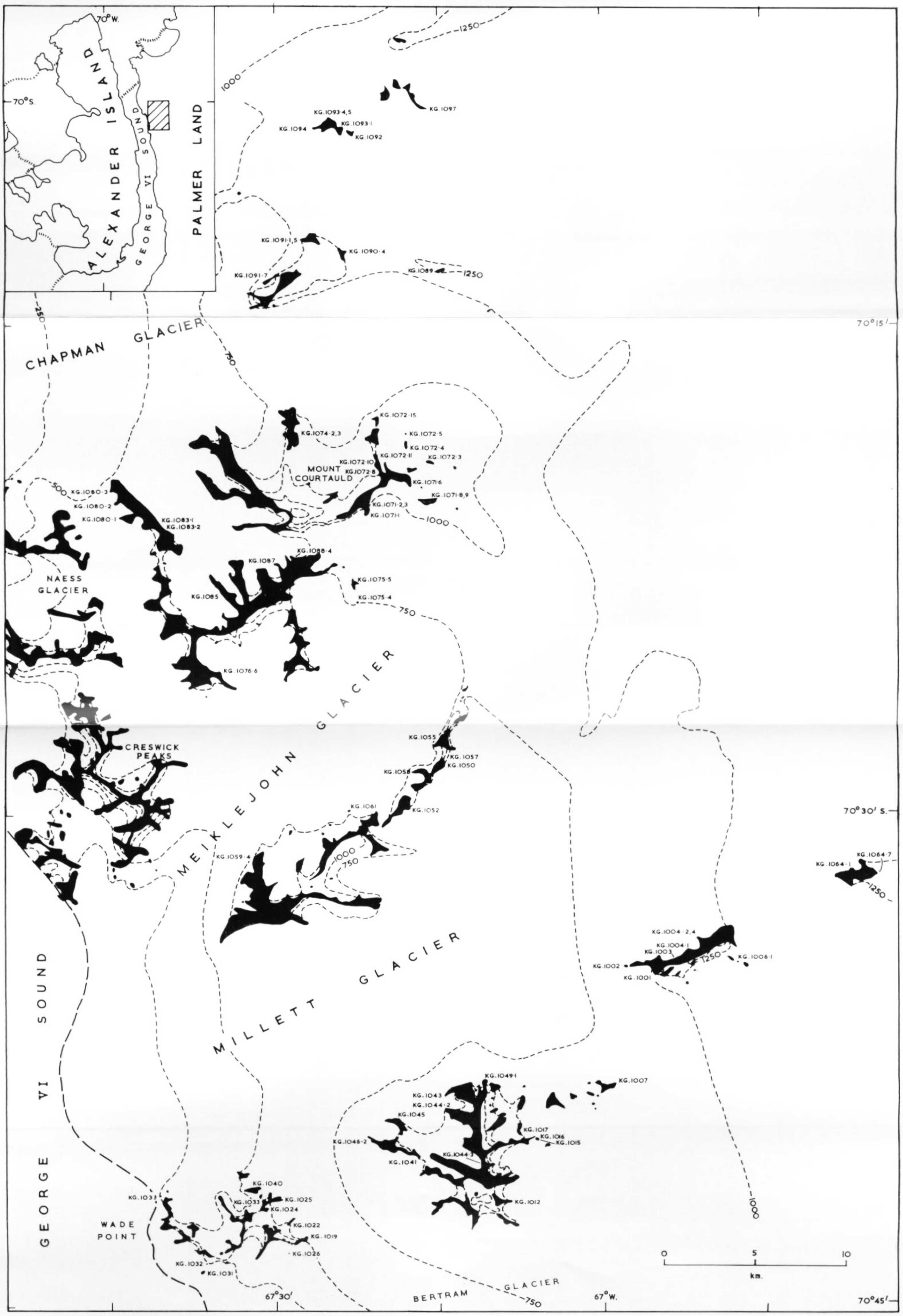

Fig. 1. Sketch map of the area between Riley and Bertram Glaciers, north-western Palmer Land, showing the physiography, place-names and station numbers; the contours are at 250 m. intervals. The inset shows the position of this area in the Antarctic Peninsula.

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THE GEOLOGY OF THE AREA BETWEEN RILEY AND BERTRAM GLACIERS, PALMER LAND

By P. J. Rowe

Abstract. The oldest rocks exposed in north-western Palmer Land are a sequence of well-foliated gneisses and *ortho*-amphibolites developed under almandine-amphibolite-facies conditions of regional metamorphism. Most of the gneisses probably represent original sedimentary rocks but it is possible that some are the metamorphic derivatives of plutonic igneous rocks. "White granite" plutons intrude the gneisses and they are themselves cut by a number of altered basic and acidic sills and dykes. The overlying, horizontally bedded (?) Upper Jurassic volcanic rocks are closely associated in space, and possibly in time, with bosses and dykes of "red granite" and quartz-plagioclase-porphyries but most of the plutonic rocks in this area (basic, intermediate and rare acidic types, as well as distinctive hybrid rocks) have been referred to the younger Andean Intrusive Suite. Late basic dykes, sometimes attaining swarm proportions, and rare aplitic minor intrusions cut these plutonic rocks and the volcanic ones but they are not known to intrude the metamorphic complex or the "white granites". It is possible that the late basic dykes are Tertiary in age.

The area described here (Fig. 1) comprises about 1,900 km.^{2} of the west coast and coastal hinterland of Palmer Land between Wade Point (lat. 70°41'S., long. 67°38'W.) and the Mount Pitman massif (lat. 70°09'S., long. 67°42'W.). Its eastern part is bordered by the broad and gently undulating, ice-covered central plateau (1,500–2,200 m. in height) of Palmer Land, from which broad outlet glaciers flow westward to merge with the ice shelf in George VI Sound. Rock exposures in the coastal hinterland are confined to wedge-shaped mountainous groups, such as Mount Courtauld (1,980 m.; Fig. 2), which lie between these broad glaciers but in the north of this area, between Riley and Chapman Glaciers and to the east of Mount Pitman, there is little exposed rock.

Air-photographic surveys of this part of Palmer Land were made by members of the Ronne Antarctic Research Expedition (1946–48) and the U.S. Navy (1966–67) but no detailed ground

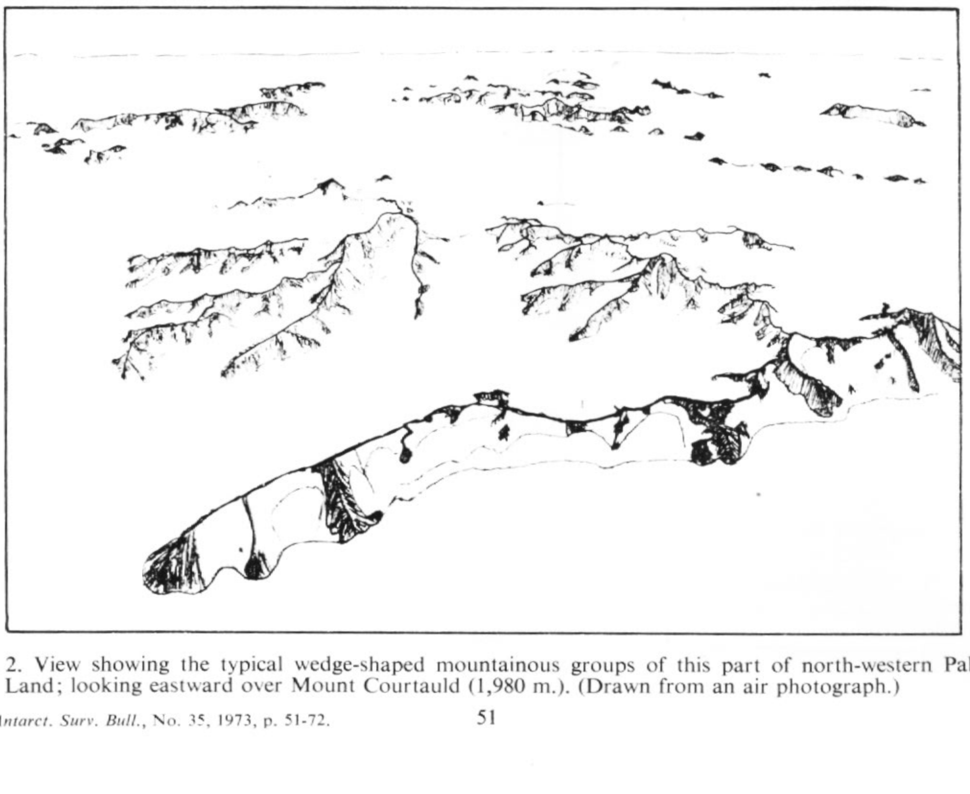

Fig. 2. View showing the typical wedge-shaped mountainous groups of this part of north-western Palmer Land; looking eastward over Mount Courtauld (1,980 m.). (Drawn from an air photograph.)

survey was made until British Antarctic Survey personnel visited the area during the austral summer of 1969–70. Adjacent areas, mostly to the south of Bertram Glacier (including the Batterbee Mountains) and to the north of Riley Glacier, have been studied by M. E. Ayling, J. F. Pagella, A. C. Skinner and C. G. Smith but most of this work is at present unpublished. The preliminary results of the author's investigations are described below.

General Stratigraphy

The stratigraphy of this area is summarized in Table I and the geographical distribution of the rock units is shown in Fig. 3. The oldest rocks, forming part of the Palmer Land metamorphic complex, are a group of sedimentary, and possibly igneous, rocks which have been subjected to regional metamorphism of almandine-amphibolite-facies grade. They are represented

Table I. Stratigraphical succession for the area between Riley and Bertram Glaciers, Palmer Land

	Volcanic and sedimentary rocks	*Plutonic rocks*	*Hypabyssal rocks*
Tertiary to Cretaceous		"Pink granite" Granodiorite Diorite Gabbro	Aplite and porphyry dykes and sills Basic dykes
(?) Upper Jurassic	Agglomerates, Tuffs, Lavas with rare sedimentary horizons	"Red granite" and quartz-plagioclase-porphyry bosses	Potash feldspar- and quartz-plagioclase-porphyry dykes Granodiorite dykes Acid sills and dykes, Basic sills and dykes (age uncertain)
(?) Triassic		"White granite"	
	Metamorphic complex		

by basic and acidic gneisses and also by amphibolites. Many of the amphibolites were probably originally dykes intruded prior to, or during, the final stages of metamorphism and they therefore form part of the metamorphic complex; from field observations they can be subdivided into an older and a younger group. The regional metamorphism of the Palmer Land rocks has been provisionally correlated with a similar metamorphic episode in the Oscar II and Foyn Coasts, which Marsh (1968, p. 24) believed to be of (?) Permian age. It is thought that the "white granites" present in north-western Palmer Land could be the result of anatectic re-melting during this metamorphic phase.

Outpourings of basic lavas and andesitic tuffs, possibly the equivalents of the Upper Jurassic Volcanic Group exposed in western Graham Land (Hoskins, 1960; Curtis, 1966; Elliot, 1966; Dewar, 1970), are partly contemporaneous with small boss-like intrusions of "red granite"

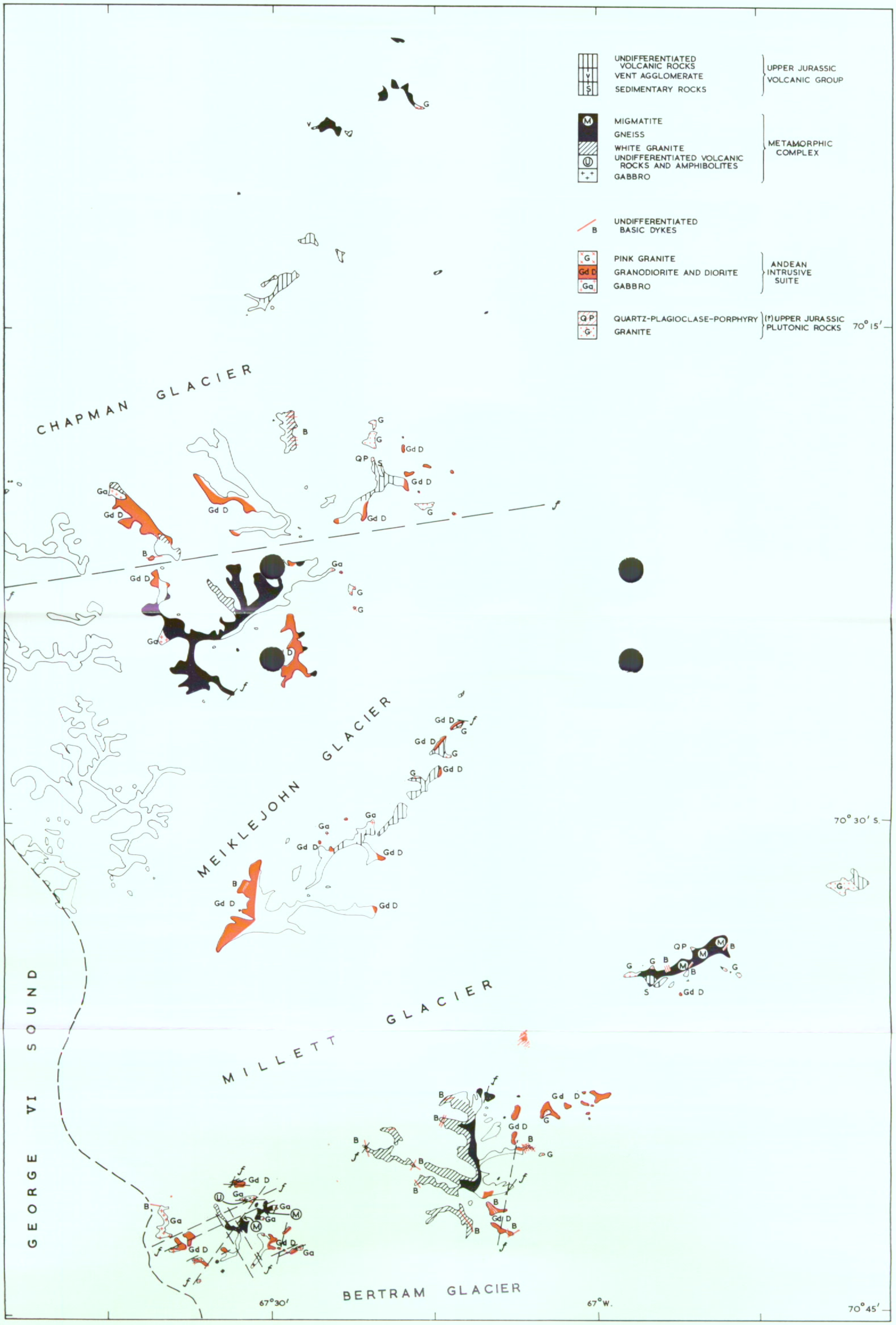

Fig. 3. Geological sketch map of the area between Riley and Bertram Glaciers, north-western Palmer Land.

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and quartz-plagioclase-porphyries. Although mainly volcanic, there are occasional thin horizons of sedimentary rocks throughout this (?) Upper Jurassic succession. Numerous plutonic rocks, referred to the late Cretaceous to early Tertiary Andean Intrusive Suite (Adie, 1955), are exposed in north-western Palmer Land but their stratigraphical position in relation to the volcanic rocks is not clear, because of the lack of intrusive contacts. However, the absence of fragments of the younger plutonic rocks within the andesitic tuffs suggests that the volcanic rocks are older than the plutonic ones. The Andean Intrusive Suite is represented by a succession of intrusions of increasing acidity, many of the intermediate ones being heterogeneous, xenolithic and schlieren-bearing rocks. Late basic dykes intrude the volcanic rocks and the "red granites" but they only cut the other intrusive rocks where these are close to members of the volcanic group. They usually form isolated intrusions but one dyke swarm, trending 145–325°, was observed in association with a tuff cone. The age of these basic dykes is not known but, by analogy with other areas, they are believed to have been emplaced during the Tertiary. Aplitic dykes, observed cutting both tuffs and "red granites", probably represent the most recent igneous event in this area.

Metamorphic Complex

Rocks belonging to the metamorphic complex occur in widely scattered outcrops throughout this area (Fig. 3). The least altered of them are the slightly migmatized, banded basic gneisses magnificently exposed in the 600+ m. cliff on the southern margin of Millett Glacier (Fig. 4). These include hornblende-biotite- and biotite-gneisses as well as plagioclase-potash feldspar-quartz- and plagioclase-quartz-gneisses. Metamorphic rocks of intermediate composition (mostly biotite-rich gneisses) are exposed in the Wade Point hinterland and weakly foliated potassium-rich gneisses crop out on several of the small nunataks farther north. Most of the foliated rocks of basic to intermediate composition exposed in the small nunataks 12 km. east of the summit of Mount Pitman are probably the marginal facies of a basic pluton injected

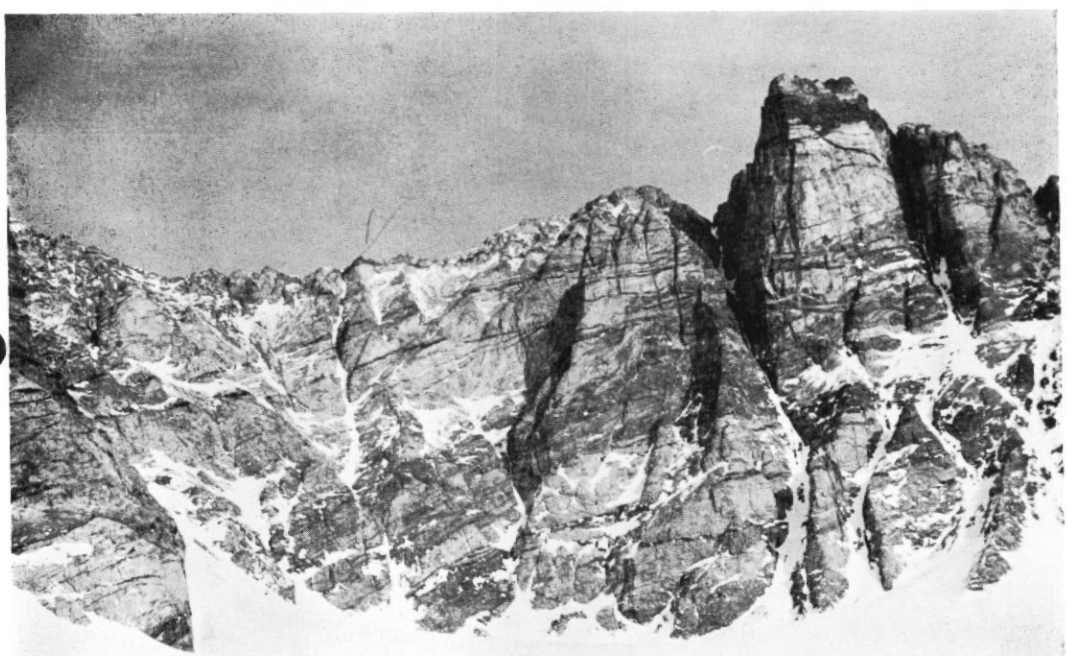


Fig. 4. Irregularly migmatized basic gneisses and thin concordant amphibolite sheets exposed in the 630 m. high cliff section at station KG.1004.

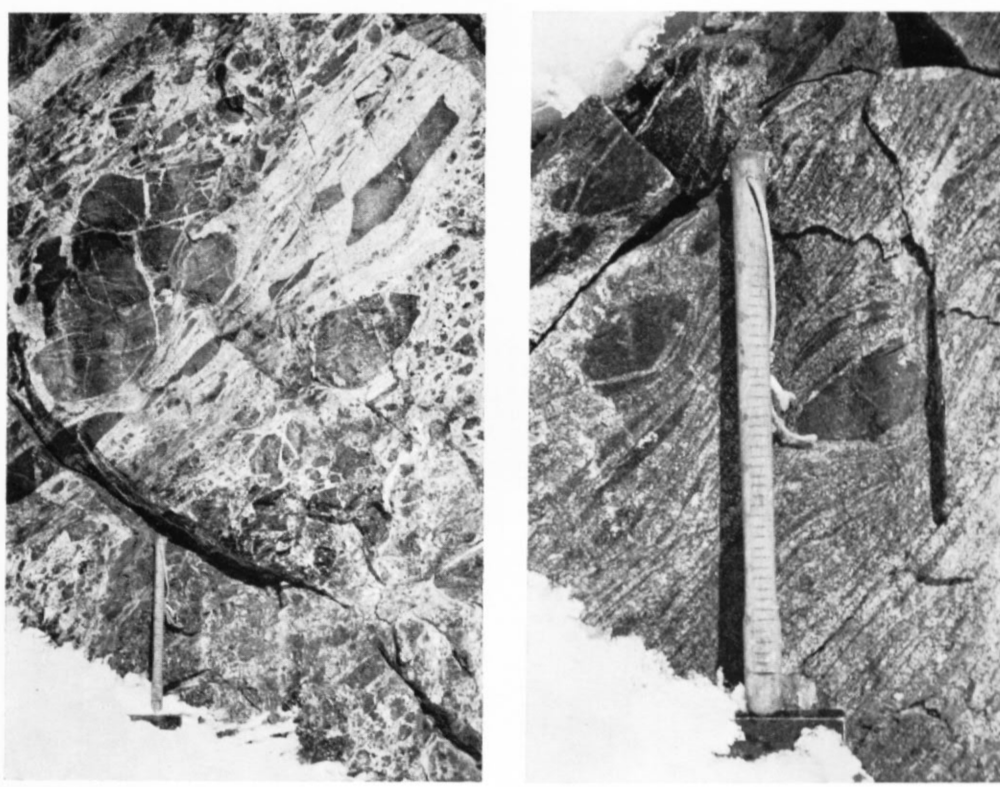
under compressional stress rather than having a metamorphic origin. The ridge between Mount Courtauld and Creswick Peaks displays the greatest variety of metamorphic rocks in this area. Amphibolites are well exposed in the Mount Courtauld area and (?) amphibolitic rafts, sometimes broken up into agmatitic blocks (up to 8 m. by 30 m. in size), are present in leucocratic gneisses near stations KG.1050.2 and 1078.2.

Few metamorphic/plutonic contacts were observed in this area but a thin veneer of metamorphic rocks is exposed on the northern wall of the "white granite" pluton forming most of the mountain group 15 km. east-north-east of Wade Point. Closer to Wade Point, a diorite body exposed near, but not cutting, metamorphic rocks is presumably the source of the aplitic veins which cut the gneisses at this locality.

The intensity of foliation and fissility of the more coarsely banded gneisses varies noticeably and the thickness and regularity of the laminae also varies although their mineralogy remains constant. The bulk foliation of all the gneisses dips north-eastwards at about 35°, except in the Wade Point hinterland where dips of 10–50° to the north-east (KG.1033 and 1036) or 70–80° to the north (KG.1035.1) were recorded. Table II gives the modal analyses of a few of the metamorphic rocks described below.

Basic gneisses

Although it has been impossible to determine their exact field relationships, it is probable that the more acidic gneisses were derived from the basic ones by migmatization during regional metamorphism (Fig. 5a and b). Leucocratic material is not always concordant with the foliation of the basic gneisses and it sometimes occurs in irregular patches (Fig. 4).



a b

Fig. 5. a. Agmatites developed at a relatively early stage of migmatization; station KG.1033.
b. Gneisses showing a more advanced stage of migmatization at the same locality.

TABLE II. MODAL ANALYSES OF ROCKS FROM NORTH-WESTERN PALMER LAND

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Quartz	45·9	9·5	31·6	—	25·1	18·5	11·2	3·8	—	*	—	—	2·3	8·0	14·8	1·3	—	26·3
Potash feldspar	0·3	4·3	26·9	—	6·7	23·2	50·4	5·9	—	—	—	—	—	2·0	8·5	65·1‡	—	16·6
Plagioclase	51·8‡	68·4‡	40·2‡	44·7	52·5†	47·8†	37·8	9·4	30·4	17·7	57·3	60·6	49·8	69·6	75·4	32·1	30·8	51·4
Olivine	—	—	—	—	—	—	—	—	—	—	18·8	2·7	*	—	—	—	—	—
Pyroxene	—	—	—	—	—	—	—	—	6·2	0·1	23·1	10·2	*	0·7	—	—	*	—
Hornblende	—	0·8	—	39·6	5·2	—	—	—	—	—	0·7	23·1	37·4	12·9	—	—	*	—
Micas	0·4	1·0	0·3	—	5·7	1·2	*	0·1	1·0	*	—	0·2	5·1	3·9	tr	*	—	3·0
Chlorite	0·1	9·5	0·9	9·8	0·2	4·4	—	—	0·6	*	—	—	0·3	0·6	tr	1·3	*	1·0
Epidote	0·5	0·2	—	3·7	2·8	4·4	—	5·4	2·5	0·6	—	—	0·1	0·1	0·1	*	20·7	0·7
Iron ores	0·7	1·3	—	0·7	1·2	0·4	0·5	0·3	—	*	0·1	3·2	5·0	2·0	1·2	0·2	1·1	0·9
Other minerals	0·3	5·0	0·1	1·5	0·6	0·1	0·1	1·3	tr	3·2	—	—	—	0·2	tr	tr	1·0	0·1
Lithic fragments	—	—	—	—	—	—	—	—	—	24·3	—	—	—	—	—	—	—	—
Matrix or groundmass	—	—	—	—	—	—	—	73·8	59·3	54·1	—	—	—	—	—	—	46·4	—
Plagioclase composition	An_{30}	An_{34}	An_{30}	An_{34}	An_{36}	An_{29}	An_{31}	An_{27}	An_{47}	An_{37}	An_{68}	An_{67}	An_{52}	An_{44}	An_{64}	An_{33}	An_{58}	An_{39}

tr Trace. * Present but not recorded. † Includes myrmekite. ‡ Largely graphic granite.

1. KG.1033.4 Plagioclase-quartz-biotite-gneiss; 5 km. north-east of Wade Point.
2. KG.1092.1 Plagioclase-quartz-gneiss; northern margin of Chapman Glacier.
3. KG.1049.1 Potash feldspar-quartz-gneiss; southern margin of Meiklejohn Glacier.
4. KG.1076.6 Younger amphibolite; 8·6 km. south-west of the summit of Mount Courtauld.
5. KG.1043.1 Dioritic "white granite"; southern margin of Millett Glacier.
6. KG.1041.1 Granodioritic "white granite"; northern margin of Bertram Glacier.
7. KG.1072.15 Granodioritic "red granite"; southern margin of Chapman Glacier.
8. KG.1004.2 Quartz-plagioclase-porphyry; southern margin of Millett Glacier.
9. KG.1061.4 Porphyritic basaltic andesite; southern margin of Meiklejohn Glacier.
10. KG.1090.4 Andesitic crystal-lithic tuff; Chapman Glacier.
11. KG.1032.1 Olivine-gabbro; near Wade Point.
12. KG.1019.1 Hornblende-gabbro; near Wade Point.
13. KG.1025.3 Heterogeneous gabbro; near Wade Point.
14. KG.1083.1 Diorite; 7·5 km. south-west of the summit of Mount Courtauld.
15. KG.1083.2 Quartz-diorite; 7·5 km. south-west of the summit of Mount Courtauld.
16. KG.1097.1 "Pink granite"; southern margin of Riley Glacier.
17. KG.1004.4 Late basic dyke; southern margin of Millett Glacier.
18. KG.1050.8 Pink granodiorite dyke; northern margin of Millett Glacier.

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Plagioclase-hornblende-quartz-biotite-gneisses (KG.1033.2) are probably the most abundant of the basic gneisses, consisting of alternating leucocratic (0·5–2·0 mm. in thickness) and melanocratic laminae interspersed with thicker (5–12 cm.) melanocratic bands. In thin section, it is clear that brown biotite, which occurs to the virtual exclusion of hornblende in some laminae, is partially or wholly derived from green hornblende; in other laminae, biotite may be completely absent and hornblende becomes the predominant mineral. Two phases of plagioclase (An_{44}) crystallization are represented and quartz, which exhibits strained extinction, contains numerous inclusion trails. The accessory minerals sometimes occur in aggregates and they include magnetite, pyrite, haematite and sphene.

Plagioclase-hornblende-quartz-gneisses were found at only one locality (KG.1027.1), where they are intruded by trondhjemitic sills and veins. These gneisses are dense coarsely foliated rocks containing abundant felsic minerals (80 per cent) and dark laminae of green hornblende crystals (approximately 20 per cent). In thin section, they comprise hornblende (α = brownish green, β = olive-green, γ = dark green; $\gamma : c = 27°$) which is partially replaced by actinolite, rare partially chloritized biotite containing bundles of prehnite, clots of iron ore (1–4 mm. in diameter), quartz and two generations of plagioclase (An_{58}). Two forms of plagioclase are present in most of the basic gneisses and they are represented by large porphyroblasts exhibiting wavy and concentrically zoned extinction and by mosaics of small (rarely greater than 0·08 mm. in diameter), fresh crystals showing little or no twinning. Quartz occurs either in glomeroporphyroblasts up to 1·0 mm. in diameter, sometimes enclosing small plagioclase and hornblende crystals, or as individual rounded crystals less than 0·15 mm. in diameter. The iron ore is commonly ilmenite but magnetite forms a partial selvage around the larger crystals.

Plagioclase-quartz-biotite-gneisses. Many gneisses (KG.1077.1) resemble foliated diorite in the hand specimen but their metamorphic character is indicated in thin section by the growth of glomeroporphyroblastic aggregates (up to 2·4 mm. in diameter) of quartz and indeterminate plagioclase interspersed with clots of mafic and accessory minerals. The larger and older crystals of plagioclase are virtually completely sericitized so that multiple twinning is only rarely seen, whereas the younger and fresher plagioclase, occurring marginally to the altered crystals, gives rise to a "mortar" texture (Spry, 1969, p. 6). Rare myrmekite has apparently replaced the older plagioclase but no potash feldspar has been positively identified in thin section. Biotite is uncommon since it has been largely replaced by penninite and iron ore. Rare twinned hornblende crystals remain unaltered apart from the sphenitization of exsolved iron ore. Accessory minerals include epidote, iron ore and large euhedral sphene crystals.

The *plagioclase-quartz-potash feldspar-gneisses* (KG.1088.3) represent basic gneisses which have undergone potash metasomatism. Feldspathic augen-like aggregates occur in poorly defined alternating laminae of felsic and mafic minerals, and the rocks are often traversed by slightly discordant aplitic veinlets. In thin section, a small amount (10 per cent) of perthitic orthoclase and "microclinized" (Marmo, 1971, p. 171) plagioclase are present in addition to the plagioclase (An_{53}) and quartz typical of the normal basic gneisses. Brown biotite is considerably more common than the green hornblende, which it replaces, and it frequently contains bundles of prehnite. The larger hornblende crystals sometimes include tiny (?) zircons surrounded by pleochroic haloes and they show partial replacement by penninite and prehnite. The accessory minerals include skeletal sphenitized ilmenite crystals, apatite and secondary epidote.

Plagioclase-quartz-gneisses. The most northerly outcrop of basic gneiss is at station KG.1092.1 where a poorly foliated, slightly potash-metasomatized, feldspar-rich gneiss is exposed. In thin section, the plagioclase (An_{34}) is more acidic than that of the other basic gneisses but it is otherwise typical. The mafic minerals include partially chloritized hornblende, secondary epidote, euhedral to subhedral sphene and small relict grains of garnet embedded in a mass of chlorite; this rock is the only specimen from this area which contains garnet.

Acidic gneisses

The acidic gneisses include well-foliated rocks containing considerable quantities of mafic minerals (particularly biotite) and poorly foliated leucocratic rocks. The biotite-rich gneisses probably include migmatized basic gneisses (possibly *para*gneisses), although some are believed to be directly derived from igneous rocks of basic to intermediate composition. Composite gneisses exposed on the small knolls on the northern margin of Bertram Glacier (KG.1006) are composed of alternating laminae of two components: poorly foliated quartz-potash feldspar-plagioclase-gneiss and well-foliated quartz-biotite-plagioclase-gneiss. On the north-western face of the same nunatak, massive pinkish plagioclase-quartz-potash feldspar-gneiss crops out, together with more potassium-rich types, and there is an isolated exposure of well-foliated leucocratic potash feldspar-quartz-biotite-gneiss at station KG.1049. Lithologically variable biotite-rich gneisses, regarded as migmatites, are exposed in the Wade Point hinterland but much of the higher ground in that area is believed to be formed by (?) *para*gneisses similar to those exposed at station KG.1004.

The *plagioclase-quartz-biotite-gneisses* of stations KG.1033 and 1036 are finely and often uniformly banded. In thin section, plagioclase (of indeterminate composition) is less altered than that of the basic gneisses and biotite shows only minor replacement by penninite. The mica includes crystals of sphene, apatite and rare iron ore, all these mafic minerals occasionally forming loose aggregates within the gneiss.

The rocks at station KG.1006 include *composite gneisses* (Table III) consisting of alternating laminae of coarse leucocratic material (of adamellitic (Chayes, 1957) composition) and less

TABLE III. MODAL ANALYSES OF THE TWO COMPONENTS OF THE COARSELY BANDED GNEISS AT STATION KG.1006.2

	KG.1006.2a	KG.1006.2b	KG.1006.2*
Quartz	48·8	53·4	49·9
Microperthite	24·5	—	18·4
Plagioclase	24·5	22·8	24·1
Muscovite	0·3	—	0·2
Biotite	1·1	22·9	6·5
Penninite	0·3	0·2	0·3
Iron ores	—	0·5	0·1
Epidote	tr	0·2	0·1
Other minerals	0·5	—	0·4
Plagioclase composition	An_{31}	An_{34}	—

tr Trace.
* Analysis calculated on the basis of a 3 : 1 ratio for biotite-free gneiss : biotite-rich gneiss.

frequent, discontinuous melanocratic bands of plagioclase-quartz-biotite-gneiss. These rocks therefore occupy a median position between the plagioclase-potash feldspar-quartz-biotite- and plagioclase-quartz-biotite-gneisses of stations KG.1035 and 1049, respectively. The plagioclase (An_{30}) in the composite gneisses is commonly saussuritized and both it and quartz show strain features, such as secondary polysynthetic twinning in the plagioclase or undulose extinction in the quartz. Small biotite flakes, which have crystallized at crystal triple points in the quartz mosaic, emphasize the metamorphic nature of these rocks but streaks and clots of larger biotite flakes (0·5 mm. in length) are also present. The larger flakes are partially replaced by penninite and, where this replacement is extensive, there are small amounts of epidote and rare iron ore. Other accessory minerals include aggregates of magnetite, with rare haematite. Microperthitic orthoclase, rare microcline and associated myrmekite are present in the more potassium-rich gneisses. These include the *plagioclase-potash feldspar-*

quartz-biotite-gneisses (KG.1035), which contain biotite as well as the normal titanium-rich accessory minerals.

The *potash feldspar-quartz-gneisses* (Fig. 6; Table II) are exceptional rocks because they have a colour index of only 2 (Shand, 1947); much of their biotite has been penninitized, sphene is present in only trace amounts and there are no ore minerals. Many of these more acidic gneisses possess plagioclase crystals showing microclinized patches and, where microcline is in contact with plagioclase, extensive areas of myrmekite have developed. Microcline and microperthite porphyroblasts are restricted to those rock types known, or believed, to occupy the roof zones of later plutons, the porphyroblasts both distorting and cutting across the lineation exhibited by the mafic minerals. In these rocks (KG.1049.1, 1076.8, 1077.3 and 1084.7), myrmekite is also extensively developed and in many of the microperthite-quartz-gneisses (KG.1077.3 and 1088.4) microcline is occasionally graphically intergrown with quartz.

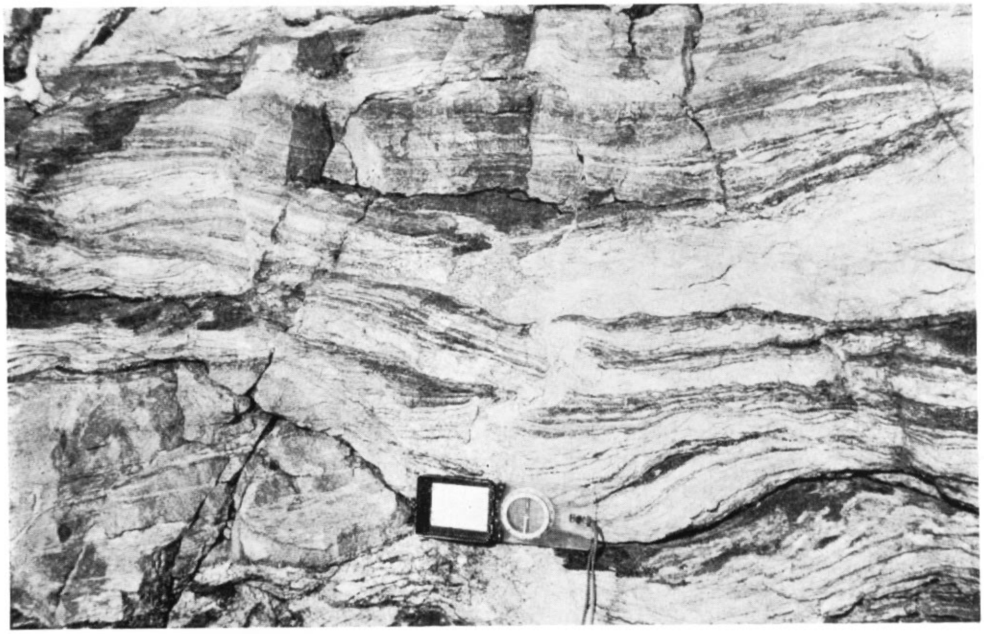


Fig. 6. Irregular but prominent banding of the potash feldspar-quartz-gneisses at station KG.1049.1.

Amphibolites

Amphibolites occur in two morphologically distinct forms: as huge rafts and sheets (of presumed amphibolitic composition) and as narrow dyke-like bodies. The huge irregularly orientated rafts, none of which are readily accessible in the field, are sharply defined macroscopically and they occur within the host gneisses at a number of localities (KG.1040, 1050.2, 1078.2 and 1093.4). They could represent basic lava flows, basic tuffs or fine-grained calcareous sedimentary rocks.

At least one set of basic dykes, now amphibolites, was intruded prior to the period of regional metamorphism. Although their temporal relationship to the other members of the metamorphic complex is unknown, they are sufficiently distinctive morphologically to be classified separately from the raft-like (?) amphibolitic bodies. These dyke-like bodies (1–300 cm. in thickness), together with associated sheets and veins, are called the "younger amphibolites" in contrast to the raft-like "older amphibolites". The younger amphibolites are widely distributed within both the basic and the migmatized gneisses; some of the veins and sheets are concordant with the foliation of the host gneiss and others are concordant with the margins of leucocratic (migmatized) masses within the basic gneiss. The number of concordant amphibolites appears to decrease towards the top of the cliff face shown in Fig. 4. They never show rheomorphic features, possibly on account of their small size, and they are generally sub-horizontal or dip north-eastwards at 10–30°.

The amphibolites are all essentially similar petrographically. Lineation of the amphibole crystals is occasionally well developed and constant in direction despite rare minor bending of some crystals. The amphibole is normally hornblende but a fibrous actinolite (KG.1025.3) is sometimes present. The hornblende is usually bleb-like and at high concentrations it is sieve-textured, containing numerous plagioclase crystal inclusions. However, hornblende is more commonly included within plagioclase. Haematite and rare minor quantities of other ore minerals are also included in the hornblende, usually as small irregular masses aligned along the cleavage or twin traces. Brown biotite occupies 0–8 per cent of the amphibolites and it appears to be derived from hornblende. Penninite occurs in ragged flakes, often in association with epidote, sieve-like plagioclase and hornblende. Epidote occurs both as porphyroblasts and as granular crystal aggregates (the result of saussuritization), while prehnite forms bundles of fibres aligned along biotite cleavage traces. Quartz is present as small and slightly strained crystals which show some preferred orientation in the plane of the fabric. Iron ore is represented by magnetite (KG.1027.2), skeletal ilmenite (KG.1033.1 and 1082.1), minor quantities of chromite (KG.1027.2) and iron pyrites (KG.1025.3 and 4). Haematite usually occurs in wispy veinlets (KG.1082.1) but a few exceptionally large crystals occur in specimen KG.1025.4.

Metamorphism

Two episodes of regional metamorphism have affected the rocks of the metamorphic complex. The first, and major, event involved the regional metamorphism, under almandine-amphibolite-facies (Fyfe and others, 1958, p. 228) conditions, of a possible sedimentary and volcanic sequence which had been intruded by plutonic and hypabyssal rocks. The well-foliated biotite-rich gneisses are probably the metamorphic derivatives of a sedimentary sequence but the leucocratic gneisses, always the least well foliated of the metamorphic rocks, are generally thought to be *ortho*gneisses; some of the hornblende-rich gneisses contain relict (?) pyroxene crystals and they may represent metamorphosed gabbros. The raft-like (?) amphibolites could originally have been basic lava flows or tuffs within a greywacke sequence, whereas the younger amphibolites are believed to be regionally metamorphosed basic dykes.

The high potash content of many of the gneisses is known to be pre-Upper Jurassic in origin, since volcanic rocks (of presumed Upper Jurassic age) contain fragments of potash-rich gneisses. This potash could have been derived from the "white granites", which were emplaced in the metamorphic rocks long before the commencement of volcanicity. However, the development of potash feldspar, oligoclase and quartz porphyroblasts (KG.1004) is a phenomenon closely associated with hydrothermal granitization (Marmo, 1971, p. 43) and the growth of these minerals in some gneisses was probably linked with the intrusion of the (?) Jurassic "red granites".

After a considerable break in time a weak prehnite-pumpellyite-facies metamorphism affected all of the rocks in this part of Palmer Land. This final metamorphic event is indicated by lenticular bundles of fibrous prehnite within biotite and chlorite flakes in many of the metamorphic, plutonic and hypabyssal rocks.

Volcanic Rocks

The age of the volcanicity in north-western Palmer Land is not known in detail but it is clearly younger than the metamorphic complex and the "white granites", and older than those plutonic rocks referred tentatively to the Andean Intrusive Suite. Nevertheless, more direct evidence for the age of the volcanic rocks in this area is present at Carse Point, where volcanic rocks conformably overlie sedimentary rocks containing a marine fauna (personal communication from N. G. Culshaw). A preliminary examination of the fossils suggests that they are of a late Jurassic age (personal communications from M. R. A. Thomson and L. E. Willey).

Lithology

Pyroclastic rocks, with rare sedimentary horizons, are apparently much more abundant than lavas in this area and they crop out in the upper reaches of Millett, Meiklejohn and Chapman Glaciers, at altitudes above 870 m. The pyroclastic rocks, which at the base of the exposed succession are interbedded with thinly laminated purplish black siltstones and shales (KG.1001; Fig. 7), comprise grey and dark brown dust-tuffs (Blyth, 1940), green and purple

Fig. 7. Horizontally bedded pyroclastic rocks overlying siltstones and shales (not visible) at station KG.1001. The cliff is 600 m. in height.

tuffs, lapilli-tuffs and agglomerates; a thin muddy siltstone is also present within the volcanic sequence at station KG.1072.11. Graded bedding at station KG.1001, the only sedimentary structure observed in the field, indicates that these horizontally bedded rocks are the correct way up. Lavas crop out at stations KG.1052, 1058, 1072, 1091 and possibly KG.1057. Those at stations KG.1057 and 1058 are massively bedded and they underlie a sequence of pyroclastic rocks consisting of crystal tuffs succeeded by crystal-lithic and lithic tuffs and agglomerates. The lithic fragments included in these pyroclastic rocks are initially of sedimentary or tuffaceous material but the higher tuffs and agglomerates contain a greater proportion of igneous ("white granite") and even metamorphic rock fragments. At station KG.1094, the agglomerates contain rounded cobbles of basaltic, trachytic or trachyandesitic lavas and granitic rock types derived from an as yet unexposed conglomerate; such coarse conglomerates crop out in an adjacent area of north-western Palmer Land (Skinner, 1973). The lavas exposed at station KG.1064.7 apparently lie above the tuff sequence, possibly because of subsequent faulting at this locality.

The volcanic rocks are intimately associated with small quartz-feldspar-porphyry bosses (KG.1072.11), believed to be their plutonic equivalents, and numerous minor intrusions of "red granite". They are also cut by basaltic and aplitic dykes of an uncertain age.

Petrography

The lower *lavas* (basalts and andesites) were extensively altered during or following the emplacement of numerous small "red granite" intrusions, and nearly all of the phenocrysts have been replaced by secondary minerals (KG.1052.1). Hornblende has been chloritized and the plagioclase phenocrysts are so epidotized and calcitized that indications of twinning and zoning are destroyed. However, in some of the lavas (KG.1058.1) the plagioclase phenocrysts are shattered, veined and only partially chloritized, and poorly defined zoning and polysynthetic twinning are still preserved. Hornblende twin pairs sometimes show different degrees of alteration and they contain numerous inclusions of magnetite, sphene and apatite. One vesicular lava (KG.1091.7) is so highly propylitized that in thin section it is virtually isotropic; heavily altered plagioclase phenocrysts, some of which are completely replaced by aggregates of epidote, are visible and calcite and chlorite are important secondary minerals.

The less altered lavas are porphyritic basalts (Fig. 8a) containing heavily saussuritized phenocrysts of labradorite (An_{64}). The groundmass (80–90 per cent) is largely cryptocrystalline, although a trachytic flow texture is shown by the alignment of plagioclase laths in specimens KG.1072.8 and 1091.1. Magnetite is present in these lavas, quartz is a minor accessory mineral and secondary calcite occurs both as discrete crystals and as veins.

The lowest exposed *pyroclastic rocks* are dust or crystal tuffs but these are rapidly superseded by crystal-lithic and lithic tuffs, the last two being the commonest volcanic rock types in this area. The dust tuffs (KG.1055.7) have a microcrystalline matrix in which crystal fragments of feldspar are rarely distinguishable but the crystal and crystal-lithic tuffs contain well-defined corroded fragments of plagioclase (An_{36-43}) up to 5·3 mm. in length, partially resorbed hornblende crystals (KG.1001.7) and rare quartz crystals (0–2 per cent). In some of the tuffs the plagioclase fragments show such effects of potash metasomatism as "dustiness" and the growth of a thin albitic rim around the crystals. In other specimens, the plagioclase fragments are altered to pistacite and magnetite with subsidiary haematite (sometimes the iron ore marks the former outline of the plagioclase phenocrysts; KG.1057.3); penninite, muscovite and pistacite (KG.1050.5); microcrystalline aggregates of iron ore, chlorite and pistacite, and some have partially recrystallized to granoblastic feldspar. Fresh crystalline plagioclase is present in specimen KG.1050.5. Epidote-prehnite veinlets cut a few of these tuffs (KG.1055.7).

The crystal-lithic and lithic tuffs contain a considerable variety of lithic detritus. Angular to rounded fragments of shale (flattened parallel to the (?) bedding), siltstone, fine-grained sandstone and microgranite (common) are present in some tuffs (KG.1001.4), whereas the coarser-grained tuffs contain fragments of both porphyritic and non-porphyritic lavas, fine tuffs, crystal tuffs and rare siltstones. In specimen KG.1001.5 all the lithic fragments are partially replaced by a fine-grained scaly aggregate of biotite (α = yellow, $\beta = \gamma$ = orange-brown). Fragments of microdiorite, aplite, microtrondhjemite and granodiorite occur, in addition to the commoner clasts of lavas and tuffs, in those tuffs exposed in the north of this area. The tuffs which crop out at the western end of station KG.1064.7 contain lithic debris derived largely from the metamorphic complex but similar fragments were not observed in the tuffs exposed elsewhere in this area. A palagonite-tuff (KG.1091.5) was collected from the scree at one locality but no outcrops of this rock were discovered nearby.

The *sediments* interbedded with the volcanic rocks are typical shales and siltstones with a cryptocrystalline groundmass in which larger grains of quartz and feldspar are embedded. However, one of the shales (KG.1001.6) is unusual because it contains randomly orientated pellets, which are possibly of organic origin (perhaps faecal pellets), and pods of microcrystalline calcite (Fig. 8b). All of the sediments are extensively epidotized with pistacite forming as much as 10 per cent of the rock. Epidote veinlets with concentrations of biotite and/or

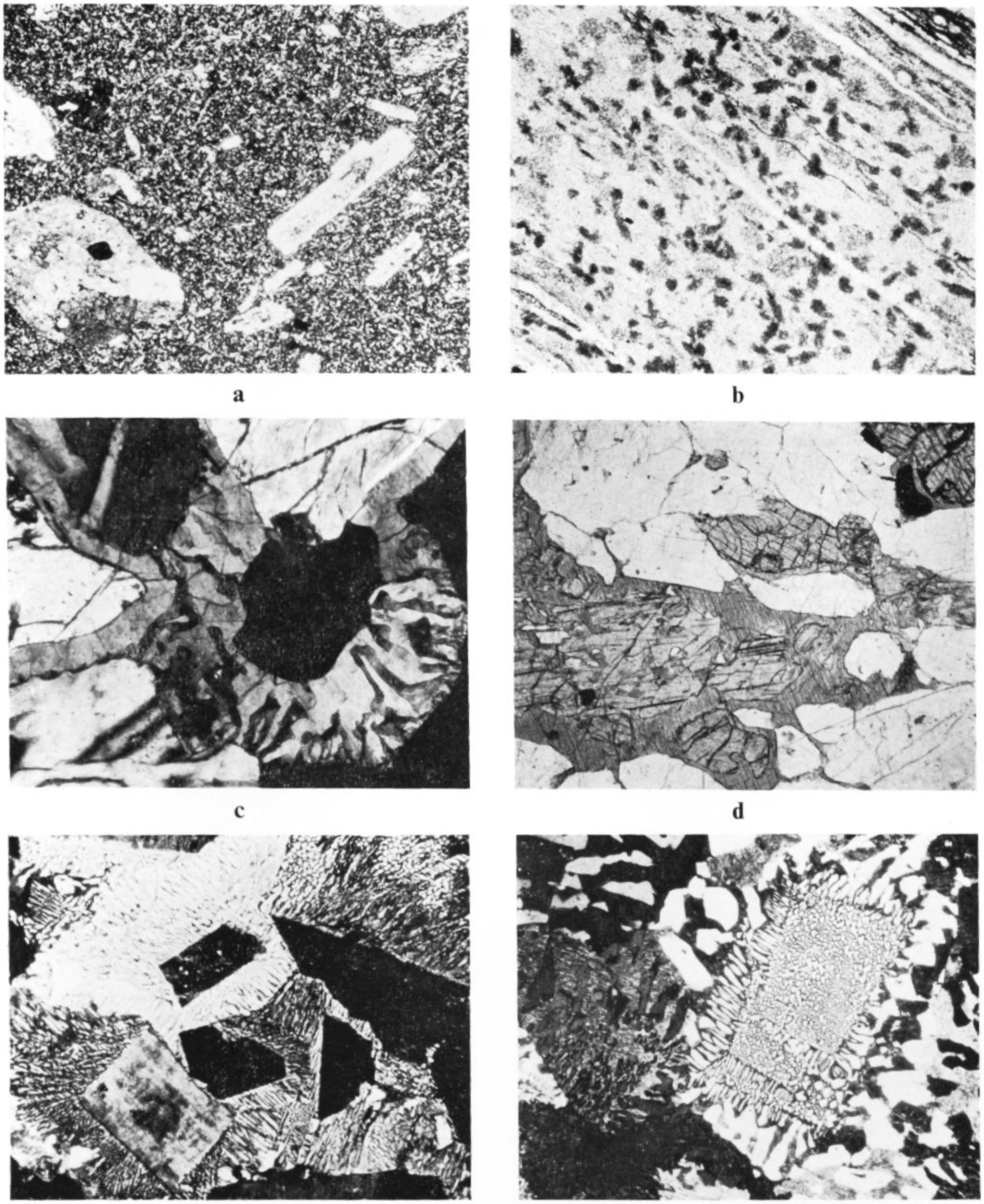


Fig. 8. a. Porphyritic basalt with altered phenocrysts of labradorite (KG.1061.4; ordinary light; ×45).
b. (?) Trace fossils (perhaps faecal pellets) and "beef"-like masses of microcrystalline calcite in a shale interbedded with pyroclastic rocks (KG.1001.6; ordinary light; ×5).
c. Hypersthene-spinel symplektite developed at the contact of pyroxene and plagioclase crystals in an olivine-gabbro; Wade Point (KG.1024.1; ordinary light; ×220).
d. Relict orthopyroxene replaced by clinopyroxene, both of which are poikilitically enclosed by hornblende; hypersthene-gabbro (KG.1026.1; ordinary light; ×45).
e. Granophyric texture in a "pink granite" (KG.1097.1; X-nicols; ×165).
f. Granophyric texture in a dyke cutting granodiorite (KG.1071.9; X-nicols; ×45).

penninite along their margins are also present in these rocks. Occasional rhyolite or chert fragments and rare aggregates of microperthitic orthoclase, derived from (?) granodiorite, are included in a muddy siltstone from station KG.1072.11.

Plutonic Rocks

The relationship of the plutonic rocks to the volcanic rocks exposed in this part of north-western Palmer Land is not clear because of the paucity of igneous contacts in the area and the complete lack of radiometric dating. However, fragments of adamellitic and trondhjemitic rocks (the "white granites") occur within the pyroclastic rocks and it is therefore believed that the "white granites" were emplaced before the volcanicity began (Table I). Although most of the other plutonic rocks apparently belong to a single phase of calc-alkaline igneous activity (the Andean Intrusive Suite), the "red granites" and their related minor intrusions are closely associated with the volcanic rocks and they may belong to the same (?) Jurassic igneous event. In the following descriptions, the various rock types are described in their apparent chronological order based largely upon the assumption that the later plutons belong to a single basic to more acidic sequence of intrusions. Modal analyses of several representative rock types are given in Table II.

"*White granites*"

The "white granites" are extensively exposed in the mountain group 15 km. east-north-east of Wade Point but they also crop out in the Mount Courtauld area and in the upper reaches of Chapman Glacier. They comprise a mafic-poor group of rocks ranging in composition from white adamellites to granodiorites and trondhjemites (Johannsen, 1948); true granites are not represented. The "white granites" display a remarkable homogeneity, not only within one exposure but also between one intrusion and another. Nevertheless, some contain thin regular schlieren, possibly orientated parallel to the roof and walls of the intrusion and rare foundered blocks of (?) gneiss occur in the roof zone (KG.1044) of the largest "white granite" pluton (Fig. 9).

Fig. 9. View (in a direction 112°) of a "white granite" cutting (?) gneisses at station KG.1044.3.

In thin section, they are hypidiomorphic granular rocks composed mainly of stubby crystals of saussuritized plagioclase (An_{36}) which have well-defined normal zoning and exhibit polysynthetic twinning on the albite and pericline laws. Irregularly distributed corroded phenocrysts of slightly more basic plagioclase (An_{40}) generally have a rim of more sodic plagioclase (An_{23}; KG.1044.2) and they exhibit more complex twinning and both normal and patchy zoning (Vance, 1962). Potash feldspar, generally a microperthitic microcline, is usually of minor importance and myrmekite is also rare in these rocks. Crystals of strained quartz are common (KG.1045.1) and they include small corroded plagioclase crystals. Biotite is normally the commonest mafic mineral and, where it has replaced bluish green hornblende ($\gamma : c = 30°$), it is accompanied by calcite and yellow epidote. It is also associated with iron ore (mostly ilmenite but sometimes magnetite and haematite), sphene and apatite (especially where the flakes are warped or fractured) and it is sometimes replaced by penninite. Other accessory minerals include tiny anhedral crystals of zircon, flakes of muscovite and rare allanite.

"*Red granites*"

Andesine-bearing "red granites", probably the plutonic equivalents of the volcanic rocks, comprise microgranites (KG.1072.12, 13 and 15), pink adamellites and granodiorites (KG.1015.1, 1064.1, 1075.4, 5 and 1097); exceptionally, the latter are xenolithic (KG.1050.1). These rocks are intruded into, or found in close association with, the volcanic rocks and they are therefore exposed in the upper reaches of many of the glaciers, especially between Bertram and Millett, and Millett and Meiklejohn Glaciers. They generally occur as small bosses and pods within the volcanic rocks, although there are also plutons up to 3 km. in diameter (KG.1064). The micrograniles are irregularly veined by calcite and epidote.

In thin section, the *pink adamellites and granodiorites* are hypidiomorphic granular rocks in which quartz occurs as large sub-rounded plates and microperthitic orthoclase forms rounded crystals replacing plagioclase (An_{41}); myrmekite is widely distributed but never extensively developed. The potash feldspar sometimes poikilitically encloses hornblende, biotite, quartz and iron ore in addition to the remnant blebs of plagioclase, and it is masked by a fine reddish dusting of minute (?) iron ore particles. It is this reddish dusting which is responsible for the characteristic pink colour of the weathered rock. Twinning and zoning of the plagioclase crystals are rare in these rocks and hornblende, which includes grains of sphene and iron ore and is sometimes altered to biotite, occurs only in irregular mafic clots.

The micrograniles are fine-grained buff-coloured rocks which contain dusty microclinized, microperthitic orthoclase (replacing and enclosing an earlier plagioclase), amoeboid phenocrysts of untwinned plagioclase and graphic intergrowths of quartz and orthoclase. Iron ore and ferromagnesian minerals are absent or rare but there is a little secondary calcite. Untwinned plagioclase occupies many of the numerous sub-parallel fractures occurring within the rock.

Quartz-plagioclase-porphyries

Pink- and cream-weathering quartz-plagioclase-porphyries (KG.1002, 1004.2 and 1072.10) intrude the volcanic rocks in this area but their age in relation to the plutonic rocks is not known. However, quartz-plagioclase-porphyries cut a granodiorite of the Andean Intrusive Suite in an adjacent area of Palmer Land (Skinner, 1973) and it is possible that some of the porphyries exposed in this area are of a similarly young age. This is also suggested by the absence of the calcite and epidote veins which are locally prominent within the micrograniles. Nevertheless, the presence of a porphyry dyke (KG.1016.2) within a pre-Andean swarm of basic dykes indicates that there were at least two phases of porphyritic acid intrusions in this part of Palmer Land, a feature noted by Marsh (1968, table II) in the Oscar II and Foyn Coasts, Graham Land.

In thin section, the porphyries are texturally distinctive rocks containing rounded quartz crystals, irregular phenocrysts of feldspar and rare blebs of ferromagnesian minerals set in an aphanitic groundmass. The plagioclase is subsidiary to quartz and it shows internal saussuritization and sericitization; all the plagioclase phenocrysts are dusty, due either to sub-microscopic ore particles (MacGregor, 1931) or bubbles of fluid, and many appear to be slightly microperthitic. No zoning is apparent but several of the crystals display albite twinning. Flakes of muscovite (KG.1004.2), chlorite and (?) pyroxene crystals (KG.1072.15) are rare constituents of these rocks and secondary minerals include limonite and calcite.

Gabbros

Gabbros crop out extensively in the Wade Point hinterland but more limited exposures occur farther north. Dark medium-grained gabbros occupy the lowest parts of the southern and western cliffs of Wade Point and much of the isolated nunatak (KG.1031) 3·4 km. south-east of the survey cairn; the rocks at stations KG.1031.1 and 2 are layered autobrecciated olivine-gabbros (Fig. 10) and a fresh medium-grained olivine-gabbro crops out at station KG.1032. The dark gabbro exposed in the 3 m. by 50 m. outcrop at station KG.1026 is olivine-free and much finer-grained than the outcrops farther west but it is similar to the locally heterogeneous gabbros at station KG.1019. Other heterogeneous gabbros are exposed in the northern part of the Wade Point hinterland (KG.1025 and 1040) but these rocks have subsequently undergone potash metasomatism by an as yet unexposed acidic pluton. Gabbroic rocks also crop out between Mount Courtauld and Creswick Peaks, where they have contact metamorphosed (KG.1080.3) the host "white granite".

Fig. 10. Autobrecciated layered gabbro at station KG.1031.

Because of their apparent intrusion into pre-existing acidic rocks, the gabbros possess a considerable heterogeneity which is not found in the other plutonic rocks. In thin section, the *olivine-gabbros* are hypidiomorphic rocks dominated by plates and laths of calcic labradorite (An_{67}), which exhibit strain-induced polysynthetic twinning and fracturing caused by the expansion of olivine during its alteration. Clinopyroxene and olivine are essential minerals and orthopyroxene is also present. The olivine is characterized by deep fractures lined with antigorite and associated iron-ore segregations, some of which radiate out into adjacent plagioclase crystals. In some of the gabbros (KG.1031.1), olivine occurs as discrete crystals up to 3 mm. in diameter but it is usually less than 1 mm. in diameter and either poikilitically enclosed by faintly pleochroic hypersthene (α = colourless, $\beta = \gamma$ = pale green; $\gamma : c = 3°$;

KG.1024.1) or surrounded by a thin selvage of uralitic hornblende. The replacement of hypersthene by augite ($\gamma : c = 44°$) is a common feature. The augite poikilitically encloses the other mafic minerals and ophitically includes smaller plagioclase laths; it is usually fresh and shows only marginal uralitization, although segregations of iron ore, sometimes accompanied by a dark green spinel, are occasionally present in plagioclase crystals bordering the augite (Fig. 8c).

The *hypersthene-gabbros* contain larger and more frequent orthopyroxene crystals than the olivine-gabbros but clinopyroxene is still dominant. The pinkish hypersthene is only slightly pleochroic and it is largely replaced by yellowish (?) antigorite and finely disseminated iron ore. Poikilitic augite ($\gamma : c = 40°$) is bleached where it is in contact with orthopyroxene or any of its alteration products, and it is itself poikilitically enclosed by a green hornblende (Fig. 8d); this hornblende is occasionally altered to brown biotite. Unzoned labradorite laths (An_{64}) are commonly polysynthetically twinned; simple twins are rare and there has been little sericitization of the plagioclase. Interstitial patches of clear untwinned feldspar, tiny zircons and rare quartz crystals are minor constituents of the rock.

The *hornblende-gabbros* are distinguished from the olivine- and hypersthene-gabbros by the presence of at least 10 per cent of amphibole replacing orthopyroxene. Most of this is hornblende (α = buff, β = yellowish-green, γ = dark green; $\gamma : c = 33°$), which forms coronas around the pyroxenes, but sometimes there are aggregates of actinolite with minor tremolite. Plagioclase with a core composition of An_{67} is concentrically and patchily zoned and some mantling of the larger laths by more albitic plagioclase is occasionally present. Accessory minerals include large bladed apatite crystals, rare interstitial quartz and myrmekite; iron ore crystals are frequently large and they are included in hornblende.

Heterogeneous gabbros. These rocks, possibly the products of the contamination of gabbroic magmas by pre-existing acidic rocks, are exposed at the northern tip of the nunataks near Wade Point (KG.1038.1). In thin section, olivine is absent or rare but its former presence is indicated by sinuous ore-filled fractures set in a mass of antigoritic fibres. Augite ($\gamma : c = 40°$) is often bleached in the presence of orthopyroxene, which it poikilitically includes, and it is commonly bounded by hornblende (α = pale green, β = green, γ = dark green), whilst hypersthene-ore symplektites have crystallized at the contact of pyroxene and hornblende or plagioclase crystals. Plagioclase (An_{52-78}) is commonly zoned but only rarely twinned; its alteration products and inclusions comprise small crystals of a clear plagioclase, calcite, (?) pyroxene, sphene and iron ore minerals. Quartz is rare except in those altered gabbros which contain biotite (rather than hornblende), chlorite and apatite.

Diorites

Although diorites are generally scarce in Palmer Land (Adie, 1955), they are nevertheless exposed in this area, particularly between Mount Courtauld and Creswick Peaks. Many exhibit such a well-developed foliation that they are best described as gneisses (cf. p. 55), even though they possibly represent the foliated marginal facies of plutonic intrusions. The least foliated diorites appear to be hybrid rocks. They are exposed marginally to gabbros intruding pre-existing acidic rocks and they contain clots of ferromagnesian minerals and some xenoliths. Other xenolithic diorites intrude members of the metamorphic complex (KG.1084.4, 1085 and 1087.1). Foliated diorite is exposed in the small group of nunataks 12 km. east of the summit of Mount Pitman (KG.1093.1) and a xenolithic variety crops out at station KG.1093.4. There are several small outcrops of xenolithic diorite in the Wade Point hinterland (KG.1016 and 1017) and at station KG.1007.

The *homogeneous diorites* have essentially similar textures and mineralogy but they differ considerably in grain-size. Nevertheless, they are noticeably finer-grained than the other plutonic rocks from north-western Palmer Land. They are hypidiomorphic granular rocks composed mainly of elongate or stumpy andesine crystals (An_{46}) which have indistinct normal and patchy zoning; twinning is well developed on the Carlsbad and pericline laws but only poorly developed on the albite law. Irregularly distributed phenocrysts of more calcic plagioclase, sometimes with narrow albitic rims, are often bordered by strained quartz crystals (KG.1012.2); in places these coronas coalesce to form interstitial "pools" of granular quartz. Microperthitic orthoclase is dusted with (?) haematite and it corrodes and occasionally completely replaces plagioclase. Lobate symplektites of several mineral pairs occur in these rocks, the commonest being myrmekite, but biotite intergrowths with quartz, apatite and plagioclase are also present.

The *xenolithic* variety is the most widely distributed of the dioritic rocks and it varies enormously depending on the degree of assimilation of the xenoliths. In thin section, plagioclase forms heavily altered phenocrysts displaying twinning according to the albite law. Rare and stubby secondary plagioclase crystals occasionally possess a narrow albitic rim. Interstitial quartz is present in the relict xenoliths (now mafic clots) but in the rest of the rock it occurs as unstrained crystals and in myrmekitic intergrowths (KG.1080.1). In the rocks which have undergone potash metasomatism (KG.1059.4), the quartz is strained and it contains dusty inclusions. The mafic minerals comprise subhedral hornblende crystals (α = buff, β = green, γ = dark green), probably derived from pyroxene (diopside, $\gamma : c = 42°$ in specimen KG.1085.2) and accessory minerals similar to those of the heterogeneous gabbros (p.65). Some of the iron ore is marginally altered to sphene (KG.1080.2) and strongly pleochroic allanite is present in specimen KG.1072.3. The secondary minerals include calcite and prehnite.

Quartz-diorites and granodiorites

Grey and pink quartz-diorites and granodiorites are exposed on the north-eastern margin of the Mount Courtauld massif, between Mount Courtauld and Creswick Peaks, and in the western part of the mountainous wedge between Millett and Meiklejohn Glaciers. Possible contact metasomatic (and metamorphic) effects of a pluton of intermediate composition have been observed at scattered localities in the Wade Point hinterland and on the southern margin of Meiklejohn Glacier, but only a few outcrops of such intermediate plutonic rocks were found. The quartz-diorites and granodiorites are typically heterogeneous and frequently xenolithic; they are possibly formed by potash metasomatism of either more basic plutonic rocks or their contamination products. They contain a greater proportion of mafic minerals and are considerably more xenolithic than the essentially homogeneous "white granites".

In thin section, they are hypidiomorphic granular rocks in which large saussuritized plagioclase crystals (An_{41}; KG.1072.4) with irregular extinction and rare twinning are replaced by perthitic orthoclase. Potash feldspar, although largely interstitial, is occasionally large enough to poikilitically include other minerals (especially iron ore and ferromagnesian minerals) and it sometimes forms micrographic intergrowths with quartz (KG.1072.4). In specimens KG.1071.6 (granodiorite) and 1072.5 (trondhjemite), extensive micrographic (occasionally dactylitic) intergrowths between quartz and plagioclase were observed, although myrmekite is apparently absent. Clear quartz is generally an interstitial mineral and it is rarely strained but it sometimes contains inclusions, occasionally aligned in trails (KG.1071.3 and 6).

The mafic minerals are irregularly distributed through these rocks, sometimes occurring in wispy aggregates or clots. Subhedral hornblende (α = pale brown, β = greenish, γ = dark green; $\gamma : c = 37°$), probably derived from pyroxene (KG.1073.1) but now commonly replaced by biotite, occasionally contains exsolved iron ore and sphene. The biotite (α = buff, $\beta = \gamma$ = dark brown) is largely derived from hornblende but fresh and inclusion-free primary biotite is also present (KG.1073.1); the secondary biotite is closely associated with and sometimes includes apatite, iron ore and sphene and is itself frequently partially chloritized. The penninite contains rare sheaves of fibrous prehnite (KG.1072.4), although exsolved iron ore and sphene are much commoner. Other accessory and secondary minerals include anhedral allanite and pistacite and occasional minute zircon crystals (KG.1071.8) included in biotite; calcite occurs both as discrete crystals and as veinlets.

"Pink granite"

An isolated exposure of "pink granite" (KG.1097.1) crops out 15 km. east of the summit of Mount Pitman. The rock is essentially homogeneous but exceedingly rare xenoliths of potash-metasomatized (?) microdiorite occur (KG.1097.2). Its age relative to the other plutonic rocks is not apparent in the field but it is believed to be younger than the "white granites" or "red granites" described on p. 62–63 because of its similarity to a granophyric vein cutting a (?) Andean granodiorite at station KG.1071.9. In thin section, the "pink granite" has a micrographic texture (Fig. 8e). Intergrowths of quartz and orthoclase have largely replaced the slightly saussuritized, potash-metasomatized plagioclase crystals (An_{31}) but some fresh untwinned plagioclase crystals are present. Remnant flakes of penninite are discernible and the accessory minerals include rare iron ore, sphene and apatite. Myrmekite is apparently absent but there is a little secondary calcite.

Minor Intrusions

Minor intrusions are widespread throughout this area and they generally post-date the volcanic rocks of (?) Upper Jurassic age, indicating an association with the plutonic rocks of the Andean Intrusive Suite. However, an earlier group of dykes and sills intrudes only the "white granites" and rocks of the metamorphic complex. Apart from the varied and numerous veins, there are at least six different groups of minor intrusions and these will be described in their apparent chronological order.

Altered basic sills and dykes

These rocks form an homogeneous group displaying clear-cut and generally planar contacts with the host gneisses and "white granites". Although altered, they still retain an essentially igneous texture in thin section, the presence of a preferred mineral orientation (KG.1087.3) being a slightly anomalous feature. However, two dykes (KG.1071.2 and 4), which crop out 4·5 km. from a "red granite" boss to the south and 4·5 km. from a quartz-plagioclase-porphyry boss (KG.1072.10) to the north, show the effects of contact metamorphism. Most of these basic rocks have undergone late magmatic recrystallization and/or hydrothermal alteration and they are readily distinguishable from their fresher and (?) younger equivalents by the absence of fresh olivine and pyroxene. Plagioclase (An_{54-59}) is lath-like and it is often almost completely sericitized (KG.1093.5) but heavily altered relict phenocrysts occasionally occur. The original ferromagnesian minerals show a considerable range in their degree of alteration, all the olivine and pyroxene having been replaced by aggregates of semi-fibrous green hornblende, small iron ore crystals and biotite flakes (KG.1074.3 and 1087.2); calcite and/or chlorite (KG.1046.2 and 1089.1); or greenish brown hornblende (groundmass of specimen KG.1045.2). Ilmenite frequently indicates the former extent of the original pyroxene crystals and it is the commonest iron ore.

Altered acidic sills and dykes

These pink-weathering acidic rocks are frequently found as sills within the "white granites" and metamorphic rocks but the dykes are poorly represented and have been recognized only at stations KG.1043 and 1088. The rock type is a coarse-grained, microcline-rich granite (KG.1088.4) in which microcline and microperthitic microcline are dominant over, and appear to be replacing, plagioclase. This microcline forms large crystals which occasionally display "tartan" twinning and frequently contain numerous inclusions. Plagioclase is dusted with (?) iron ore and has been so altered that virtually all traces of twinning have been destroyed; it contains inclusions of allanite, pistacite, occasional flakes of chlorite and stumpy subhedral apatite crystals. Quartz occurs in aggregates of strained crystals, while the interstices between the larger feldspar crystals are occupied by a microcrystalline quartzo-feldspathic groundmass which shows some replacement by slightly microperthitic potash feldspar. The accessory minerals are penninite with sheaves of fibrous prehnite, iron ore and rare sphene. Secondary calcite is widely distributed especially in the thin and irregular veinlets which are prolific in some microbrecciated rocks (KG.1088.4).

The acid sills which intrude the "white granites" are similar to the aplites cutting the metamorphic rocks and they probably belong to the same suite. However, the microperthitic microcline is fresher but considerably less common, and the plagioclase frequently shows normal magmatic zoning and is less altered than that found in the aplites intruding the metamorphic rocks.

Pink granodiorite

The two pink granodiorite dykes which intrude members of the metamorphic complex (KG.1003.1) and lavas of a (?) Upper Jurassic age (KG.1050.8; Table II) are grouped together on the basis of their intermediate composition. Although one of the dykes is cut by numerous sub-vertical, (?) late-stage basaltic dykes throughout its exposed 200+ m. height, the other smaller dyke is unaffected by any subsequent igneous event. Hence no accurate age correlations can be made between the two dykes. In thin section, the larger dyke is considerably richer in mafic minerals and it appears to have been heavily contaminated by its host rock. The smaller one, having a much smaller thermal capacity, was unable to assimilate much from its host and is thus apparently uncontaminated. However, both dykes have been considerably potash metasomatized. Plagioclase (An_{39}) is saussuritized and partially replaced by microperthitic potash feldspar but indistinct concentric and patchy zoning are still distinguishable; clear secondary albite veins and also forms rims around the large plagioclase crystals. Augite is almost completely replaced by hornblende (α = pale brown, β = greenish, γ = dark green) and this shows some alteration to dark brown biotite and/or penninite. The accessory minerals include acicular apatite, zircon and allanite crystals and secondary sphene derived from the iron ore exsolved from biotite.

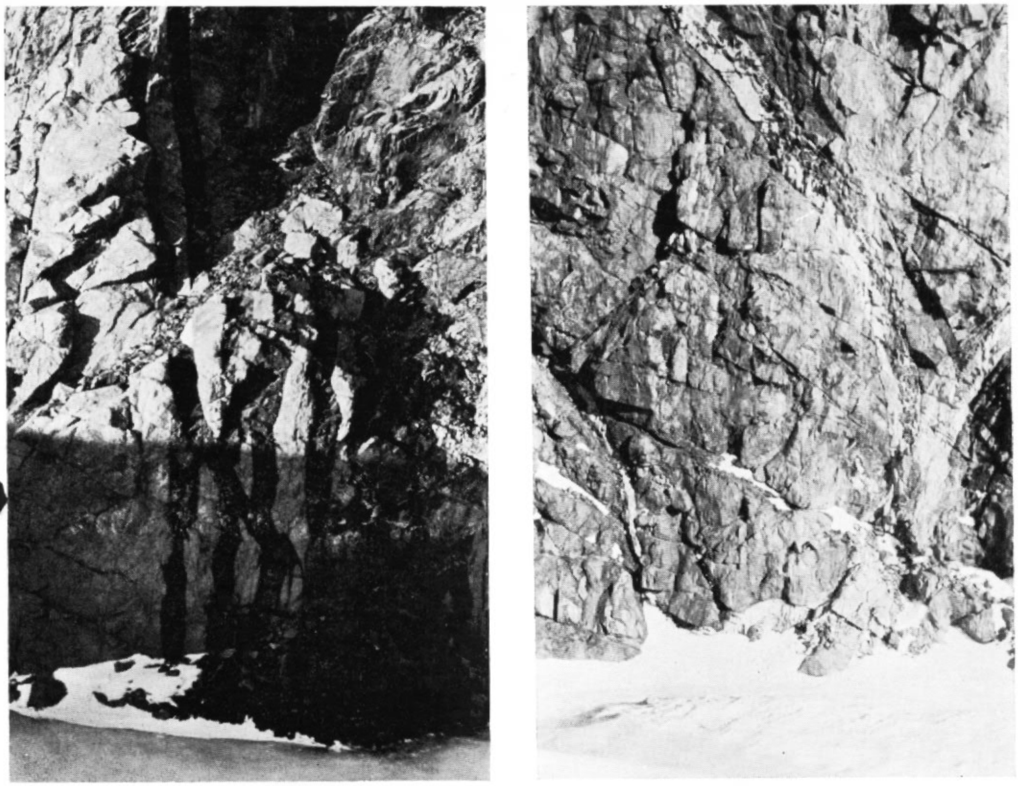
Porphyry dykes

Quartz-plagioclase-porphyries (KG.1092.4 and 5) and potash feldspar-quartz-porphyries (KG.1016.2) occur within the volcanic rocks as bosses and dykes (p. 60). A single xenolithic potash feldspar-porphyry occurs within the swarm of dominantly basaltic dyke rocks associated with the volcanic centre at station KG.1015, and the quartz-plagioclase-porphyry at station KG.1092.5 contains rare (?) basaltic xenoliths. In thin section, these porphyries are essentially similar to those which crop out as bosses. However, rare spherules (KG.1016.2 and 1092.5), possibly representing the initial phase in the development of a granophyric texture, occur in the porphyritic dyke rocks.

Later basic dykes

Porphyritic basic dykes cut a quartz-plagioclase-porphyry intrusion at station KG.1004.4 and xenolithic diorite at station KG.1007.1. Although considerably altered, the presence of labradorite phenocrysts in a plagioclase-hornblende or plagioclase-biotite groundmass distinguishes these from the earlier basic dykes. In thin section, plagioclase (An_{57-70}) occurs as euhedral or corroded phenocrysts which are slightly saussuritized and occasionally normally or oscillatorily zoned; inclusions of tiny clinopyroxene, hornblende and iron ore crystals, usually aligned along the (001) cleavage traces, are common. Rare anhedral phenocrysts of augite ($\gamma : c = 50°$) are sometimes altered to chlorite or hornblende and they are occasionally extensively replaced by calcite. Aggregates of penninite and epidote apparently pseudomorph pyroxene (KG.1007.3) and rare calcite replacement of plagioclase (generally with minor penninite) also occurs. The groundmass of these rocks is usually a fine-grained aggregate of plagioclase laths, augite, pyrite cubes associated with interstitial penninite, and secondary calcite and epidote. However, in some dykes (KG.1007.3) there is also a large amount of interstitial and indeterminate microcrystalline material.

Non-porphyritic basic dykes of a basaltic composition are by far the commonest type of minor intrusion in this area. Almost all of them show some degree of alteration but this is probably a result only of late magmatic processes. These dykes sometimes display chilled margins (KG.1006.1), frequently show sudden and considerable changes in attitude (Fig. 11a) and in places they are bordered by a band of epidote which apparently infills a (?) later shear zone. They range from 5 cm. to more than 1 m. in width and are occasionally cut by late aplite dykes (KG.1074.2). However, at station KG.1097.3 a single basic dyke, possibly belonging to the same suite, cuts granophyric "pink granite". In thin section, laths and plates of plagioclase occasionally exhibit a trachytic texture, while the larger plagioclase crystals show twinning and sometimes zoning (KG.1006.1b and 1074.3); their composition is largely unknown although a value of An_{61} was obtained from one crystal. Hornblende, generally present



a b

Fig. 11. a. Basaltic dykes intruded into joint-controlled fractures in diorite at station KG.1092.1. The cliff is 10 m. in height.
b. An aplite dyke, with numerous rounded basic xenoliths, cutting a gabbro at station KG.1031.5. It is apparently cut by a later, xenolith-free aplite dyke (bottom right) and there is a third aplite dyke (left) which also contains basic blocks. The cliff is 26 m. in height.

as a matted mass of tiny laths, is commonly greenish but some hornblende is orange-brown (KG.1074.3) and several brownish patches, some with a central cavity, appear to represent devitrifying glass. Ilmenite, associated with haematite, generally forms interstitial crystals but it also occurs within hornblende crystals. The rare secondary minerals include calcite, ng and delicate needles of an indeterminate mineral and occasional thin veinlets of haematite.

Later acidic dykes and sills

The later acidic dykes are represented by granophyric microgranites (KG.1038.2 and 1071.9) (a similar rock (KG.1092.4 and 5) has been tentatively assigned to the earlier, porphyritic acid intrusions but it could belong to the same suite) and numerous aplite dykes and sills which cut rocks of the Andean Intrusive Suite. They are usually sharply defined intrusions (a notable exception occurs at station KG.1038.2) and they appear to be less dependent upon the dominant local joint directions than the late, non-porphyritic basic dykes (p. 68). In thin section, the granophyric dyke (Fig. 8f) is similar to those described on p. 67 except that microperthite is rare and the plagioclase phenocrysts, which sometimes occur in glomeroporphyritic aggregates, are occasionally partially replaced by myrmekite or water-clear albite. Microcline shows lobate interfaces towards the quartz-orthoclase intergrowths and it displays typical "tartan" twinning. The only secondary mineral is epidote and this forms rare pseudomorphs after plagioclase.

The aplite dykes and sills exposed in this area were never seen to be cutting the "pink granites" but they are widespread within the other plutonic rocks; they possibly represent apophyses associated with the "pink granites". They range in size from 1–2 mm. to 60 cm. in width and are frequently seen in contact with basic dykes. The contacts between these two rock types are invariably linear but there is no consistency in the order of intrusion. However, the wider aplites generally appear to post-date the basic dykes. The aplites are readily distinguishable from older rocks of a similar appearance by their sharp contacts with the country rock in the field and, in thin section, by the apparent absence (apart from one exception: KG.1074.2) of twinned microcline. They are also characterized microscopically by a weak saccharoidal texture. Quartz, andesine and microperthite crystals are common. The plagioclase is saussuritized and often replaced by myrmekite, quartz or potash feldspar, while quartz crystals although commonly rounded sometimes have fretted margins (KG.1022.1 and 1085.2). Mafic minerals are characteristically rare; biotite is generally penninitized and the iron ore is usually replaced by sphene; muscovite and epidote are also present.

The aplites are usually xenolith-free but one, intruding a gabbro at Wade Point, is exceptional because it contains rounded xenoliths of basalt (Fig. 11b). These xenoliths are much commoner in the lower parts of the exposure than they are elsewhere and they are also generally more frequent near the upper margin of the dyke. It is possible that this unusual dyke was formed by a mechanism such as the one invoked by Bailey and McCallien (1956). They postulated the melting of material of acidic composition by the presence of a recently intruded hot basic mass; the acidic material in this case could be a gneiss or a "white granite". Fraser (1965) described similar occurrences of basified aplite dykes on Stonington Island and he drew attention to the difficulties in finding a suitable mechanism for the transportation of basic material for considerable distances in an acid medium. At station KG.1031.5, rounded xenoliths occur along the bottom 20 m. of the exposed 60 m. length of acid dyke, indicating that the aplitic fluid was capable of transporting basic material only for limited distances.

Summary

In its broadest context, the area described here forms part of the circum-Pacific orogenic belt, which extends from the South American Andes into the Antarctic Peninsula and Marie Byrd Land. The oldest rocks exposed in this area belong to a metamorphic complex of regionally metamorphosed and, in places, migmatized gneisses developed under almandine-amphibolite-facies conditions; they possibly represent the metamorphic derivatives of a sequence of geosynclinal sediments and volcanic rocks which may have been intruded by plutonic and hypabyssal rocks before metamorphism commenced. Possible equivalents of these metamorphic rocks have been reported from localities in Graham Land: in Marguerite Bay (Adie, 1954; Hoskins, 1963; Fraser, 1965), on the Oscar II Coast (Marsh, 1968, p. 55) and on the Foyn and Bowman Coasts (Stubbs, 1968, p. 30). No radiometric age determinations have been made on any of the metamorphic rocks from this part of north-western Palmer Land but it is probable that the main metamorphism took place 200–245 m. yr. ago (Marsh, 1968, table III; Halpern, 1971). Age determinations on a younger amphibolite from northern Palmer Land indicate that a more recent metamorphic episode took place at 152±7 m. yr. (Rex, 1971).

A (?) Upper Jurassic succession of lavas, tuffs and rare sediments overlies the metamorphic rocks and apparently also the "white granites"; the pre-volcanic age of the "white granites" is indicated by their presence as angular fragments (and locally as rounded pebbles derived from conglomerates) within a few of the agglomerates. A comparable (?) Upper Jurassic sedimentary–volcanic sequence has been described from adjacent areas of Palmer Land (Procter, 1959; Ayling, 1966, p. 106; Skinner, 1973) and also from farther north in Graham Land, where conglomerates containing pebbles of "white granite" (Adie, 1953), granite or gneiss (Dewar, 1970) crop out.

A number of acidic minor intrusions, ranging in size from pipes 3–4 m. in diameter to bosses up to 4 km. in diameter, are closely associated with, and are possibly the hypabyssal and plutonic equivalents of, the (?) Upper Jurassic volcanic rocks. However, it is thought that most of the plutonic rocks are younger than the volcanic rocks and they have been tentatively referred to the Andean Intrusive Suite. These range in composition from gabbros to the less common granites. The gabbros are frequently heavily contaminated with more acidic country rocks in their roof and wall zones, whereas those rocks of intermediate and acid composition are considerably less affected. Late basic, aplitic and quartz-plagioclase-porphyry minor intrusions probably represent the most recent igneous event in this area.

The structural trends reported by Procter (1959), Ayling (1966, p. 101) and Dewar (1970) are less well developed in this area, and linear and platy flow structures are absent from the plutonic rocks. However, block-faulting, which shows a marked parallelism with the longitudinal joints (and their associated dykes) and with the local trend of the Antarctic Peninsula, has probably had a considerable influence on the geomorphology of north-western Palmer Land.

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REFERENCES

ADIE, R. J. 1953. *The rocks of Graham Land.* Ph.D. thesis, University of Cambridge, 259 pp. [Unpublished.]

———. 1954. The petrology of Graham Land: I. The Basement Complex; early Palaeozoic plutonic and volcanic rocks. *Falkland Islands Dependencies Survey Scientific Reports*, No. 11, 22 pp.

———. 1955. The petrology of Graham Land: II. The Andean Granite–Gabbro Intrusive Suite. *Falkland Islands Dependencies Survey Scientific Reports*, No. 12, 39 pp.

AYLING, M. E. 1966. *The geology of the "St. Valentine's" area, and related observations in the Batterbee Mountains, Palmer Land.* M.Sc. thesis, University of Birmingham, 119 pp. [Unpublished.]

BAILEY, E. B. *and* W. J. MCCALLIEN. 1956. Composite minor intrusions, and the Slieve Gullion complex, Ireland. *Lpool Manchr geol. J.*, **1**, Pt. 6, 466–501.

BLYTH, F. G. H. 1940. The nomenclature of pyroclastic deposits. *Bull. volcan.*, Sér. 2, **6**, 145–56.

CHAYES, F. 1957. A provisional reclassification of granite. *Geol. Mag.*, **94**, No. 1, 58–68.

CURTIS, R. 1966. The petrology of the Graham Coast, Graham Land. *British Antarctic Survey Scientific Reports*, No. 50, 51 pp.

DEWAR, G. J. 1970. The geology of Adelaide Island. *British Antarctic Survey Scientific Reports*, No. 57, 66 pp.

ELLIOT, D. H. 1966. Geology of the Nordenskjöld Coast and a comparison with north-west Trinity Peninsula, Graham Land. *British Antarctic Survey Bulletin*, No. 10, 1–43.

FRASER, A. G. 1965. The petrology of Stonington and Trepassey Islands, Marguerite Bay. *British Antarctic Survey Scientific Reports*, No. 52, 51 pp.

FYFE, W. S., TURNER, F. J. *and* J. VERHOOGEN. 1958. Metamorphic reactions and metamorphic facies. *Mem. geol. Soc. Am.*, No. 73, 259 pp.

HALPERN, M. 1971. Rb-Sr total-rock and mineral ages from the Marguerite Bay area, Kohler Range and Fosdick Mountains. (*In* ADIE, R. J., *ed. Antarctic geology and geophysics.* Oslo, Universitetsforlaget, 197–204.)

HOSKINS, A. K. 1960. The geology of parts of the Loubet and Fallières Coasts, Graham Land. *Falkland Islands Dependencies Survey Preliminary Geological Report*, No. 6, 38 pp. [Unpublished.]

———. 1963. The Basement Complex of Neny Fjord, Graham Land. *British Antarctic Survey Scientific Reports*, No. 43, 49 pp.

JOHANNSEN, A. 1948. *A descriptive petrography of the igneous rocks. Vol. I. Introduction, textures, classifications and glossary.* 3rd impression. Chicago, The University of Chicago Press.

MACGREGOR, A. G. 1931. Clouded felspars and thermal metamorphism. *Mineralog. Mag.*, **22**, No. 133, 524–38.

MARMO, V. 1971. *Developments in petrology. Vol. 2. Granite petrology and the granite problem.* Amsterdam, London, New York, Elsevier Publishing Company.

MARSH, A. F. 1968. *Geology of parts of the Oscar II and Foyn Coasts, Graham Land.* Ph.D. thesis, University of Birmingham, 291 pp. [Unpublished.]

PROCTER, N. A. A. 1959. The geology of northern Marguerite Bay and the Mount Edgell area. *Falkland Islands Dependencies Survey Preliminary Geological Report*, No. 4, 18 pp. [Unpublished.]

REX, D. C. 1971. K-Ar age determinations on volcanic and associated rocks from the Antarctic Peninsula and Dronning Maud Land. (*In* ADIE, R. J., *ed. Antarctic geology and geophysics*. Oslo, Universitetsforlaget, 133–36.)

SHAND, S. J. 1947. *Eruptive rocks. Their genesis, composition, classification, and their relation to ore-deposits with a chapter on meteorites*. 3rd edition. London, Thomas Murby & Co.; New York, John Wiley & Sons, Inc.

SKINNER, A. C. 1973. The geology of north-western Palmer Land between Eureka and Meiklejohn Glaciers. *British Antarctic Survey Bulletin*, No. 35, 1–22.

SPRY, A. 1969. *Metamorphic textures*. Oxford, London, Edinburgh, etc., Pergamon Press.

STUBBS, G. M. 1968. *Geology of parts of the Foyn and Bowman Coasts, Graham Land*. Ph.D. thesis, University of Birmingham, 244 pp. [Unpublished.]

VANCE, J. A. 1962. Zoning in igneous plagioclase: normal and oscillatory zoning. *Am. J. Sci.*, **260**, No. 10, 746–60.