).

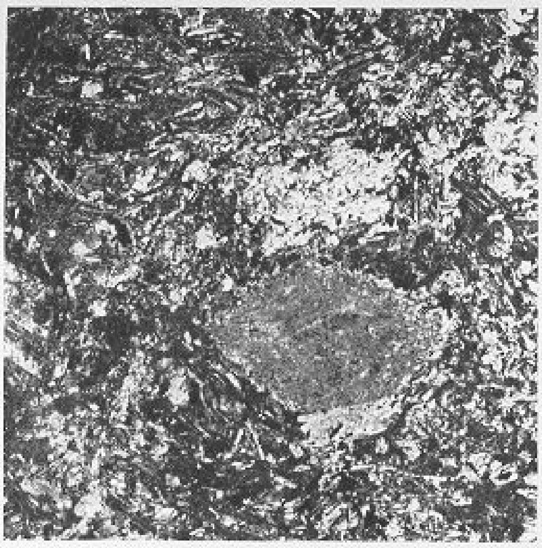
b. Granulitic texture in a thermally metamorphosed fragmental lava. A matrix of clinopyroxene and subordinate quartz encloses relatively leucocratic, silicic lithic fragments; Bond Nunatak (T.289.1; ordinary light; × 18).

c. Phenocrysts of albite-oligoclase, iron ore and altered clinopyroxene in the flow-layered, devitrified groundmass of a rhyolite; Webb Island (T.51.1; ordinary light; × 10).

d. Foliated texture of granitized schist forming a boulder in the conglomeratic country rock of the Léonie Islands. Ore-dusted lenticular plicated biotite is contained in a groundmass of quartz, cloudy potassium feldspar and iron ore crystals (T.137.1; ordinary light; × 46).

e. Altered olivine crystals in dark gabbro. A mass of talc encloses iron ore and straight fibrous anthophyllite crystals, and it is surrounded by a border of bleached hornblende; Léonie Island (T.129.1; ordinary light; × 25).

f. Rounded crystals of olivine and plagioclase enclosed by clinopyroxene which has been partially altered to bleached hornblende; Brockhamp Islands (T.139.3; X-nicols; × 48).



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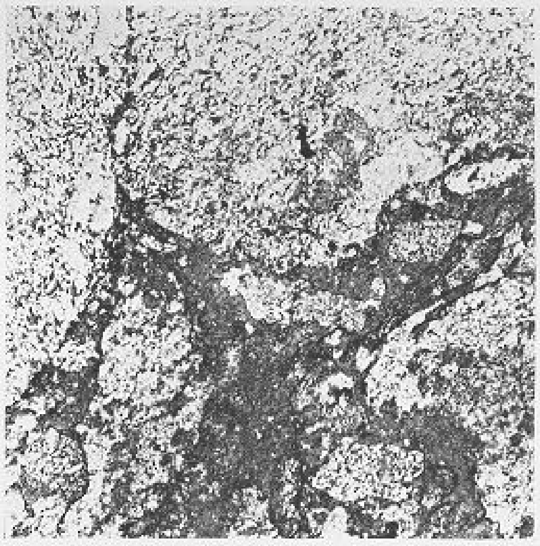

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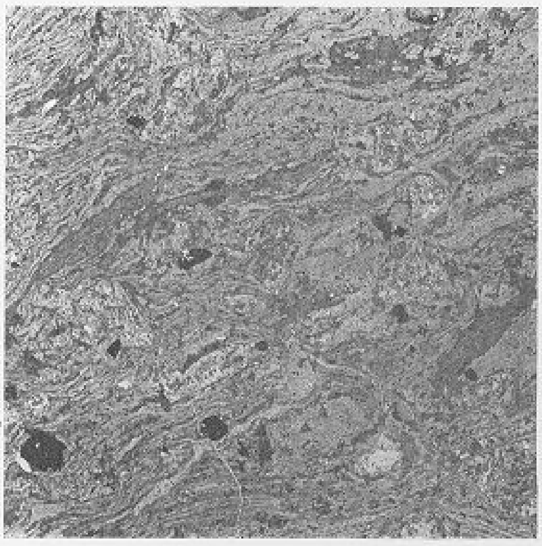

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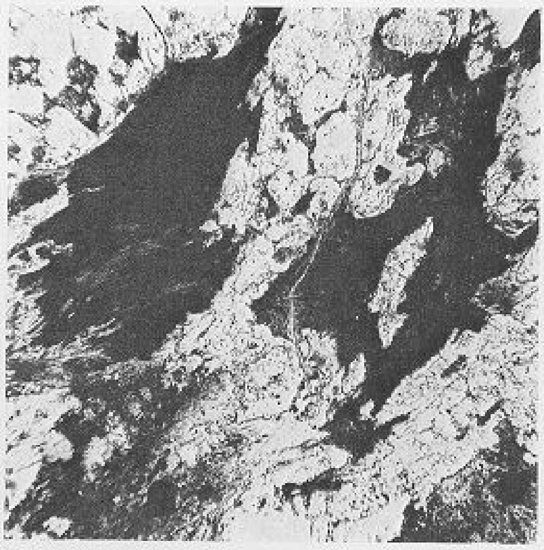

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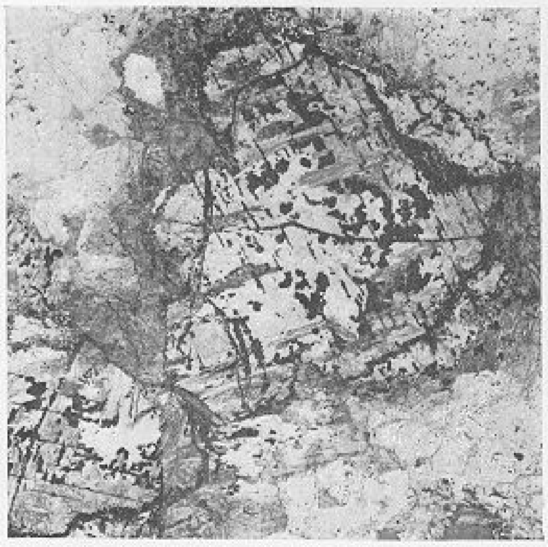

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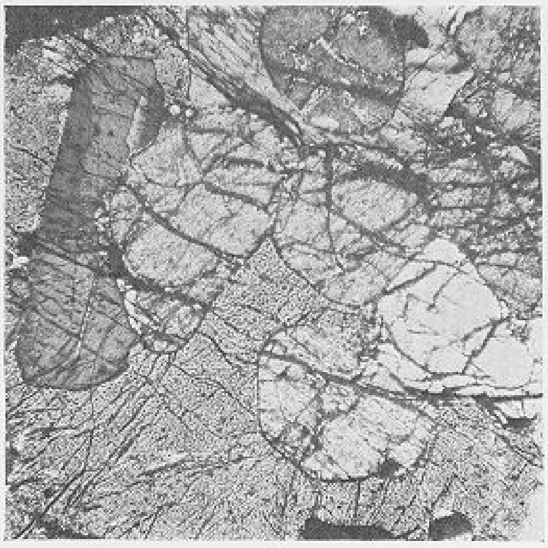

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PLATE VI

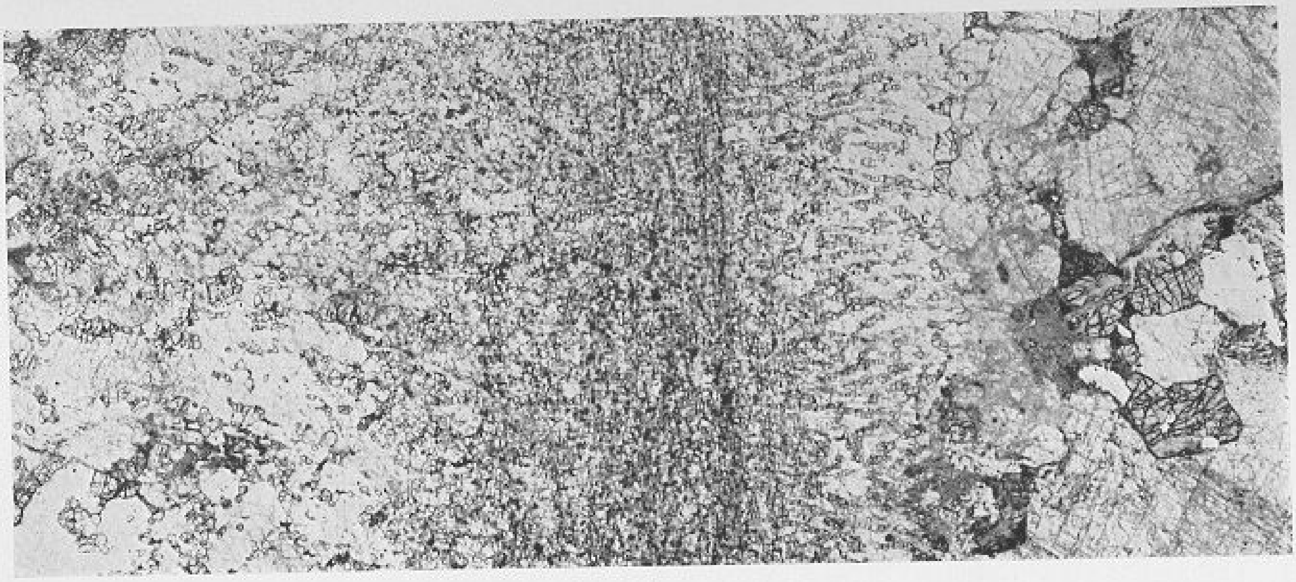
a. The outer zone of an orbicule in gabbro (Plate IIc). Acicular olivine crystals are disposed radially to the orbicule margin. The core of the orbicule is to the left of the acicular zone; Brockhamp Islands (T.139.6; ordinary light; × 8·5).

b. Typical hypidiomorphic texture of the Andean intrusive rocks of the Adelaide Island area. A large hornblende crystal encloses remnants of clinopyroxene and small crystals of plagioclase and quartz, and it is coarsely intergrown with iron ore (lower left). The plagioclase is zoned and the quartz is typically interstitial; diorite; Anchorage Island (T.125.1; X-nicols; × 20).

c. A zoned labradorite xenocryst in tonalite. Polysynthetic twinning is bent on the transition to the outer zones; Jenny Island (T.214.1; X-nicols; × 27).

d. Aggregated texture of a recrystallized fine-grained xenolith in granodiorite. Small plagioclase crystals are set between clusters of small clinopyroxene, iron ore and less common hypersthene crystals; north-western Square Peninsula (T.274.1; ordinary light; × 45).

e. Minute globular anhedra of clinopyroxene and iron ore enclosed in a tabular plagioclase crystal in granodiorite. A wide overgrowth of sodic plagioclase, which has crystallized around the calcic centre of the crystal, contains none of these inclusions; north-western Square Peninsula (T.274.1; ordinary light; × 45).



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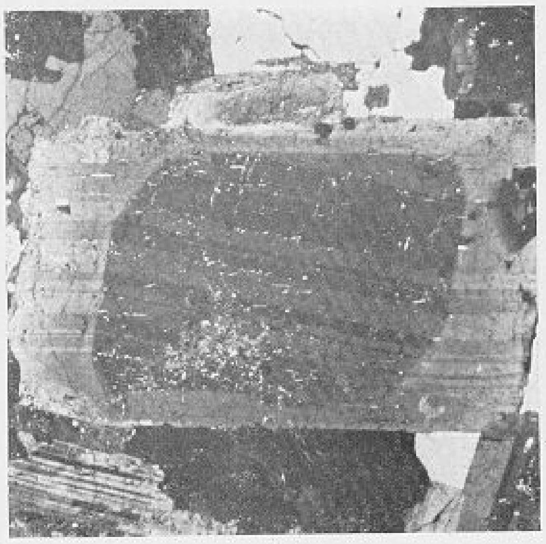

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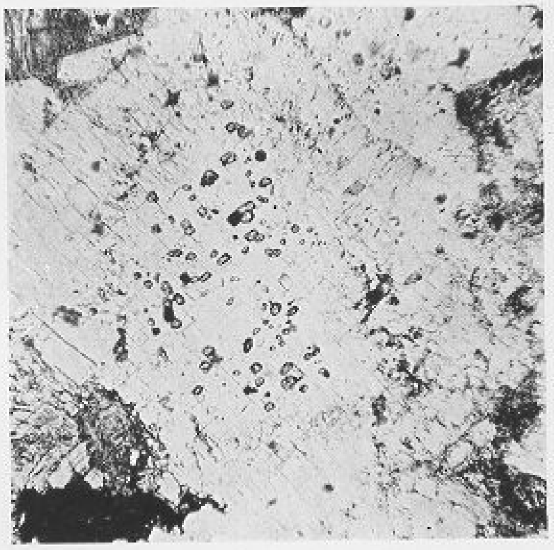

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PLATE VII

a. Quartz (illuminated) corroding irregularly zoned plagioclase in granodiorite; northern Mount Mangin (T.235.1; X-nicols; × 19).

b. Clinopyroxene mantled by biotite and iron ore in tonalite; northern Mount Mangin (T.237.1; ordinary light; × 20).

c. Potassium feldspar corroding plagioclase in granodiorite; eastern Mount Mangin (T.281.1; X-nicols; × 46).

d. Recrystallization in a vein of coarse-grained gabbro intruded into gabbro. Skeletal amphibole is contained in the chloritic centre of a mass of aggregated hornblende crystals; Blümcke Knoll (T.16.7; ordinary light; × 14).

e. Augite-granophyre containing euhedral clinopyroxene and iron ore phenocrysts and conspicuous apatite needles; northern Square Peninsula (T.157.2B; ordinary light; × 47).

f. Harrisitic texture developed in one of a series of textural discontinuities at a contact between hypabyssal basalts (Fig. 19B). Plumose titanaugite crystals have crystallized perpendicular to the contact, showing the direction in which crystallization proceeded; central Square Peninsula (T.64.6; ordinary light; × 3·5).

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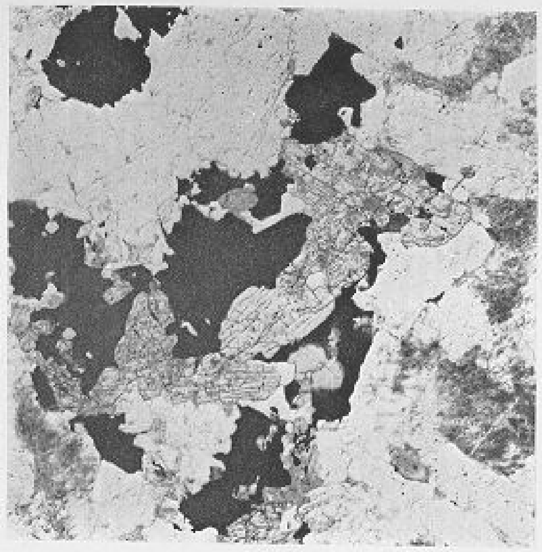

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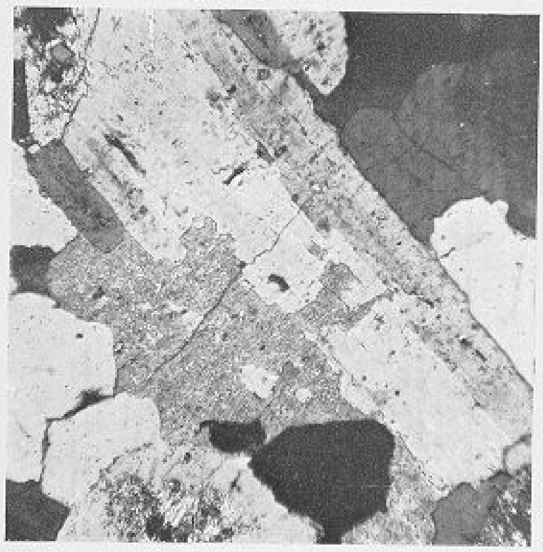

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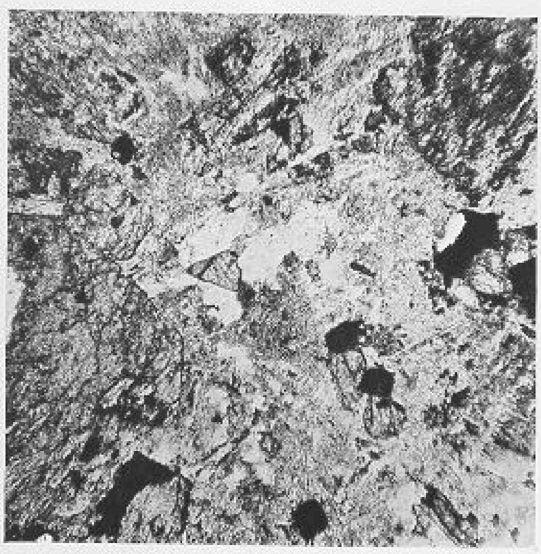

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