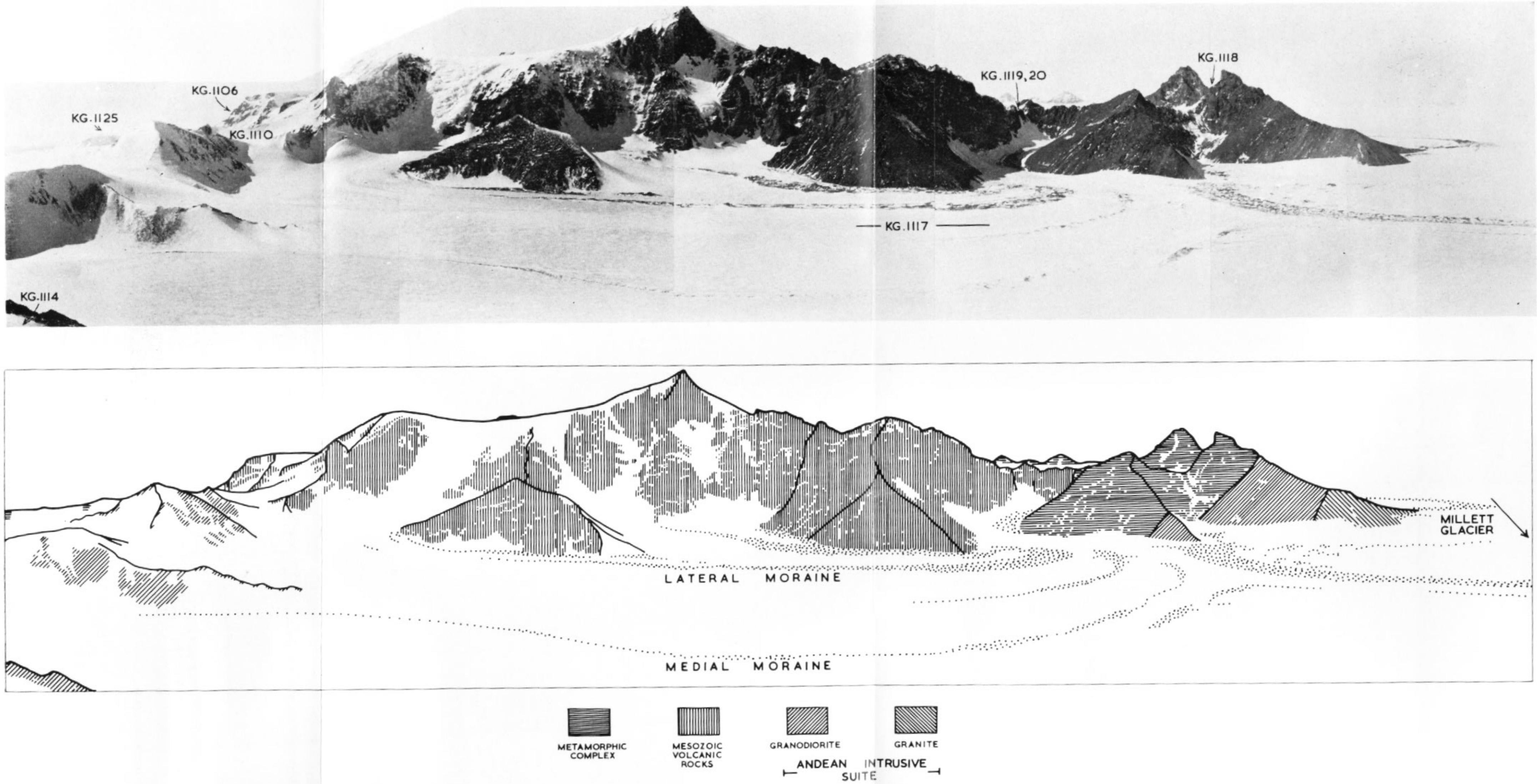


Fig. 3. Panorama at station KG.1114 looking east. All of the main rock types of this area are exposed here, each displaying characteristic topography. Ronne descended from the plateau east of station KG.1125 and camped near the nunatak beside station KG.1110 (cf. Fig. 2 and Ronne (1945, fig. 3)).

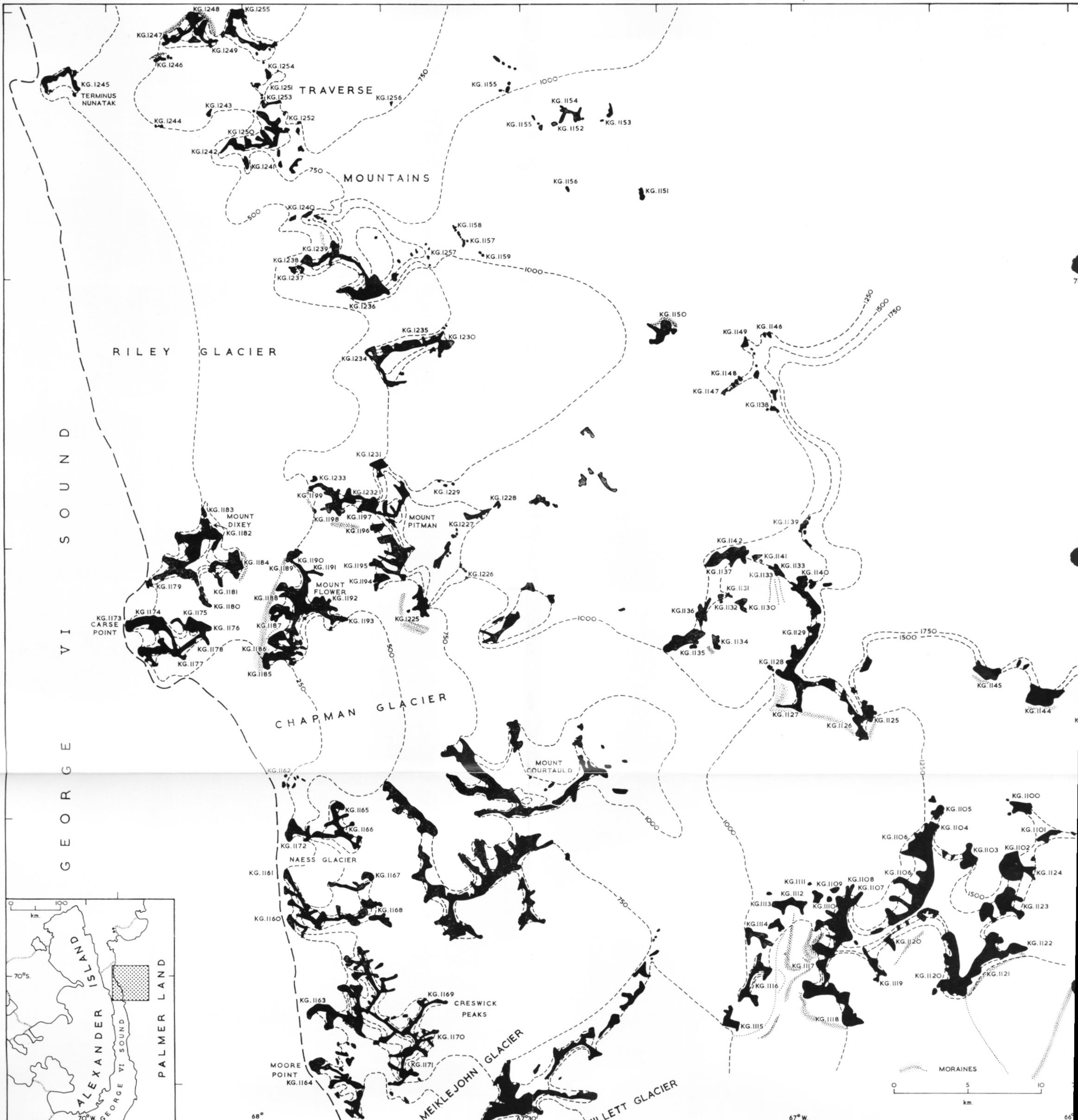


Fig. 1. Topographical map of the area between Eureka and Meiklejohn Glaciers, western Palmer Land. Form lines are at 250 m. intervals and the rock outcrops are shown in black. The positions of geological stations are also indicated.

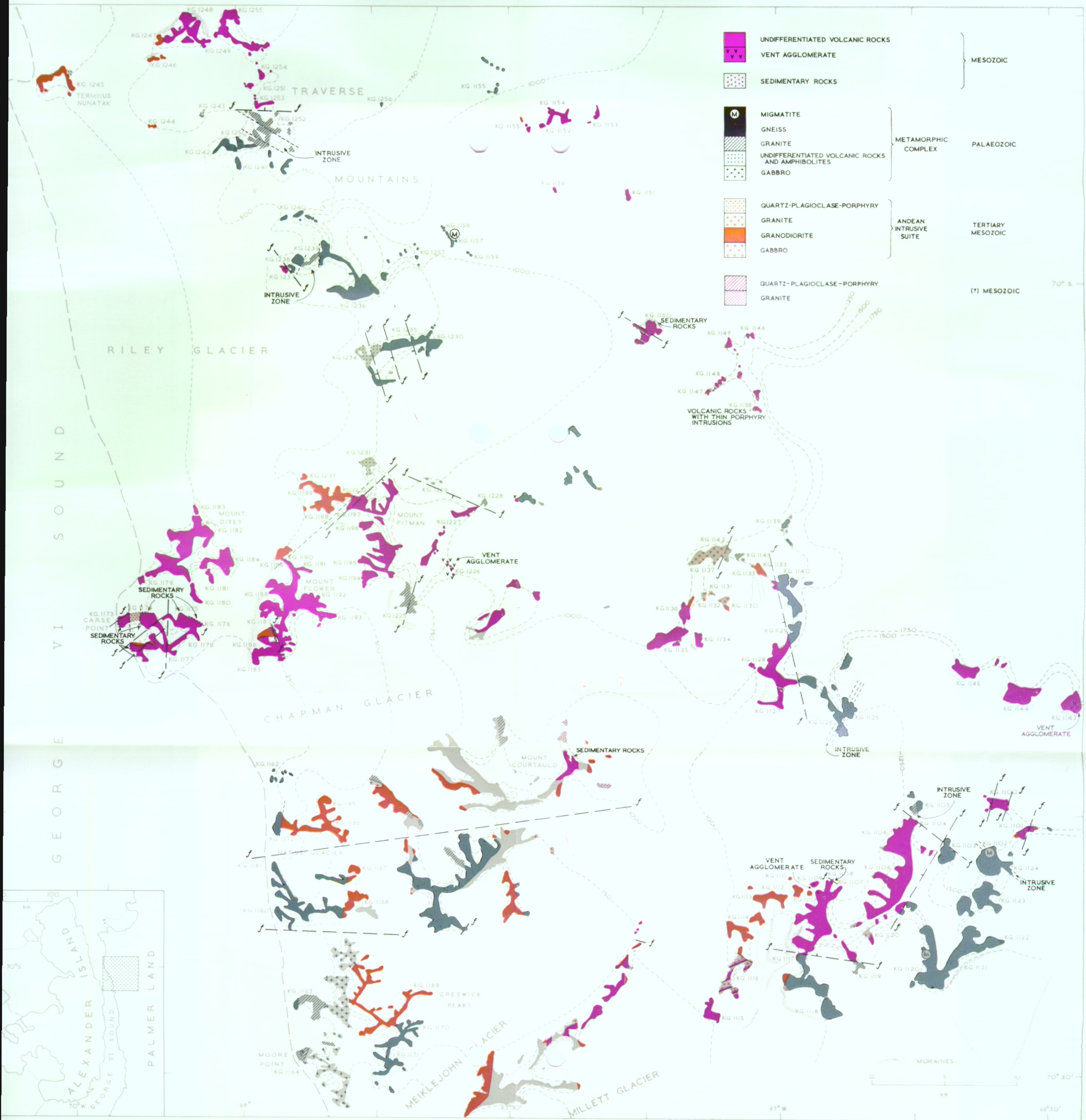


Fig. 2. Geological sketch map of the area between Eureka and Meiklejohn Glaciers, western Palmer Land.

GEOLOGY OF NORTH-WESTERN PALMER LAND BETWEEN EUREKA AND MEIKLEJOHN GLACIERS

By A. C. SKINNER

ABSTRACT. The general geology of part of north-western Palmer Land is described. The oldest and most deformed rocks are those belonging to the Metamorphic Complex. Younger sedimentary and volcanic rocks lie unconformably on the Metamorphic Complex and they are intruded by granodiorite batholiths and minor basic and acid intrusions. Block faulting is largely responsible for the present-day distribution of the rock types. No folding is evident in rocks younger than the Metamorphic Complex.

THE area described here is situated between lat. 69°35′ and 70°35′S., and long. 66°25′ and 68°30′W. It is bounded by Eureka and Meiklejohn Glaciers, George VI Sound and an undulating plateau 75 km. to the east (Fig. 1).

The physiography of this area has been described by Skinner and Smith (in press). It is a deeply dissected and glaciated plateau which drains westward via broad glaciers and narrow defiles into George VI Sound. The western edge of the plateau is defined by a line of ice-capped rocky cliffs, ice falls and gentle snow-covered gradients.

The initial geological work in this part of Palmer Land was described by Knowles (1945), who used geological observations made by Eklund (Ronne, 1945). Knowles stated that "A buff-coloured hornfels outcrops in massive sharp peaks in lat. 70°25′S., long. 67°15′W." Evidence from a plot of Ronne's journey, together with photographic identification, indicates that this specimen was collected near station KG.1110 (Figs. 1 and 3).

Adie (1954) indicated that Basement Complex rocks were present in the vicinity of the hornfels described by Knowles and that diorite occurred on the east coast of George VI Sound immediately south of Meiklejohn Glacier (Adie, 1955).

Reconnaissance geological mapping of western Palmer Land re-commenced in 1963 and 1964 when R. R. Horne, J. F. Pagella and M. E. Ayling mapped part of the Batterbee Mountains and areas farther east and north (Ayling, 1966). C. G. Smith later mapped from Gurney Point north-eastward to the plateau edge at lat. 70°20′S. and also coastal exposures of George VI Sound from Wade Point to Carse Point (Smith, in press).

In the summer season of 1969–70, P. J. Rowe and the author commenced mapping on the Palmer Land plateau. Rowe mapped the hinterland of George VI Sound between Bertram and Chapman Glaciers as far east as the sub-plateau (Skinner and Smith, in press), while the author mapped the plateau-edge exposures from lat. 70°20′S. northward to Eureka Glacier at lat. 69°50′S. In the following year, the author completed the reconnaissance mapping from lat. 70°30′ to 69°50′S., while T. G. Davies mapped the remaining areas of north-western Palmer Land. The fossiliferous sedimentary rocks at Carse Point were examined in detail by Culshaw (in press).

Figs. 1 and 2 show the topography and geology of the area described in this paper together with the overlap and continuation from previous surveys.

The stratigraphy of this area is outlined in Table I. Field relationships are generally well exposed and the pattern of events can be readily established. Fossils from the sedimentary rocks underlying the volcanic rocks have been dated as Upper Jurassic and thus the whole succession can be related to events already described from the Antarctic Peninsula (Adie, 1964*a*). A varied volcanic succession was established within this area and Table II gives more detail of this succession.

METAMORPHIC COMPLEX

Exposures of regionally metamorphosed rocks are widespread in the Antarctic Peninsula and have been termed "Basement Complex" by Adie (1954), who at that time assigned an (?) Archaean age to them. However, the only rocks in this whole region which have so far been assigned a pre-Cambrian age are those exposed on Clarence Island (Iltchenko, 1971).

TABLE I. GENERAL STRATIGRAPHICAL SUCCESSION IN NORTH-WESTERN PALMER LAND

Age	*Rock group*	*Rock types*
Recent	Moraines	
Tertiary		Dolerite dykes
	Hypabyssal intrusive rocks	Microdiorite dykes
	Andean Intrusive Suite	Quartz-plagioclase-porphyry
		Granite
Mesozoic		Granodiorite
	Extrusive rocks	Lavas
		Tuffs
		Agglomerates
	Sedimentary rocks	Siltstones
		Sandstones
Palaeozoic	Hypabyssal intrusive rocks	Basic dykes
		Basic sills
	Metamorphic Complex	Granite
		Gabbro
		Amphibolitic basic rocks
		Migmatites
		Gneisses

Although the metamorphic rocks are undoubtedly amongst some of the oldest known in the Antarctic Peninsula, they are unlikely to be older than the Middle Palaeozoic, as ages greater than this have not been recorded so far. It is also unlikely that pre-Middle Palaeozoic age determinations have been completely masked by later metamorphisms because this does not occur in other metamorphic terrains (Stockwell and others, 1970; Moorbath and Park, 1972).

The Metamorphic Complex is believed to represent the roots of a geosyncline now occupied by the Antarctic Peninsula and Andean Cordillera. The Palaeozoic volcanic and intrusive rocks (Adie, 1954, 1971) indicate that the geosyncline was subjected to contemporaneous volcanicity and synkinematic intrusion prior to its final infilling with the sedimentary rocks of the Trinity Peninsula Series. Within the complex are intermixed basic and acid igneous rocks, possibly intruded into sedimentary rocks, and the whole was subsequently metamorphosed to form gneisses and migmatites. Granite intruded the gneisses and migmatites to give *lit-par-lit* injection phenomena, and the earlier basic volcanic rocks now appear as amphibolites and metabasalts sometimes veined by the granite. Some of the more micaceous gneisses with well-defined banding are probably *para*gneisses.

The main rock types recognizable within the complex are: granite, gabbro, metavolcanic rock, migmatite and gneiss. Of these, the granite is the youngest.

Gneiss

Gneiss is the commonest rock type in the Metamorphic Complex and it is exposed in the Creswick Peaks area (KG.1160–1163), on the eastern side of the massif east of Mount Courtauld (KG.1120–1124 area) and in the southern Traverse Mountains (KG.1230, 1159 and 1257).

The gneisses can be readily subdivided into two types: massive *ortho*gneiss and banded gneiss, probably containing both *ortho-* and *para*gneiss. *Lit-par-lit* intrusion is common in the banded gneisses but only occasional veins cut the massive gneisses.

The massive *ortho*gneisses are foliated granite-, granodiorite- and diorite-gneisses, which still retain their igneous appearance though it is slightly modified by foliation bands. In thin section (Fig. 6a–c), the characteristic igneous mineralogy and texture are still evident but metamorphic features are also present. The oscillatory zoned, albite- and pericline-twinned plagioclase frequently has a recrystallized margin and deformation of the twin lamellae. Myrmekite is commonly developed, granular mosaics of quartz and feldspar are apparent, and there is alignment of the ferromagnesian minerals along the foliation planes of the rock. Xenoliths are relatively rare in the *ortho*gneisses but a study of the migmatites (p. 4–5) indicates that all of these gneisses could possibly have had the same parent, minor compositional differences arising from differentiation and hybridization with the country rock.

The banded gneisses (Fig. 4) are variable in composition, medium- to fine-grained in texture and have a variable band thickness (1 cm. to 1 m.). *Lit-par-lit* intrusion of granite produces pink bands but there is little mixing of this granite with the gneiss. Slight foliation along marginal planes is apparent and there is a concentration of dark minerals in the gneiss at the contact in some cases. Biotite- and hornblende-gneisses are the common types. Amphibolite lenses and sheared-out amphibolite dykes are present and probably belong to an early dyke phase disturbed during one of the movement phases affecting the Metamorphic Complex.

The gneiss bands are foliated on a much smaller scale than in the massive gneisses, and thin sections show bands of orientated and interlocking hornblende and biotite laths alternating with quartz-orthoclase-plagioclase mosaics. Here the igneous texture is virtually obliterated but the zoning of the plagioclase and deformation of the twin lamellae continue to indicate an

Fig. 4. Banded gneiss at station KG.1159. The depot cairn is 1 m. high.

igneous origin. The plagioclase displays albite, Carlsbad/albite and pericline twinning, and where a composition can be determined it is in the andesine (An_{33-45}) range. Original (igneous) plagioclase crystals also show much saussuritization and sericitization, especially in their cores. Quartz and orthoclase both appear as fractured, inclusion-filled or clear crystals indicating progressive metamorphism and subsequent recrystallization. The "clean" crystals are invariably found in the mosaic areas.

The metamorphic grade of the gneisses cannot be determined with accuracy because of the absence of distinctive metamorphic minerals. At station KG.1102, a narrow granite vein cutting diorite-gneiss contains a brown garnet which gives an indication that the metamorphism at least reached the *almandine-amphibolite facies* of regional metamorphism.

Migmatite

Flow-folded and banded metamorphic rocks, frequently containing zones of brecciated country rock, occur at stations KG.1120, 1158 and 1236 (Fig. 5). These rocks are similar to the various types of massive and banded gneisses but here there is less homogeneity and processes of assimilation, hybridization and differentiation can be observed. In all cases, it appears to be an acid magma which disturbs a basic rock type. This basic rock now appears

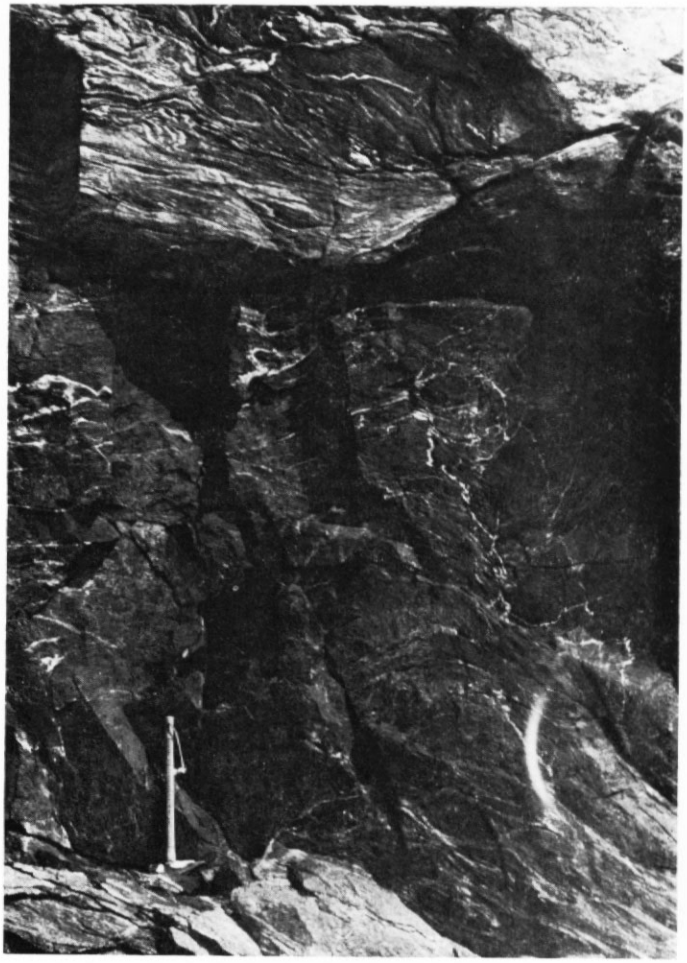


Fig. 5. Migmatite-gneiss at station KG.1157. The hammer shaft is graduated in 1 cm. intervals.

as amphibolite lenses and xenoliths when they are least altered, and as gabbro where maximum differentiation has occurred. As the later granite is to some extent involved with the migmatite, it is possible that many of the xenoliths are of the metavolcanic rocks. It is also possible that some of the basic material is sedimentary in origin and that some also belongs to earlier hypabyssal and plutonic intrusions.

The migmatites are mixed rocks with a mineralogy corresponding to their individual counterparts in the earlier gneisses. The banding is always irregular, occasionally with the development of some augen. Microcline and myrmekite are commonly present together with relict oscillatory zoned and albite-twinned plagioclase of oligoclase or andesine composition. Hornblende, biotite and chlorite are the common ferromagnesian minerals and pyroxene is occasionally present. In the relatively unaltered xenoliths, hornblende and andesine are the dominant minerals, but when assimilation has taken place a concentration of hornblende occurs in the xenolith and a hornblende-gabbro is formed. This gabbro is similar in texture and appearance to the uralitized gabbro described from the Moore Point area (p. 6). Many of the dioritic gneiss patches in the migmatite are believed to have formed through complete assimilation and re-distribution of xenolithic material.

The acid parent of the migmatite is of a granite or granodiorite composition as indicated by the relatively unaltered magmatic parts in the gneiss. Some of the foliated *ortho*gneisses are probably intimately connected with the migmatite zones.

Metavolcanic rocks

In areas where gneisses and migmatites occur schistose metavolcanic rocks are not uncommon. At stations KG.1231, 1234 and 1236, this rock type is well displayed and is associated with later granite. In outcrop it is black in colour with no flow banding apparent though many fractures and a schistose foliation are present. Narrow granite intrusions vein the complex and occasionally brecciation of the volcanic rock occurs. It is possible that some of the migmatite's basic xenolith content is formed by dislodged and assimilated or partially assimilated metavolcanic blocks. There is much shearing and fracturing, mainly in iron-stained zones orientated 100–165° mag. in strike and vertical. Lensoid acid rock is sometimes included in the metavolcanic rocks, and at station KG.1250 the granite intrudes the metavolcanic rocks to such an extent that it appears the metavolcanics are, in fact, later basic dykes.

It is thought that these rocks belong to the pre-Jurassic volcanic suite described by Fraser and Grimley (1972) from the Kenyon Peninsula area.

In the hand specimen the volcanic rock is fine-grained, sometimes porphyritic and invariably foliated. Frequent white feldspathic veins and lenses, green and black epidote veins and crystals occur together with calcite and pyrite staining on weathered surfaces. Occasionally, the rock is thinly banded with lensed-out parts and a shiny brittle fracture.

Thin sections reveal widespread alteration and a marked foliation, all of which is indicated by elongated laths of brown biotite, green hornblende and chlorite. The fine-grained groundmass of feldspar and sericite also contains euhedral albite-twinned andesine crystals which disturb the schistosity.

The volcanic rock possibly contains fragments which are now indicated by the slightly anomalous occurrence of unorientated hornblende and chlorite "knots" in the matrix of the rocks and which do not seem to be the alteration products of a single mineral.

The lensoid inclusions are variable in size from 10 m. in diameter upwards. They are granitic or felsitic in composition with a fine-grained matrix of quartz, feldspar, muscovite and biotite containing rounded and fractured quartz crystals together with subhedral perthitic feldspar, possibly microcline, enclosing relict albite-twinned plagioclase crystals. Muscovite is common in alteration areas, and it is possible that these bodies are related to the granite intrusion which was later than or synchronous with the volcanicity.

Gabbro

The only gabbroic intrusion in this area occurs at Moore Point and Creswick Peaks. Xenoliths of gabbro present throughout the metamorphic rocks are either uprooted blocks of a previous intrusion or hybridization products within the complex. Blocks of gabbro at Moore Point (KG.1163 and 1164) are included in the granite which uparches it.

This gabbro has been examined by Smith (in press), who has considered that there are three types present: olivine-, hypersthene- and quartz-gabbro, all of which are derived from the same parental magma by crystal differentiation and subsequent modification by an acid magma.

A similar mechanism could produce gabbroic xenoliths during migmatization of the complex. Thus, the formation of the gabbro is believed to be contemporaneous with the migmatization and intrusion of the granite.

In the hand specimen, the gabbro is coarse-grained and dark in colour. Specimens from the contact or blocks included in the granite are occasionally greenish coloured with a suggestion of foliation.

The complete reaction series, olivine ⟶ orthopyroxene ⟶ clinopyroxene ⟶ amphibole ⟶ mica, can be seen in selected thin sections. In the olivine-gabbro, anhedral olivine and hypersthene show alteration to magnetite and clinopyroxene, and are associated with albite-, Carlsbad- and pericline-twinned bytownite (An_{92-84}) crystals. This plagioclase becomes more albitic (An_{80-74}) in the hypersthene-gabbro in which pigeonitic augite and brown hornblende are also present. By the time the quartz-gabbro end member is reached, the plagioclase, which in other sections is remarkably fresh, now contains much sericitic alteration in a central core (An_{60}) and is surrounded by a clear recrystallized (An_{32}) rim. This uralitization also involves the formation of green hornblende, biotite and chlorite together with interstitial quartz and orthoclase.

Primary and secondary magnetite with ilmenite are common in all of the gabbro types. Pyrite and haematite are occasionally present together with rare spinel in the more basic gabbro.

Granite

The granite is a homogeneous rock with few metamorphic features. It is the youngest rock type in the Metamorphic Complex; it intrudes the massive gneisses, forms bands in the banded gneisses and intermixes with the migmatites. It has also been observed as isolated outcrops, in intrusive contact with gabbro and as pebbles in the Mesozoic volcanic rocks. Within the complex, the metavolcanic rock is veined by offshoots of this granite and in some areas assimilation of basic rock has produced a dioritic gneiss.

The granite is white to pale pink in colour with a holocrystalline texture. Crystals of quartz, white and pink feldspar, mica and occasional hornblende are all visible in the hand specimen, and the rock is frequently cut by epidote veins or coated with a brownish calcite staining. Occasionally, partially assimilated xenoliths are surrounded by a concentration of ferromagnesian minerals.

In thin section, all of the granites contain large, anhedral crystals of microcline, some displaying characteristic tartan twinning (Fig. 6d). Within the microcline are blebs of quartz and albite-twinned plagioclase (An_{30}) together with marginal inclusions of saussuritized oligoclase crystals and small myrmekitic blebs. The oligoclase is invariably saussuritized and frequently has graphic intergrowths with quartz. Epidote is present in some of the altered plagioclase cores and also in narrow veins. The quartz is often fractured and occasionally shows undulose extinction. Chlorite is common as an alteration mineral replacing biotite and hornblende. The latter is the common mineral in the ferromagnesian concentration surrounding partially assimilated xenoliths. Sphene, allanite, apatite and zircon are common accessory minerals together with some ilmenite and pyrite.

Mesozoic Sedimentary Rocks

At Carse Point and station KG.1107 beds of sandstone and mudstone underlie the Mesozoic volcanic rocks (Figs. 7 and 8). Those at Carse Point are fossiliferous and have been described in detail by Culshaw (in press) but no fossils have been found in the 20 m. of sedimentary rocks exposed at station KG.1107.

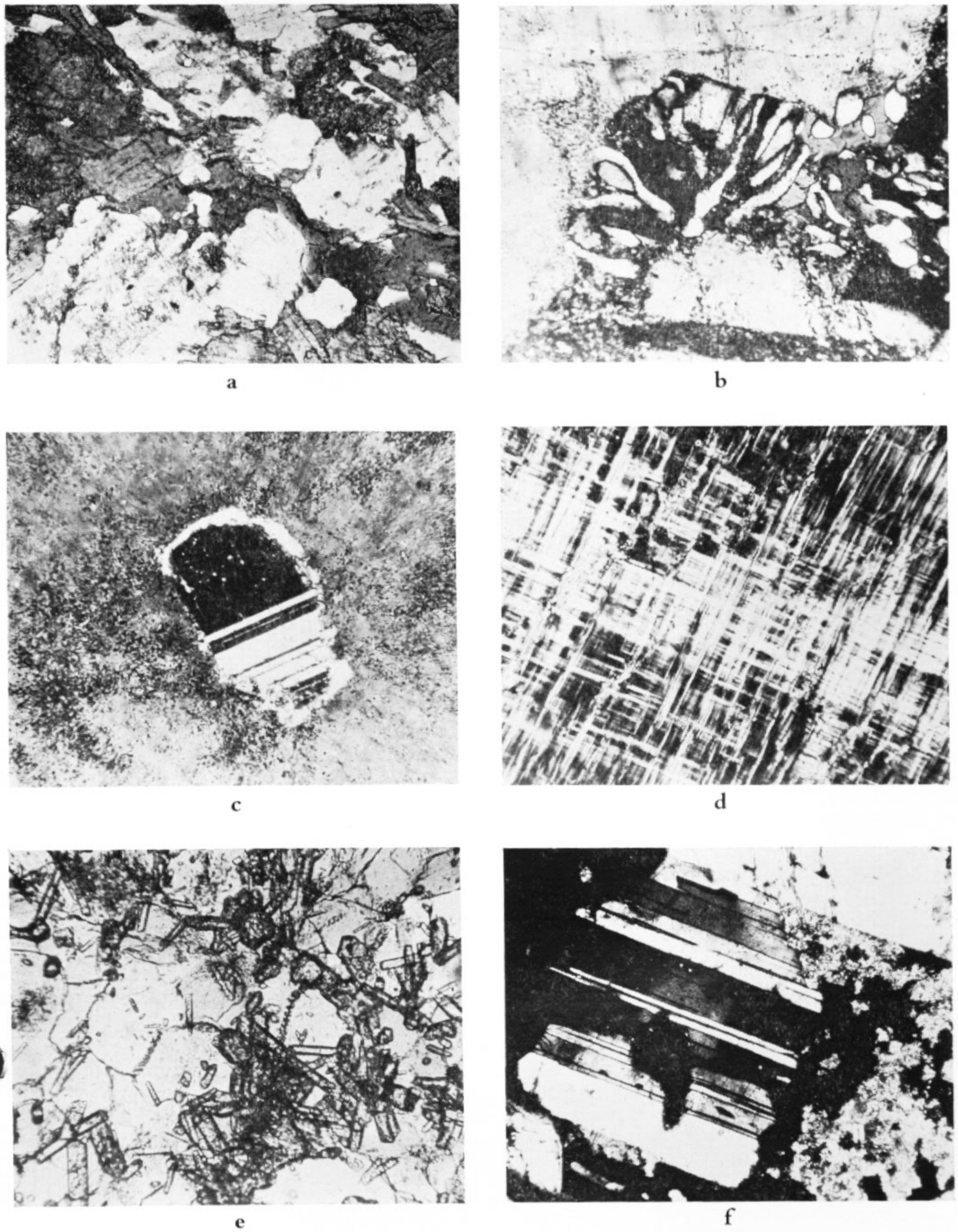


Fig. 6. a. Granodiorite-*ortho*gneiss (KG.1125.1; ordinary light; ×40).
b. Myrmekitic *ortho*gneiss. Cloudy and inclusion-filled orthoclase with myrmekite developing at its margin (KG.1122.1; X-nicols; ×125).
c. Tonalite-*ortho*gneiss. Relict albite-twinned plagioclase in an untwinned, altered plagioclase crystal (KG.1129.1; X-nicols; ×80).
d. Characteristic twinning in the microcline-granite (KG.1126.1; X-nicols; ×90).
e. Epidote needles in a fine-grained sandstone (KG.1107.3; ordinary light; ×90).
f. Calcite aggregate in the matrix of an altered basalt encroaching on the plagioclase crystals (KG.1106.14; X-nicols; ×80).

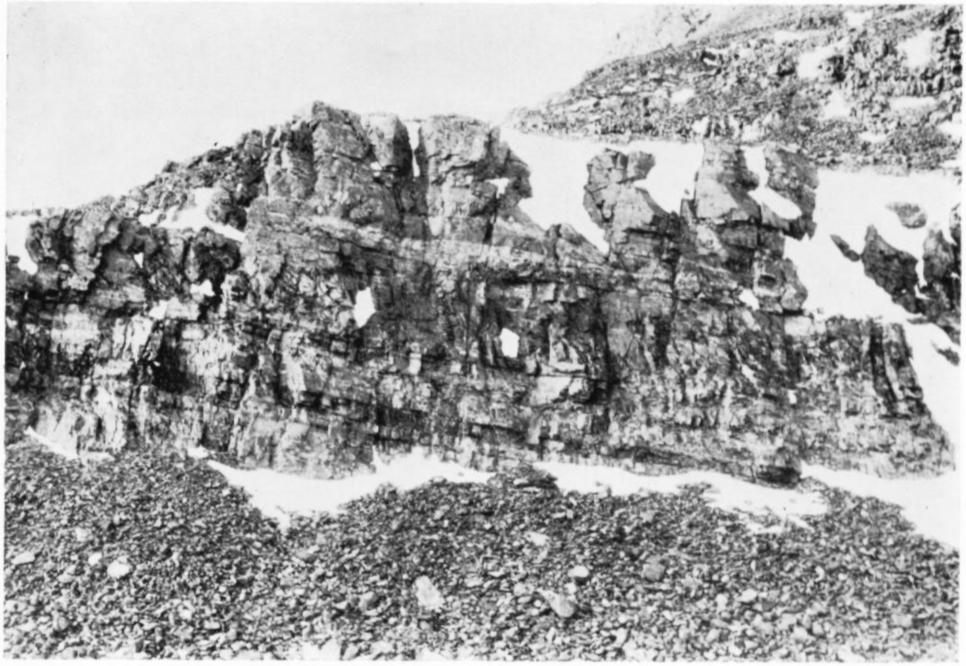


Fig. 7. Alternating mudstones and sandstones at station KG.1173, Carse Point.

The rocks of both localities are lithologically similar. In the larger outcrop at Carse Point, numerous small and some large faults affect both the sedimentary and overlying volcanic rocks but at station KG.1107 a single fault separates the two rock types.

The fine-grained dark-coloured mudstones of Carse Point have a brittle fracture and a brown iron staining. A microcrystalline groundmass contains small, twinned plagioclase fragments (some with an andesine composition) and untwinned feldspar with some sericitic alteration. Unstrained quartz fragments, commonly with inclusions, flakes of muscovite and biotite and aggregates of pyrite, are also present. Trace fossils have been described by Smith (in press) from this rock type.

The sandy beds are petrographically similar but coarser in grain-size and contain volcanic and crystal fragments. A 5 m. thick microdiorite sill with elongated lighter-coloured xenoliths is conformable with the sedimentary beds at Carse Point.

Similar rocks at station KG.1107 are much altered but they display the same mineralogy as those at Carse Point. Epidote is abundant both as single crystals and veins, and in many cases it has formed complete pseudomorphs after the feldspar fragments. Similarly, pseudomorphs of chlorite have replaced mica. The groundmass contains dark patches, some of which are still recognizable as altered volcanic fragments. In some thin sections there is a regular lattice-type arrangement of the epidote needles (Fig. 6e).

Mesozoic Volcanic Rocks

Volcanic rocks overlying sedimentary and interstratified sedimentary and volcanic rocks occur throughout this area. They are exposed on Carse Point (Fig. 9a), Mount Dixey, Mount Flower, Mount Pitman, east of Mount Courtauld, in the Traverse Mountains and also in more restricted outcrops along the plateau edge and in nunataks east of the Traverse Mountains.

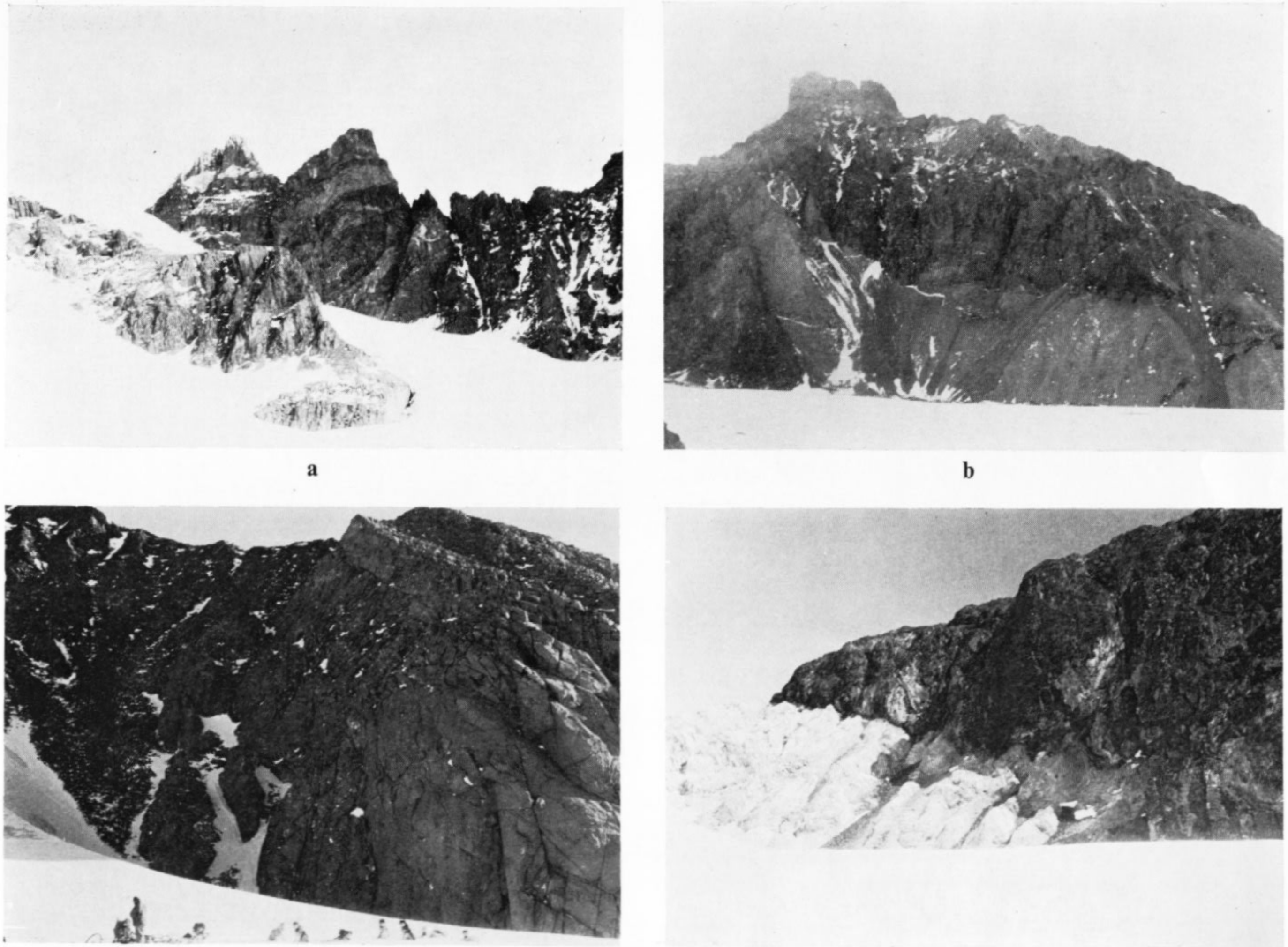
The thickest stratigraphical successions are between 1,000 and 1,250 m. thick but in no single area is the complete succession seen. All of the rocks are stratified with a fairly constant dip direction in any one locality, but it varies throughout this area and is affected by later

Fig. 8. The total sedimentary succession exposed at station KG.1107.

faulting. Most of the beds have a shallow dip to the north, south or west, and steeply inclined strata occur only in close proximity to a fault line.

Table II shows the stratigraphical succession determined for the volcanic rocks. They belong to a basalt–andesite–rhyolite assemblage which has completed at least one eruptive cycle.

Parts of this assemblage are already well-documented in other areas of Palmer Land (Ayling, 1966; Rowe, 1973; Smith, in press) and they are almost certainly similar to the volcanic rocks of Adelaide Island (Dewar, 1970) and elsewhere in Graham Land (Adie, 1953, 1964*a*; Goldring, 1962; Hooper, 1962; Curtis, 1966). Adie (1953) dated the volcanic rocks of Graham Land as post-Middle Jurassic but pre-Aptian from field evidence in the Marguerite Bay area (Hooper, 1962) and later (Adie, 1964*a*) as Upper Jurassic. The recent discovery of fossils in the sedimentary succession of Carse Point (Culshaw, in press) confirms the Upper Jurassic as the start of the volcanicity in this area. Because the sedimentary rocks, which lie conformably below the 2,000 m. of volcanic rocks, are of a late Jurassic age, it is possible that the eruptions continued into the Lower Cretaceous. This would coincide with the "Upper Jurassic" and "(?) early Cretaceous" episodes of volcanicity proposed by Adie (1971).



a b c d

Fig. 9. a. A faulted block of purple and green tuffs in the Mesozoic volcanic rocks at station KG.1175.
b. Granodiorite intrusion into Mesozoic volcanic rocks at station KG.1186, Mount Flower. The neck of the intrusion is cut by three faults and, at the lower left, blocks of included country rock are present.
c. Granite intrusion into Mesozoic volcanic rocks at station KG.1106.
d. Quartz-plagioclase-porphyry intrusion into Mesozoic volcanic rocks at station KG.1135.

Table II. Stratigraphical succession for the Mesozoic volcanic rocks*

Carse Point	*Mount Flower*	*Traverse Mountains*	*KG.1153–1154*	*KG.1106, etc.*
				Vent agglomerate
	Andesitic lavas and tuffs		Andesitic lavas and tuffs	Andesitic lavas and tuffs
			Purple and green tuffs	
			Purple agglomerates	Purple agglomerates
	Rhyolite/rhyolitic tuffs		Rhyolite/rhyolitic tuffs	Rhyolitic tuffs
Lavas and tuffs	Lavas and tuffs	Lavas and tuffs	Lavas and tuffs	Lavas and tuffs
Volcanic conglomerates		Volcanic conglomerates		Volcanic conglomerates
Siltstones				Siltstones
Sandstones				Sandstones

* Only those localities which best illustrate the succession are discussed here.

Cutting the volcanic rocks, displacing and marginally altering them is a suite of granodiorite and granite bosses, quartz-plagioclase-porphyry dykes and dolerite dykes together with smaller acid dykes (Fig. 9b–d).

Later faults, probably associated with the Tertiary uplift of the Antarctic Peninsula, are largely responsible for the present distribution of the volcanic rocks within this area.

Although the volcanic succession (Table II) is never completely seen in any one locality, distinctive horizons within the succession allow an accurate correlation to be made. Thicknesses vary and anomalies exist but all can be satisfactorily related by assuming that there were various eruptive centres co-existing, possibly on slightly different terrains, but all tapping the same magma. A short description of each unit shows how the succession was built up.

Volcanic conglomerate

This horizon is well-exposed at stations KG.1101 and 1237 and at Carse Point. At the first two localities it forms the basal exposures but at Carse Point it can be seen to lie between the sedimentary rocks and the first stratified volcanic beds. The thickness is variable but approximately 30 m. are exposed at Carse Point. Invariably the largest cobbles (1–10 cm. in diameter) are well-rounded granite or granodiorite, but there are also large angular andesitic boulders (0·5–1·0 m. in diameter). The smaller cobbles include sandstones and other sedimentary rocks but metamorphic inclusions are uncommon. Overlying and within the uppermost conglomeratic beds are basaltic and andesitic lavas and tuffs.

Clasts in the conglomerate are variable in size and composition. Sectioned cobbles include microcline-bearing granite, quartzite or granular gneiss, lava and agglomerate, mudstone and sandstone. The smaller purple fragments are of metasedimentary, volcanic or sedimentary origin.

Most of the inclusions are 1–10 cm. in size and all are less than 1 m. in diameter. The larger boulders are volcanic blocks themselves composed of the smaller fragments.

The matrix of the conglomerate is fine-grained with plagioclase of an indeterminate composition together with larger broken crystals of twinned plagioclase (An_{35}). Scattered crystals of untwinned feldspar and corroded quartz are also present. Dark patches in the groundmass with a concentration of chlorite and frequently with a margin of haematite and magnetite indicate small altered volcanic fragments. Recrystallized acid igneous or sedimentary fragments are represented by even-grained mosaics of quartz and feldspar. Chlorite, calcite, epidote and sericite are always present, and frequently in abundance. All are alteration products or have been introduced by secondary mineralization. Little remains of the original ferromagnesian minerals and the plagioclase crystals are frequently sericitized and saussuritized.

Lavas and tuffs

Between the volcanic conglomerate and the rhyolitic beds is a thick sequence of stratified volcanic rocks, mainly tuffs with intermittent lava flows. Basaltic beds are concentrated at the base of the unit and there is a predominance of lava flows at the top.

Thicknesses cannot be measured with any degree of accuracy because the base and top of the units are never exposed together and there are no marker horizons. At Carse Point, 850 m. of tuffs and lavas overlie the volcanic conglomerate, and at Mount Flower (KG.1191) 500 m. of tuffs and lavas underlie the rhyolitic beds. At station KG.1106, 700 m. of similar strata are exposed.

The tuffaceous beds contain acid and basic lapilli up to 2 cm. but generally less than 1 cm. in diameter. Basic volcanic fragments predominate but exotic granite and sedimentary fragments also occur.

The matrix of the tuff is similar to that of the volcanic conglomerate with a range of plagioclase composition (An_{44-51}). Some crystal tuffs contain corroded quartz and brown untwinned feldspar crystals together with fragmentary plagioclase crystals displaying oscillatory zoning and albite twinning. Some of the large twinned phenocrysts have an oligoclase composition. Small glassy shards and streaky lava blebs are also present.

The lavas are porphyritic andesites and basalts with prominent epidotized plagioclase phenocrysts. The basalts are less common and occupy thin beds near the base of the sequence.

The most basic plagioclase has a composition of An_{51} together with much oscillatory zoning. The commoner andesites display less zoning of the plagioclase crystals, which have a composition of about An_{44}.

In both lava types there is much alteration. The basalt flows occasionally display some original augite crystals together with hornblende and chlorite. Biotite, chlorite and epidote are the common alteration products of the ferromagnesian minerals, and epidote also occurs as a secondary mineral in association with calcite, especially in plagioclase alteration (Fig. 6f).

Common in the groundmass of the lavas are small, chlorite-rimmed areas containing partly devitrified glass (Fig. 10b).

Pale tuffs and rhyolites

At stations KG.1108, 1109, 1153 and Mount Flower (KG.1191), pale tuffs and rhyolitic lavas crop out. The thickness is again variable and at station KG.1153 50 m. of rhyolitic flows are exposed, whereas elsewhere 10–15 m. of pale tuffaceous rock or iron-stained flinty rock occurs. Fragments in the pale tuffs have the same compositional range as the darker tuffs and in most areas they have a similar size range. At station KG.1109 there may be a vent agglomerate consisting of a lighter-coloured matrix and containing larger blocks. The black lavas are fine-grained and glassy with occasional phenocrysts or spherules. Some are pale green or white with green patches of epidote crystals. All are iron-stained and some are shattered by closely spaced fractures.

Although fragments in the tuffaceous beds are similar to those of the earlier units, the matrix material is more glassy and viscous flow structures can be seen in all sections. The matrix, which flows around the rock fragments and zoned plagioclase (An_{32-28}) crystals, consists of microcrystalline feldspar with numerous glassy shards.

The massive lavas are glassy with a conchoidal or brittle fracture, black or pale grey in colour with a few small plagioclase phenocrysts. A microcrystalline feldspar groundmass has zoned and albite-twinned plagioclase (An_{30-32}) and small radiating spherules. Patches of secondary epidote and calcite are associated with plagioclase alteration. Masking and kinking of plagioclase twinning is common. Patches of chlorite and biotite in the groundmass suggest that some interstitial glass has devitrified.

Purple agglomerate

Mount Pitman (KG.1226 and 1227) and stations KG.1100 and 1154 display the best exposures of the purple agglomerate. The total thickness is estimated at 15 m. at station KG.1154. The top contact is a gradational one into tuff of a similar colour and composition.

Inclusions over 3 cm. in diameter are well rounded but the smaller fragments are more angular. Volcanic bombs frequently show reaction rims and cooling cracks at their margins. The purple coloration comes from the high iron content and degree of weathering. This coloration affects the bombs and the groundmass to the same extent but the smaller fragments retain their own colour.

In contrast to the earlier volcanic conglomerate, these rocks do not contain exotic boulders and pebbles but instead are composed of deeply weathered volcanic bombs 3–50 cm. in diameter together with smaller basic fragments. The bombs are frequently elongated in the plane of the bedding.

The iron-, copper- and sulphur-stained agglomerate at station KG.1226 is coarser and lighter in colour than the other agglomerates of this area. It is probably a vent agglomerate with blocks and bombs of agglomerate and lava up to 1·5 m. in diameter. No dykes were observed but the shearing and mineralization is similar to that associated with a vent agglomerate at station KG.1143.

The purple agglomerate matrix is microcrystalline with plagioclase crystals and fragments, epidote pseudomorphs after plagioclase, rock fragments and glass shards set in it. Abundant iron staining affects the matrix and produces the red contact rims on the bombs. The rock fragments are again similar to those already described. The volcanic bombs consist of flow-orientated plagioclase crystals enclosing phenocrysts of plagioclase, epidote and magnetite. Pseudomorphs of calcite have replaced many plagioclase phenocrysts.

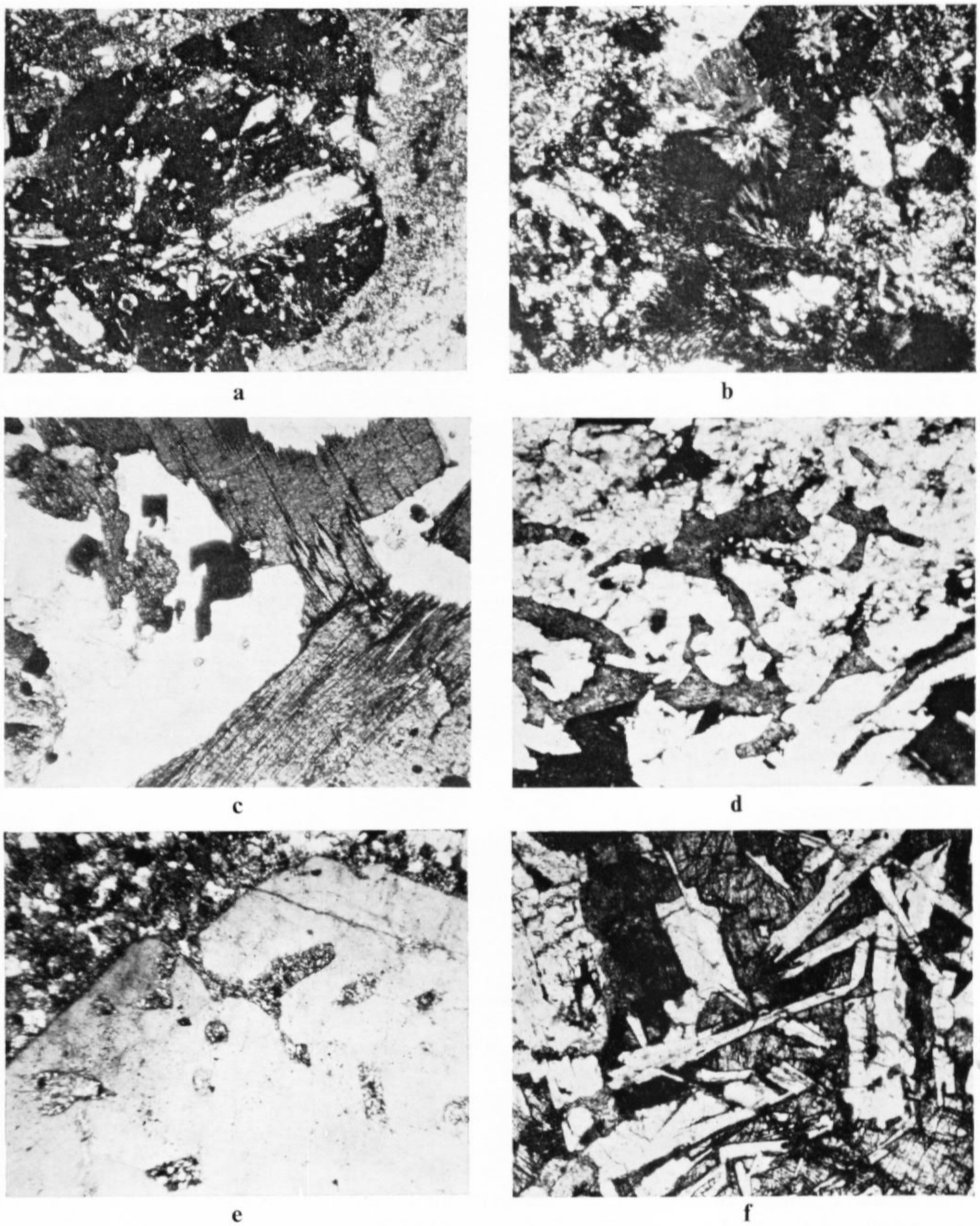


Fig. 10. a. Porphyritic glassy fragment in a fine-grained porphyritic andesite tuff (KG.1128.4; X-nicols; ×30).
b. Devitrified glassy spherules and chlorite-rimmed glass in the altered matrix of an andesite tuff (KG.1103.6; X-nicols; ×40).
c. Partial alteration of hornblende to biotite (with bent lamellae) and accessory minerals in a granodiorite (KG.1111.3; ordinary light; ×33).
d. Graphic intergrowth of quartz and orthoclase in an Andean granite (KG.1118.6; X-nicols; ×35).
e. Corroded quartz crystal in a quartz-plagioclase-porphyry (KG.1116.9; X-nicols; ×30).
f. Ophitic texture displayed by the dolerite dyke suite (KG.1125.2; ordinary light; ×35).

Purple and green tuffs

At stations KG.1154 and 1100 the purple agglomerates grade upwards into purple tuffs and then into green andesitic tuffs with a maximum thickness of 50 m. (KG.1154). At station KG.1150, purple and green volcanic sandstones also grade upwards into similar green andesitic tuffs. The uppermost tuffaceous horizons are interbedded with andesitic lava flows which increase upwards in thickness and number.

The purple tuff is equivalent to the matrix and smaller fragment content of the underlying purple agglomerate. However, the green tuff is more closely related to the overlying andesitic lavas. The water-lain purple and green sandstones at station KG.1150 are of volcanic origin and possibly represent deposition of the tuffs in a shallow water-filled basin close to the eruptive centre. These sediments are apparently conformably overlain by green andesitic lavas and tuffs.

In this unit there is a gradual colour change from the base to the top of the unit. Few bombs are present and the rock fragments are generally less than 1 cm. in diameter. The matrix is similar in composition to that of the purple agglomerate but there is progressively less iron staining and more epidotization in the green tuffaceous horizons.

The volcanic sandstones are sedimentary rocks with a high proportion of volcanic fragments. The feldspathic matrix has abundant andesine crystals and saussuritization of the plagioclase is common together with sericitization of the orthoclase. Secondary calcite, epidote and chlorite occur throughout the rock together with some pyrite and haematite in the matrix. Some of the volcanic fragments have a trachytic texture, whereas others consist of chloritized glass with enclosed microlites.

Andesitic lavas and tuffs

Above the purple and green tuffs the succession is characterized by lava outpourings initially accompanied by tuffs. The top of these lavas and tuffs was not seen but a 700 m. thick succession occurs at Mount Flower. It is largely a repetition of the earlier tuff and lava phase but basaltic outpourings are absent from the initial stages.

Individual flows are between 10 and 15 m. thick (considerably thicker than the 1·5 m. thick flows of the petrographically similar earlier tuff and lava unit). The greater thickness of flows has resulted in the development of larger phenocrysts and in places columnar jointing is well displayed (KG.1106).

The mineralogy of these tuffs and lavas is similar to that of the earlier unit, including the development of abundant epidote and calcite. Most ferromagnesian minerals have been altered to chlorite, green hornblende and brown biotite, but relict augite, pigeonite and hornblende are still present. Abundant magnetite is associated with some ilmenite, but pyrite and haematite also occur in the tuffaceous beds. The plagioclase composition averages An_{44} but some of the more altered and thinner flows are basaltic and contain labradorite (An_{51-53}).

Vent agglomerate

The only definite volcanic vent occurs at station KG.1143, where sub-horizontal tuffs with subsidiary agglomerates and lava flows are cut by coarser-grained massive agglomerate. Swarms of vertical basic dykes striking 021° mag. cut the stratified volcanic rocks and surrounding the vent is a contact area with much shearing and iron staining. This vent, which is approximately 0·5 km. in diameter, is inaccessible but the boulders in it can be related both in colour and size ranges to ones seen elsewhere (KG.1226).

Coarse blocks of agglomerate associated with shearing at stations KG.1109, 1110 and 1226 indicate that volcanic vents probably exist throughout the area. However, the outcrop is too limited to identify these with certainty.

In the vent agglomerate at station KG.1226, copper, iron and sulphur mineralization is very prominent. The copper and sulphur compounds coat the agglomerate blocks and are concentrated in cracks and fissures in a manner similar to present-day sublimation deposits at active volcanic fissures. The iron is mainly specular haematite which is concentrated in gas cavities within the rock. Common rust staining is also present. At station KG.1226, the large blocks of agglomerate occur in a less coarse agglomerate of a similar composition and the "matrix agglomerate" is similar to the agglomerates described previously. The enclosed blocks (up to 1·5 m. in diameter) are composed of agglomerate, tuff and andesite, and some are deeply weathered with many mineralized gas vesicles. No exotic blocks were found though exotic fragments can be found in the smaller size ranges of the agglomerate.

Andean Intrusive Suite

Intrusive rocks cut the Mesozoic volcanic rocks throughout this area. Large granodiorite outcrops, which have no visible contacts with other rock types, are thought to have a similar age to those cutting the volcanic rocks.

Although no radiometric ages are available, field relationships define an order of intrusion and establish their age as younger than the Mesozoic volcanic rocks. Comparison with similar rocks from elsewhere in the Antarctic Peninsula indicates an "Andean" age. "Andean" (Adie, 1955) intrusive rocks range in age from Upper Jurassic to Lower Tertiary with the main intrusive phase during the Aptian (Adie, 1964*b*, *c*).

Three main phases of intrusion have been recognized here: the earliest and most important is a granodiorite phase, followed by a granite phase, and finally a quartz-plagioclase-porphyry phase.

Granodiorite

Granodiorite is by far the commonest intrusive rock present. It is invariably xenolithic and generally forms isolated nunataks but also occurs in contact with the Mesozoic volcanic rocks. Contact metamorphism is minimal, but at Mount Flower (KG.1186) a xenolithic granodiorite intruding the Mesozoic volcanic rocks has metasomatized some of the volcanic rock forming a dioritic gneiss.

The granodiorite is light to dark grey in colour with a medium-grained holocrystalline texture. It contains basic xenoliths and is cut by thin, late-stage acid veins. The xenoliths are generally small (less than 3 cm. in diameter) but larger ones (up to 5 m. in diameter) do occur. These xenoliths are all fine-grained and basic in appearance, and thin sections show that they are largely amphibolitized. Close to the roof of one intrusion large blocks (up to 10 m. in diameter) of original country rock are present (Fig. 9b). Many of the xenoliths are almost completely assimilated while others still retain their sharp outlines.

Feldspar in the granodiorite is invariably sericitized and saussuritized though twinning and some of the original crystal outlines are still visible. The orthoclase exhibits some Carlsbad twinning and is brown and cloudy with incipient alteration. Plagioclase (An_{47}) displays albite, pericline and Carlsbad/albite twinning together with oscillatory zoning. The twinned plagioclase crystals frequently enclose epidote in their cores, while the untwinned crystals are generally less altered. Twinned plagioclase crystals commonly have rims of untwinned (recrystallized) plagioclase.

Highly fractured quartz commonly with inclusions occurs interstitially and is graphically intergrown with the cloudy orthoclase. Some recrystallization is displayed in rounded and corroded crystal faces.

Irregular laths of biotite and hornblende are the common ferromagnesian minerals and some are kinked, possibly indicating movement during crystallization. However, hornblende crystals also display regular crystal outlines and cleavage patterns. Secondary chlorite and magnetite are associated with both the biotite and hornblende, and the accessory minerals sphene, apatite and zircon are concentrated near hornblende crystals (Fig. 10c).

Granite

Granite intrudes the Mesozoic volcanic rocks at station KG.1106 and also the granodiorite with a sheared contact at station KG.1116. The granite–granodiorite relationship is also exposed in isolated nunataks at stations KG.1133 and 1137. There is little disturbance or alteration of the volcanic rocks at contacts.

The medium- to coarse-grained holocrystalline granite is pink to grey in colour. It contains some small basic xenoliths which have undergone partial assimilation and frequently display a diffuse outline at the contact with the host rock.

Widespread feldspar alteration is evident in thin section. The plagioclase (oligoclase) is often intergrown with orthoclase and displays oscillatory zoning and irregular crystal outlines. Orthoclase, the common feldspar, is brown and cloudy, and is frequently graphically intergrown with both quartz and plagioclase (Fig. 10d).

Abundant quartz crystals are fractured and have irregular crystal faces. Brown biotite (with replacement by chlorite, magnetite and haematite) is the dominant ferromagnesian mineral. Hornblende is also present and partly altered to chlorite.

The common accessory minerals are subhedral magnetite, sphene, zircon and apatite. Abundant epidote, calcite, chlorite and sericite are of secondary origin.

Quartz-plagioclase-porphyry

Quartz-plagioclase-porphyry, the youngest of the plutonic rocks, cuts the Mesozoic volcanic rocks at Carse Point (KG.1174) and on the plateau edge (KG.1127 and 1135). It also intrudes the granite at stations KG.1116 and 1133.

The pink-coloured porphyry has a glassy matrix enclosing phenocrysts of plagioclase and clear quartz. Generally, the centres of intrusions are pinker than the margins and at Carse Point marginal basic xenoliths are present. Phenocrysts are of constant size throughout each intrusion irrespective of the volume of the intrusion.

In thin section the microcrystalline matrix of the porphyry appears to be feldspathic and sericitic, and encloses plagioclase, orthoclase, quartz, muscovite and secondary calcite and epidote crystals.

The altered plagioclase (andesine) contains much epidote and calcite. Whole phenocrysts are often pseudomorphed by calcite but in others the albite twinning is still visible despite the alteration. Some brown untwinned crystals with incipient alteration may be orthoclase.

The faces of the fractured and clear quartz crystals are deeply embayed by partial resorption (Fig. 10e) but in general they are free from inclusions. Large ragged flakes of muscovite together with rosettes and small flakes in alteration areas all display a characteristic "twinkle". The small xenoliths are much altered and in thin sections they appear as kinked chlorite and hornblende aggregates.

Dyke Suites

Many dykes occur throughout this area and five suites can be demonstrated:

Dolerite dykes
Microdiorite dykes
Altered acid dykes
Altered basic dykes
Amphibolite dykes.

Of these five suites the dolerite is the youngest.

Amphibolite dykes

Within the Metamorphic Complex, amphibolite lenses, sheared-out schistose amphibolite layers and continuous foliated basic bands in the banded gneiss, all represent one, and possibly two, phases of dyke intrusion. The lenses and bands are rarely more than 1 m. in width but can continue as dyke forms throughout an entire outcrop. Two phases of dyke intrusion are suggested by outcrops where discrete lenses and continuous dykes of similar appearance occur together.

In outcrop these dykes appear as medium- to fine-grained dark bands parallel to the bands in the gneiss and probably as xenoliths in the other metamorphic types. They are always schistose with hornblende and feldspar crystals identifiable from the hand specimen. Occasionally, later pegmatitic veining cuts them or occupies dilation fractures within the amphibolite.

In thin section, green hornblende is the most obvious mineral and some of the more altered ones with chlorite and magnetite in association are probably primary. Saussuritized and sericitized andesine still with recognizable albite and pericline twins is also present. Nearly all of the smaller plagioclase crystals have recrystallized but the larger ones still display bent twin lamellae and fracture infillings. Epidote is common both as crystals and veins, and chlorite is also present as a secondary mineral. Sphene, apatite and magnetite as euhedral and subhedral crystals are common accessory minerals.

Altered basic dykes

At station KG.1225, the microcline-bearing granite is cut by an early suite of basic dykes; the whole is then intruded by a later suite of granodioritic to felsitic dykes.

The altered basic dykes are black or greenish in colour and usually less than 2 m. wide. They exploit earlier joint planes (Fig. 11) and have themselves been affected by later movements, as some are partly foliated though the country rock/dyke contact is always sharp. They are more weathered than the later dolerite dykes, and iron staining, calcite-coated fractures and epidote veining is commoner.

Fig. 11. Banded gneiss (KG.1230) containing amphibolite lenses cut by later basic dykes and a thin microdiorite dyke.

The rock is medium- to fine-grained with small feldspar phenocrysts and black laths visible in the hand specimen, especially on weathered surfaces. It is invariably altered and has a plagioclase groundmass containing epidote, chlorite, calcite and sericite as the alteration minerals. Epidote pseudomorphs after plagioclase are common but albite-twinned plagioclase of an indeterminate composition is still recognizable. All of the ferromagnesian minerals have now been altered to hornblende and biotite, both of which are associated with secondary chlorite as an alteration product. Apatite and magnetite are present as small euhedral or subhedral crystals.

It is possible that these dykes could be feeders to the Mesozoic volcanic rocks.

Altered acid dykes

In outcrop these rocks cut the altered basic dykes. They are 1–5 m. in width and have a chilled contact with the granite host rock. The colour is variable from grey to reddish brown with green and brown weathering, and alteration staining on exposed faces. Quartz and feldspar phenocrysts together with calcite and epidote crystals and veins are visible in the hand specimen.

In thin section, these dykes display a microcrystalline groundmass of quartz, feldspar and secondary minerals such as epidote, calcite, chlorite and sericite. Set in this groundmass are albite- and Carlsbad/albite-twinned andesine (An_{36}) crystals with secondary saussuritization, perthitic orthoclase which is brown with sericitic alteration and corroded quartz crystals with fractures and undulating extinction. Muscovite is also present together with radiating fibrous spherules which often have a quartz-feldspar mosaic in their cores. These spherules appear to be infilled bubble cavities or a devitrified glass, and it is possible that this suite of dykes could be feeders to the rhyolitic phase of the Mesozoic volcanic rocks.

Microdiorite dykes

Cutting the Mesozoic volcanic rocks in the northern Traverse Mountains and conformable with the sediments at Carse Point are 5 m. wide microdiorite dykes. Other light-coloured dykes also cut these volcanic rocks and the Andean plutonic rocks, and they may belong to this phase of intrusion or could be late-stage effects of the Andean intrusive rocks.

In outcrop these rocks are grey in colour with phenocrysts of epidotized feldspar and ferro-magnesian minerals visible. A white or brown staining coats some of the weathered surfaces.

The matrix is a feldspar lath-work containing euhedral, oscillatory zoned labradorite crystals with albite twinning. Frequently, the twinned crystals are mantled by similarly twinned material. Augite cross-sections, green hornblende sections and prisms also occur; both are twinned and contain much secondary epidote. Groundmass alteration is shown by the development of chlorite and epidote, and magnetite occurs as an accessory mineral.

The other acid dykes are granitic, granodioritic or felsitic in composition, similar to the plutonic intrusions but finer in grain-size. Occasionally a pegmatitic intrusion contains euhedral quartz and tourmaline.

Dolerite dykes

Fresh-looking basic dykes cutting all other rock types are the last major dyke phase present in this area. These dykes attain widths of 5–7 m. but they are generally only 1–2 m. wide, joint-controlled and with sharp contacts with the country rock.

The rock is medium-grained, black in colour, occasionally with iron staining and calcite coating on weathered surfaces. Sectioned specimens show the main characteristic of these dykes—the ophitic intergrowth of pyroxene and plagioclase (Fig. 10f).

The plagioclase is labradorite (An_{50-52}) present as albite-twinned, small altered laths and oscillatory zoned, pericline-twinned or untwinned crystals with sericitic alteration. Pigeonitic augite, which is faintly pleochroic with a purplish tinge, shows a characteristic pyroxene cleavage and alteration to chlorite. Subhedral magnetite is the common ore mineral together with some ilmenite and pyrite.

Structural Features

The major structural feature of this area is George VI Sound, a fault-controlled channel separating Palmer Land from Alexander Island (Fig. 1). The sub-plateau and many of the major faults in this area also follow this trend (Fig. 2).

Fig. 12 shows various structural trends plotted with data from the entire area. The rose diagrams confirm field observations such as the close relationship between faults and dykes and the intrusion of microcline-granite into the metamorphic rocks along existing and new joint and fracture planes. The dips of the lava flows and the orientation of bands in the banded gneiss vary throughout this area and they often change across faults. This is reflected in the spread of points on the stereograms.

The Metamorphic Complex has undergone extensive movements prior to the formation of the younger rocks. They display folding, ptygmatic veining, tension-gash infilling, lensoid bodies, sheared out dykes and migmatization, all of which are absent from the younger rocks.

The Mesozoic volcanic rocks, Andean Intrusive Suite and the later dykes are affected by faulting, which downthrows them to the same topographical level as the Metamorphic Complex Fig. 13). These later faults are associated with the Tertiary block faulting which affected the

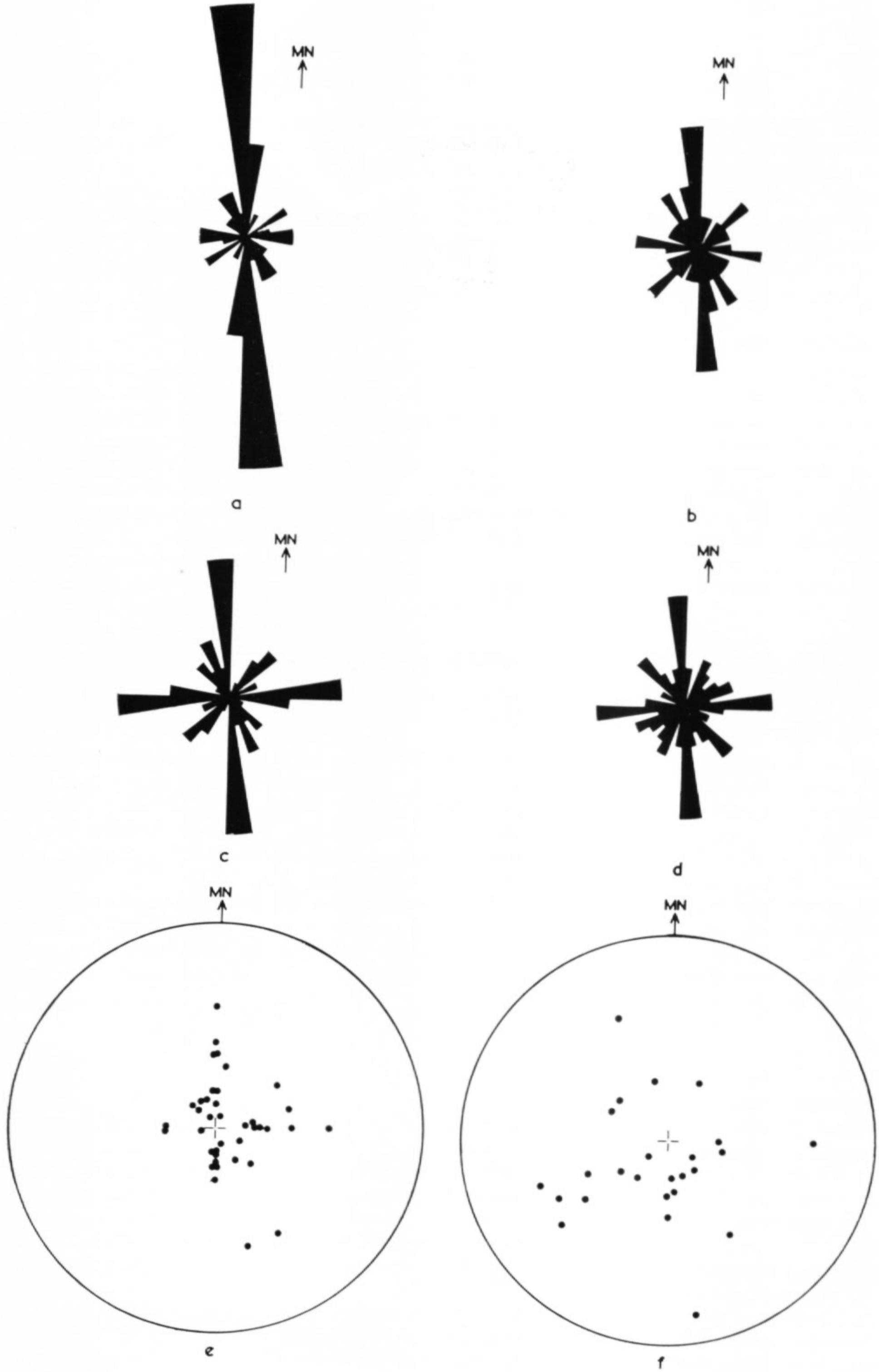


Fig. 12. a–d. Orientated distributions of vertical or high-angle structural features plotted on a polar projection.
a. Faults affecting all rock types.
b. Intrusive zones in the Metamorphic Complex.
c. Dykes belonging to all suites.
d. Foliations, fractures and joints in the Metamorphic Complex.
e and f. Lower hemisphere equal-area plots of low-angle structural features.
e. Poles to planes of lava flows.
f. Poles to planes of banded gneisses.

Fig. 13. Mesozoic volcanic rocks (right) down-faulted alongside Metamorphic Complex rocks at station KG.1129. Cloud obscures the plateau edge which is present at the top left.

Antarctic Peninsula during its uplift in Tertiary times and which is largely responsible for the present geomorphology of the area (Linton, 1964; Marsh and Stubbs, 1969).

Geological History

The history of this area is explained in terms of a developing mountain belt. In the Palaeozoic, a deep trench existing along the axis of the present Antarctic Peninsula was filled with erosional debris. Associated with the trench were intrusive and extrusive igneous activity, and movement and metamorphism of the sediments within the trench. This phase is now represented by the Metamorphic Complex rocks (cf. Fraser, 1965) and possibly the Trinity Peninsula Series rocks found elsewhere in the Antarctic Peninsula (Adie, 1957; Fraser and Grimley, 1972).

Uplift and erosion followed as the younger rocks rest on an eroded Metamorphic Complex surface. Marine basins were infilled with sediments containing much volcanic debris and individual volcanoes on land gave rise to extensive thicknesses of lava. The erosional break cannot be demonstrated here but it has been well documented elsewhere (Adie, 1954). Metamorphic Complex pebbles in the volcanic rocks are further evidence of the erosional episode. Individual vents have been recorded from a number of closely spaced localities (Ayling, 1966; Smith, in press; Fig. 2). There is no well-displayed dyke suite associated with the volcanic rocks.

A later igneous phase, in which much granodiorite together with other acid and basic intrusions occurred, ended with a dolerite dyke suite. This was followed by further uplift, extensive faulting and erosion. The resulting topography was then subjected to glacial processes which continue to the present day.

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