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ABSTRACT

IN this report, the previous and current topographical and geological investigations in north-eastern Palmer Land are summarized and a brief description of the physiography and glacial geomorphology of this area is given.

The rocks of this part of the Wilkins and Black Coasts have been subdivided into six groups comprising (from oldest to youngest):

i. A (?) Palaeozoic metamorphic complex consisting of a group of *ortho-* and *para*gneisses intruded by metamorphosed amphibolitic dykes, all presumably overlain by a sequence of quartz-mica-schists.
ii. Also believed to be of a Palaeozoic age are the (?) Palaeozoic intrusive rocks, which intrude the metamorphic complex but are similarly metamorphosed by a low-pressure, moderate-temperature Abukuma-type metamorphism.
iii. An isolated dacitic crystal-lapilli-tuff assigned to the Upper Jurassic Volcanic Group.
iv. An extensive sequence of altered basic (oldest) to relatively fresh intermediate to acid intrusive rocks which is correlated with the Andean Intrusive Suite of the Antarctandes.
v. A group of late Tertiary basic, acid and intermediate dyke rocks intruded along a previously established joint system.
vi. Recent lateral moraines and other superficial glacial debris.

The history, lithology, structure and distribution of each rock type are discussed and, where possible, they are correlated with rocks in other areas of Palmer Land. In conclusion, the existence and trends of major Tertiary block faults are discussed.

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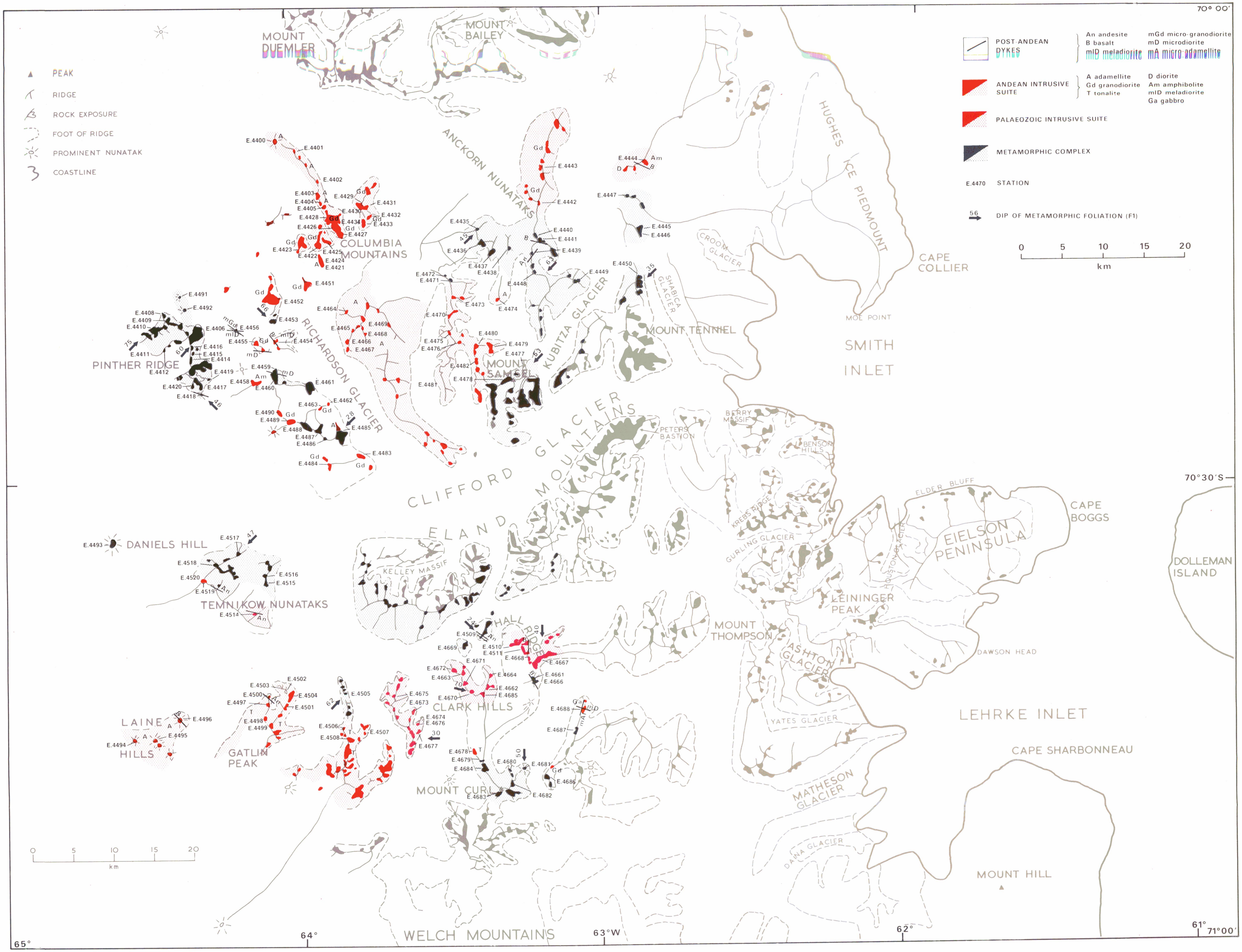

FIGURE 1

Geological sketch map of parts of the Wilkins and Black Coasts. Rocks belonging to the Upper Jurassic Volcanic Group occur only at Station E.4493.

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I. INTRODUCTION

1. *Locality*

Palmer Land, the southern half of the Antarctic Peninsula, lies between lat. 68° 30′ and 75° 00′S. The area studied is bounded by lat. 70° 00′ and 71° 00′S and long. 61° 00′ and 65° 00′W. This covers an area of 2 016 km^2 but problems of access reduced the actual area mapped in detail. Geological mapping was therefore restricted to the area north and south of the Eland Mountains and along the plateau edge to include all the exposed rock except that on Eielson Peninsula.

2. *Previous work and scope of the present study*

Exploration of the east coast of Palmer Land began in 1928 with the historic flight of Sir Hubert Wilkins (1929) and, in 1935, that of Lincoln Ellsworth (Joerg, 1936). However, it was not until the British Graham Land Expedition, 1934–37, that more detailed study began (Rymill, 1938). A survey party led by J. R. Rymill reached the Columbia Mountains in December 1936 after a successful cross-plateau traverse. In 1947–48, a joint British and American sledge party under D. P. Mason surveyed the coast from the Larsen Ice Shelf as far south as lat. 75° 00′S, and trimetrogon air-photographic coverage was undertaken (Mason, 1950). This was extended by the United States Navy air survey in 1966–67 and the current US Geological Survey sketch map of Palmer Land at a scale of 1 : 500 000 is based on this air photography. Control for this map was provided by the British Antarctic Survey, whose systematic exploration of the area began in 1966 with geological and topographical mapping at a scale of at least 1 : 200 000. The findings presented here are a continuation of this survey.

Field work was carried out during the austral summers of 1973–74 and 1974–75, the main objective being to link up the mapping completed by Davies (1980) and Holmes (1967) north of Mount Bailey with that of Singleton (1980) in the Mount Jackson area. Travelling was by dog sledge and geological mapping was carried out using sketch maps at a scale of 1 : 200 000 combined with air photographs. The unit was transported to and from the work area and re-supplied by the aircraft of the British Antarctic Survey.

3. *Physiography*

The Wilkins and Black Coasts are dominated physiographically by the north–south-trending 2 000 m high plateau ice cap. This is flanked to the east by a chain of ridges and nunataks breached by Clifford Glacier, whose southern side is bounded by the precipitous Eland Mountains. The drop from the plateau to the Larsen Ice Shelf is accomplished in a series of terraces which mask a rugged subglacial terrain.

A detailed account of the physiography of this area has been given by Anckorn (1980).

II. GENERAL STRATIGRAPHY

Due to the lack of fossiliferous horizons in the sequence of rock types described below (Table I), the stratigraphy of this area has been determined mainly by field relations. The distribution of these rocks is shown on the geological sketch map (Fig. 1). The ages of the rocks have been inferred by correlation with other localities but it is hoped that radiometric dating in the future will provide a more accurate time-scale.

Metamorphic rocks. These are represented by a sequence of *para*gneisses and *ortho*gneisses intruded by a metadiorite and metadolerite dyke system. A younger succession of banded quartz-mica-schists in fault contact with these gneisses is unaffected by the early dyke swarm. These two groups comprise the *metamorphic complex*, the oldest rocks exposed. The area of outcrop is extensive, including the whole of Pinther Ridge (Fig. 2) and southward to the Eland Mountains and Hall Ridge. These rocks are also exposed on Mount Tenniel, Mount Samsel and the Anckorn Nunataks.

FIGURE 2
The main summit of Pinther Ridge viewed from the west.

TABLE I

SUMMARY OF THE GENERAL STRATIGRAPHY OF NORTH-EASTERN PALMER LAND

Recent		Moraines
Late Tertiary		Basalt, microdiorite, andesite and micro-adamellite dykes
Early Tertiary to late Cretaceous	Andean Intrusive Suite	Aplite dykes Adamellite Granodiorite Tonalite Diorite
		Altered diorite, meladiorite (appinite), altered gabbro, meladiorite and microgranodiorite dykes
Upper Jurassic	Upper Jurassic Volcanic Group	Dacitic crystal-lapilli-tuff
(?) Palaeozoic	(?) Palaeozoic intrusive rocks	Metagranodiorite Metatonalite
	Metamorphic complex	Quartz-mica-schist
		*Ortho*gneiss, *para*gneiss and amphibolite

Volcanic rocks. The only exposure of the volcanic sequence is at Daniels Hill, an isolated nunatak. Here, a massive dacitic crystal-lapilli-tuff crops out but its relationship with other rock types is unknown. Pyroclastic rocks of a similar type have been described from north-western Palmer Land, 60 km west of Daniels Hill (Rowe, 1973; Skinner, 1973). This rock has been assigned to the group of Upper Jurassic volcanic rocks.

Plutonic rocks. The oldest plutons, whose intrusive characteristics and cross-cutting relationships are still preserved, are granodioritic and tonalitic bodies which intrude the metamorphic complex. They possess a metamorphic foliation continuous with that of the country rock but, unlike the *ortho*gneisses of that group, they are not affected by metamorphic segregation, they are not intruded by the metadolerite and metadiorite dyke swarm, and hornblendic xenoliths are well preserved.

A younger unmetamorphosed sequence of coarse-grained plutonic rocks, ranging in composition from gabbroic to adamellitic, intrudes the metamorphic complex. From the field relations, it is known that the earliest intruded plutons were basic, successive phases becoming progressively more acid in a manner typical of the Andean Intrusive Suite to which these rocks have been assigned. Two large plutons, of adamellite and granodiorite, respectively, comprising much of the outcrop area, are exposed in a broad belt from the Columbia Mountains (see Fig. 3) to the Temnikow Nunataks. The dioritic and tonalitic members are believed to have resulted from contamination of a more acid magma by a previously emplaced suite of gabbroic and appinitic rocks, which now occupy a marginal position relative to the main acid plutons. This type of relationship has been described in the study of the Peruvian batholith (Cobbing and Pitcher, 1972).

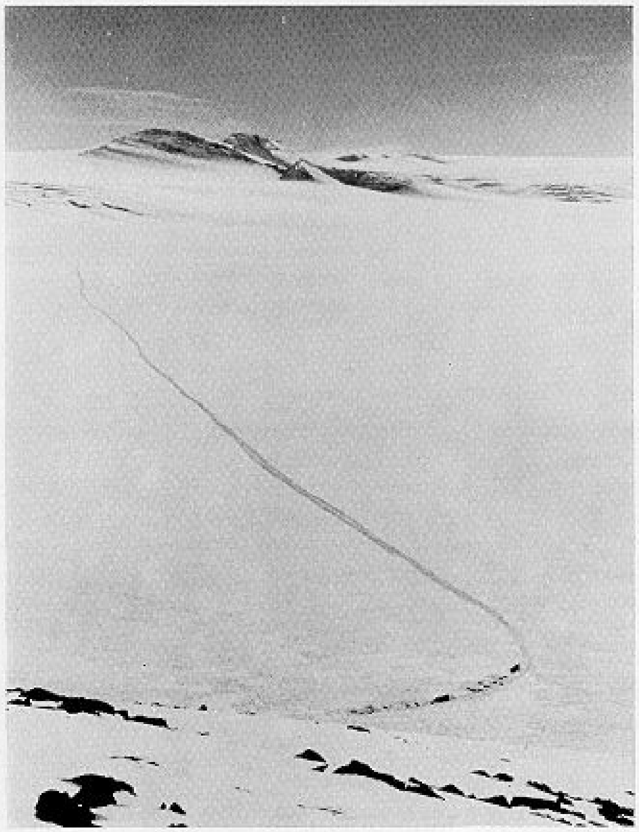


FIGURE 3

The view north-east towards the headwall of Richardson Glacier, where the nunatak at station E.4452 marks the plateau edge.

Hypabyssal rocks. Of the seven dyke-rock types found in this area, only two of them, a microgranodiorite and meladiorite, appear to pre-date the intermediate and acid phases of the Andean Intrusive Suite. These two early dykes bear a rudimentary metamorphic foliation and have recrystallized extensively. The remainder are fresh textured and intrude both the metamorphic complex and the Andean Intrusive Suite along a well-developed joint system. The youngest of these are the microdiorites and basalts which invade the youngest plutons exposed.

III. METAMORPHIC COMPLEX

THIS very extensive group of metamorphic rocks represents the oldest exposed sequence in the area studied and it has been sub-divided into seven main rock types:

7. Quartz-mica-schists.
6. Hornblende-feldspar-gneiss.
5. Feldspar-hornblende-quartz-gneiss.
4. Feldspar-quartz-biotite-gneiss.
3. Banded feldspar-quartz-biotite-gneiss.
2. Banded quartz-feldspar-biotite-gneiss.
1. Banded quartz-biotite-feldspar-gneiss.

This sub-division is based on field occurrence and petrological characteristics, but there is also a genetic significance in that the non-banded and banded gneisses are thought to be *ortho*gneisses and *para*gneisses, respectively. Undoubtedly, the two types are closely related in field occurrence, so that neither group is mutually exclusive in origin. It is apparent that groups 5 and 6 represent the metamorphosed equivalents of a dyke suite intruding both the *ortho-* and *para*gneisses. The quartz-mica-schists are not affected and they are assumed to be the youngest of the metamorphic complex rocks.

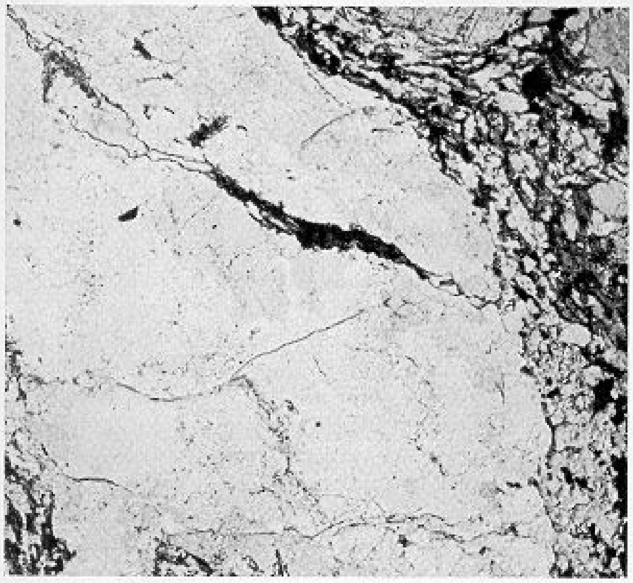
There are no indications relating to the absolute ages of this assemblage, but there is no doubt that it can be correlated with the metamorphic gneisses and schists described from western Palmer Land (Rowe, 1973; Skinner, 1973) and Marguerite Bay (Adie, 1954). These rocks were originally assigned a tentative Archaean age by Adie (1954) but more recent Rb-Sr and K-Ar dating (Grikurov and others, 1966; Stubbs, 1968; Halpern, 1971) led both Rowe (1973) and Skinner (1973) to postulate a Middle or late Palaeozoic age for the main period (F_1) of metamorphism. This interpretation remains open to speculation due to the limited scope of the dating undertaken so far.

A. FIELD RELATIONS AND PETROGRAPHY

1. *Banded quartz-biotite-feldspar-gneiss*

Of limited outcrop, these feldspar-poor gneisses are exposed on the northern flanks of Mount Curl. An Andean granodiorite is also exposed on this mountain and it appears that this intrusion is responsible for the thermal metamorphic characteristics displayed by these gneisses. At station E.4687, well-banded foliated gneisses are exposed. These are generally medium-grained and biotite-rich with a patchy augen texture due to the development of quartz and feldspar porphyroblasts up to 7 mm across. Coarse-grained leucocratic and medium-grained melanocratic horizons up to 1 m thick alternate but these are laterally impersistent. This is the only exposure which displays the normal regional metamorphic gneissose texture and, even here, spotting due to the aggregation of mafic minerals is developed.

At the other exposures to the west (E.4685 and 4686), only the ill-defined 5–10 mm thick quartz-rich layers remain of the gneissose texture, which is replaced here by a hornfelsic texture. This exposure is approximately 10 m from the contact with the granodiorite. 500 m to the south, at station E.4685, lenses of a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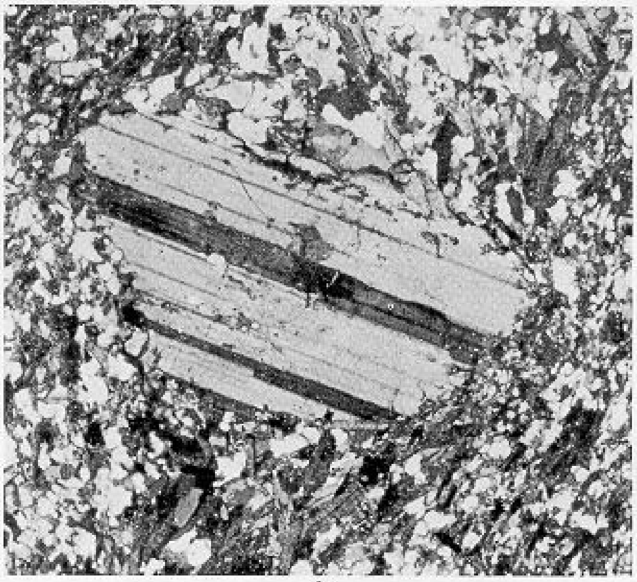

b

FIGURE 4

a. A large quartz porphyroblast in a banded gneiss cut by a biotite-filled S_2 fracture. (E.4687.1; ordinary light; ×30)

b. A large plagioclase crystal lying sub-parallel to S_1 due to rotation caused by F_2. (E.4687.1; X-nicols; ×25) coarse hornblende-hornfels occur within the quartz-biotite-feldspar-hornfels. On average these measure 1.5 m wide by 5 m long; they are aligned parallel to a poor foliation (presumably S_1) and are thought to be the thermally metamorphosed equivalent of the amphibolitic dyke remnants preserved in the other members of the metamorphic complex.

The texture of the relatively unaffected medium-grained spotted gneisses at station E.4687.1 is granoblastic, elongated quartz and feldspar occurring with continuous trains of intergranular biotite. This fabric is disrupted by the formation of polycrystalline quartz and single-crystal feldspar porphyroblasts up to 5 mm long. The former are well aligned parallel to S_1, the crystal boundaries are highly lobate and extinction of individual crystals is undulose. S_2, a crenulation cleavage, is easily distinguished in thin section by the orientation of the biotite laths in the groundmass and the presence of trains of tiny biotites which penetrate fractures in the quartz porphyroblasts (Fig. 4a). The plagioclase porphyroblasts tend to lie sub-parallel to S_1 and it appears that most of these large crystals have suffered a rotational movement due to the effects of F_2 (Fig. 4b).

Biotite has mainly a straw to dark brown pleochroism scheme but there are a few green biotite crystals. The plagioclase component is andesine; potash feldspar was not identified. Accessory minerals include interstitial calcite blebs, zircon and highly corroded rounded garnets up to 2 mm across. The formation of the latter is either syn- or pre-S_1.

At station E.4685, the contact-metamorphosed equivalent of this gneiss shows several interesting developments. First, the texture of this hornfels is a granoblastic aggregate of quartz, biotite and clinozoisite (Fig. 5), modified by the development of fibrolite along crystal boundaries. Plagioclase occurs only as an accessory mineral and the quartz has a fresh unstrained appearance. Biotite has a characteristic pale orange to foxy-red pleochroism scheme and zircon inclusions rimmed by pleochroic haloes are very common. Small rounded and corroded garnet crystals are accessory in addition to blebs of iron ore and plates of muscovite.

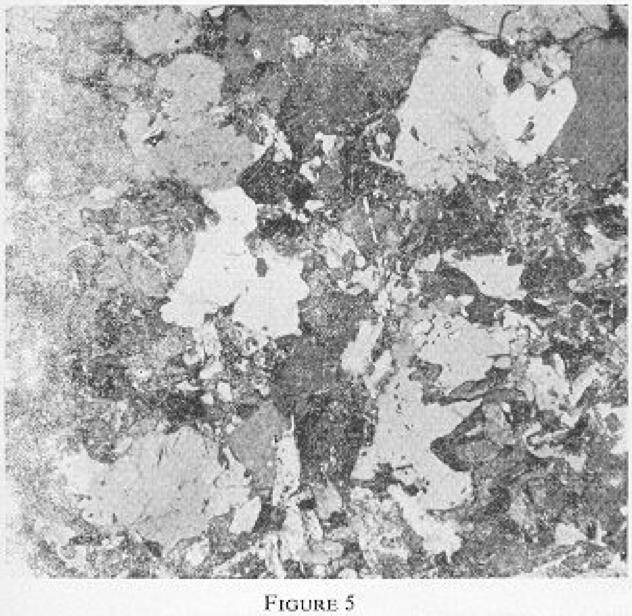


FIGURE 5

A hornfels displaying a granoblastic texture. Bundles of fibrolite are present at crystal boundaries. (E.4685.2; X-nicols; ×30)

Thus the effect of contact metamorphism on these gneisses has been effectively to change the metamorphic sub-facies from the lower grades of an Abukuma-type facies sequence to the sillimanite-cordierite-muscovite-almandine sub-facies.

2. *Banded quartz-feldspar-biotite-gneiss*

In common with the banded feldspathic gneisses, these quartzose units have a distinct *para*gneissic character and contain sheared-out dykes and xenoliths. It is therefore likely that the two rock types are members of the same metamorphosed sedimentary assemblage. Thus the outcrop pattern is very similar with exposures at the southern end of Pinther Ridge and on the eastern side of the Anckorn Nunataks. There is also one good exposure at the southern end of Hall Ridge (E.4661). Here, the compositional banding is kinked and crumpled in places, and pods of quartz are often present in the hinges of these structures (Fig. 6). Post-tectonic ptygmatic veins are also present and they are commonly only a few millimetres thick. More intense crumpling is developed at station E.4456 on the northern side of Clifford Glacier, producing a distinct S_2 foliation (Fig. 7). Rotational structures are also found in this exposure (Fig. 8), where biotite-rich horizons have formed boudins in response to this second minor period of deformation.

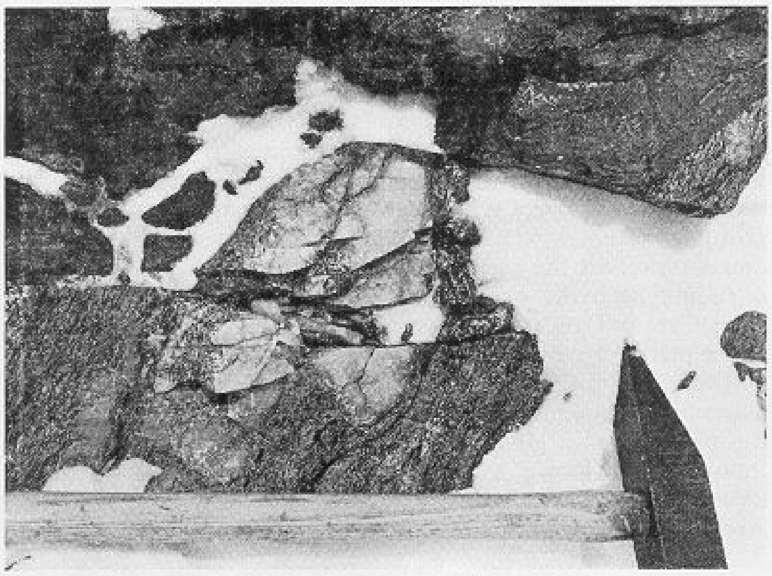


FIGURE 6

A quartz pod developed at the hinge of a small fold in a banded quartz-feldspar-biotite-gneiss at station E.4661. The hammer shaft is 3 cm thick.

Mineralogically, this is a fairly uniform group of gneisses with a constant high quartz content (at least 50%). Both potash and plagioclase feldspar are present in varying concentrations and biotite is the only important mafic mineral. The distinct fine banding is due to the relative proportion of biotite, the grain-size and the development of quartzitic horizons 1–2 mm thick. Coarse units up to 1 m thick comprise alternating biotite- and felsic-rich sheets, the melasomes being much finer-grained than the granular leucosomes. Thus, the latter display a well-developed granoblastic texture and the former a granoblastic elongate texture.

Quartz has the usual patchy extinction and, as in the other *para*gneisses, it occurs as both welded masses forming schlieren up to 4 mm long and as an intergranular matrix mineral. Grain

FIGURE 7

Crumpling of S_1 by F_2 movements in a banded quartz-feldspar-biotite-gneiss at station E.4456. The compass is 6.5 cm wide.

FIGURE 8

Rotational structure developed in response to F_2 movements in a banded quartz-feldspar-biotite-gneiss at station E.4456. The compass is 6.5 cm wide.

boundaries are characteristically sutured except where they are bounded by more euhedral feldspar and biotite. The quartz is mainly inclusion-free but tiny rounded plagioclase grains do occur in the larger crystals. These have the same composition as the rest of plagioclase (andesine) and indicate a replacement of that phase by quartz and microcline-microperthite, both of which have a distinctly poikiloblastic character in the coarser leucocratic horizons. Oscillatory zoning is fairly common in this plagioclase and it accompanies multiple twinning. Very patchy sericitization occurs but the only common inclusions are small biotite plates, due to the poikiloblastic nature of the plagioclase with that phase.

Potash feldspar is present in various plagioclase : potash feldspar ratios from 1 : 6 to 8 : 1 but it is always characteristically poikiloblastic with quartz, biotite and plagioclase inclusions. Contacts with plagioclase are accompanied by rims and pools of myrmekite and there is a strong dimensionally preferred orientation parallel to the gneissosity (S_1).

Biotite is mainly intergranular with inclusions of zircon and it is often altered to granular epidote. In the more melanocratic horizons, biotite is associated with shreds of hornblende and is often altered to chlorite. Post-tectonic muscovite (cross-cutting the metamorphic textures) is a rare accessory and clinozoisite, apatite, iron ore and allanite are also present.

3. *Banded feldspar-quartz-biotite-gneiss*

This group of gneisses is readily distinguished from the *ortho*gneisses by its finely laminated appearance; it has been locally folded on a minor scale (Fig. 9). The alternation of leucocratic and melanocratic horizons indicates a *para*gneissic character which agrees with their acid composition. These flaggy rocks have a widespread outcrop to the north of Clifford Glacier, on the eastern side of Pinther Ridge and in the Anckorn Nunataks, where they are intruded by the (?) Palaeozoic intrusive rocks. Their relationship with the *ortho*gneisses is unknown; at station E.4418 and probably at other localities, the two types are interleaved but the contacts are tectonic. In common with the *ortho*gneisses, the *para*gneisses contain xenoliths and sheared-out bodies of basic material, up to 1.5 m across, the remnants of the early period of dyke intrusion. Similarly, veins and pods of felsic material up to 1.0 m thick also occur, lying sub-parallel to the gneissosity.

Mineralogically and texturally, this is the most uniform group of the metamorphic complex gneisses. Potash feldspar, plagioclase, quartz and biotite are always present and comprise the bulk of the rock. The accessory minerals are limited to epidote, zircon, apatite, magnetite and rare allanite, and these are present in all rocks in this group. The gneisses have a mortar texture with porphyroblasts of plagioclase, potash feldspar and welded knots of quartz set in a fine granular groundmass of quartz, biotite and myrmekite.

The plagioclase is oligoclase-andesine in composition but in contrast to the *ortho*gneisses it is only rarely zoned. Multiple and deformation twinning are common and reveal much fracturing and deformation of the porphyroblasts. Their form is sub-

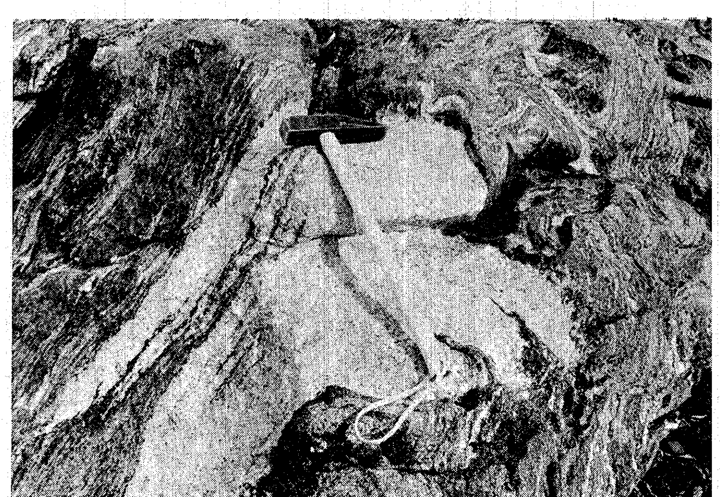


FIGURE 9

Crumpled and migmatized banded feldspar-quartz-biotite-gneiss at station E.4406. The hammer shaft is 60 cm long.

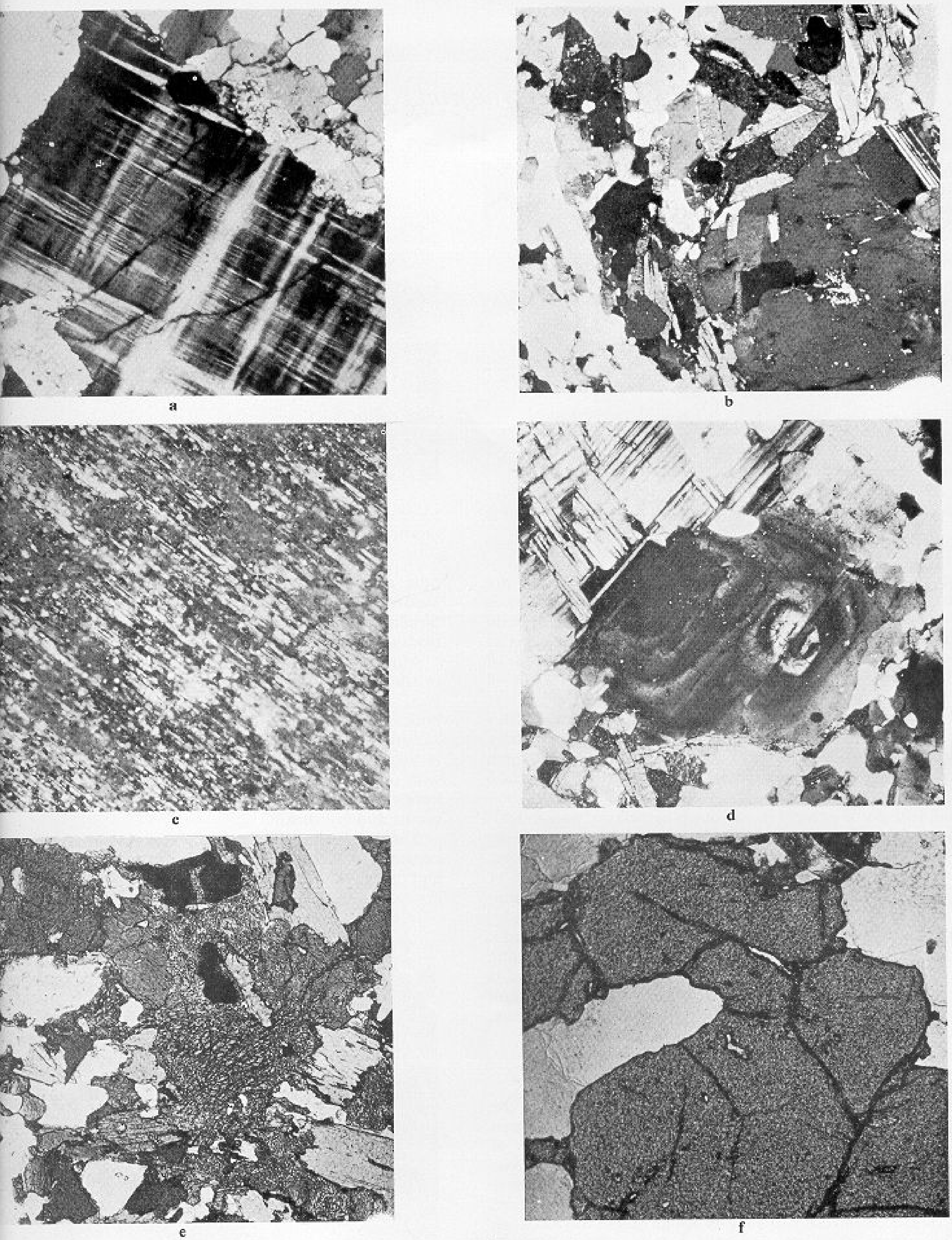


FIGURE 10

a. A large poikiloblastic microcline crystal in a banded feldspar-quartz-biotite-gneiss. Note the presence of the partially included plagioclase crystal. (E.4415.1; X-nicols; ×25)

b. Aligned (parallel to S_1) biotite and quartz crystals swinging round a large feldspar augen in a feldspar-quartz-biotite-gneiss. (E.4519; X-nicols; ×30)

c. String microperthite in a feldspar-quartz-biotite-gneiss. (E.4472.2; X-nicols; ×150)

d. Highly corroded plagioclase with asymmetric zoning in a feldspar-quartz-biotite-gneiss. (E.4452.2; X-nicols; ×30)

e. Relict corroded green hornblende (centre) surrounded by biotite, chlorite and other alteration products in a feldspar-quartz-biotite-gneiss. (E.4409.1; ordinary light; ×30)

f. Corroded almandine garnet in a feldspar-quartz-biotite-gneiss. (E.4518.1; ordinary light; ×30) rounded, the crystal margins are highly corroded and in the larger crystals (1–2 mm across) biotite and quartz-filled fractures are common. Small rounded inclusions of microcline and quartz are also very common and indicate a general breakdown of plagioclase to the advantage of the potash feldspar phase. This is substantiated by the poikiloblastic nature of the large microcline porphyroblasts with respect to the corroded plagioclase (Fig. 10a). These large microcline crystals range in size up to 4 mm across and inclusions of small rounded quartz, plagioclase and biotite crystals are always present. Dimensionally preferred orientation of these and the plagioclase porphyroblasts enhance the foliation. Perthitic textures are not very common in this group of gneisses and they are restricted to patches of string and bead perthite in the microcline. Myrmekite-filled embayments give the potash feldspar a corroded aspect but it is clear that their development post-dates that of the plagioclase.

The quartz is strained and forms the bulk of the granular matrix. It also forms annealed polycrystalline schlieren aligned parallel to the foliation. Biotite has a straw to dark brown pleochroism scheme and occupies an intergranular position. Its abundance at various tectonic horizons accounts for the finely laminated appearance of these gneisses. Alteration of the biotite to chlorite is incipient at several localities.

Apatite, epidote and iron ore are the commonest accessory minerals and they are closely associated with the biotite. The presence of epidote is probably a late-stage phenomenon as epidote-coated joints also occur in the acid members of the Andean intrusive rocks. A metamorphic regime identical to that experienced by the *ortho*gneisses is postulated, i.e. in the higher-grade sub-facies of the greenschist facies or the cordierite-amphibolite facies.

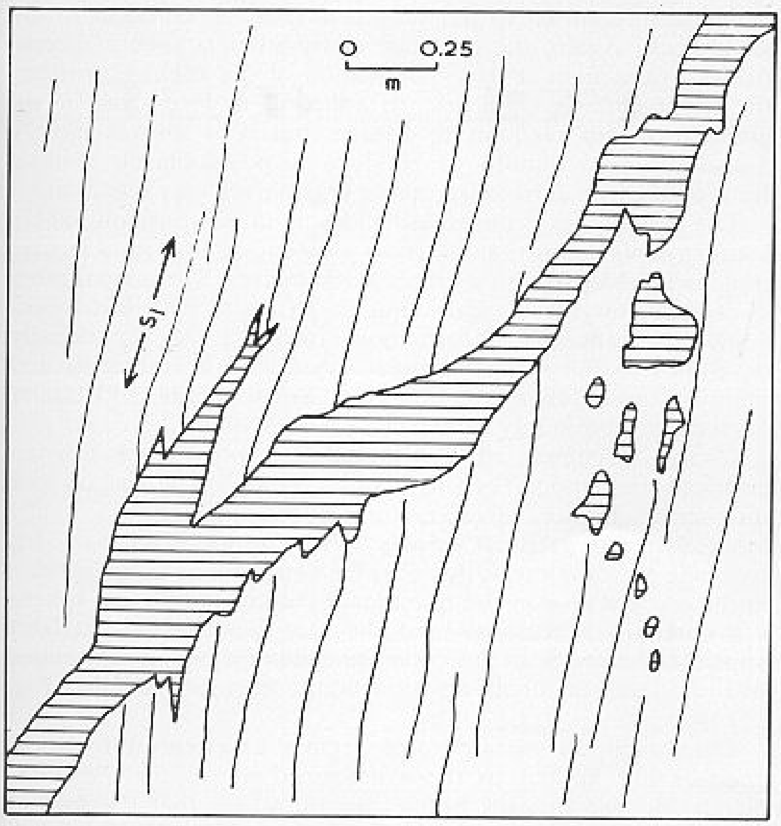


FIGURE 11

Field sketch of a pre-F_1 dyke which intrudes feldspar-quartz-biotite-gneiss at station E.4413.

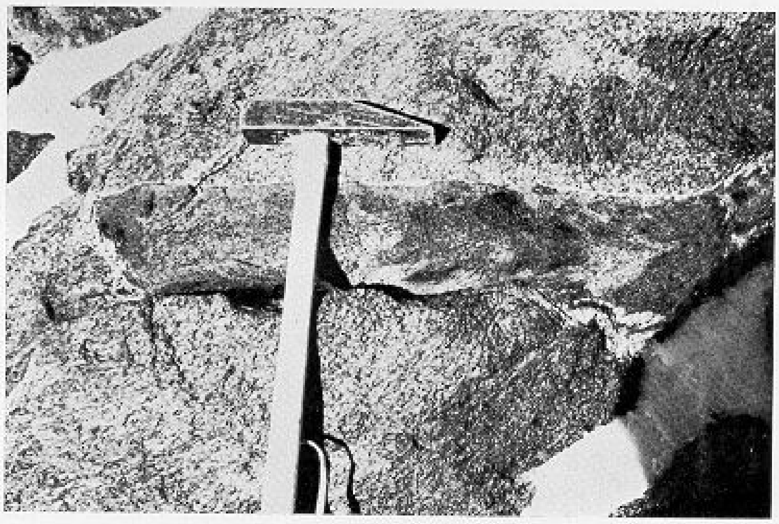


FIGURE 12

A small raft of dyke material in a feldspar-quartz-biotite-gneiss at station E.4492. The hammer head is 20 cm long.

4. *Feldspar-quartz-biotite-gneiss*

The main exposures of these massive augen-*ortho*gneisses are on the northern and western sides of Pinther Ridge and in the scattered nunataks to the south and east. They are generally non-laminated but ill-defined leucocratic and mesocratic horizons parallel the gneissosity. In common with the banded feldspar-quartz-biotite-*para*gneisses, they are invaded by the metamorphosed dyke rocks (Fig. 11). At station E.4491, at the northern end of Pinther Ridge, a large body of brecciated dyke material is exposed with the gneissosity flowing around this dyke remnant. Such large xenoliths are less common than the smaller fragments present at most localities (Fig. 12). In addition, two examples of similarly metamorphosed 0.5 m thick felsic dykes were noted with the same characteristic sheared-out relationship. These are exposed at the northern end of Pinther Ridge and lie sub-parallel to the gneissosity. They are well foliated, the structure being continuous with that of the country rock. Both S_1 and S_2 are developed, the latter somewhat patchily, and a coarse augen texture is characteristic of the group.

A wide range of composition is found in this group of gneisses from granitic to dioritic. There is a marked disparity in the plagioclase : potash feldspar ratio (12 : 1 to 1 : 14) and the amounts of quartz present (5–45%). Biotite is the major mafic constituent but hornblende is also present, each invariably accompanied by abundant accessory minerals. The typical coarse augen texture is somewhat modified by the presence of medium-grained quartz around the feldspar augen to give a patchy mortar texture. The gneissosity is expressed by a dimensionally preferred orientation in the felsic minerals and more obviously in the aligned intergranular biotite plates (Fig. 10b).

Potash feldspar is present in two modes. In the granitic gneisses, it occurs as large augen (1–15 mm across) of microperthitic microcline. These are string microperthites (Fig. 10c) with corroded margins, invaded by tongues of myrmekite and veined by a fine-grained quartz–myrmekite mix. Twinned plagioclase, corroded hornblende, sphene and quartz are all found as inclusions in the potash feldspar so that, unlike the plagioclase augen, these masses are not phenoblasts and they probably indicate a period of potash metasomatism. Microperthitic microcline also occurs in the groundmass of the less potash-rich gneisses and occupies an interstitial position relative to quartz and plagioclase as small granules. Identification of these small crystals is made possible by the patches of myrmekite which invariably accompany them.

Plagioclase tends to form polycrystalline augen up to 20 mm across with much intergranular quartz and biotite. Strain solution has produced sutured interlocking crystals with embayments filled by blebs of quartz and small biotites. Multiple twinning indicates a general composition in the oligoclase-andesine range but strong zoning with cores as basic as labradorite are also found, implying an igneous origin. Whereas deformation twinning and kinking suggest a late-stage deformation of the plagioclase, asymmetric zoning shows very well the extensive corrosion of the original plagioclase phenocrysts (Fig. 10d). The plagioclase also tends to be dusty with inclusions, mainly of sericite, but larger inclusions of biotite and quartz are also common. These are probably associated with the fracturing of the crystals and thus post-date the formation of the plagioclases.

Quartz is invariably strained, highly inequigranular, forming knots and schlieren aligned parallel to the foliation, and also occurring as a fine-grained granular matrix around the feldspar augen. The mafic minerals (biotite, iron ore, sphene and epidote) occur in knots and rafts which probably represent relicts of hornblende. Ragged, corroded hornblende crystals remain, bearing inclusions of quartz and surrounded by its alteration products (Fig. 10e). Sphene, zircon, allanite, muscovite and chlorite after biotite are all fairly common accessories in these rocks, again associated with the mafic knots. At station E.4518, almandine garnets (up to 4 mm across) are highly corroded, although they are generally round in profile (Fig. 10f). They contain inclusions of quartz and indicate a metamorphism which at least reached the quartz-albite-muscovite-biotite-chlorite subfacies (Abukuma type). The upper limits can only be restricted to below the granulite facies.

5. *Feldspar-hornblende-quartz-gneiss*

Like the hornblende-feldspar-gneisses, these more acid gneisses are the remnants of dyke rocks intruded into the *ortho*- and *para*gneisses of Pinther Ridge. Their field occurrence is identical to that of the basic gneiss with sheared-out pods and xenoliths aligned parallel to the S_1 foliation (Fig. 13) which is generally well developed. Streaks of fine-grained quartz and feldspar enhance the foliation of this mesocratic rock and readily distinguish it in the field from the basic dyke remnants.

With a high percentage of biotite, banding is well defined, but variable amounts of deformation have brought about a range of metamorphic textures from incipient mortar texture to a mylonitic texture. The former is more common with large porphyroblasts of corroded plagioclase, hornblende and quartz surrounded by small intergranular orientated biotite, quartz, sphene and zircon crystals (Fig. 14a). Biotite is also a common inclusion in the plagioclase. With a reduction in grain-size, which is the result of more intense deformation, a mylonitic texture has developed (Fig. 14b) with porphyroblasts up to

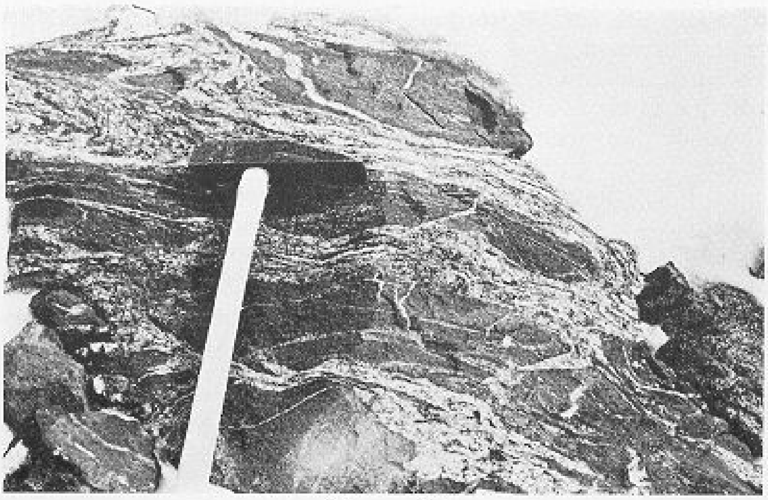


FIGURE 13

Sheared-out basic dyke remnants in a partially migmatized feldspar-hornblende-quartz-gneiss at station E.4406. The hammer head is 20 cm long.

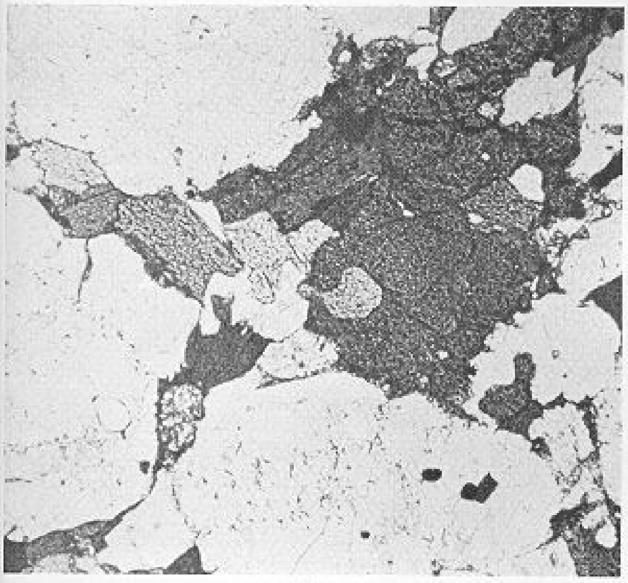
2 mm across in a fine-grained granular groundmass. It is apparent, therefore, that these and the preceding group of gneisses were particularly sensitive to dynamic metamorphism associated with the pinching-out and disruption of the dykes.

The amphibole is secondary green hornblende with an olive-green to light brown pleochroism scheme. However, at station E.4417 this is replaced by tremolite-actinolite in bands corresponding with S_1. This amphibole is markedly poikiloblastic and anhedral in contrast to the subhedral laths which occur in the same rock. Again, the presence of tremolite-actinolite accompanies granulation and mylonitization of the rock. Elsewhere, the hornblende is subhedral to anhedral in form, varying in grain-size from medium to coarse, but it is always closely associated with biotite to produce a poikiloblastic texture. Inclusions of small rounded quartz crystals are very common.

The plagioclase is oligoclase-andesine in composition, highly inequigranular up to 3 mm across and tending to form a mosaic of quartz–feldspar with a granoblastic texture. Twinning is often ill-defined and the crystals tend to be dusty with inclusions; zoning is absent. Deformation twinning is occasionally developed in the smaller tabular crystals, and fracturing and marginal granulation are common. Small biotite and quartz crystals are commonly included.

Quartz occupies an intergranular position and has an undulose extinction. There is a variation in crystal size up to 2 mm across. Biotite is fresh and undeformed and is occasionally associated with granular epidote. Where mylonitization occurs, biotite is not developed; this absence corresponds to an increase in the content of iron ore granules. Epidote, apatite and sphene are common accessories and the last two minerals at least appear to be pre-S_1 in age, whereas epidote is closely associated with the incipient break-down of biotite at station E.4406 (Fig. 15).

Details of the metamorphic regime experienced by these gneisses are limited to those described above for the hornblende-feldspar-gneisses but it can be added that the loss of biotite and the development of tremolite-actinolite with mylonitization can be attributed to a period of retrograde metamorphism accompanying post-S_1 shearing.



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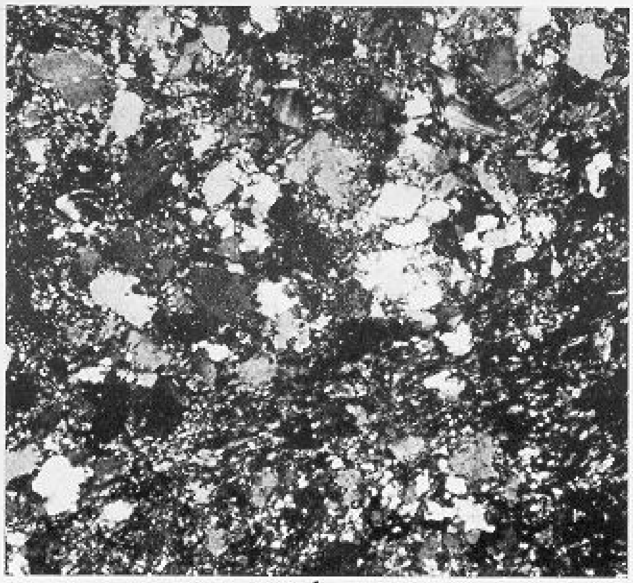


b

FIGURE 14

a. Incipient mortar texture in a feldspar-hornblende-quartz-gneiss. (E.4407.2; ordinary light; ×30)

b. Mylonitic texture developed in a feldspar-hornblende-quartz-gneiss. (E.4417.1; X-nicols; ×30)

rnblende-feldspar-gneiss

s group of rocks is closely associated with all the meta-
nic complex rocks, except the quartz-mica-schists, and
ents the metamorphosed equivalent of a suite of basic
. This ancient dyke intrusion must have been of swarm
sions as traces of metamorphosed dyke material are
t in most exposures of the feldspathic gneisses. Several
on Pinther Ridge display the sheared-out dykes (2–3 m
s), which are laterally impersistent and are sub-parallel to
neissosity (Fig. 16). More commonly, however, this horn-
c material is preserved as elongated xenoliths and schlieren aligned parallel to the foliation (Fig. 17). Such material is also preserved as xenoliths in both the (?) Palaeozoic intrusive rocks and in the Andean granodiorites. Metamorphic foliation in these rocks is variably developed and S_1 only can be discerned. The rock varies from a fissile gneiss at station E.4436.2 to a more compact rock at other exposures.

Although the hornblende : feldspar ratio varies from 4 : 1 to 3 : 7, quartz is present only as an accessory mineral in this group of rocks. A granoblastic elongate texture is typical but the variable development of foliation is expressed in minor textural differences. At station E.4411, this gneiss is coarse- and even-grained with strain solution producing an interlocking mosaic of

FIGURE 15

l biotite crystal (centre) surrounded by turbid epidote, its alteration
, in a feldspar-hornblende-quartz-gneiss. (E.4406.2; ordinary light;
×150)

FIGURE 16

A large sheared-out dyke and satellite xenoliths exposed at the south-western end of Pinther Ridge. The staff in the foreground is 2 m long.

FIGURE 17
Xenoliths of dyke material aligned parallel to S_1 at station E.4492. The hammer head is 20 cm long.

equigranular hornblende and plagioclase. In thin section the better-foliated gneisses are markedly inequigranular and trains of small crystals outline F_1 with an incipient mortar texture (Fig. 18a). The gneiss at station E.4446 is crushed and hornblende is replaced by tremolite-actinolite, deformed into felted augen. The plagioclase is also fractured and shows incipient marginal granulation.

Hornblende has generally a subhedral tabular form and felsic inclusions are very common, in one example taking the form of definite zones of bleb and string-like inclusions (Fig. 18b). The pleochroism scheme is α = brown, β = greenish brown, γ = olive-green, and inclusions of biotite and sphene are also common.

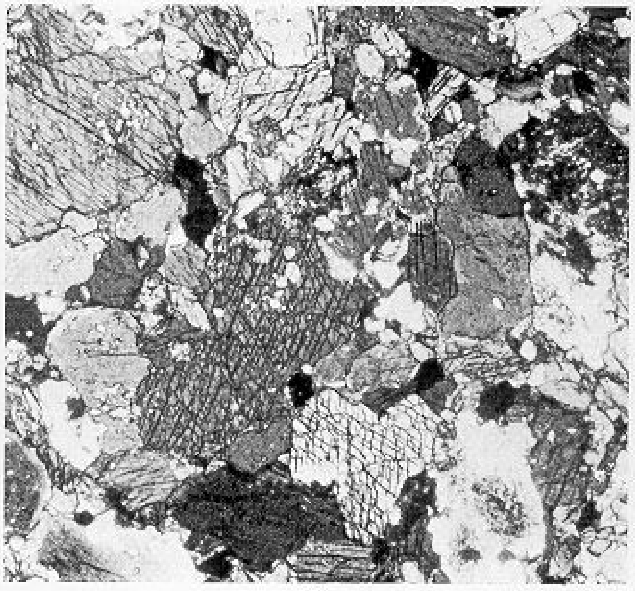
The plagioclase composition ranges from andesine to labradorite; multiple twinning is universal but zoning is only rarely developed. Inclusions of small fresh biotites and hornblendes are frequently found and feldspar–feldspar boundaries appear to be of the sutured strain-solution type. Strained interstitial quartz also indicates a period of moderate deformation. Relict sphene, iron ore and biotite are the only accessory minerals, and the development of the latter two phases appears to be post-F_1.

This mineral assemblage is indicative of at least the quartz-albite-muscovite-biotite-chlorite sub-facies (Abukuma type) and probably not higher than the andalusite-cordierite-muscovite sub-facies.

7. *Quartz-mica-schists*

These schists have a widespread outcrop, mainly around the head of Clifford Glacier. There are major exposures at Mount Samsel and at the western end of the Eland Mountains. Their disruption by frost shattering to form *felsenmeere* and scree slopes did not allow any internal lithological divisions to be determined but they appear to be a fairly uniform thick succession of fissile pelitic schists and intercalated quartzites. They are the youngest rocks of the metamorphic complex and are undoubtedly of sedimentary origin. They are mainly quartzitic with subsidiary amounts of micaceous material and a well-defined flaser type of metamorphic foliation is commonly exhibited.

Whereas no sedimentary structures are preserved, the thin quartzite units (0.1–0.25 m) are believed to be indicative of an original sedimentary bedding. In addition, the quartzitic schlieren are also assigned to a primary sedimentary origin. Disruption of these sedimentary structures has taken place through two periods of deformation. The first major period (F_1) produced a foliation sub-parallel to the sedimentary bedding and with localized recrystallization formed small boudins of coarsely crystalline quartz as at station E.4509. The effect of the second minor period of deformation has been a small-scale crumpling of



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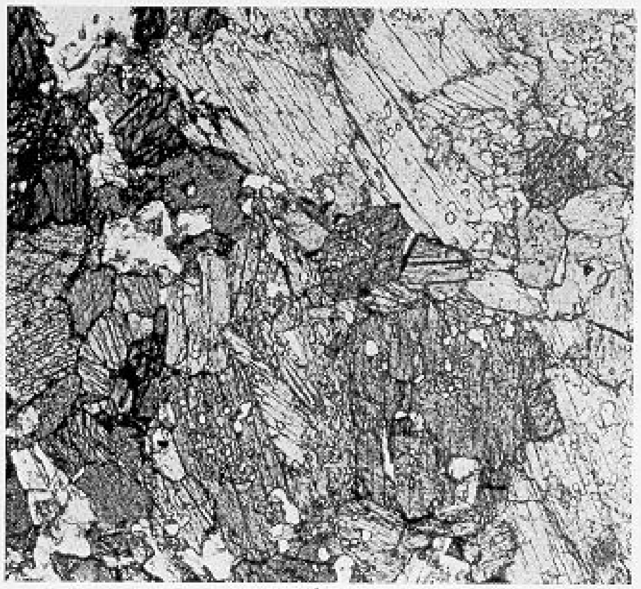


b

FIGURE 18
a. Partially developed mortar texture in a hornblende-feldspar-gneiss. (E.4436.2; ordinary light; ×25)
b. Tabular green hornblende bearing zoned bleb and string-like inclusions in a hornblende-feldspar-gneiss. (E.4436.2; ordinary light; ×25)

FIGURE 19
Faulted contact between the quartz-mica-schists (left) and the massive intrusive metagranodiorite at station E.4510 in the Clark Hills.

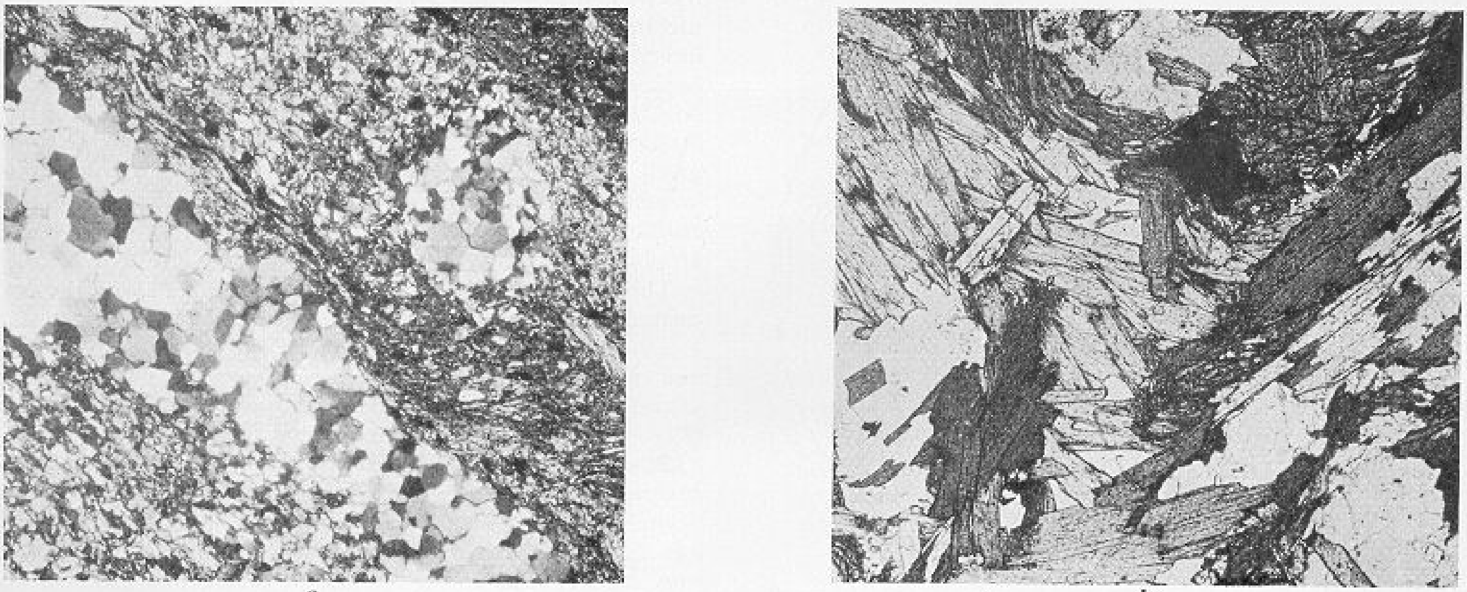
S_1 to produce a well-defined crenulation cleavage and a crenulation lineation on S_1 with re-alignment of the quartz boudins.

In contrast to the other members of the metamorphic complex, no hornblende-gneiss is intercalated in these schists either as discrete horizons or xenoliths. At station E.4510, an exposure of 10 m of feldspar-hornblende-quartz-gneiss represents the contact zone between a metagranodioritic body and the older quartz-mica-schists. The actual plane of contact between the metagranodiorite and these altered schists appears to be a fault and the same contact is exposed at station E.4672 (Fig. 19).

The texture in thin section is mainly granoblastic elongate quartz with interleaved muscovite and biotite. A granoblastic texture appears in the more competent quartz-rich horizons and quartz boudins. The percentage of quartz in these schists is high, ranging from 40 to 95% in the quartzitic horizons. The quartz tends to be fairly equigranular (0.1–0.2 mm across), dusty with inclusions and variably strained. Quartzitic schlieren up to 4 mm long are common and trend parallel to S_1, whereas porphyroblasts of annealed crystals (0.5–1.5 mm across) tend to disrupt this foliation (Fig. 20a). Such structures are clearly pre-S_2 in age, the later foliation being defined by the orientation of the micas. The variety of mica developed to some extent reflects the variability of the metamorphic grade reached.

Where large biotites are developed, quartz and muscovite are interstitial but, in general, the micas are small (0.05–0.1 mm long) and intergranular. The amounts of muscovite present are low, generally 10% and the form varies from small (0.05–0.2 mm) anhedral interstitial crystals with inclusions of quartz and iron ore to large subhedral plates up to 3 mm long whose development is later than that of the biotite. This latter form was only observed at station E.4681 where the micaceous content is considerably higher. However, in common with the more quartzose members, muscovite formation seems to have been generally contemporaneous with F_2. Whereas the biotites may be crushed and bent by S_2, the muscovites are fresh and aligned to this foliation. At station E.4515 there was little crystallographic re-arrangement during the F_2 episode, and both the muscovite and the biotite are merely deformed to produce a crenulation cleavage (Fig. 20b).

Biotite commonly occurs as small (0.1–0.3 mm) crystals with a straw to red-brown pleochroism; occasionally it is altered to chlorite. Specks of iron ore are a common accessory (1–2% in some schists) and their development is post-S_1 at least. Other accessory minerals include zircon, sphene, epidote, apatite and plagioclase as scattered small crystals which, except for the epidote, are probably pre-tectonic in origin. Epidotization has



a b

FIGURE 20

a. Schlieren of annealed quartz lying parallel to S_1 with a porphyroblast of the same material interrupting the foliation. (E.4509.1; X-nicols; ×25)

b. The orientation of the biotite and muscovite laths reveals a crenulation cleavage (top right to bottom left) in quartz-mica-schists. (E.4680.1; ordinary light; ×30) affected the entire sequence from the metamorphic complex to the Andean intrusive rocks.

With the lack of index minerals, the type of metamorphic regime is not clear. However, the grade did not exceed the sillimanite-cordierite-orthoclase-almandine sub-facies of an Abukuma-type regime (Winkler, 1974). This essentially low-pressure metamorphism is indicated by the sparse distribution of the almandine phase. Small garnets in a quartz boudin at station E.4460 indicate that the metamorphism exceeded the quartz-albite-muscovite-biotite-chlorite sub-facies.

B. Structure

Although every opportunity was taken to record structural data, the nature of the terrain with its scattered nunataks and ridges makes the picture an incomplete one. In particular, the metamorphic complex is structurally disjointed due to the Tertiary block faulting, which is responsible for much of the present-day outcrop pattern. Additionally, typical accessible exposures of these gneisses and schists are the sites of *felsenmeer* with very limited amounts of *in situ* rock. However, the results of a survey of the structural information obtained are discussed below and a stereographic plot has been compiled, revealing the broad regional trends (Fig. 21).

Pinther Ridge is the most extensive continuous exposure of the metamorphic complex and here the strike of the S_1 foliation trends roughly north–south with a moderate to steep dip to the east. However, this is only an average trend with a considerable variation about this mean. At stations E.4417 and 4418 the strike swings to approximately west-south-west with a dip of 46° to the north. The only measurement of S_2 was made at the north end of Pinther Ridge (E.4491), where it strikes north-east, dipping at 60° to the north-west. In the nunataks east of Pinther

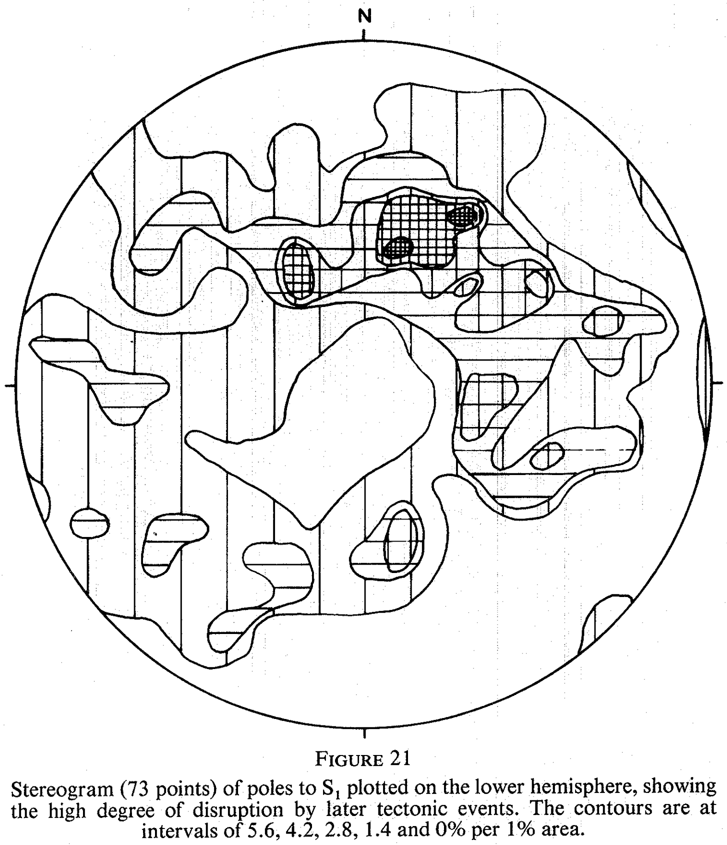


FIGURE 21

Stereogram (73 points) of poles to S_1 plotted on the lower hemisphere, showing the high degree of disruption by later tectonic events. The contours are at intervals of 5.6, 4.2, 2.8, 1.4 and 0% per 1% area.

Ridge, S_1 strikes approximately north–south with a moderate to steep dip to the east or the west, which may indicate the presence of large-scale open folding. Lineations on S_1 are common in this area and are an expression of the S_2 crenulation cleavage. South of Clifford Glacier, the main outcrop of the quartz-mica-schists, in common with the other members of the metamorphic complex around Hall Ridge, has a dominant east-south-east strike in the S_1 foliation. A moderate dip to the south-south-west was noted. Sporadic major deviations in strike are due mainly to faulting, although open folding may also be present despite the lack of direct evidence for this.

It is suggested, therefore, that F_1 folding took place about an approximately north–south axis. Deviations from this trend originated from the emplacement of the Andean plutons which disturbed structural trends at the southern end of Pinther Ridge and at Mount Curl.

The quartz-mica-schists also have a well-defined lineation associated with the crenulation cleavage which represents S_2. This F_2 episode was clearly a minor event and was probably accompanied by shearing and retrograde metamorphism. As with F_1, F_2 also post-dates the intrusion of the (?) Palaeozoic intrusive group. The few measurements of S_2 available indicate a general strike along 067° with a moderate northerly dip, approximately perpendicular to S_1. Where the dip of S_1 swings to the north or south, S_2 is still approximately perpendicular to it, indicating that the deviations in direction of strike of both S_1 and S_2 are due mainly to later faulting.

From the above evidence, there is little doubt that the metamorphic complex represents a structurally continuous group which extends into the (?) Palaeozoic intrusive group. The (?) Tertiary block faulting which affects these rocks is discussed on p. 29.

C. Metamorphic History

With the lack of a definitive mineralogy, the regional metamorphic history may only be defined within broad limits. The metamorphism is of the lower-pressure Abukuma type. This is indicated mainly by a lack of the almandine phase in both the basic rocks and the quartz-mica-schists. Although it may also be added that kyanite and andalusite are absent, this is not a satisfactory criterion. In much of the assemblage, the metamorphic grade probably did not exceed that of the greenschist facies but, in general, the upper limits can only be set at the sillimanite-cordierite-muscovite-almandine sub-facies of the cordierite-amphibolite facies.

This period of metamorphism can be linked with the development of S_1, whereas the crenulation cleavage and minor shearing associated with S_2 are linked with the introduction of epidote and a slight retrograde metamorphism. Such a history has already been described for western and northern Palmer Land (Rowe, 1973; Skinner, 1973; Davies, 1980).

Post-tectonic migmatization and granitization has affected several outcrops, notably at stations E.4436 and 4456, where ptygmatic veining and disruption of the metamorphic foliation has occurred. The age of this mobilization is uncertain but it may be associated with the rise in geothermal gradient accompanying the (?) late Cretaceous magmatic episode. Thus, at station E.4463, migmatites disrupted by aplite veins are in contact with an Andean granodiorite and at station E.4485 the granodiorite contains corroded almandine garnets derived from the schists with which it is in contact.

IV. (?) PALAEOZOIC INTRUSIVE ROCKS

THESE metamorphosed intrusive rocks are structurally continuous with the metamorphic complex gneisses; at station E.4436 a metatonalite is in contact with banded feldspar-quartz-biotite-gneiss and the S_1 foliation continues across this contact. Elsewhere, measurements of S_1 and S_2 are in accord with nearby outcrops of metamorphic complex gneisses. The metatonalite also intrudes the quartz-mica-schists at station E.4510 and is therefore clearly younger than the assemblage of metamorphic complex rocks but it pre-dates the F_1 and F_2 metamorphic episodes.

Adie (1954) described a "pink granite" and a "white granite" of inferred Palaeozoic age but neither display metamorphic structures or textures. Skinner (1973) assigned a homogenous granite to the metamorphic complex of north-western Palmer Land, although it displays few metamorphic features. However, as the latter is presumably pre-F_1 in age, i.e. pre-Middle or pre-late Palaeozoic, it is probably more closely related to the metamorphosed intrusive rocks of north-eastern Palmer Land.

On the basis of a petrographic analysis, the (?) Palaeozoic intrusive rocks have been subdivided into two types:

1. Metatonalite.
2. Metagranodiorite.

Although each appears to occur as a discrete body, they are closely related, show similar metamorphic textures and crop out in the same areas. At station E.4662 a metatonalite is veined by metagranodiorite and, at other outcrops, the latter rock type frequently contains xenoliths of tonalitic material. The metatonalite is therefore regarded as the older rock type, although the two rock types are probably part of the same intrusive episode.

1. *Metatonalite*

The main exposure of this coarse-grained potash feldspar-poor rock is Clark Hills, 4 km west of the metagranodiorite at Hall Ridge. Isolated exposures also occur at the southernmost nunatak in Temnikow Nunataks (E.4514) and at station E.4436, where there is also a small exposure of metagranodiorite 0.5 km to the north (E.4435). It has a reasonably fresh appearance, overprinted by a metamorphic foliation which is usually well developed with dimensionally preferred orientation of the feldspar, biotite and hornblende. Gneissic layering (about 50–100 mm thick), consisting of mafic-rich (finer-grained) and mafic-poor horizons, is common. These melasomes are occasionally disrupted into ramifying schlieren or xenoblasts but they always parallel the foliation. At station E.4436, where the metatonalite intrudes older *para*gneisses, the plane of contact is abrupt with little evidence of chilling or thermal metamorphism. However, epidote veining is common at this boundary, penetrating both *para*gneiss and metatonalite along common joint planes. These veins are usually weathered out but where they are preserved they can be seen to have a thickness of 5–15 cm of grass-green epidote surrounded by a 5 cm wide bleached zone where biotite and hornblende are replaced by epidote. Also occurring along this contact is a ramifying vein (5–50 cm wide) of quartz-biotite-muscovite-pegmatite, which contains knots of large euhedral garnet crystals, indicating the former establishment of unique conditions at this interface. In common with the meta-

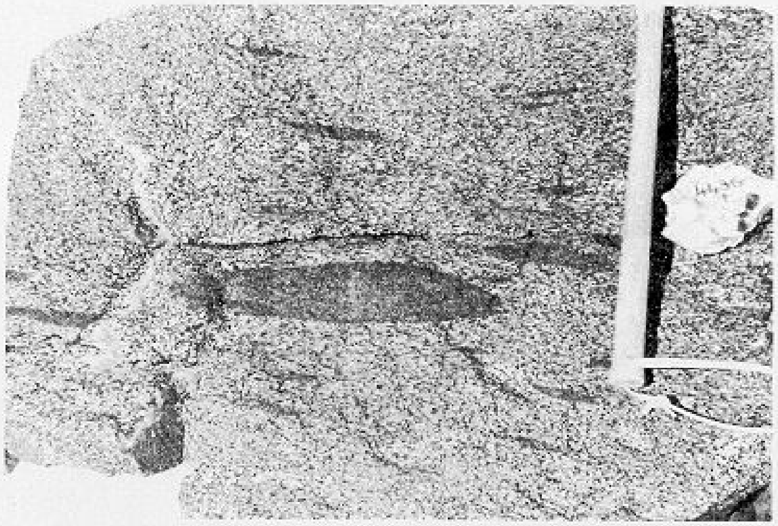


FIGURE 22
Amphibolitic xenoblasts in a metatonalite at station E.4436. The hammer shaft is 3 cm thick.

granodiorites, xenoblasts of amphibolitic material aligned parallel to the foliation are common (Fig. 22); they probably originated from the disrupted basic dykes included in the metamorphic complex.

In thin section, the metatonalites are characterized by their composition and texture. No metamorphic index minerals have been identified in either the metatonalite or the metagranodiorite, but the dominant granoblastic elongate texture readily distinguishes them from the younger Andean intrusive rocks. At station E.4676 and at several other exposures, 1–5 mm thick veinlets of a greenish cherty material cut the rock, defining a series of very small-scale shears with a dip of 67° in a direction 352° true. These veins are threads of mylonitic crush rock (Fig. 23a) consisting of highly angular fragments of quartz, feldspar and green hornblende set in an amorphous matrix. Epidote and chlorite tend to coat the veins as smeared-out relicts of biotite, giving a characteristic green colour to the hand specimen.

The metatonalites are fairly uniform compositionally with an almost complete lack of potash feldspar and a high content of quartz (around 15–30%). Occasionally, a dioritic composition is attained but this is a subsidiary type restricted to a few small outcrops 5 km west of Clark Hills. The plagioclase is of two types, both having a corroded subhedral form and often being extensively sericitized. First, there is a zoned and twinned andesine. The zoning is from An_{40} to An_{35} (core to margin) and is occasionally oscillatory; twinning is multiple and deformation forms are very common, the tabular crystals often being noticeably kinked (Fig. 23b). Secondly, there are minor amounts of untwinned dusty albite, the crystals being usually rather small and interstitial to the andesine.

The dusty quartz displays a typical regional metamorphic texture, occurring in polycrystalline schlieren up to 6 mm long and aligned parallel to the foliation. Inter-quartz boundaries are lobate and inclusions of small albite, biotite and plagioclase crystals are common. Strained extinction is variably developed

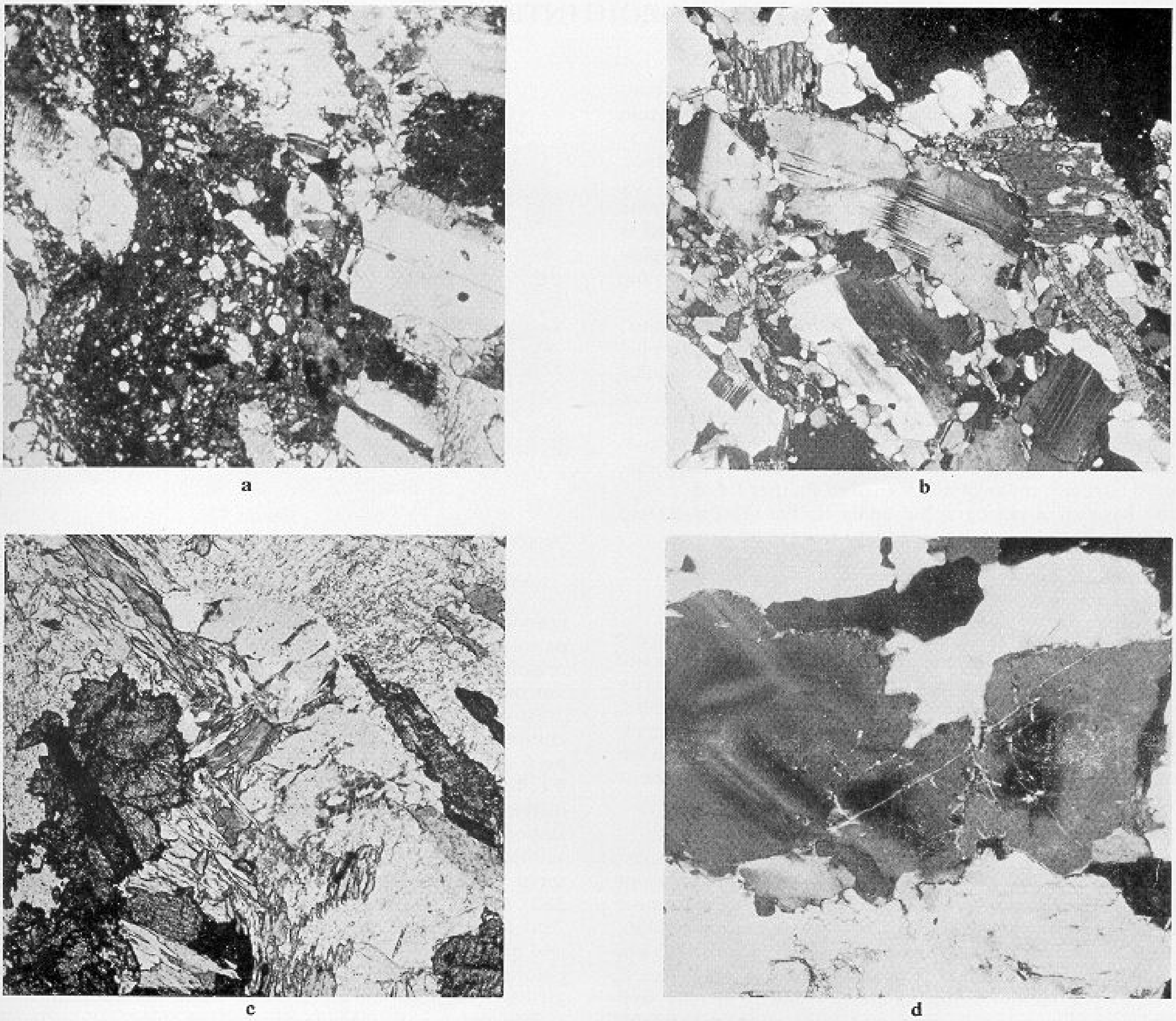


FIGURE 23

a. Vein of mylonitic crush rock in a metatonalite. (E.4676.1; X-nicols; ×30)

b. Metatonalite containing a kinked tabular plagioclase crystal (centre) in a granular matrix. (E.4436.7; X-nicols; × 30)

c. Mafic minerals replaced by granular epidote in a metatonalite. (E.4673.5; ordinary light; ×30)

d. Off-centre zoning of a corroded plagioclase crystal in a metagranodiorite. (E.4662.2; X-nicols; ×30)

ut it is always present. Hornblende and biotite are the common afic minerals, both demonstrating a strong dimensionally pre- erred orientation. They occur in highly variable proportions, roducing a characteristic banded or xenoblastic appearance to e rock. The biotite (pleochroism α = straw, $\beta = \gamma$ = dark rown) is generally intergranular and forms knots of large ystals 3–4 mm across with much alteration to chlorite, epidote nd iron ore in the coarser bands. These crystals are frequently inked and often have an undulose extinction. Finer-grained ock types contain small fresh biotite plates forming an inter- granular mosaic with quartz and feldspar. The hornblende phase occurs both as large broken and corroded phenoblasts up to 5 mm long and as small interstitial fragments. Inclusions of all the other mineral phases are common in these large spongy crystals. At station E.4673 these mafic minerals have been entirely replaced along epidotized fractures and their place is taken by granular epidote, sphene, chlorite and muscovite (Fig. 23c). In unaffected rocks, common accessory minerals are zircon, apatite, calcite, sphene and allanite. Epidote and chlorite are ubiquitous alteration products.

There is, therefore, a complete lack of metamorphic index minerals but the textures indicate that deformation and recrystallization were of the same order as that noted in the metamorphic complex rocks.

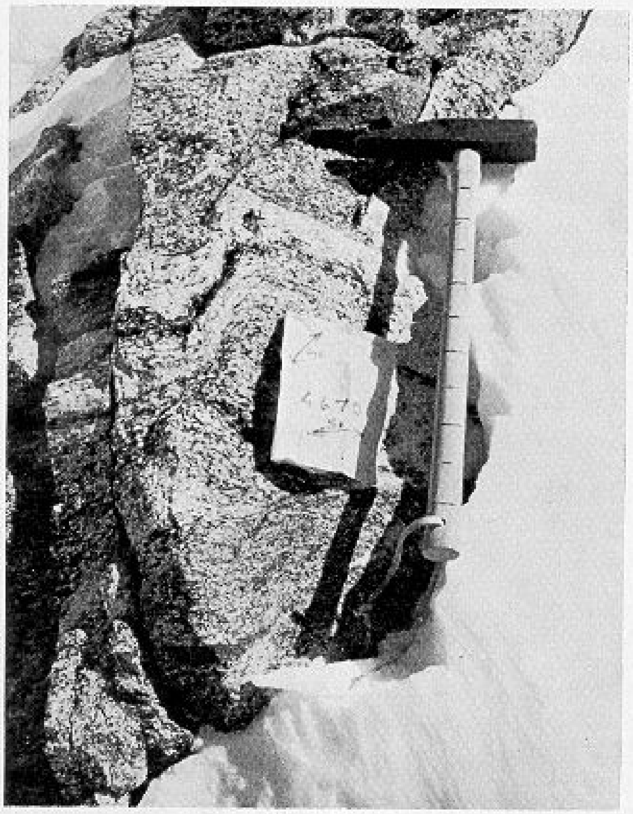


FIGURE 24
Well-developed S_2 foliation in a banded metagranodiorite at station E.4670. The hammer shaft is graduated in 5 cm units.

FIGURE 25
Xenolith of metatonalite in a metagranodiorite at Hall Ridge (E.4668). The hammer head is 20 cm long.

2. *Metagranodiorite*

These coarse-grained leucocratic rocks are largely confined to a single extensive exposure on Hall Ridge with one isolated outcrop north of Clifford Glacier (E.4435). On Hall Ridge, at station E.4510 and to the west at station E.4672, the metagranodiorite is in contact with quartz-mica-schist. The contact is marked by a 10 m wide zone of amphibole-gneiss, which grades into the normal metagranodiorite and is aligned parallel to S_1.

Banding is well developed at several localities and at station E.4670 it clearly defines both S_1 and S_2 (Fig. 24). The metagranodiorite at Hall Ridge is generally homogeneous but it contains numerous large xenoliths of three main types:

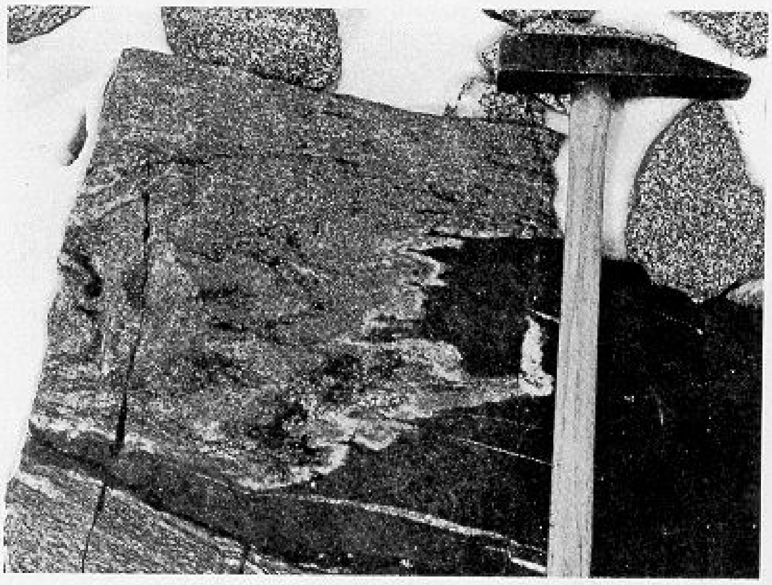


FIGURE 26
Xenolith of amphibole-feldspar-quartz-gneiss in a metagranodiorite at Hall Ridge (E.4668). The hammer head is 20 cm long.

FIGURE 27
A raft of banded feldspathic gneiss in a metagranodiorite at Hall Ridge (E.4668). The hammer head is 20 cm long.

i. A coarse metatonalitic rock (Fig. 25) which may represent remnants of an earlier pluton.
ii. A medium-grained amphibole-feldspar-quartz-gneiss, probably derived from the early metamorphic dyke swarm (Fig. 26).
iii. Rafts of a banded feldspar-quartz-biotite-hornblende-gneiss derived from the metamorphic complex (Fig. 27).

These xenoliths reach several metres across and parallel S_1 which wraps around them.

The metagranodiorite resembles the metatonalite with an identical metamorphic texture and a similar mineralogy, including zoning of the slightly less calcic plagioclase. Off-centre zoning is particularly common in this rock type (Fig. 23d) and indicates extensive corrosion of that phase in response to the F_1 metamorphic episode. Albite has not been identified but up to 30% of the feldspar content is an anhedral microcline-microperthite. This has a characteristic streaky extinction with patchy cross-hatched twinning; it is accompanied by pools of myrmekite and inclusions of small plagioclase crystals. Quartz is strained and large schlieren of rose quartz up to 10 mm across are fairly common, possibly indicating a manganese content.

Hornblende is less common but identical in type to that in the metatonalites with inclusions of epidote, quartz, feldspar and iron ore. Biotite is present as large corroded crystals up to 3 mm long with ragged ends and inclusions of quartz, epidote and plagioclase. Both mafic minerals are therefore moderately epidotized, giving the rock a green tinge in places. At station E.4668, on Hall Ridge, a 10 cm wide quartz-epidote-filled vein cuts through several narrow fresh post-Andean dykes. It is therefore probable that the main period of epidotization was a comparatively late-stage event unconnected with the major periods of deformation.

V. UPPER JURASSIC VOLCANIC GROUP

The sole representative of this sequence of extrusive rocks is a dacitic crystal-lapilli-tuff, the only exposure of which is at Daniels Hill (E.4493). This contrasts with the west coast of northern Palmer Land, where a succession of lavas, tuffs and intercalated sediments is exposed (Rowe, 1973; Skinner, 1973). A fossiliferous sedimentary horizon at Carse Point confirms the age of these volcanic rocks (Culshaw, 1975) and it is probable that this tuff is part of the same succession. A similar sequence of volcanic rocks also crops out to the north, east and west of the Eternity Range and it has likewise been assigned an Upper Jurassic age (Davies, 1980).

In the hand specimen, the rock is grey-green, highly porphyritic, fine-grained and compact with conspicuous plagioclase phenocrysts up to 10 mm long. Blebs of smoky quartz (1–3 mm) and epidote are also easily identified; they are set in a fine-grained matrix in which little structure can be identified. However, the phenocrysts display a dimensionally preferred orientation which indicates a flow foliation. On the cut face of specimen E.4493.1, vague outlines of dacitic lapilli are discernible by their slightly darker coloration. The few identifiable lapilli are of approximately pebble grade and sub-angular in outline but the ratio of lithic fragments to matrix is unknown.

In thin section, using plane-polarized light, the structure is much more easily determined. Devitrified glassy shards, fragments of pumice (1–2 mm), spherulites (0.5–1.0 mm in diameter) and phenocrysts of quartz, plagioclase, magnetite, calcite and biotite have been identified (Fig. 28a). These are set in a finely crystalline matrix of quartz, feldspar and granular calcite. A felsitic texture is dominant but distinct flow lines are present, particularly around large aligned phenocrysts and fragments of pumice (Fig. 28b).

The quartz phenocrysts have a well-developed embayed outline, the embayments being filled by distorted devitrified quartz shards (Fig. 28c). Re-absorption prior to extrusion is the best substantiated explanation for these forms which contrast sharply with the other euhedral, sub-angular or fractured phenocrysts. Quartz also occurs as small unstrained angular fragments up to 1 mm across, resisting the alteration which affects the other primary minerals. Plagioclase is euhedral in form and strong oscillatory zoning overprinted by multiple twinning is characteristic (Fig. 28d). The composition varies from An_{42} at the margin to An_{60} in the core of zoned crystals and down to An_{35} in unzoned examples. The feldspar phase is dusty with inclusions of calcite, iron ore blebs and rarer biotite and euhedral zircon. Marginal granulation and fracturing are common in the larger plagioclase crystals but this is sometimes masked by almost complete alteration to calcite and sericite, producing a cloudy texture within vague outlines of the original phenocrysts.

The only recognizable mafic minerals preserved are magnetite and biotite. The former comprises almost 5% of the rock and replaces biotite. Rounded blebs up to 1 mm across are common; strings of smaller beads are parallel to the flow and they appear to outline lithic fragments whose shape is otherwise indiscernible. Biotite is an accessory mineral, altering to magnetite, calcite and epidote. It is medium-grained and often bent, bearing inclusions of epidote and plagioclase.

Up to 30% of the rock is composed of calcite, mainly as fine granules and strings of small crystals outlining lapilli and gas bubbles, and replacing biotite and plagioclase in plates up to 0.5 mm across. This calcitization is a late-stage event which also affects the undeformed hypabyssal rocks in the same area. Coupled with devitrification and recrystallization, it has obscured the minor details so that it is impossible to determine the genesis of this pyroclastic rock.

The presence of welded shards, fragments of pumice and flow lines around the phenocrysts suggested an ignimbrite but the evidence is not conclusive.

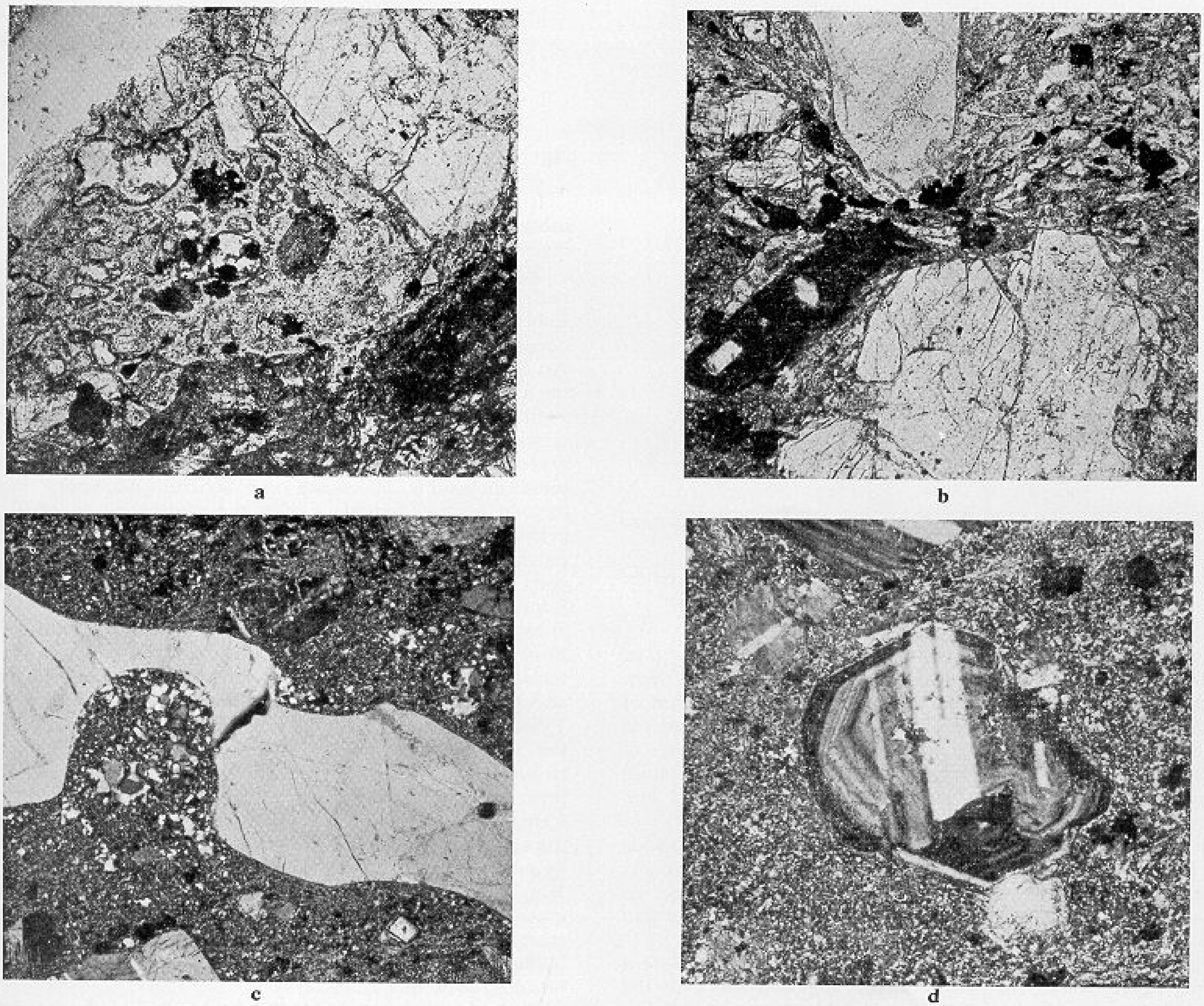
TABLE II

MODAL ANALYSES OF SELECTED ANDEAN INTRUSIVE ROCKS FROM NORTH-EASTERN PALMER LAND

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Plagioclase	21.3	48.1	61.5	48.6	50.1	56.7	48.6	32.0	32.0	47.8	31.5	–	46.0	34.9	59.7	60.3	69.5	50.3	58.3	37.5	55.4	35.5	27.3	30.6
K feldspar	36.1	37.7	16.9	10.9	20.7	3.4	4.5	31.6	15.0	29.9	27.7	45.5	10.2	33.6	–	4.5	–	–	13.7	–	–	–	–	–
Quartz	26.6	6.2	13.6	30.2	18.7	20.5	45.6	32.6	19.3	14.6	37.4	52.1	42.0	20.7	13.1	12.3	20.0	8.6	23.0	1.3	0.4	7.7	0.7	–
Biotite*	10.0	5.0	2.9	5.2	4.1	17.0	0.7	3.5	14.1	–	–	1.6	1.1	8.4	15.8	4.6	6.5	20.0	1.7	4.4	13.4	0.1	7.5	16.2
Hornblende	2.7	2.2	3.5	4.3	3.1	1.3	–	–	9.0	–	–	–	0.1	1.5	8.7	16.3	3.3	19.1	2.1	57.5	26.8	55.9	58.2	31.2
Iron ores	0.8	0.2	0.2	0.2	1.1	0.7	0.5	†	6.2	–	0.1	0.3	0.1	0.5	1.6	0.3	0.5	1.8	0.5	0.3	3.4	0.7	0.4	5.4
Epidote	–	0.1	0.1	†	1.0	0.1	0.1	0.1	0.9	–	–	0.2	–	†	0.6	1.0	–	†	–	–	0.6	0.3	4.7	13.5
Sphene	0.1	–	0.1	0.2	0.6	†	†	†	0.2	–	–	–	–	0.3	0.4	†	–	–	0.4	–	–	0.4	0.3	0.1
Zircon	0.1	0.1	–	–	–	0.2	–	–	0.1	–	–	–	†	0.1	0.1	0.1	–	0.1	–	–	–	†	–	–
Muscovite	–	–	–	–	–	0.1	–	–	–	6.8	3.2	0.3	–	–	–	–	–	–	–	–	–	–	0.7	–
Garnet	–	–	–	–	–	–	–	–	–	0.9	0.1	–	–	–	–	–	–	–	–	–	–	–	–	–
Myrmekite	2.2	0.4	1.2	0.3	0.6	–	–	0.2	3.2	–	–	–	0.5	–	–	0.5	–	–	–	–	–	–	–	–
Apatite	0.1	–	–	0.1	–	–	–	–	†	–	–	–	†	–	†	†	†	0.1	0.2	–	–	0.1	0.1	–
Calcite	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.1	–	–	–	–	–	–	0.1	†
Augite	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.2	–	–	–	†	–	–	3.0

* Includes chlorite after biotite.
† Present.

1. E.4403.1 Adamellite; Columbia Mountains.
2. E.4405.1 Adamellite; Columbia Mountains.
3. E.4429.1 Granodiorite; Columbia Mountains.
4. E.4432.1 Granodiorite; Columbia Mountains.
5. E.4443.1 Granodiorite; Anckorn Nunataks.
6. E.4462.1 Granodiorite; west side of Richardson Glacier.
7. E.4463.1 Granodiorite; west side of Richardson Glacier.
8. E.4456.1 Microgranodiorite dyke; nunatak east of Pinther Ridge.
9. E.4483.1 Granodiorite; west side of Richardson Glacier.
10. E.4485.2 Adamellite; west side of Richardson Glacier.
11. E.4485.3 Adamellite; west side of Richardson Glacier.
12. E.4485.5 Adamellite; west side of Richardson Glacier.
13. E.4489.1 Granodiorite; nunatak south-east of Pinther Ridge.
14. E.4495.1 Adamellite; Laine Hills.
15. E.4497.1 Tonalite; Catlin Peak.
16. E.4498.3 Tonalite; Catlin Peak.
17. E.4520.1 Tonalite; Temnikow Nunataks.
18. E.4678.3 Tonalite; north-west of Mount Curl.
19. E.4685.1 Granodiorite; east of Mount Curl.
20. E.4439.2 ? Andesitic dyke; Anckorn Nunataks.
21. E.4444.2 Altered diorite; nunatak east of Anckorn Nunataks.
22. E.4457.1 Diorite; nunatak west of Richardson Glacier.
23. E.4510.2 ? Andesitic dyke; Hall Ridge.
24. E.4688.1 Altered gabbro; ridge north-east of Mount Curl.



a b c d

FIGURE 28

a. A fragment of pumice and abundant phenocrysts in a dacitic tuff. (E.4689.2; ordinary light; ×40)

b. Indications of flow in the matrix between two large phenocrysts in a dacitic tuff with alignment of shards and crystals. (E.4689.2; X-nicols; ×40)

c. An embayed quartz crystal in a tuff. (E.4689.2; X-nicols; ×40)

d. Euhedral plagioclase showing zoning overprinted by twinning in a tuff. (E.4689.2; X-nicols; ×40)

VI. ANDEAN INTRUSIVE SUITE

OF very extensive outcrop, the Andean Intrusive Suite is a complex group of basic, intermediate and acid plutonic rocks. Modal analyses of selected rocks belonging to this suite are given in Table II and these are plotted on a triangular diagram with the coordinates quartz–plagioclase–potash feldspar in Fig. 29. The suite has been subdivided into the following types, which range in age from oldest to youngest:

1. Meladiorite (appinite), amphibolite and gabbro.
2. Diorite.
3. Tonalite.
4. Granodiorite.
5. Adamellite.
6. Aplite.

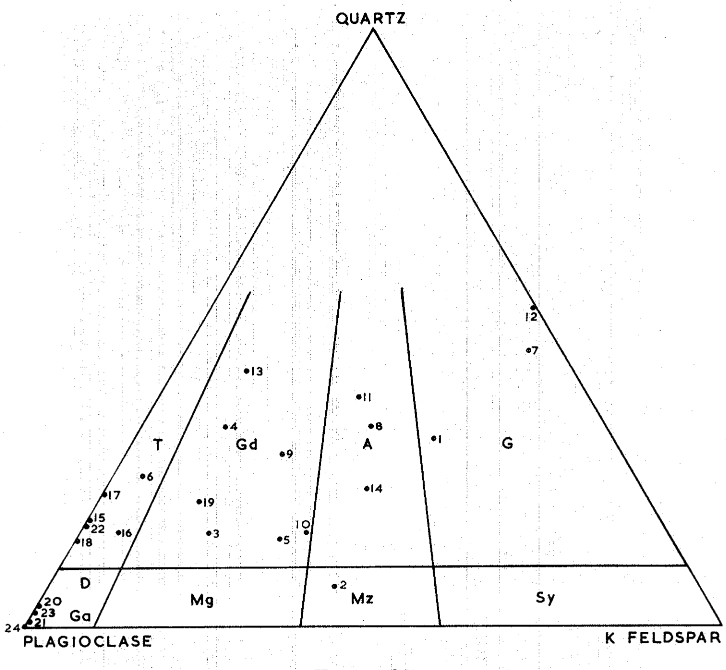


FIGURE 29

A plot of the modal analyses of Andean plutonic rocks (Table II) on the coordinates quartz–plagioclase–potash feldspar.

Plutons of these types are exposed over the entire length of northern Palmer Land, Graham Land and possibly in northern Alexander Island. These appear to be a direct continuation of the calc-alkaline intrusive suite of southern Patagonia and the South American Andes (Adie, 1955) which has an age range of Upper Jurassic to Lower Tertiary, the main intrusive phase taking place in the Aptian (Adie, 1964). Rowe (1973) and Skinner (1973) also correlated the younger intrusive rocks of north-western Palmer Land with the Andean intrusive episode and here it is known that the former intrude the Mesozoic volcanic rocks. At the southern end of the Eternity Range, an Andean granodiorite is overlain by a sequence of arenites and rudites of unknown age (Davies, 1980).

No such field evidence is available in this part of north-eastern Palmer Land, where the only contacts exposed are with the metamorphic complex and Tertiary dykes. However, lithological and textural evidence indicates a very close affiliation to Andean-type rocks. It is this correlation with a known differentiated series, coupled with field evidence and petrographic observations, that has allowed the relative ages of these plutons to be determined.

A. Field Relations and Petrography

1. *Meladiorite (appinite), amphibolite and gabbro*

The outcrop of this group of rocks is significant with a marginal position relative to the large adamellite and granodiorite plutons. One isolated exposure of gabbro is present at station E.4688, 9 km east of a fresh granodiorite, but the commonest of these marginal intrusive bodies are the amphibolites. Knowles (1945) described a "coarse-grained hypidiomorphic hornblendite" forming Cape Boggs and this can be correlated with the amphibolites which crop out to the north. These have three main modes of occurrence:

i. As small bodies of the order of 0.5 km across (E.4444) containing occasional quartz-feldspar-garnet (spessartine) veins.

ii. As thin (5–10 m) sheets at the contact of younger acid intrusive rocks with the metamorphic complex.

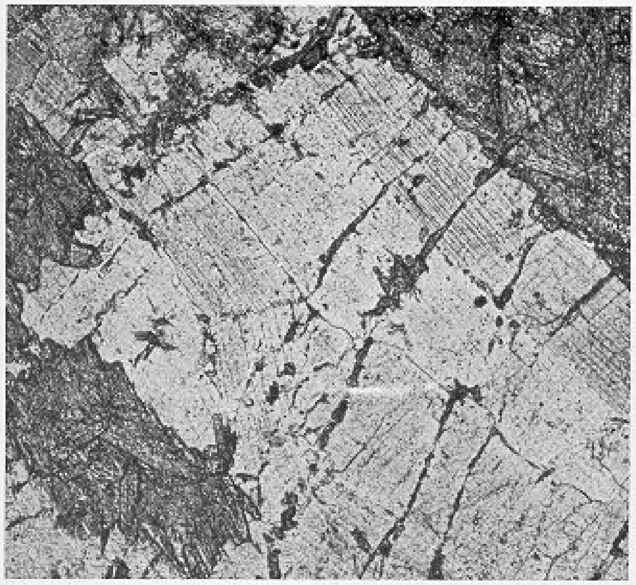
iii. As small xenoliths preserved in the later dioritic phase.

It is possible that these early basic intrusive rocks formed far more extensive plutons which were subsequently disrupted and digested by later pulses of acidic magma.

Meladiorite bodies intrude the metamorphic complex as dykes and pipes, the best example of which is exposed at station E.4418. The pegmatitic texture suggests an appinitic mode of occurrence, a volatile-rich phase of the amphibolite intrusion. An altered diorite is exposed at station E.4444 where it intrudes the amphibolite, breaking up the latter into small xenoliths.

In thin section, the massive fresh amphibolites are characterized by an interlocking network of euhedral to subhedral green hornblende, mainly relatively unaltered and bearing scattered inclusions of quartz and sericite. Accessory minerals include quartz, sericite, pyrite and microcline as small intergranular crystals. Such rock types bear only an indistinct and patchy foliation but at station E.4454, where deformation has been stronger, a meladiorite is transected by closely spaced fractures and a foliation appears on joint surfaces as a distinct lineation. Such deformation may be connected with a similar form described in the Palaeozoic intrusive rocks. In this meladiorite, green hornblende is replaced by actinolite and accessory biotite has a foxy-red to yellow pleochroism. Typically, plagioclase (An_{60-65}) comprises 50–60% of the rest of the rock with accessory iron ore and quartz. Deformation twinning and fracturing is common and the plagioclases tend to form fields of fused crystals aligned parallel to the foliation. The formation of actinolite is closely connected with deformation as the crystals are interstitial to the partially recrystallized feldspar masses and penetrate the fractures as trains of tiny crystals (Fig. 30a). The appinitic meladiorites are apparently less deformed; green hornblende and plagioclase (An_{50}) crystals are kinked and marginal granulation is apparent but recrystallization has not taken place. Grain-size is highly variable with interstitial hornblendes reaching 15 mm across.

The gabbro at station E.4688 displays a high degree of alteration. This dark green speckled rock is heavily epidotized and displays a probable primary igneous banding. Completely epidotized gabbro occurs along the contact with a younger micro-adamellite dyke. Recrystallization has taken place and the mafic minerals especially are concentrated into specific fields. Brown hornblende and large chloritized green amphiboles form the distinct bands, the former with a skeletal form, largely replaced by epidote and bearing inclusions of iron ore, plagioclase and green amphibole. This latter phase is mainly secondary hornblende, with small amounts of actinolite occurring as large fibrous subhedral crystals. Alteration to chlorite is occasionally complete. The plagioclase (An_{60-70}) is corroded and extensively sericitized. Chlorite-filled fractures cut the crystals which display deformation twinning but there is no zoning. The iron ore is pyrite and it forms 5% of the total rock as rounded embayed crystals up to 4.0 mm across. It is interstitial to the hornblende and plagioclase but it appears to be replaced by epidote where epidotization is most severe.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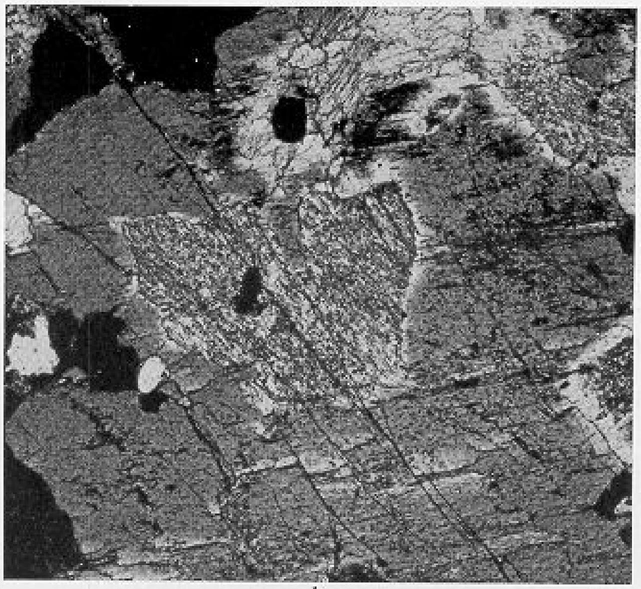
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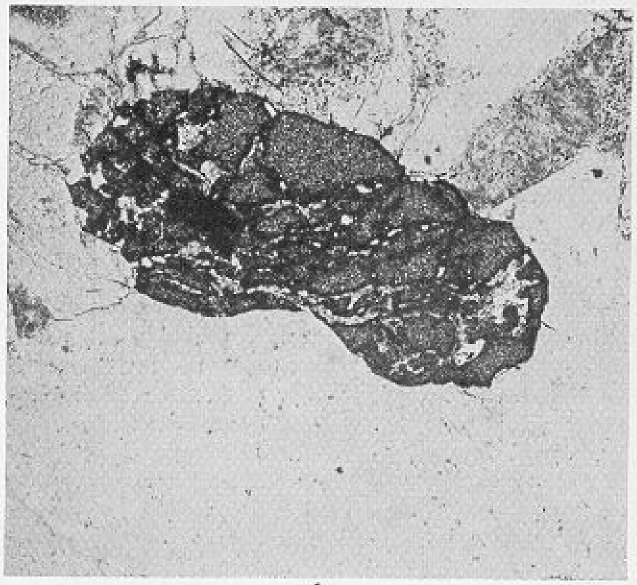
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FIGURE 30

a. Fractures in deformed plagioclase filled by strings of actinolite crystals. (E.4454.1; ordinary light; ×40)

b. A residual colourless augite core surrounded by secondary green hornblende in a diorite. (E.4444.2; X-nicols; ×30)

c. A vein of crushed crystals and amorphous matrix in a deformed tonalite. (E.4678.3; X-nicols; ×40)

d. Corroded euhedral garnets (? spessartine) in an adamellite. (E.4485.2; ordinary light; ×40)

2. *Diorite*

These fairly fresh diorites appear to have a very limited outcrop and are exposed only at stations E.4444, 4457 and 4673. At station E.4457 it is intruded and brecciated by an Andean granodiorite, and at station E.4673 it intrudes a meta-tonalite of the Palaeozoic intrusive suite. Station E.4444 displays the contact between diorite and amphibolite, both of which are somewhat altered and deformed at this exposure. Therefore, while younger than the amphibolites and gabbro, these diorites are probably more closely allied in time to those groups than to the acid intrusive rocks. Again, the diorite has a marginal position relative to the acid plutons.

The freshest diorite is the one at station E.4457, where it is a coarse equigranular rock with no obvious foliation. In thin section, it is evident that, whilst the texture is reasonably fresh, some recrystallization has taken place. The plagioclase is andesine; twinned and zoned crystals are interstitial to the green hornblende and they contain many small inclusions of hornblende, sphene and quartz. The latter phase is also interstitial and contains hornblende inclusions. The only important mafic ineral present is green hornblende which is corroded and oikilitically enclosed by plagioclase. Its form is subhedral to nhedral with a great range in size from 0.05 to 3.0 mm across. 'hlorite (after hornblende), sphene and apatite are common iclusions.

The diorite at station E.4444 is of a radically different texture, eing markedly inhomogeneous in the hand specimen with atches of hornblendic material up to 50 mm across. Extensive ecrystallization has taken place with a break-down of colour-ss augite to green hornblende the former remaining as a oudy core (Fig. 30b). Hornblende occurs as needle-shaped uhedral to subhedral crystals in large conglomerations with iotite crystals marginal to these masses. The plagioclase is ndesine and has an anhedral to subhedral form up to 6 mm cross and disrupted by the recrystallized hornblende crystals.)eformation twinning is very common and some crystals are lso fractured. There are occasional subhedral interstitial micro-erthites containing inclusions of fractured plagioclase.

Strong epidotization is present at station E.4673, where the iorite is cut by epidote-filled fractures. These are unique in aving diffuse zoned margins with the epidote-rich vein coated n each side by a chloritized zone. In all other respects this iorite is similar to the one at station E.4457, although it is finer-rained and foliated.

. *Tonalite*

After the intrusion of the basic and intermediate rocks, there ollowed a period of minor deformation and recrystallization efore the sequence of acid intrusions began. The relative ages f these younger intrusions is not revealed by the field relations with the exception of the aplite dykes) but they have been entatively arranged in a sequence of potash enrichment con-orming to typical Andean examples.

The tonalite is a coarse-grained mesocratic rock, extensive in utcrop but restricted in occurrence within the area mapped to a ugged plateau-edge ridge 30 km south-west of the Eland Moun-ains. This pluton intrudes metamorphic complex gneisses and, t station E.4498, it carries a 30 m wide raft of partially digested neiss. One isolated exposure occurs east of this ridge at station E.4678 and this, although sheared along minor movement lanes, is easily distinguished from the nearby metatonalites by ts relatively fresh texture and appearance. Typically, the onalite has a well-developed igneous foliation and numerous onalitic and dioritic xenoliths aligned parallel to it. This folia-ion is only locally uniform and there are substantial changes of orientation. These characteristics are shared by the later grano-diorite and the two rock types probably had a very similar ntrusive history. It is possible that the tonalite was not derived from a primary magma but originated through assimilation of the early dioritic, gabbroic and amphibolitic material by a more acid magma. Goldring (1962) listed six characteristics which he regarded as indicative of such an origin and at least three of these are common to this tonalite:

i. Extreme variation in grain-size.
ii. Intense zoning of the plagioclase.
iii. The aggregated nature of the mafic constituents.

In thin section, the foliation can be discerned by the preferred orientation of the tabular feldspar, biotite and hornblende crystals. The latter are subhedral in form, corroded and poikilitic with respect to the leucocratic minerals. The biotite is fairly fresh but occasionally bent. This deformation is also displayed by the feldspar crystals (An_{35-40}) which are zoned and multiply twinned.

Quartz occurs in large euhedral crystals up to 4 mm across and is fresh and unstrained. Common accessory minerals include zircon, epidote (associated with biotite) and iron ore, and these constituents tend to form aggregates with the other mafic minerals. These mafic clots reach up to 5 mm long and are aligned parallel to the foliation.

A deformed tonalite at station E.4678 is cut by a thread-like green vein along the contact between a dioritic xenolith and the host rock. Under the microscope, this can be discerned as a "crush" vein full of tiny angular mineral fragments set in an amorphous matrix (Fig. 30c). This occurrence is identical to that noted in a metatonalite at station E.4676, a few kilometres to the north-west.

The xenoliths examined in thin section were found to be tonalitic in composition, although dioritic types were noted in the field. Their texture is fairly fresh and the foliation is aligned parallel to that in the host rock. Indeed, although minor differ-ences in composition are found between xenolith (tonalitic) and host rock (slightly less melanocratic), the finer grain-size of the xenolith is the only obvious distinction. It is possible, therefore, that the tonalitic xenoliths were derived from a previously cooled part of the same pluton.

4. *Granodiorite*

North of lat. 70°40′S, the tonalite pluton disappears below a cover of Upper Jurassic volcanic and metamorphic complex rocks, and its place is taken by a large adamellite and grano-diorite body. It is probable that these two potash-rich intrusions are closely related in time, hence their injection into the same chamber. Although no contacts between the two rock types were observed, the granodiorites tends to occupy a marginal position around an adamellitic core, thus completing the approximately concentric arrangement of the Andean Intrusive Suite in this area. Aplite dykes cut both the granodiorite and adamellite, and it is likely that these had as their origin a residual melt from the adamellite. For these reasons, the latter is regarded as the youngest of the plutonic rocks exposed.

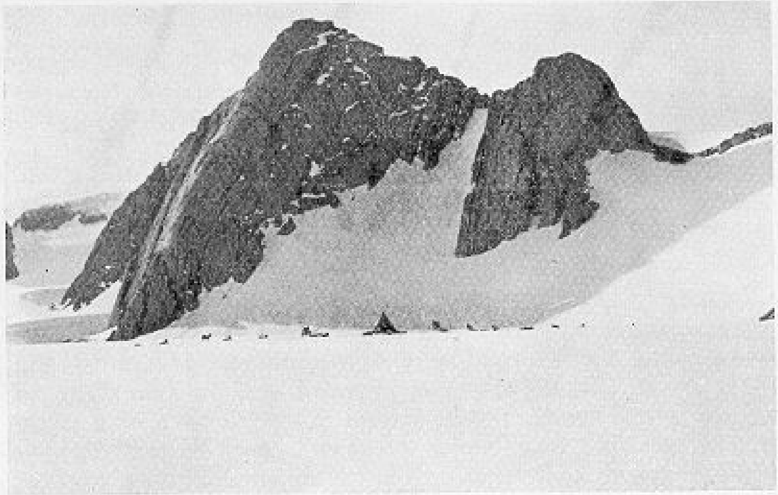


FIGURE 31
A typical exposure of granodiorite at station E.4421 at the south-western end of the Columbia Mountains.

The most extensive exposure of the coarse equigranular granodiorite is in the Columbia Mountains (Fig. 31), where it is in contact with the metamorphic complex. Here, the coarse pink-weathering rock has an igneous foliation with a general dip of 30–85° to the west or north-west and it carries abundant dioritic xenoliths orientated parallel to this foliation. These are metasomatized and contain strings of large quartz blebs aligned parallel to the foliation in the host rock. In addition, where small xenoliths (10–50 mm across) occur in knots, presumably as relicts of a larger body, they are surrounded by a potash feldspar-porphyry (Fig. 32). Mineralization is indicated by malachite and limonite deposits in joints and niches, but no primary deposits were located.

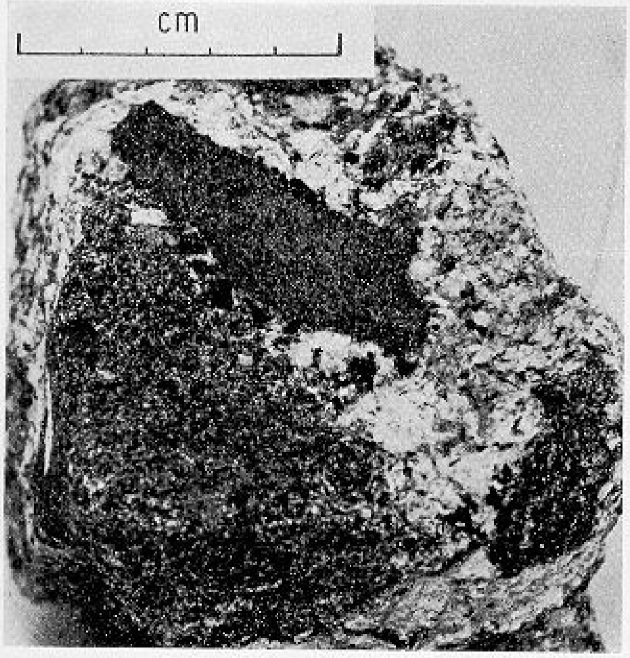


FIGURE 32
Dioritic xenoliths in a granodiorite, surrounded by coarse feldspar-porphyry (E.4427). The scale is in centimetres.

These characteristics are repeated at other exposures and, to the south at station E.4483, compositional banding is very well developed with depositional structures indicating the action of local strong convection currents in the magma chamber (Fig. 33). Thermal metamorphic effects on the country rock are limited to slight migmatization of the acid gneisses and veining by granodioritic apophyses. This aureole is of unknown extent but it is probably less than 1 km wide. At station E.4685, the basic gneisses are hornfelsed but this zone does not appear to extend more than 0.5 km.

An outlying exposure of the inequigranular granodiorite occurs at station E.4520, 10 km south-east of Daniels Hill. Distinctive phenocrysts of biotite "books" and subhedral hornblende laths are present. Although potash feldspar is absent, quartz is too abundant for a typical tonalitic composition. The plagioclase is andesine in contrast to the oligoclase of the typical granodiorite and corroded subhedral augite is an accessory. It is likely, therefore, that this plateau-edge exposure is a marginal (to the main pluton) hybrid rock.

The texture of the normal granodiorite seen in the hand specimen is typically an equigranular network of subhedral to euhedral oligoclase set in a groundmass of poikilitic potash feldspars and polycrystalline quartz. Thin-section analysis reveals that the potash feldspar is a string microperthite. As in all the potash feldspar encountered, the optic sign is positive and common boundaries with plagioclase are marked by myrmekitic growths. The plagioclase is twinned and has a faint oscillatory zoning, while the quartz has a shadowy extinction. Sparse euhedral corroded biotite and hornblende crystals occur as small inclusions in the potash feldspar and are associated with overgrowths of piedmontite and pistacite. Large intergranular biotites (up to 1.5 mm long) carry inclusions of quartz and plagioclase. Common accessory minerals include magnetite, sphene, allanite, zircon and apatite.

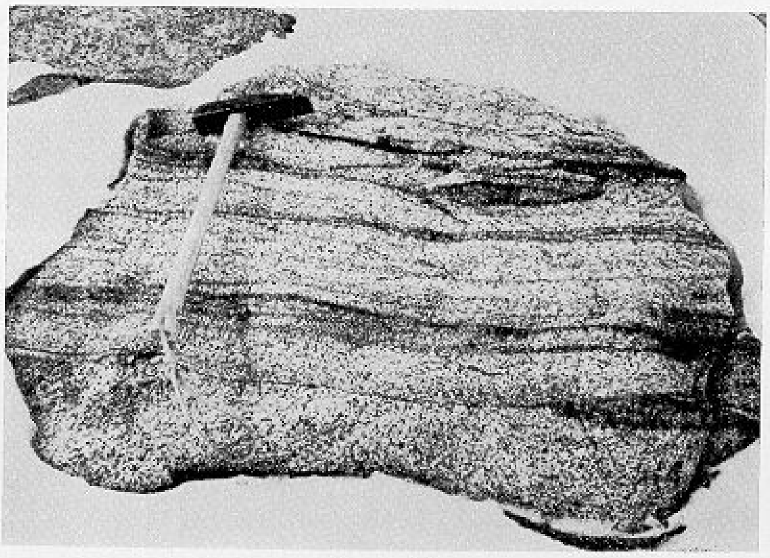


FIGURE 33
"Cross-bedded" layered granodiorite at station E.4483. The hammer shaft is 60 cm long.

5. *Adamellite*

Exposure of the adamellite pluton is limited to small scattered nunataks, their position indicating a large intrusion 10 km south of the Columbia Mountains. Other bodies are also present at the Laine Hills and on the northern arm of the Columbia Mountains; however, the extent of these is unknown. At station E.4485 there is a well-exposed contact with the metamorphic complex schists but there is little evidence of thermal metamorphism. Nearby, the country rock is cut by tenuous aplite veins and, at the actual contact, there is a pod of potash feldspar-pegmatite of the order of 1 m wide and unknown extent along the contact plane. This is a biotite-rich aplitic rock in which are set numerous pink branching potash feldspar phenocrysts up to 20 mm long (Fig. 34). At the same location, the adamellite contains euhedral corroded garnets (? spessartine) (Fig. 30d) and these are not uncommon in pegmatites associated with the later aplite intrusions.

In the hand specimen, the adamellite is found to vary in character between the three main intrusions noted above. South of the Columbia Mountains, on the eastern side of Richardson Glacier, the adamellite is a distinctive homogeneous non-foliated pink equigranular rock containing numerous xenoliths up to 0.7 m across. The northern Columbia Mountains adamellite is por-

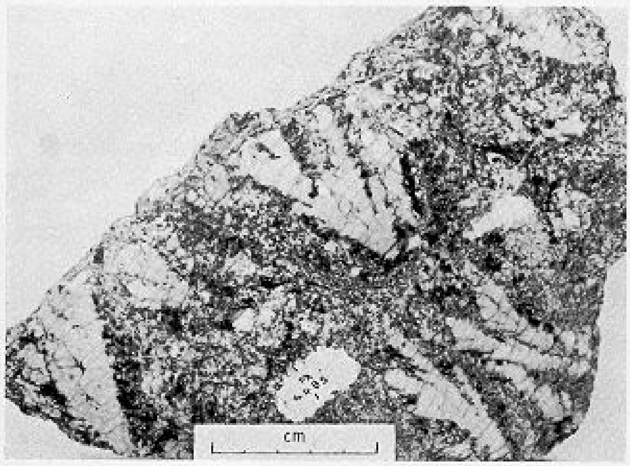


FIGURE 34
A hand specimen of a feldspar-pegmatite from station E.4485. The scale is in centimetres.

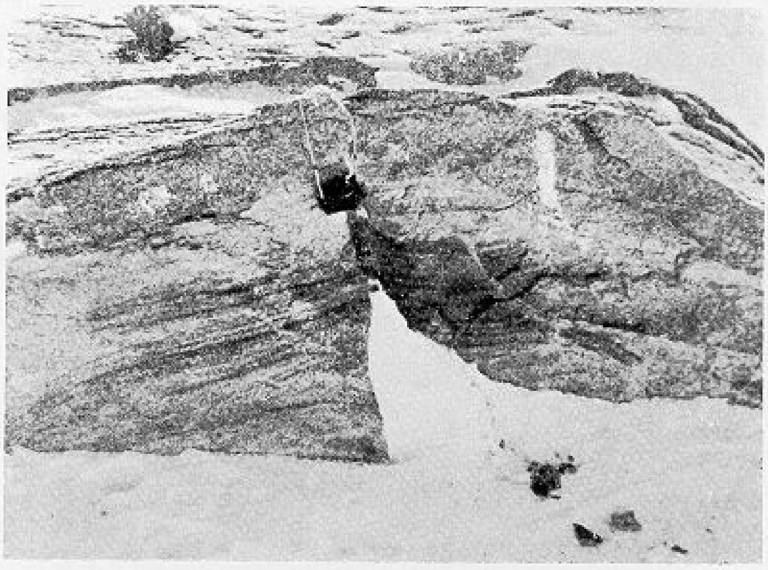


FIGURE 35
Layered adamellite in the northern Columbia Mountains (E.4402). The camera case is 18 cm wide.

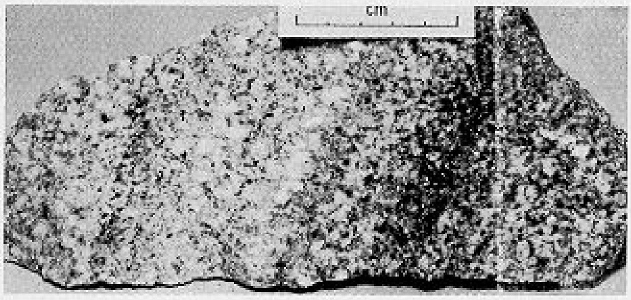


FIGURE 36
A hand specimen of a layered adamellite from station E.4402. The scale is in centimetres.

phyritic with large euhedral pink potash feldspars set in a coarse granodiorite matrix. It is possible, therefore, that this particular rock type does not represent a discrete intrusive body but is a potash-rich offshoot of the Columbia Mountains granodiorite which it greatly resembles. In common with the granodiorite, primary igneous layering is patchily developed (Figs 35 and 36) and diorite xenoliths are very common. The most southerly adamellite exposure at the Laine Hills is again a distinct type, being much finer-grained and equigranular. It contains metasomatized dioritic inclusions orientated parallel to a compositional layering which dips at 30° in a direction 260°.

Thin-section analysis of the extensive Richardson Glacier adamellite reveals a texture much akin to that of the granodiorite with a higher percentage of interstitial perthitic feldspar. The plagioclase is zoned and twinned oligoclase. Plates of muscovite, small euhedral green hornblendes and accessory minerals (magnetite and zircon) are associated with the knots of biotite.

In contrast, the potash feldspar of the porphyritic adamellite is a patchy microcline (up to 30 mm long) full of biotite and plagioclase inclusions. However, both rock types have an identical assemblage of mafic and accessory minerals (zircon, apatite, sphene and epidote), and the plagioclase composition is similar. The finer-grained adamellite at the head of Clifford Glacier appears to be similar to the equigranular type with interstitial perthite and rather indistinctly twinned oligoclase. Alteration of occasionally bent biotite to chlorite and epidote is common in this rock type and the plagioclase crystals are often veined by finely recrystallized quartz, indicating some deformation after emplacement.

6. *Aplite dykes*

These medium-grained quartz–potash feldspar dykes intrude all the Andean and pre-Andean rock types but they are clearly closely associated with the granodiorite and adamellite plutons which they most commonly invade. They range in size up to 1.0 m across and discontinuous pegmatitic cores are occasionally developed, with smoky quartz, large pink feldspar laths and books of biotite and muscovite. They are generally vertical or steeply dipping and have a variable trend with a north-west to south-east strike most common. It is probable, therefore, that they represent the final phase of Andean intrusive activity in this area, when residual potash-rich fluids were injected along fractures and lines of weakness in the cooling plutons. Trapped volatiles produced pegmatitic pockets along these dykes. Thus, although aplites occur in the surrounding country rock, these locations are all within a few kilometres of a granitic pluton. It is of interest to note that the aplites found intruding the metamorphic complex are slighly more quartz-rich than those within the plutons due to a loss of the potash phases.

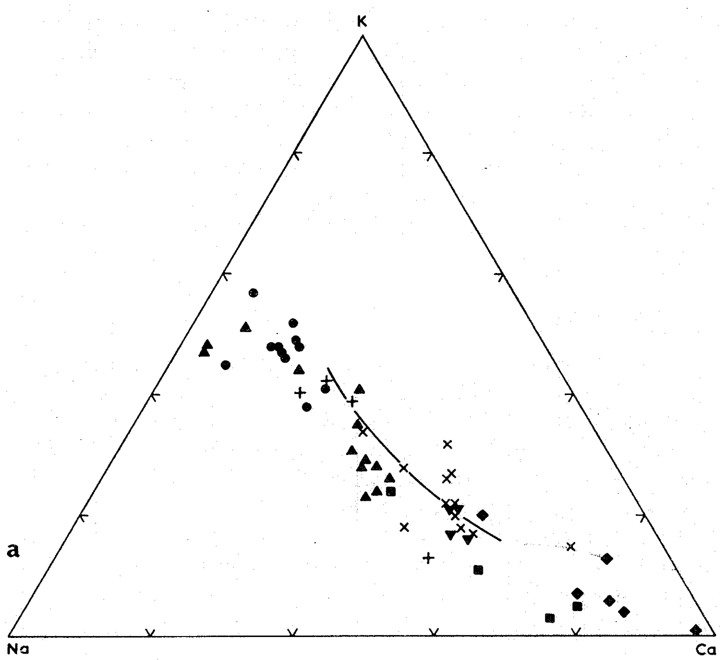
In the hand specimen, the aplite is a pink saccharoidal equigranular rock, occasionally showing signs of flow with swirls of muscovite or biotite crystals, the common mafic minerals. Up to 60% of the rock is composed of subhedral perthitic feldspar, which forms an interlocking network with the abundant granular quartz. This latter phase also occurs as sutured polycrystalline masses up to 1.0 mm across. Biotite and muscovite are intergranular and generally comprise less than 5% of the total rock. Accessory minerals include piedmontite, magnetite and chlorite (after biotite). Garnets (spessartine) are present in the quartzitic veins intruding a metatonalite (E.4436) and an amphibolite (E.4458). These veins may represent the distal equivalent of the aplites.

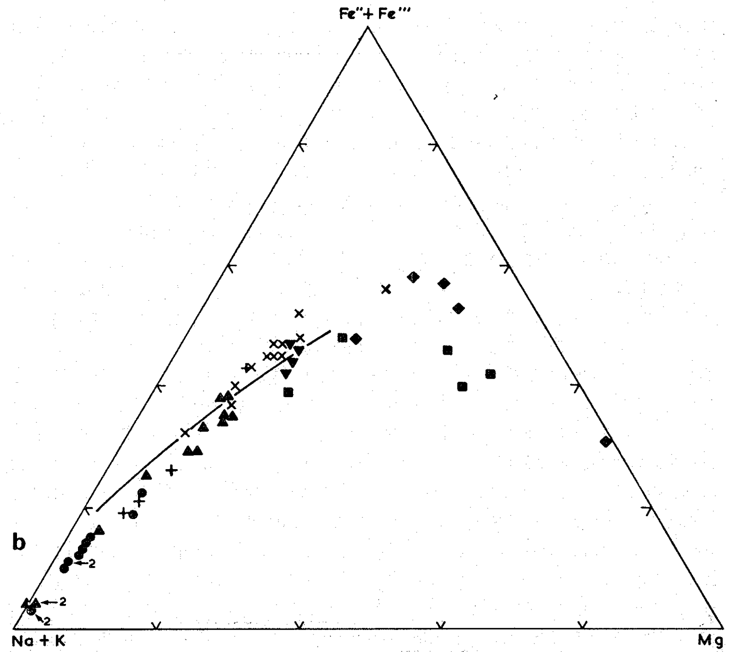
B. Geochemistry
(By P. D. Clarkson, B.Sc., Ph.D.)

New chemical analyses are presented for 42 rocks from the Andean Intrusive Suite and 12 metamorphosed intrusive rocks of (?) Palaeozoic age (Table III). The analyses are plotted together in all variation diagrams; major oxides (Fig. 37), trace elements (Fig. 38) and selected element ratios (Fig. 39) are plotted against the modified Larsen index (Nockolds and Allen, 1953), and additional plots are of Y_N against Ce_N/Y_N, Ca against Sr, and Rb against Sr (Fig. 39). In general, these graphs show the expected smooth trends of a fractionated sequence, although there is rather more scatter among the trace elements. It is interesting that the older meta-intrusive rocks frequently plot close to the rocks of the Andean Intrusive Suite, although they are noticeably depleted in Al_2O_3 and Na_2O, and in the plot of K_2O values they show markedly greater scatter. This may be due to alkali metasomatism which, while not specifically recorded in the present study, has been reported in "Basement Complex" rocks from adjacent areas in the central Black Coast (Singleton, 1980) and in northern Palmer Land (Davies, 1980).

In the triangular variation diagrams (Fig. 40a and b), the analyses plot sub-parallel to the trend of the Andean Intrusive Suite (Adie, 1955) but they are notably richer in Mg and Na. The older intrusive rocks are generally slightly iron- and potassium-rich compared with the Andean Intrusive Suite. The triangular diagram of normative feldspar composition (Fig. 40c) with fields modified after O'Connor (1965) demonstrates how the nomenclature for these rocks differs from that determined from modal analysis of the thin sections (Fig. 29).

For the purpose of the geochemical study, four intermediate rocks of possible hybrid origin were selected (Table III, analyses 41–44). Hybrid rocks have been described from the Andean Intrusive Suite by earlier workers (e.g. West, 1974) but Saunders and others (in press) have shown that hybridization is not a workable hypothesis in the Antarctic Peninsula, at least in the





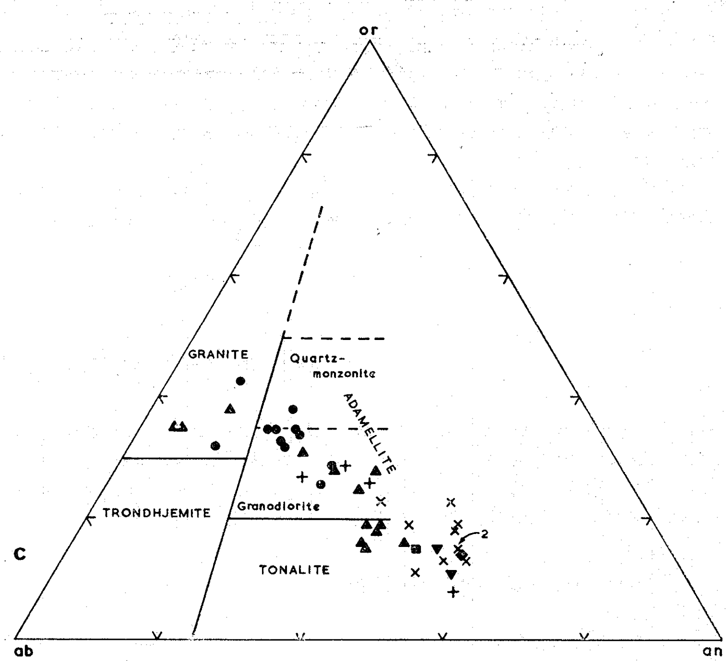


Figure 40

Triangular variation diagrams for analyses in Table III. Analyses 1 and 2 are plotted as a single mean value. Figures beside symbols indicate the number of analyses plotting as a single point. The symbols are the same as in Fig. 37.

a. Triangular variation diagram on the coordinates K–Ca–Na. The trend of the Andean granite–gabbro intrusive suite (Adie, 1955) is shown.
b. Triangular variation diagram on the coordinates Fe'' + Fe–Mg–(Na+K). The trend of the Andean granite-gabbro intrusive suite (Adie, 1955) is shown.
c. Triangular variation diagram on the coordinates or–an–ab. The petrological fields are after O'Connor (1965).

general case. Zr and Ba values should indicate whether or not the rocks could have hybrid origins. Three of the four rocks considered here do have Zr and Ba values comparable to those of more acid and more basic members of the suite but only one of these (E.4496.2) is markedly lower and the fourth one

(E.4494.1) is considerably higher. This would suggest that hybridization is possible for the rocks with the lowest Zr and Ba values but that it is an unlikely origin for the remainder. However, the presence of numerous xenoliths in these rocks may indicate a degree of contamination by pre-existing diorite, gabbro and amphibolite. Thus it would seem that hybridization is unlikely in the general case, as suggested by Saunders and others (in press), but that it cannot be discounted entirely.

The close chemical similarity between the older intrusive rocks and those of the Andean Intrusive Suite suggests either a previous episode of subduction or, more likely, an early phase of the main period of subduction along the western margin of the Antarctic Peninsula. Older calc-alkaline plutonic rocks have also been described from other parts of Palmer Land, e.g. from the central Black Coast area (Singleton, 1980) and from the Engel Peaks area (Davies, 1980). Smellie and Clarkson (1975) described glaucophane-schists from Smith Island, South Shetland Islands, as evidence of pre-Jurassic subduction along the north-western margin of the Antarctic Peninsula, and similar low-temperature–high-pressure mineral assemblages have been reported from the LeMay Formation in Alexander Island (Edwards, in press). Smellie (in press) has further recognized a complete arc–trench system in the Gondwana sequences of the Antarctic Peninsula. Therefore, it seems likely that the Antarctic Peninsula formed part of the Pacific margin of the ancient super-continent of Gondwana prior to its fragmentation, although its exact position in any Gondwana reconstruction is uncertain (e.g. Ford, 1972, fig. 3).

The plutonic rocks of the Andean Intrusive Suite follow closely the calc-alkaline trends noted for similar rocks in other parts of the Antarctic Peninsula. Saunders and others (in press) analysed a large number of rocks from Graham Land to determine the "pattern of Antarctic Peninsula plutonism". They made a broad distinction between east coast and west coast plutons, principally by the potash content of the rocks. By this criterion, the rocks of north-eastern Palmer Land conform to the east coast type of intrusions, i.e. relatively richer in potash and, less conclusively, in Rb and Th. The few chemical analyses available for plutonic and hypabyssal rocks from Rothschild Island (Care, 1980), at approximately the same latitude as north-eastern Palmer Land, show slightly lower values for K_2O, Rb and Th at given silical values in most cases, implying general conformity to the east coast–west coast pattern. Dating studies have shown that in Graham Land the focus of magmatic activity migrated trenchward (westward) with time (Saunders and others, in press, fig. 1). Jakes and White (1969) have demonstrated that in some areas the potash content may increase with time so that, if the pattern of plutonism in Graham Land holds true for Palmer Land, the slight differences in potash content between north-eastern Palmer Land and Rothschild Island may be time-dependent, at least in part, although Care (1980) suggested that they may reflect an increased depth to the Benioff Zone, the "K-h variation" (Dickinson, 1975). However, as subduction beneath the Antarctic Peninsula ceased progressively northward, it would be expected that potash values should increase northward; this does not appear to be the case but the absolute ages are not known for any of the plutons in Rothschild Island or Palmer Land. Radiometric and chemical data for the plutonic rocks of the southern Antarctic Peninsula are badly needed to clarify the situation.

VII. POST-ANDEAN HYPABYSSAL ROCKS

WITH the exception of the meladiorite, these are fresh-textured medium- to fine-grained dyke rocks intruding the metamorphic complex and later intrusive rocks. Five types have been recognized (arranged tentatively from oldest to youngest):

1. Meladiorite.
2. Micro-adamellite/granodiorite.
3. Basalt.
4. Microdiorite.
5. Andesite.

The meladiorite and micro-adamellite/granodiorite may represent an early period of dyke intrusion, possibly part of the Andean episode as the former was found to intrude only metamorphic complex rocks and the latter metamorphic complex and altered gabbro. In addition, at station E.4688, a micro-adamellite dyke is cut by a microdiorite dyke. However, these early dykes conform to the general north-west to south-east trend of the later dykes and the lack of exposure may explain their apparent restriction to lower stratigraphical levels. For these reasons, they are included in this post-Andean group of rocks.

The fairly constant trend of all these dykes and the earlier aplites corresponds to a set of master joints which affects all the pre-Tertiary massive rocks (Fig. 41). These joints are often coated with epidote and show signs of movement with slickensiding and offset (by up to 0.5 m) of minor structures. At station E.4496, a narrow basalt dyke is controlled by two joint sets (Fig. 42), one trending approximately north-west to south-east and the other north to south. This latter joint set appears to control the emplacement of a basalt dyke at station E.4668 and a micro-adamellite dyke at station E.4688. Thus, emplacement of the hypabyssal rocks was largely controlled by pre-existing lines of structural weakness. Deformation of some of these dykes reveals that movement along the joint planes continued after their intrusion and was accompanied by the introduction of epidote and calcite.

1. *Meladiorite*

Both exposures of this show intrusion into metamorphic complex gneisses and, at station E.4418, also into a meladiorite (appinite) body. They attain a width of 2 m but more commonly 0.5–1.0 m and chilled margins appear to be absent. The rock is medium- to coarse-grained with needles of hornblende set in a mesocratic equigranular groundmass.

In thin section, the rock has an altered appearance (explaining the lack of chilled margins) with granulated crystal boundaries and crushed mafic minerals. Subhedral green hornblende comprises at least 40% of the rock, and most of the remainder is lath-shaped plagioclase (An_{45}), occasionally zoned. Common

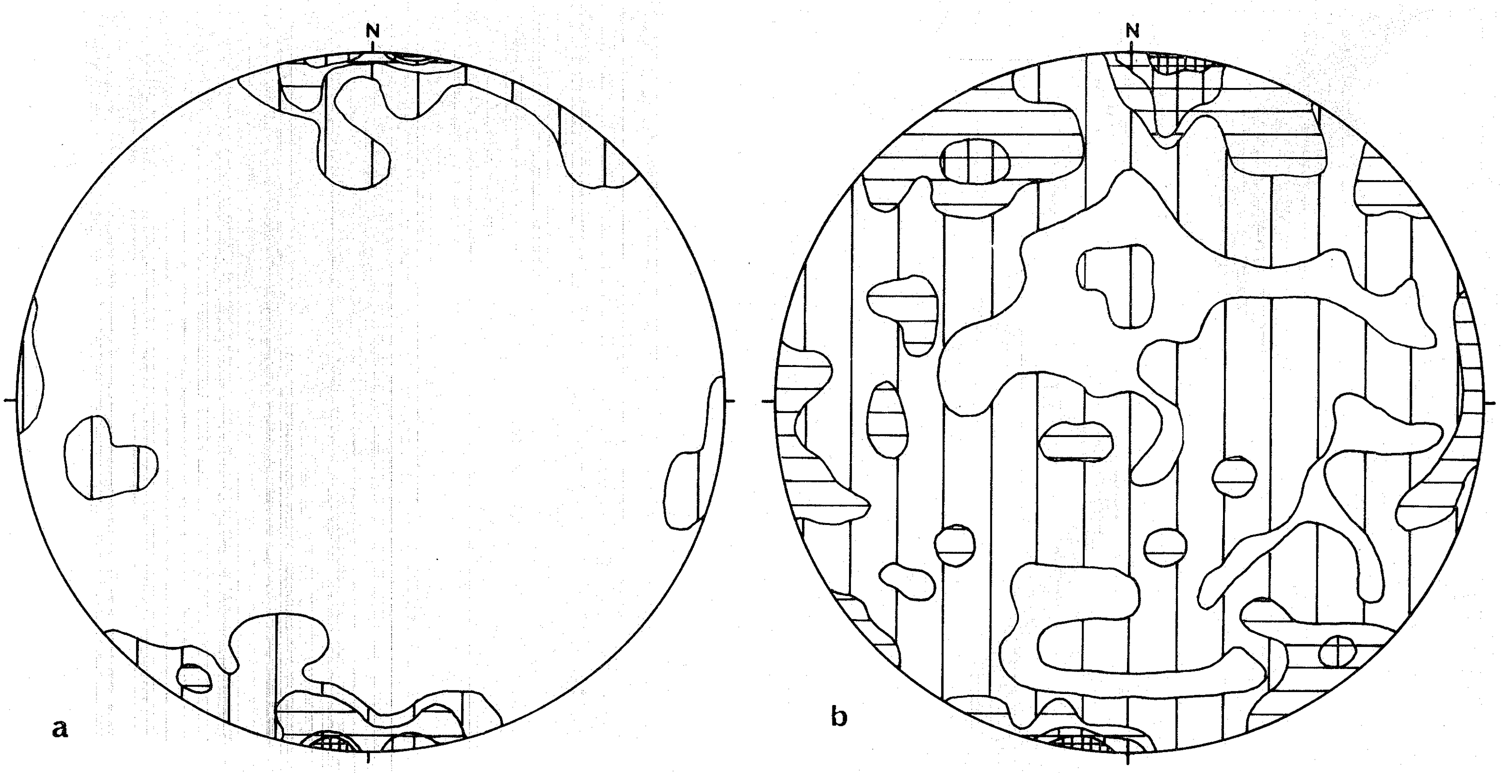


FIGURE 41

a. Stereogram (19 points) of poles to plane of post-Andean dyke intrusion plotted on the lower hemisphere. The contours are at intervals of 15.75, 10.5 and 5.25% per 1% area.

b. Stereogram (138 points) of poles to major joints plotted on the lower hemisphere. The contours are at intervals of 4.5, 3.0 and 1.5% per 1% area.

Comparison of the two diagrams illustrates the control of intrusion by jointing.

accessory minerals include ragged quartz crystals up to 1.5 mm across and small biotite flakes, often occurring with plagioclase as inclusions in the skeletal hornblende. Strings of epidote (pistacite) and hornblende granules define a rough foliation which transects the subhedral hornblende. These strings are intergranular to the quartz and feldspar, indicating that deformation was accompanied by partial recrystallization of the latter two phases.

2. *Micro-adamellite/granodiorite*

A 1.2 m wide microgranodiorite dyke is exposed at station E.4456 where it intrudes metamorphic complex gneisses. It is a medium- to fine-grained grey porphyritic rock containing scattered euhedral feldspar phenocrysts in a leucocratic groundmass. In thin section, these phenocrysts can be seen to be zoned with a Na-rich rim and a composition in the labradorite range. The groundmass plagioclase is oligoclase, associated with rounded patches of myrmekite. The quartz is anhedral, forming sutured polycrystalline masses up to 1.0 mm across. Small amounts of biotite and muscovite are interstitial and reveal a patchy flow foliation.

The micro-adamellite dyke at station E.4688 is 1.5 m wide and heavily epidotized at the contact with the country rock, an altered gabbro. The zone of epidotization spreads from the contact into the gabbro, a distance of several metres, but the dyke is relatively unaffected. This dyke pinches out within 16 m but the plane of intrusion continues as an epidote-filled fracture.

Quartz, potash feldspar (perthite) and plagioclase (andesine) form the bulk of the rock in the proportions 1 : 2 : 2, respectively. Perthite and quartz are interstitial to subhedral zoned plagioclase and some granulation is evident. Accessory intergranular mafic minerals are abundant, including green hornblende, sphene, magnetite, apatite, allanite and chlorite.

3. *Basalt*

These dykes attain a width of at least 1 m, although they are usually less than half that, often occurring as mere veins up to 40 mm wide, rigidly controlled by the joint system (Fig. 43). They are porphyritic with chilled margins and mafic minerals commonly altered to chlorite and epidote in a groundmass which is turbid with iron ore specks. However, olivine-, augite- and hornblende-basalts have been identified. All contain a high proportion (up to 20%) of calcite as large cleaved blebs and finely divided material.

Where olivine is present, alteration to chlorite, serpentine and iddingsite has taken place. Lamprobolite is also a minor constituent of the olivine-basalts, associated with augite and set in a fine-grained groundmass. The augite-basalts are characterized by a spotted altered groundmass, containing euhedral augites altered to penninite and epidote. No such alteration is present in the hornblende-rich varieties and euhedral brown hornblendes reach 3 mm in length. The phenocrysts in all these rock types are aligned approximately parallel to the contacts, indicating flow.

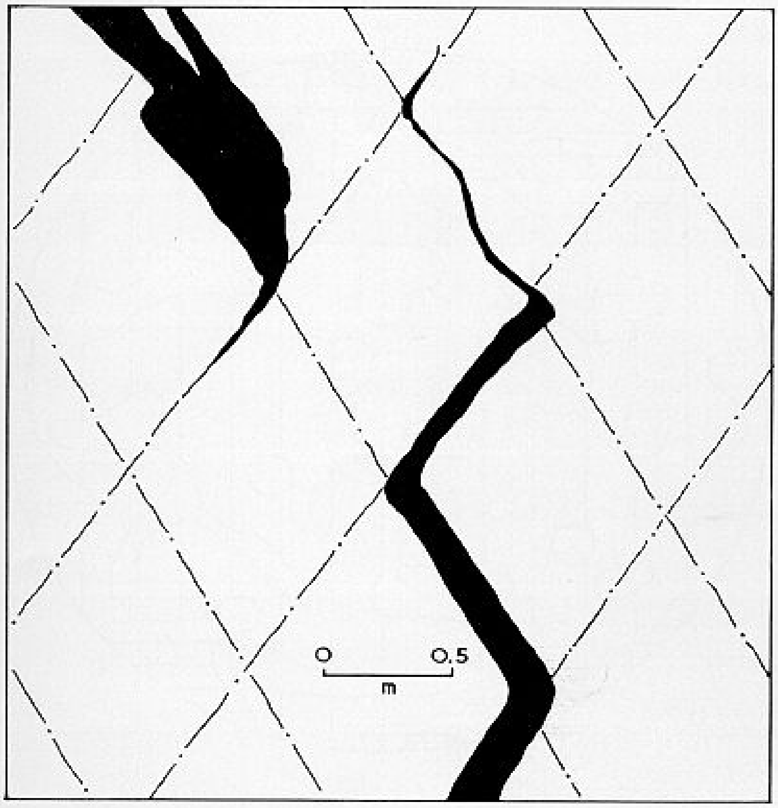


FIGURE 42
Field sketch of a narrow joint-controlled basalt dyke intruding an Andean adamellite.

FIGURE 43
Joint-controlled vein-like basalt dyke intruding metagranodiorite at Hall Ridge (E.4668). The hammer shaft is graduated in 5 cm units.

4. *Microdiorite*

Only two exposures of this rock type were located; at station E.4688 it intrudes both a gabbro and a micro-adamellite dyke. The latter is offset 0.5 m by several well-defined movement planes and the 1.0 m thick microdiorite dyke trends approximately parallel to these. Chilled margins are very well developed at station E.4457, where several of these dykes intrude an adamellite and attain a maximum width of 4.0 m.

In the hand specimen, the rock is equigranular and medium-grained with recognizable black biotite and hornblende crystals in a groundmass of plagioclase and scattered quartz. The mafic minerals display a strong dimensional preferred orientation parallel to the dyke margins. In thin section, a decussate texture is dominant with intergranular biotite and brown hornblende in an interlocking mass of andesine and occasional quartz blebs. Up to 50% of the rock is composed of irregular fields of chlorite and calcite, replacing both the mafic and leucocratic minerals. Epidote is also present as an accessory mineral.

5. *Andesite*

In common with all the Tertiary dyke rocks, these have a widespread distribution, intruding metamorphic complex gneisses and schists, and an Andean tonalite. Chilled margins are well developed and dykes up to 3 m wide were measured. Again, intrusion along a previously established joint system is indicated and a west-north-west to east-south-east trend is consistent over a wide area.

It is a fine-grained grey porphyritic rock containing small chloritic phenocrysts. In thin section, these are found to be augite crystals and a brown amphibole (? lamprobolite). They are set in an intersertal matrix of sericitized plagioclase, amphibole and scattered quartz. Calcite and chlorite are important secondary minerals replacing up to 60% of the rock. Scattered grains of epidote are accessory.

VIII. TERTIARY BLOCK FAULTING AND RELATED EARTH MOVEMENTS

THE paucity of exposure in this area, coupled with the masking of pre-glacial terrain by a thick cover of ice, has allowed little evidence of faulting to be discerned. It appears that at least three major periods of faulting occurred, the first associated with the F_1 and F_2 episodes, affecting Palaeozoic rocks. It is known that the contact between the Palaeozoic intrusive rocks and the metamorphic complex is faulted and the basic dykes of the swarm intruding the *ortho*- and *para*gneisses are sheared out and disrupted by movements accompanying their metamorphism.

Further deformation occurred after the emplacement of the Andean gabbros, amphibolites and diorites with accompanying recrystallization. It is also probable that the emplacement of the later acid plutons was accompanied by faulting and stoping of the basic plutons and overlying country rocks. Finally, Tertiary block faulting produced the basis for the land forms that are present today (Linton, 1964), although physiographical features expressing these movements are less well developed here than to the north and west. The presence of the offshore islands, the north–south-trending linear depression separating Eielson Peninsula from the hinterland and the plateau-edge ranges are believed to be largely fault-controlled. Unfortunately, geological evidence for block faulting is lacking, although the structural and lithological fabric of Palmer Land closely follows the trend of these faults. In addition, disruption of structures such as metamorphic and primary igneous foliation indicate widespread Tertiary faulting.

However, minor earth movements are well recorded and a late-stage shearing affects all Andean and pre-Andean rocks. This shearing probably accompanied Tertiary dyke intrusion and widespread epidotization.

IX. SUMMARY AND CONCLUSIONS

THE area immediately to the north and south of Clifford Glacier is heavily glaciated and mountainous, bounded to the west by a plateau ice cap and to the east by the Larsen Ice Shelf and the Weddell Sea.

The oldest rocks exposed in this area are assigned to the (?) Palaeozoic metamorphic complex, a group of *ortho*- and *para*gneisses intruded by an ancient basic dyke swarm. This appears to be overlain by a sequence of quartz-mica-schists (originally sediments), the youngest rocks of the metamorphic complex. Both groups are intruded by an acid intrusive phase, the Palaeozoic intrusive rocks, and this entire assemblage has been metamorphosed under a low-pressure moderate-temperature regime. Late Palaeozoic F_1 folding took place about a north–south axis (the other main factor controlling topographic linearity) and this was followed by a period of minor F_2 folding about a sub-parallel axis. This pattern was disturbed by the emplacement of the Andean plutons.

The sole exposure of the Upper Jurassic volcanic rocks occurs at Daniels Hill on the plateau edge. More widely exposed are the Cretaceous to early Tertiary rocks of the Andean Intrusive Suite. Their field occurrence and lithology suggest that the first plutons emplaced were basic in character and comprised gabbros, meladiorites and appinites. These rocks are much altered and apparently thrust aside and disrupted by the emplacement of progressively potash-enriched acid rocks, the tonalites, granodiorites and adamellites. The resulting outcrop pattern is therefore approximately concentric with an adamellitic and granodioritic core surrounded by a discontinuous shell of altered basic rocks. The final stages of this episode were accompanied by the intrusion of aplites and pegmatites into the cooling plutons and country rock.

The development of a major joint system evidently occurred prior to the intrusion of the late Tertiary dyke rocks as emplacement is clearly joint controlled. Field relations have enabled a tentative sub-division into an early acid phase (micro-adamellite) followed by a dominant intermediate to basic phase (andesite, microdiorite and basalt). These manifestations of Tertiary crustal tension are part of the same event that resulted in widespread block faulting, which is continuous with the horst-and-graben features more clearly represented to the north around Cape Keeler. It is hoped that future geophysical surveys will clarify this picture in an area where rock exposure is too sparse or inaccessible to enable a more detailed unambiguous structural pattern to be determined.

X. ACKNOWLEDGEMENTS

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