BRITISH ANTARCTIC SURVEY

SCIENTIFIC REPORTS

No. 105

THE GEOLOGY OF PARTS OF CENTRAL WEST PALMER LAND

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CAMBRIDGE: PUBLISHED BY THE BRITISH ANTARCTIC SURVEY: 1984
NATURAL ENVIRONMENT RESEARCH COUNCIL

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ABSTRACT

THIS report embodies the results of an investigation of the volcanic, plutonic and hypabyssal rocks in two geologically related areas of Palmer Land which are about 40 km apart.

In the first of these, the Taurus Nunataks–Braddock Nunataks area, volcanic rocks of probable Upper Jurassic age form the relic of a composite cone. Its components grade from andesitic tuffs and infrequent breccias, with interbedded basaltic lava-flow horizons, into a restricted horizon of rhyolitic lavas, and into further andesitic tuffs with interbedded augite-andesite lava flows. The upper tuffaceous sequence and agglomerates which occur in a prominent vent contain large rounded granodiorite boulders, apparently derived from earlier intrusive rocks which have not been found *in situ*.

Andean granodiorite, which has subsequently invaded these volcanic rocks, contains elongated basic inclusions and distinct linear flow structures which trend slightly west of north. Intrusion breccias developed at sharp contacts and the hybrid nature of the marginal granodiorites indicate that its advance was controlled by assimilation rather than by granitization of the volcanic rocks, which are hornfelsed or metasomatized over a narrow contact zone. Pegmatite dykes cut the coarser-grained granodiorites but mineralized minor intrusions allied to the granodiorite, which strike sub-parallel to the contacts, cut both the plutonic and volcanic rocks. A basaltic dyke swarm trends slightly west of north throughout this area.

In the second area, the Batterbee Mountains, acid extrusive rocks crop out around Swine Hill. The lowest sub-aqueous pillow lavas are succeeded by an apparently terrestrial succession of rhyolite flow lavas with interbedded tuffs and volcanic breccias, which are most abundant in the upper horizons. Quartz-porphyry lavas, exposed at the top of this succession, may be equivalent to similar rocks at Horse Bluff. A vent agglomerate of indeterminate age in Norman Glacier also contains rounded boulders of earlier intrusive rocks.

The volcanic rocks in the western Batterbee Mountains are intruded by granite, which is considered to be genetically related to gabbro and granodiorite intrusions farther east. These probably represent the Andean Intrusive Suite, and the granodiorite, which is similar to the Braddock Nunataks representatives, intrudes heterogeneous gabbroic rocks north-east of Mount Bagshawe. Several mineralized quartz-porphyry minor intrusions and a north-north-west trending basaltic dyke swarm are the most recent geological features.

CONTENTS

1. INTRODUCTION

1. *Locality*

The original intention of this survey was to prepare a reconnaissance geological map of Palmer Land betwen lat. 70° 00′ and 71° 30′S, using the existing depots and working eastward from the eastern margin of George VI Sound (Fig. 1).

Working from the advance field station at Fossil Bluff on Alexander Island, the first observations were made between 24 September and 28 October 1964. Between 9 and 15 November 1964, a detailed plane-table map was made at a scale of 1 : 100 000 of part of the western edge of the Batterbee Mountains between lat. 71° 13′ and 71° 30′S, and geological field observations made at Swine Hill and Horse Bluff were incorporated. The resulting composite map (Fig. 1), compiled from previous topographic survey work, from relevant Ronne Antarctic Research Expedition (RARE), 1946–48, air photographs and from the author's plane-table survey, covers the area between lat. 71° 10′ and 71° 30′S, and long. 66° 45′ and 67° 45′W.

The final and most important part of this topographic and geological survey was made between 17 November and 30 December 1964. Working from the depot sited at the central member of the Taurus Nunataks, a range-finder was used to measure a base line between fixed points on two nunataks bracketing the depot site. Using this base line, a 1 : 50 000 plane-table map was made of an area of about 1 800 km^2 of the Palmer Land plateau between lat. 70° 45′ and 71° 45′S, and long. 65° 30′ and 66° 30′W. At the same time, geological observations were made in the nunataks.

2. *Previous work*

Prior to this survey work, the area of Palmer Land between lat. 70° and 72°S had been seen from the air and had been travelled over on two reconnaissance journeys. First seen by Sir Hubert Wilkins in 1928 and then by L. Ellsworth in 1935 on their historic flights down the east coast of the Antarctic Peninsula, no part of it had been surveyed until the exploratory journeys undertaken by the British Graham Land Expedition (BGLE), 1934–37. Much of the northern and western parts of this area was broadly mapped by W. L. S. Fleming, G. C. L. Bertram and A. Stephenson, who made a survey journey down George VI Sound to lat. 72°S in the last months of 1936. Records of this journey were published (Stephenson and Fleming, 1940). Between October 1936 and January 1937, J. Rymill and E. W. Bingham made a survey journey eastward across the plateau along lat. 69° 45′S to the area including Wakefield Highland. Their observations were incorporated in a further report (Stephenson, 1940), while notes on the scientific work of the expedition were also published (Fleming and others, 1938).

Between November 1940 and January 1941, F. Ronne and C. Eklund, members of the United States Antarctic Service Expedition (USASE), 1939–41, made a reconnaissance sledge journey from Stonington Island to Ronne Entrance. Travelling over the plateau of Palmer Land from the Wordie Ice Shelf to the Batterbee Mountains, between long, 67° 00′ and 66° 30′W, they eventually descended from the plateau down Norman Glacier (Fig. 1). The geological specimens collected by them were examined and reported on by Knowles (1945). This journey, which was to some extent intended to provide ground control for a subsequent air-photographic survey, motivated the RARE, 1946–48. Trimetrogon photographs of flight lines M3 and M7 of this expedition partly cover the western mountain ranges of Palmer Land. Some detail in the southern central part of the 1 : 500 000 Directorate of Overseas Surveys (DOS) map of this area has also been sketched from the RARE trimetrogon photographs of the east coast of Palmer Land.

In 1948–49 and 1949–50, V. E. Fuchs and R. J. Adie made two survey journeys down George VI Sound as far south as lat. 73° 12′S, adding to the detail of the survey and collecting geological specimens from the Batterbee Mountains.

It was in 1960 that the Falkland Islands Dependencies Survey (FIDS) advance field station at Fossil Bluff was established to enable more detailed surveys to be made in Alexander Island and in the southern part of the Antarctic Peninsula. In 1963, I. Morgan and D. Nash (surveyors) and R. R. Horne (geologist) made the first reconnaissance journeys on to the Palmer Land plateau, travelling as far eastward as Mount Cadbury. The geological information obtained during this journey has been incorporated into the present work. To assist this and future reconnaissance journeys, large depots were laid by aircraft at Thomson Rock and at the central member of the Taurus Nunataks early in 1964. It was by working from these depots that the field observations recorded here were made.

3. *Scope of the present study*

Considering the degree of accessibility of the outcrops on the plateau and in the Batterbee Mountains, the large distances between nunataks exposed on the plateau and the time available, it was decided to select the most important exposures as "type areas", and to compare the other outcrops with them. Relatively detailed geological observations were made at Swine Hill, station KG.214 in the Braddock Nunataks and station KG.227 in the nunatak group 10 km north-west of Cetus Hill; the extent of the field mapping in other areas depended on their geological significance.

In addition to making a regional geological survey of the Taurus Nunataks area, the following particular aspects were studied:

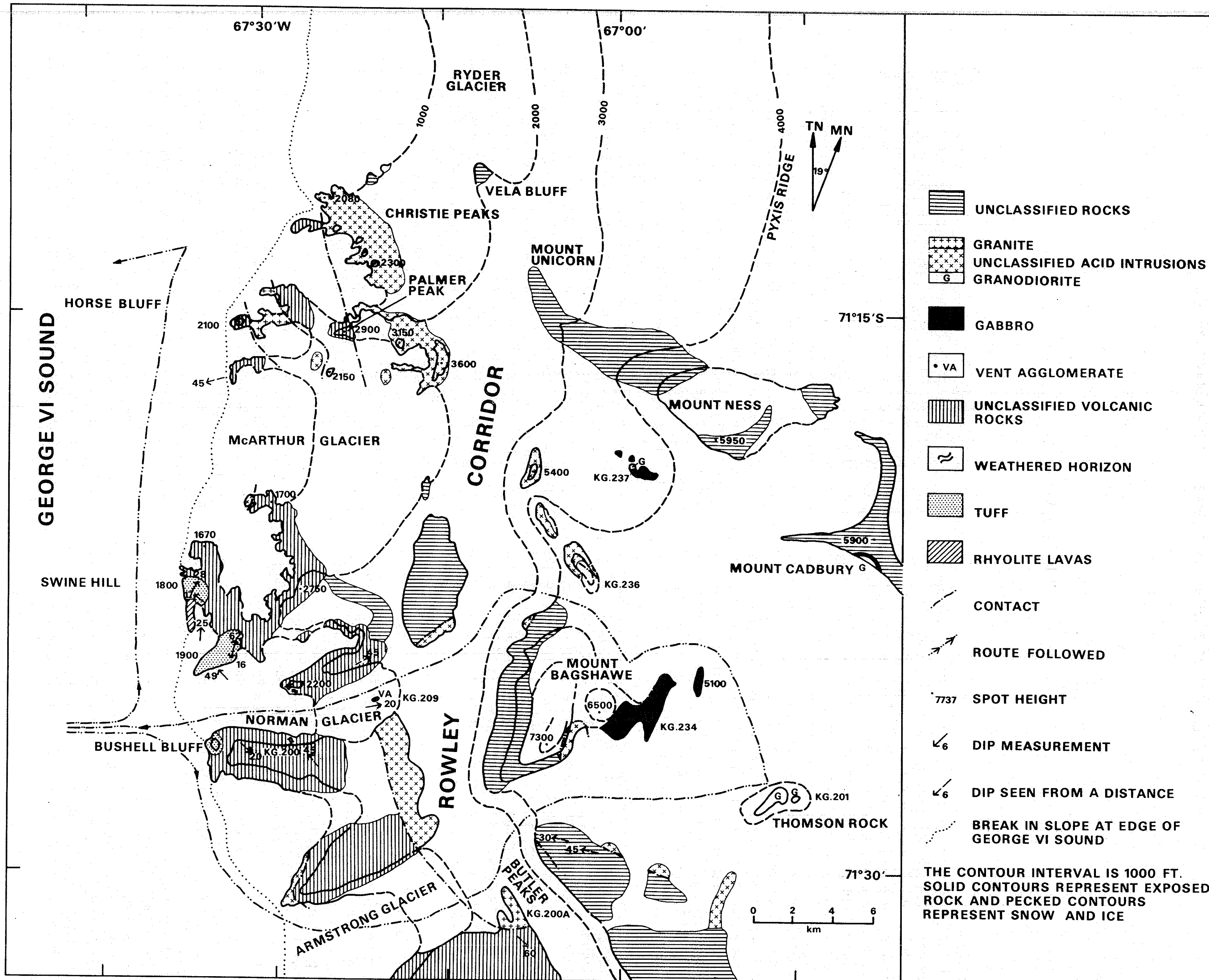

FIGURE 1
A composite geological sketch map of the northern part of the Batterbee Mountains discussed in this report.

i. The stratigraphical succession in the volcanic rocks and its correlation between adjacent nunataks.
ii. The thermal metamorphic effects observed at the contacts between the granodiorites and the volcanic rocks.
iii. The structural pattern in the granodiorite which was built up from systematic joint and lineation measurements.

In the Batterbee Mountains the following further aspects were studied:

i. The relationship between the various plutonic rock types.
ii. The correlation of the stratigraphical succession in the Batterbee Mountains with that in the Taurus Nunataks area.

In general, the conclusions reached on the physiographic evolution, stratigraphy, structure and petrology of the Taurus Nunataks area are compared with the less detailed observations made in the Batterbee Mountains.

II. PHYSIOGRAPHY

THE Antarctic Peninsula between lat. 70° and 72°S is largely covered by an ice cap which falls gradually from approximately 1 525 m at its centre westward to George VI Sound and eastward to the Weddell Sea.

The ice cover in the Taurus and Braddock Nunataks area forms a plateau which slopes gently westward and is penetrated by many nunataks. Each isolated nunatak and group of nunataks forms a barrier to the westward flow of the ice and causes it to bank up against the inland edges of the rock outcrops. Consequently, the plateau surface in this area falls towards the west in a series of steps (Fig. 2).

FIGURE 2
A view of part of the escarpment of the north-central part of the Braddock Nunataks; this shows the ice banked against its eastern flanks. A wide glacier flows through the gap between the north-easternmost and the south-western group of the Braddock Nunataks.

FIGURE 3
A view northward from the east summit of Mount Bagshawe showing the east–west-trending glaciated ridges of Horse Bluff, Gurney Point and Wade Point, each of which is separated by broad crevassed glaciers.

In contrast to the previous area, at the eastern margin of George VI Sound the Batterbee Mountains form a high mountain massif which has recently been deeply dissected by valley glaciers. Ice flows down these glaciers from the Antarctic Peninsula plateau to George VI Sound between the east–west-trending ridges of Wade Point, Gurney Point, Horse Bluff, Swine Hill and Bushell Bluff (Fig. 3).

1. *The Taurus and Braddock Nunataks area*

Superimposed on the convex profile of the ice cover in the Taurus and Braddock Nunataks area are local variations caused by a combination of the westward movement of the ice around the nunataks and over the sub-ice topography, and by the accumulated drift snow banked against the northern and eastern sides of the nunataks.

Two groups of nunataks form barriers to the westward flow of the ice. The first comprises the north–south-trending nunatak ridges of the south-western and south-eastern groups of the Braddock Nunataks, including the north-easternmost nunatak (KG.213). Ice banked against the eastern flanks of these nunatak ridges flows down steep crevassed ice cliffs and ice falls as it is constricted between the individual peaks (Fig. 2). The steep western faces of many of these nunataks are to some extent the result of the eastward regional dip of the volcanic succession forming them, but they may also indicate that at an earlier period in the plateau's history westward-flowing ice completely

FIGURE 4
The group of nunataks 10 km north-west of Cetus Hill viewed from the north. The western nunatak has a glaciated pavement on the summit.

covered the nunataks and accentuated the asymmetry of the escarpment. However, this conclusion cannot be applied to the south-eastern group of the Braddock Nunataks, which are almost completely submerged by the ice.

South of the Braddock Nunataks, the nunatak group 10 km north-west of Cetus Hill forms a less formidable barrier to the westward ice flow. A large snow and ice dome has formed east of the nunatak group 10 km north-west of Cetus Hill and the nunataks which contain this mass of ice also possess steep cliff faces on the lee side of the ice flow (Fig. 4).

Because of their isolation, individual nunataks such as the easternmost and westernmost of the Taurus Nunataks, the nunatak 6.5 km north-east of Cetus Hill and the main peak in the nunatak group 10 km north-west of Cetus Hill have been carved into ridges and arêtes trending in the direction of the westward ice flow (Fig. 4).

The surface topography in this part of the plateau is also modified by accumulated drift snow. The prevailing wind in summer is a katabatic north-easterly, which, judging by the height of the sastrugi, is more powerful among the nunataks than on the flat snowfields. The windscoops north and east of many of these nunataks owe their position to this prevailing wind, which has also contributed to the long shallow snow banks north and east of the Taurus Nunataks, the isolated nunatak 12 km west of the Braddock Nunataks, the south-western group of the Braddock Nunataks and the nunatak group 10 km north-west of Cetus Hill (Fig. 4).

Several other features of the topography are worthy of mention. Continuous lines of morainic debris up to 1.6 km in length, which occur on the plateau surface west of the south-western group of the Braddock Nunataks are medial between adjacent ice streams and trend westward with the dominant ice flow. Bergschrunds are always present around the nunataks but crevasses which originated in a different way occur south of the nunatak 2.5 km south-south-east of Cetus Hill. Here, ice, which is flowing rapidly past the southern edge of the nunatak, is broken into pressure ridges by the friction at the ice/rock interface. Similarly formed arcuate crevasses were observed south of the westernmost of the Taurus Nunataks and the Friedmann Nunataks. Ice falls and crevasses also occur along the lip of the ice cliff where the westward-flowing ice is constricted between the nunataks forming the south-western group of the Braddock Nunataks. For the same reason, the steep section of the glacier separating the northern and southern groups of the Braddock Nunataks is heavily crevassed (Fig. 2). However, crevasses which occur on the lip of the ice cliff, which extends east of the nunatak 6.5 km north-east of Cetus Hill are considered to be due to irregularities in the sub-ice topography which are sufficiently close to the surface to interrupt the regular ice flow.

Avalanches are derived from the ice cliff between the north-westernmost and north-easternmost of the Braddock Nunataks. Both this cliff and the ice cliff joining the nunataks of the south-western group of the Braddock Nunataks are strewn with debris which has avalanched in the warmer weather.

For a relatively short time in the summer, water is formed from the snow melting on the rock outcrops and it was seen to form small pools on the surface of the blue ice in the wind-scoops around the nunataks of the group 10 km north-west of Cetus Hill. This phenomenon was recorded in December and the large flat area of blue ice which was observed in the windscoop at the foot of the northernmost of the south-western group of the Braddock Nunataks 1 month earlier may have been similarly derived. It is doubtful whether running water could or has modified the shape of the rock outcrops in this part of the plateau. The only evidence to support this was the occurrence of a pothole 15 cm in diameter on the rounded summit of the north-western nunatak of the group 10 km north-west of Cetus Hill (Fig. 5), which is similar to those found in the beds of fast-running streams. This may have been formed by melt water as this nunatak was emerging from its ice cover.

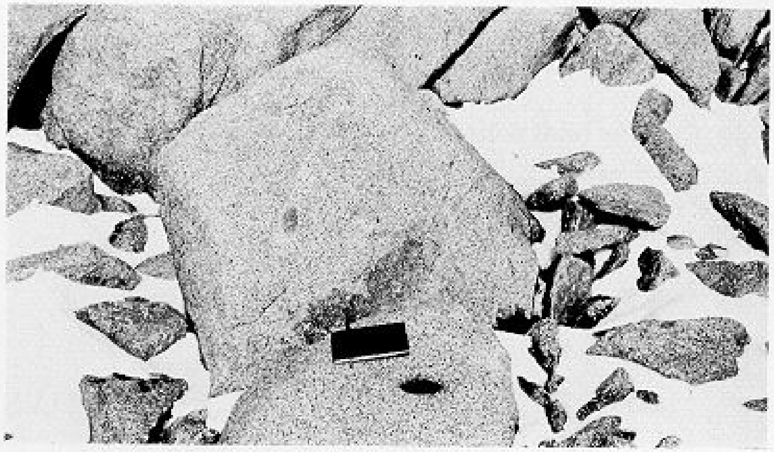

FIGURE 5
A pothole in granodiorite on the rounded summit of the north-westernmost of the nunatak group 10 km north-west of Cetus Hill.

2. *Batterbee Mountains*

In contrast to the Taurus and Braddock Nunataks area, the Batterbee Mountains and their outlying nunataks are a dissected mountain massif with a residual ice cover. Near the coast of George VI Sound, the outcrops tend to be high steep-sided blocks with relatively flat summits (Fig. 6). These are separated

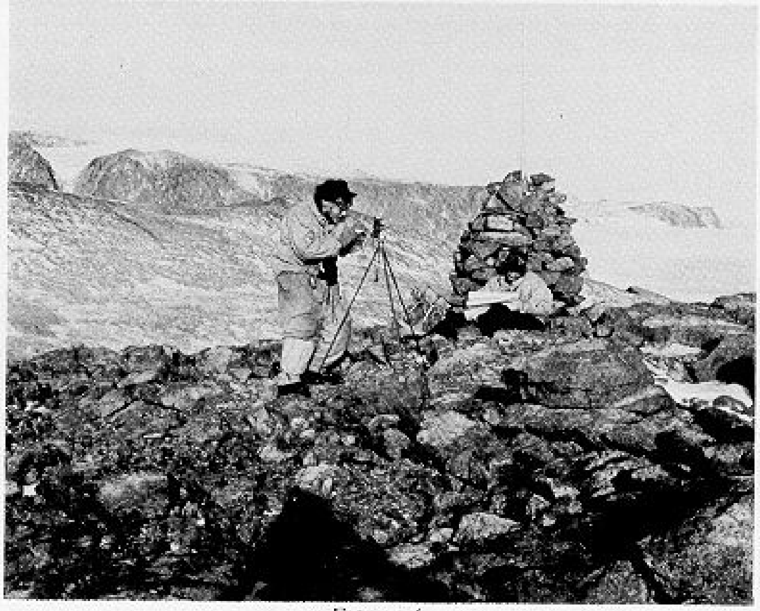

FIGURE 6
A view southward from the Bushell Bluff survey cairn showing the flat summits and steep western cliff faces of the rock massifs bordering George VI Sound.

by trenches occupied by heavily crevassed valley glaciers descending westward from the plateau.

Where the glaciers from the plateau flow into the ice shelf of George VI Sound, an area of pressure ice always develops and in summer melt-water pools frequently fill depressions in the pressure ice. At the foot of Bushell Bluff, a small ice-collapse structure (cf. Fleming and others, 1938, p. 512) was observed (Fig. 7) and this may have been caused by subsidence along a tide crack. At the same locality, moraine debris between ice streams from Norman Glacier and from an adjacent minor glacier to the south extends about 1.6 km westward on to the ice shelf of George VI Sound.

Towards the east, the ice covers the mountain peaks more extensively and beyond Mount Bagshawe only the highest summits penetrate the ice cover (Fig. 8). The configuration of the plateau here is similar to that of the Taurus and Braddock Nunataks area. The ridge of Thomson Rock and the arête of the nunatak 25 km north-east of Mount Cadbury trend in the direction of westward ice flow, while the windscoops north and east of Thomson Rock (Fig. 9) and of the main north–south ridges 5 km east of Mount Bagshawe also indicate that a north-easterly wind prevails in this part of the plateau. However, the arêtes of these ridges (Fig. 10) have a north–south trend which is considered to have resulted from a pronounced mineral lineation in the gabbroic rocks forming them.

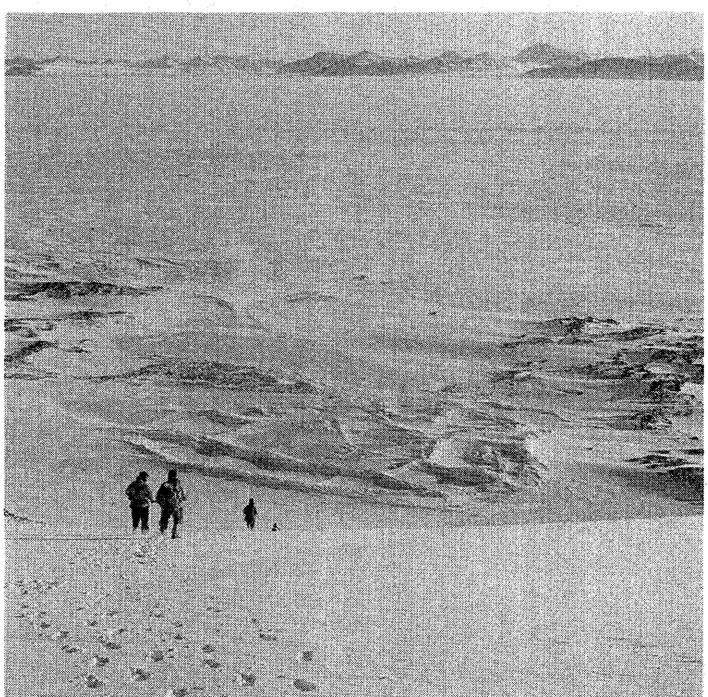

FIGURE 7
The ice-collapse structure at the foot of Bushell Bluff and the morainic debris accumulated on the ice shelf of George VI Sound.

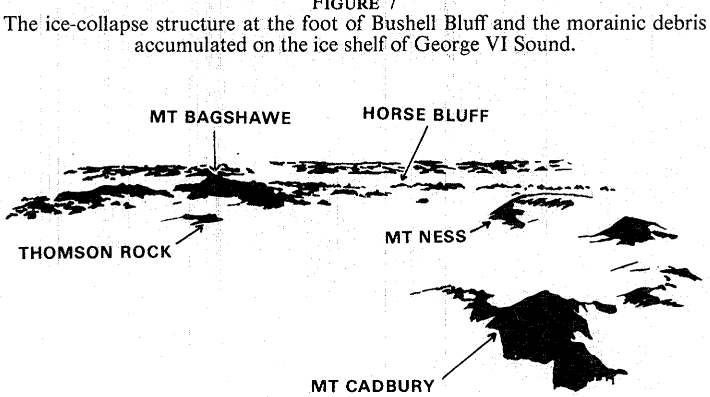

FIGURE 8
A reconstruction (from the RARE air photographs; RT M7 163–176) showing the increasing ice cover towards the east in the Batterbee Mountains.

FIGURE 9
A view of the 30 m deep windscoop at the north-east of Thomson Rock showing the overhanging lip and the layered ice in the windscoop face.

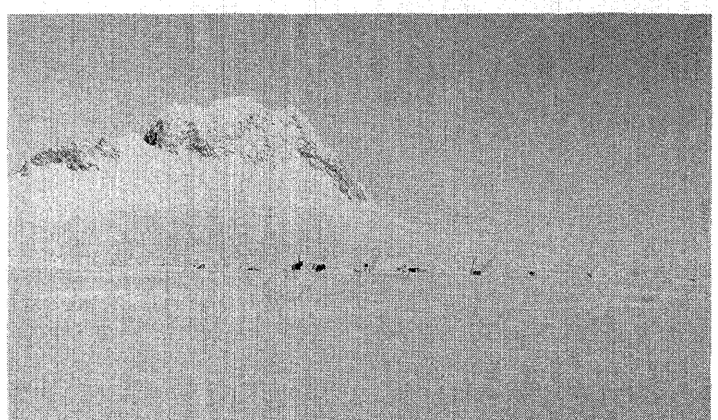

FIGURE 10
The arête of the eastern nunatak of the main north–south ridge 5 km east of Mount Bagshawe. The trend of these ridges is considered to have resulted from the mineral lineation in the gabbros forming them.

Avalanches were more frequently observed in the Batterbee Mountains than in the Taurus and Braddock Nunataks area, and these were particularly derived from the cirques and ice falls on the flanks of Mounts Bagshawe and Ness.

3. *Landscape evolution*

There are many features which indicate an earlier, more extensive ice cover as postulated by Knowles (1945, p. 134). Large ice caps, which may be the remnants of a former more complete ice cover, occur on the summits of Swine Hill (Fig. 11), Bushell Bluff and the ridges south of Armstrong Glacier. In the coastal mountains north of Swine Hill and around Horse Bluff, there are several large north-west-facing cirques. Although these by trenches occupied by heavily crevassed valley glaciers descending westward from the plateau.

Where the glaciers from the plateau flow into the ice shelf of George VI Sound, an area of pressure ice always develops and in summer melt-water pools frequently fill depressions in the pressure ice. At the foot of Bushell Bluff, a small ice-collapse structure (cf. Fleming and others, 1938, p. 512) was observed (Fig. 7) and this may have been caused by subsidence along a tide crack. At the same locality, moraine debris between ice streams from Norman Glacier and from an adjacent minor glacier to the south extends about 1.6 km westward on to the ice shelf of George VI Sound.

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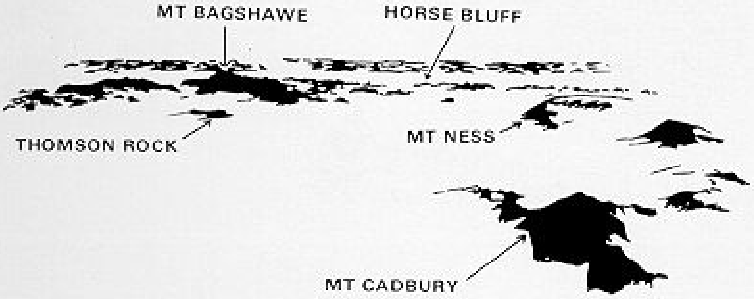

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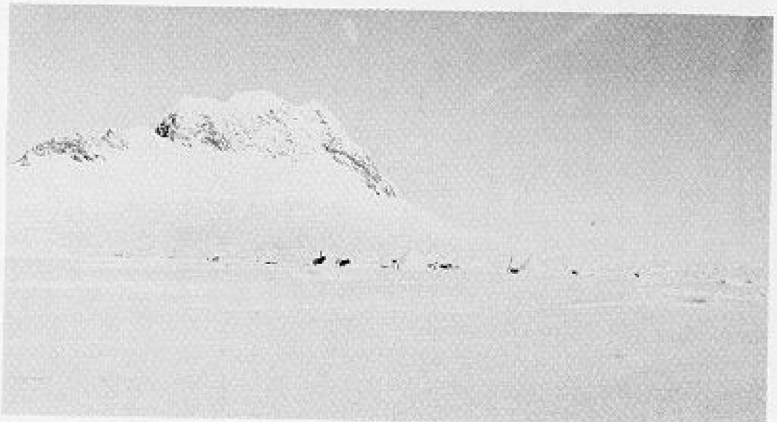

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A geological contact follows and probably determines the north-west-trending valley north of Mount Bagshawe and the north–south-trending valley on the western side of Mount Bagshawe (Fig. 1). In both cases, acid intrusive rocks crop out on one side of the valley while dark-coloured unidentified rocks form the sheer northern and western cliff faces of Mount Bagshawe itself.

It is probable that only the summits of Mounts Bagshawe and Ness, protected by a layer of *névé*, were not covered by the ice at its maximum extent and that the glaciated forms of the nunataks and mountains which are described above were formed as the ice receded.

III. STRATIGRAPHY

A. The Taurus and Braddock Nunataks Area

In this area the following generalized stratigraphical succession has been established:

3. Dyke swarm.
2. Granodiorite and associated minor intrusions.
1. Volcanic group.

Since only a few of these rocks have been radiometrically dated, the available results cannot be used to plot any definitive pattern or to define intrusive episodes. It is therefore only possible to assign tentative ages based on evidence from elsewhere in the Antarctic Peninsula. The volcanic group may form part of the Upper Jurassic volcanicity recorded elsewhere in the Antarctic Peninsula and the granodiorites are tentatively correlated with the Andean intrusive rocks. The dyke swarm may represent a late phase of the intrusive cycle of the Andean orogeny or, alternatively, it may belong to a later episode.

1. *Volcanic group*

Volcanic rocks crop out in the south-western and south-eastern groups of the Braddock Nunataks, and at nearby stations KG.213 and 214 (Fig. 16). From their aspect, it seems probable that they represent the remains of a large volcanic cone(s), centred west of station KG.215 in the Braddock Nunataks. It is probable that the isolated outcrop of rhyolite at station KG.232, 6.5 km north-east of Cetus Hill, is also related to the volcanic succession to the north.

The rocks forming this volcanic succession are typical of the basalt–andesite–rhyolite association with andesitic tuffs predominant. They are frequently impregnated with limonite and calcite but, apart from this evidence of hydrothermal activity, they are relatively unaltered. However, adjacent to the granodiorite intrusions, the volcanic rocks have been thermally and chemically altered within a contact zone up to 30 m wide. The regional dip in the volcanic succession of the Braddock Nunataks area is eastward, although variations due to depositional dips and more pronounced anomalies caused by the folding of the volcanic rocks over granodiorite intrusions have complicated this pattern.

It seems probable from the distribution and aspect of the outcrops that the oldest volcanic rocks occur at station KG.214 and on the western flanks of the south-western group of the Braddock Nunataks. At station KG.214, where the volcanic rocks are domed over a small granodiorite intrusion (Fig. 17), the volcanic succession grades upwards from a lower sequence of andesitic tuffs interbedded with occasional basalt lava flows into successive basalt lava flows (Fig. 18). These are cut by vertical dolerite dykes striking at 145° (mag.); one of these is baked by a dyke of porphyritic microgranodiorite which is derived from the later granodiorite intrusion. For this reason, these dolerite dykes at station KG.214 are considered to be feeders to the volcanic rocks rather than part of the later dyke swarm.

Basic rocks form the lowest part of the volcanic succession on the western flanks of the south-western group of the Braddock Nunataks but most of the accessible outcrops are contaminated by the granodiorite. This hybridized granodiorite of the contact zone contains many basic xenoliths and xenocrysts derived from the lower part of the volcanic succession and these indicate that the lowest volcanic rocks were basaltic.

The lowest uncontaminated outcrops recorded at stations KG.215 and 224 are andesitic tuffs which are interbedded with occasional lava flows (Fig. 19). About 60 m of these north-easterly dipping tuffs are succeeded at station KG.215 by a distinctive sequence of massive, flinty porphyritic rhyolites with a columnar jointing pattern. These rhyolites also dip steeply north-eastward and form the western walls of the large amphitheatre in the northern cliff face at station KG.215.

This distinct rhyolite horizon appears in other more southerly outcrops of the south-western group of the Braddock Nunataks and is used as marker horizon A, by which the stratigraphical successions within the individual nunataks of the Braddock Nunataks have been correlated (Fig. 16). A glassy, porphyritic spherulitic rhyolite crops out at the summit of station KG.221 but farther south at stations KG.218, 219 and 224 in the

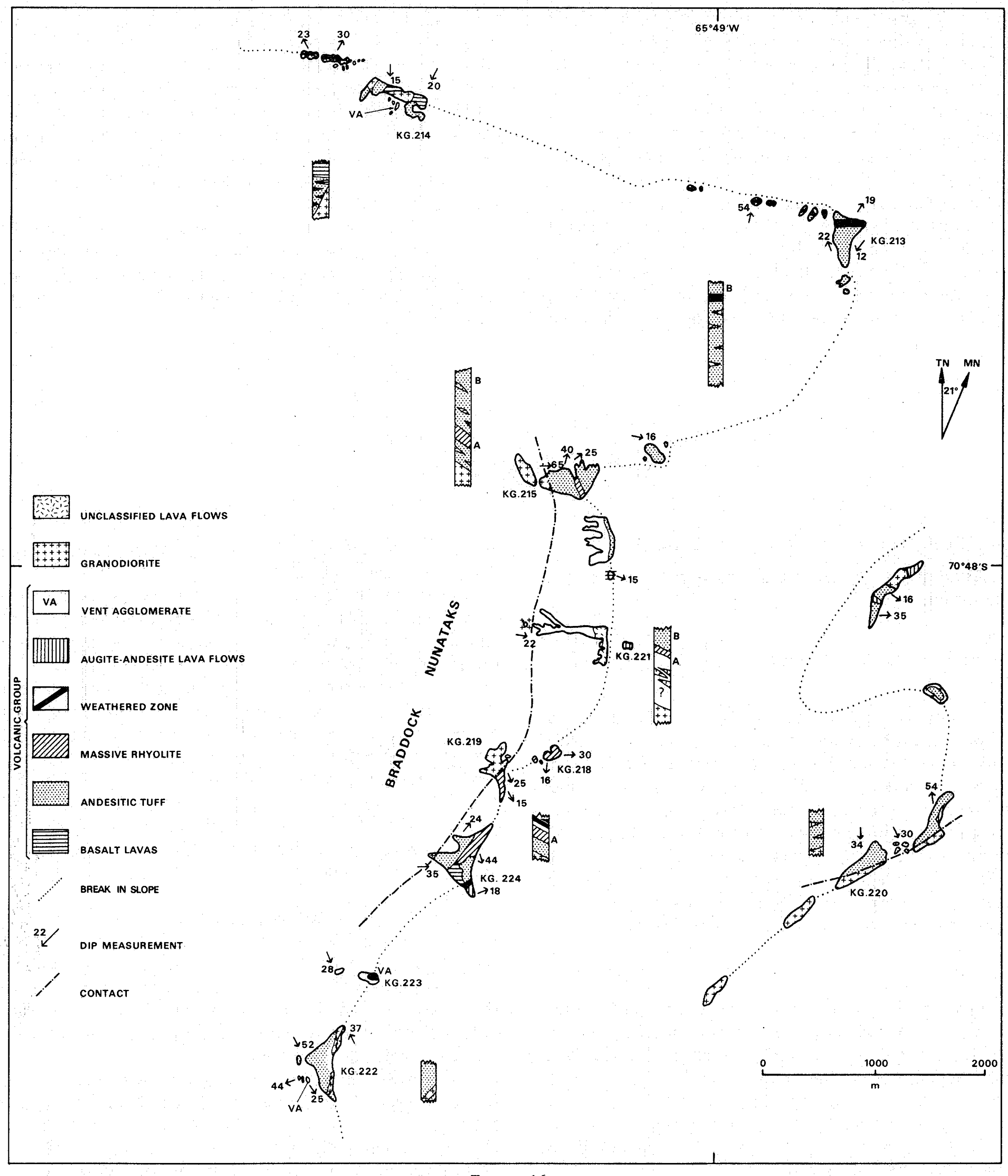


FIGURE 16

A geological sketch map of that part of the Braddock Nunataks area where volcanic rocks occur. Also included are stratigraphical columns at each group of outcrops, indicating the marker horizons A and B which may be correlated.

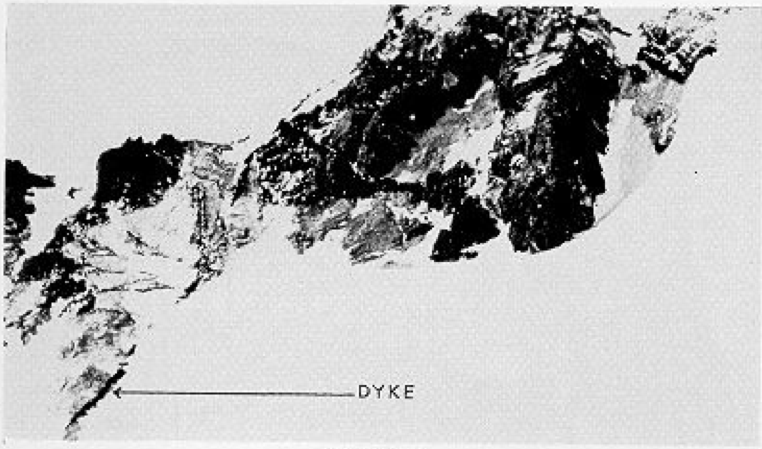


FIGURE 17
A view northward of part of the steep southward-dipping contact between the dark-coloured volcanic tuffs and light-coloured granodiorite at station KG.214 in the Braddock Nunataks. A 1.3 m wide dolerite dyke of the later dyke swarm cuts the granodiorite intrusion.

FIGURE 20
Rhyolite which forms much of the upper part of the succession at station KG.224 in the Braddock Nunataks. The adze of the ice-axe indicates the scale.

Braddock Nunataks flow-banded rhyolites similar to those at station KG.215 occur (Fig. 20). The flow-banded rhyolites at station KG.232 may also be closely related to these rhyolites of the Braddock Nunataks.

At station KG.215, the rhyolites are succeeded by further andesitic tuffs with interbedded lava flows which form the eastern wall of the amphitheatre (Fig. 19). At the summit of station KG.215, these are overlain by green well-bedded tuffs which form the uppermost part of this succession. Similar well-bedded green tuffs form the summits of stations KG.213 and 221, and are used as a second marker horizon B (Fig. 16). Although the cliff face at station KG.213 was not accessible, it was possible with the aid of binoculars to see a succession of tuffaceous rocks interbedded with lava flows exposed as darker horizons (Fig. 21). This succession of about 90 m of north-easterly dipping tuffs at station KG.213 is considered to be equivalent to the andesitic tuffs underlying marker horizon B of the green bedded tuffs at station KG.215. However, no rhyolite horizon is apparent either at station KG.213 or in the small outcrops exposed in the ice cliff to the south and west.

Directly beneath the well-bedded green tuff horizon at the summit of station KG.213 is an iron-stained zone of ashes and

FIGURE 18
Successive basalt lava flows at the summit of station KG.214 in the Braddock Nunataks. The massive flow in the photograph is 1.3 m thick.

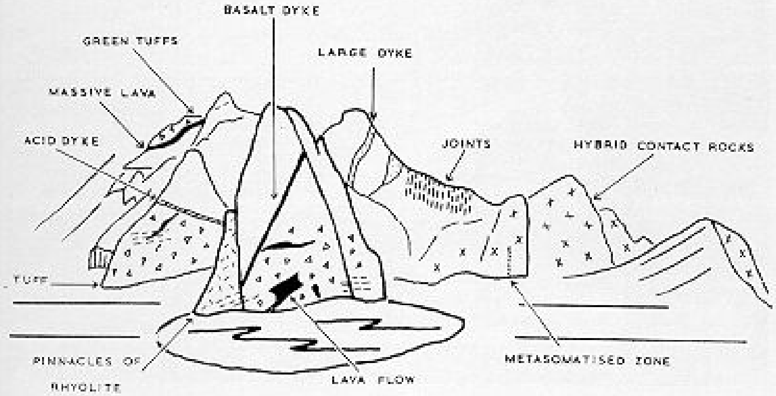


FIGURE 19
A field sketch of the 100 m high northern face of station KG.215 in the Braddock Nunataks showing the distribution of the rock types.

FIGURE 21
Station KG.213 in the Braddock Nunataks viewed from the west showing the north-eastward dip of the 100 m thick succession of volcanic rocks.

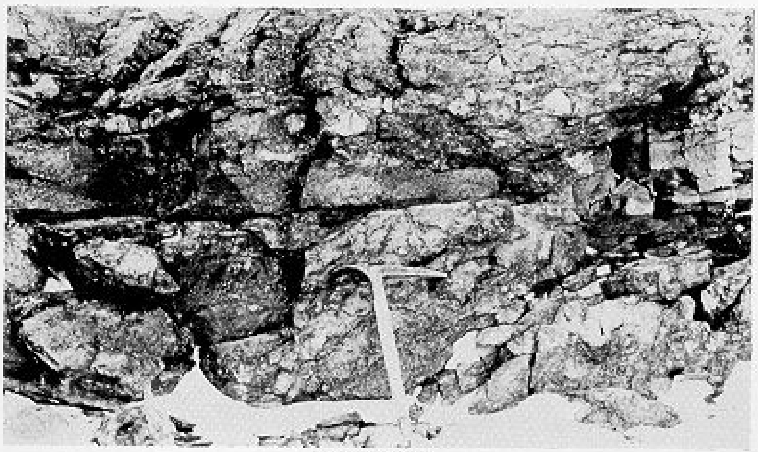


FIGURE 22
A bedded sequence of tuffs and ashes which crop out above the rhyolite horizon at the extreme south-eastern tip of station KG.224 in the Braddock Nunataks. Oval fragments of rhyolite and granodiorite are included in these tuffs.

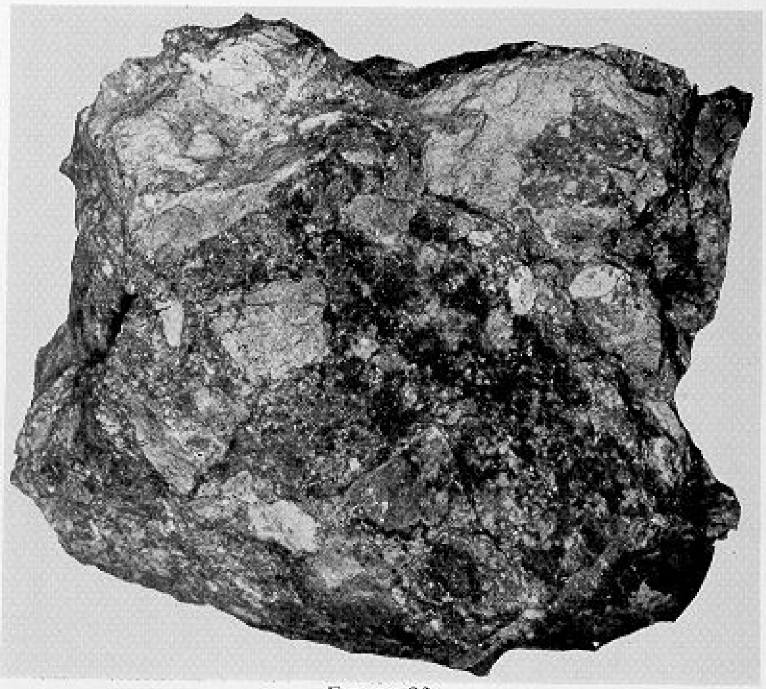


FIGURE 23
Green andesitic tuff from station KG.220 containing angular fragments of rhyolite and pumice set in the finer-grained matrix. (×0.4)

tuffs which may have been formed by weathering between successive eruptions. Although no weathered horizon was recorded at stations KG.215 and 221, a similar weathered zone does occur above the rhyolite marker horizon A at station KG.224 in the Braddock Nunataks. This zone crops out directly above an unusual sequence of bedded tuffs and ashes containing many rhyolite fragments and some granodiorite pebbles (Fig. 22), and it is succeeded by an augite-andesite lava flow. A similar lava flow occurs in the highest part of the succession at station KG.221 above the green bedded tuff horizon B and many augite-andesite lava flows occur in the youngest volcanic rocks of the south-eastern group of the Braddock Nunataks. Although no definite correlation may be made between these two weathered horizons, they do occur in a comparable part of the volcanic succession immediately below the green bedded tuff horizon B.

The south-eastern group of the Braddock Nunataks, which lie to the east of the main peaks, are composed of the youngest volcanic rocks in this area. These dip predominantly eastward and consist of green andesitic tuffs, containing many angular rhyolite, ash and pumice fragments (Fig. 23), which are interbedded with augite-andesite lava flows.

The most controversial feature of some of the andesitic tuffs which form this group of the Braddock Nunataks and of those comprising the southernmost nunataks of the south-western group is the presence of rounded granodiorite boulders within the tuffaceous matrix (Fig. 24). It is considered that these boulders were derived from an earlier granodiorite which is no longer exposed in this area (p. 30).

Vent agglomerates cut the earlier volcanic rocks at the isolated nunatak 12 km west of the Braddock Nunataks (KG.212) and at stations KG.214, 222 and 223. These agglomerates are composed of boulders of the above-mentioned granodiorite and of large blocks of earlier volcanic rocks set in a fine-grained andesitic matrix (Fig. 25). Hydrothermal activity associated with these vents has caused intensive limonite and calcite impregnation of the surrounding rocks.

At station KG.223 in the Braddock Nunataks, one such vent agglomerate is cut by a 10 m thick sill of porphyritic microgranodiorite (Fig. 26). Since this dyke is related to the grano-

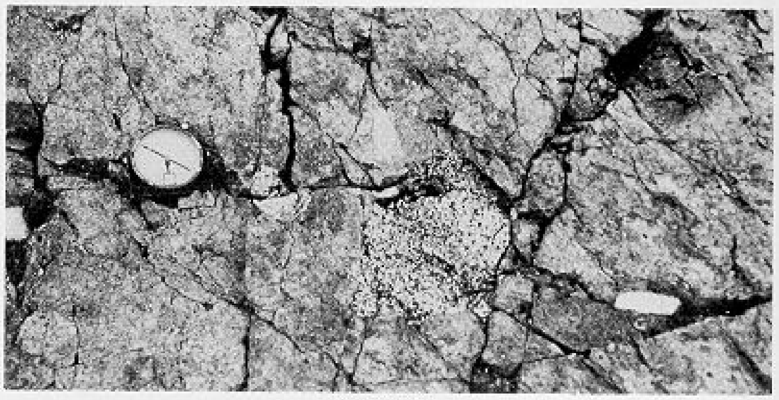


FIGURE 24
Rounded fragments of granodiorite which occur in the andesitic tuffs at station KG.222 in the Braddock Nunataks.

FIGURE 25
The vent agglomerate at station KG.214 in the Braddock Nunataks showing many large rounded boulders of its earlier volcanic rocks contained in a fine-grained andesitic matrix impregnated with calcite and limonite.

diorite, it is concluded that these vent agglomerates are part of a late phase of explosive activity within the volcanic group.

A narrow zone of laminated pink rock, which is similar to the marginal outcrops of the granodiorite intrusion at station KG.214, fringes the vent agglomerate at this locality (Fig. 27). This "dyke" and a similar acid dyke, which is adjacent to the vent at the foot of station KG.222, are considered to have been injected from the granodiorite intrusion along the earlier lines of weakness formed by the vents.

2. *Granodiorite and associated minor intrusions*

Granodiorite, which is widespread in the Taurus and Braddock Nunataks area, forms the nunatak groups surrounding the depot site in the Taurus Nunataks and at station KG.228 (Fig. 79). The isolated nunatak 12 km west of the Braddock Nunataks (KG.212) and the Friedmann Nunataks are also composed of acid rocks which are allied to the granodiorite. At the contact between this granodiorite and the volcanic rocks which are exposed along the western flank of the south-western group of the Braddock Nunataks, at station KG.214 and in the south-eastern group of the Braddock Nunataks, the marginal granodiorite is contaminated by the volcanic country rock.

The granodiorite is a coarse-grained mesocratic plutonic rock characterized by a pronounced mineral lineation. This is most conspicuous because of the alignment of the tabular mafic minerals, hornblende and biotite, but it is also accentuated by the alignment of the ubiquitous finer-grained xenoliths derived from more basic country rock (Fig. 28). The extent to which these xenoliths have been digested and their concentration within the granodiorite depends on their distance from the contact (Fig. 29). A well-defined igneous jointing pattern affects the granodiorite (Fig. 30) with the cross (*Q*) joints usually open and veneered with limonite and epidote. It is probable (p. 54)

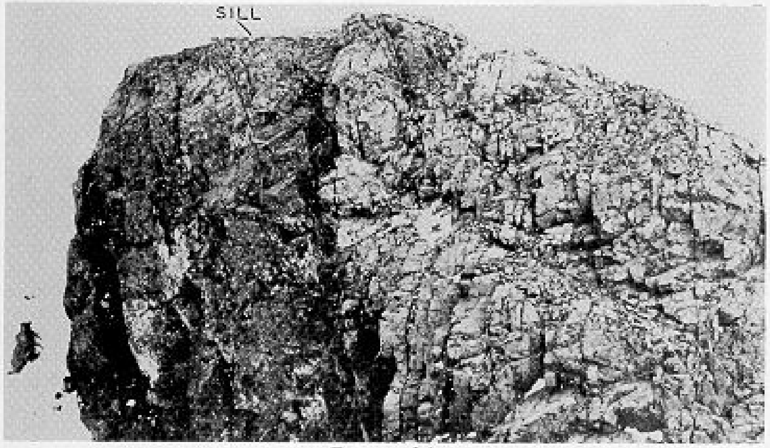


FIGURE 26
The vent at station KG.223 in the Braddock Nunataks; this cuts and has baked the earlier volcanic rocks, and in turn it is cut by a 10 m thick microgranodiorite sill at the summit.

FIGURE 28
The characteristic texture of a coarse-grained granodiorite (from station KG.228). Partly digested more basic xenoliths (4 cm long) and bands enriched with mafic minerals accentuate the overall mineral alignment.

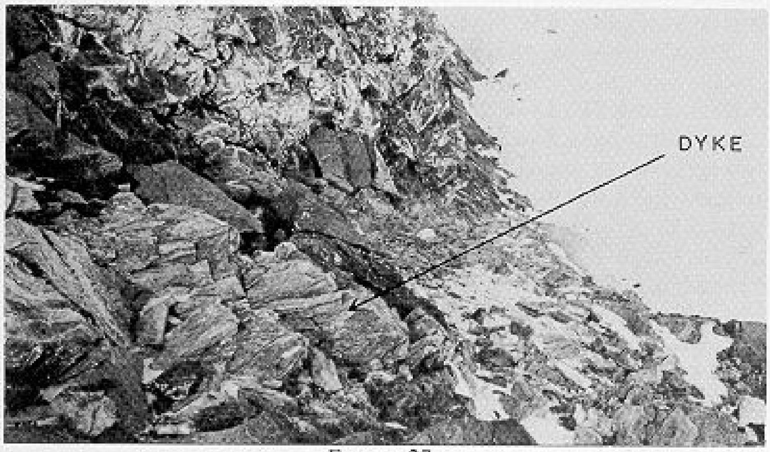


FIGURE 27
Calcite impregnation of the volcanic rocks surrounding the vent at station KG.214 in the Braddock Nunataks. A 0.8 m wide laminated acid "dyke" intrusion follows the edge of the vent.

FIGURE 29
Xenoliths of undigested volcanic rocks up to 6 cm long are contained in the porphyritic microgranodiorite marginal variant of the granodiorite at station KG.214 in the Braddock Nunataks.

FIGURE 30
An igneous jointing pattern within part of the granodiorite outcrop of the nunatak 12 km west of the Braddock Nunataks. The flat-lying joints dip north-westward at 22°, while the 6 m high south-facing wall represents the planes of the cross (*Q*) joints.

that the granodiorite outcrops represent the tops of several cupolas which are elongated in the north-north-west to south-south-east predominant trend of mineral lineation. These outcrops therefore represent only the margin of the core of Andean intrusive rocks which extends through the Antarctic Peninsula in these latitudes.

The contact between the granodiorite and the volcanic country rock is discordant in some places and concordant in others but mineralization and metamorphism of the volcanic rocks is always due to the intrusion. On the western flanks of the south-western group of the Braddock Nunataks, the contact, wherever it is visible, is discordant, and at station KG.224 it dips eastward at 50° (Fig. 31). A similar eastward-dipping discordant contact occurs at station KG.215, where the steep dip of the volcanic rocks may be partly due to the effects of the intrusion. At station KG.214 the volcanic rocks have been domed upwards by the force of this granodiorite intrusion (Fig. 17) and the contact is discordant at the sides of the intrusion but concordant at the summit. Adjacent to these discordant contacts there may be a zone of thermally metamorphosed volcanic rocks up to 30 m wide and a set of joints parallels the

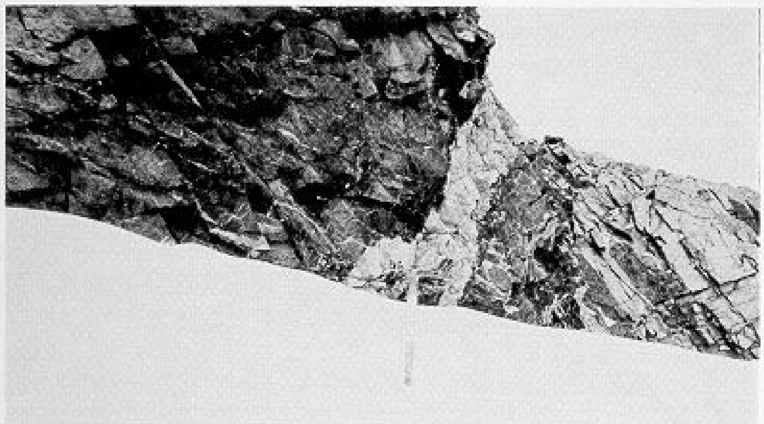


FIGURE 31
The eastward-dipping discordant contact at station KG.224 in the Braddock Nunataks between granodiorite and thermally metamorphosed andesitic tuffs. Dykes branch from the main intrusion into the volcanic rocks and a well-developed jointing system parallels the contact.

contact. Veins and dykes of porphyritic microgranodiorite branch into the adjacent volcanic country rocks (Fig. 31), which are also permeated by stringers, veins and lenses of mobile acid material. At station KG.214, pockets of red ochre derived from pyrite occur within the volcanic rocks but this and the assimilation features referred to above decrease in intensity away from the granodiorite.

The granodiorite adjacent to discordant contacts is hybridized by material absorbed from the volcanic rocks and it is consequently much darker than the uncontaminated outcrops. At station KG.215 the marginal granodiorite contains pyrite crystals and within all these hybridized rocks the texture varies from coarse- to fine-grained bands which incorporate varying amounts of derived material. These hybridized rocks are cut by pink felsite stringers (Fig. 32).

FIGURE 32
Veins of fine-grained felsite cut the hybridized granodiorite outcrops near the contact at the foot of station KG.221 in the Braddock Nunataks.

In contrast, at the concordant contacts which occur at the summit of station KG.214 and in the south-eastern group of the Braddock Nunataks, a pink porphyritic microgranodiorite is interleaved with layers of metasomatized volcanic rock. In spite of this *lit-par-lit* intrusion, the metasomatized rock frequently retains traces of its original volcanic texture but it is always strongly iron-stained. Calcite, limonite and zones of elongated zeolite-filled vesicles are abundant in the layers of metasomatized volcanic rock.

Small, irregular pegmatite intrusions with chilled margins occur in the granodiorite at the westernmost of the Taurus Nunataks (KG.211). These are characterized by the occurrence of euhedral muscovite and small garnet crystals set in a graphic intergrowth of quartz and feldspar. These intrusions vary from narrow irregular stringers to branching dykes as much as 60 cm across and they dip predominantly south-westward at moderate angles. They have been injected into a cooled granodiorite and represent a late stage of the intrusive cycle.

It has already been stated above that porphyritic microgranodiorite dykes and veins branch from the granodiorite at the discordant contacts with the volcanic country rocks. However, there are many independent minor intrusions of microgranodiorite. At station KG.214, several dykes of a porphyritic microgranodiorite, up to 3 m across, dip eastward at about 60° in a direction approximately parallel to the contact. Large dykes, which also dip steeply eastward, cut the volcanic rocks at station

FIGURE 36
A 2 m wide porphyritic augite-microdiorite dyke which cuts the granodiorite at station KG.228. Joints in the granodiorite parallel the dyke edge and a narrow zone of metasomatized granodiorite has resulted from the dyke intrusion.

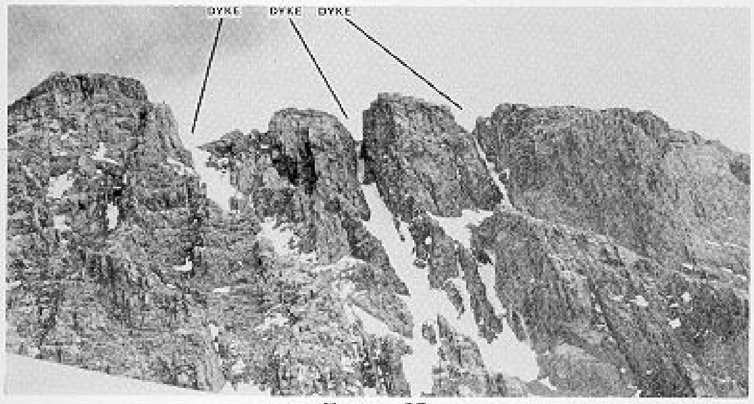


FIGURE 37
Trenches in the volcanic rocks of station KG.222 in the Braddock Nunataks due to the different rates of erosion of the dykes occupying them and the surrounding volcanic rocks.

B. BATTERBEE MOUNTAINS

The stratigraphical succession in the Batterbee Mountains is related to that in the Taurus and Braddock Nunataks area. This succession is:

3. Dyke swarm.
2. Andean intrusive rocks and associated minor intrusions.
1. Volcanic group.

1. *Volcanic group*

Volcanic rocks appear to form a large part of the western Batterbee Mountains, cropping out on the flanks of Armstrong and Norman Glaciers, inland of Swine Hill, at the west of Horse Bluff and probably also on the western and southern sides of Mount Bagshawe. However, it was only possible to make detailed geological obsevations at Swine Hill, where the volcanic succession consists of rhyolite lavas with interbedded tuffs which become more abundant in the upper parts (Fig. 38). These volcanic rocks represent material derived from a volcanic centre south of Swine Hill, from which predominantly acid rocks were erupted.

The outcrop at northern Swine Hill consists of a sequence of fine-grained porphyritic rhyolite lava flows, which dip northward and north-westward at about 20°. These rhyolites are interbedded with lenses and more consistent layers of gravelly tuffaceous rocks containing angular fragments of the rhyolites set in a matrix of quartz and feldspar crystal fragments. The tuffs, which are frequently iron-stained due to weathering that took place between the eruptions, are impregnated with calcite; this fills cavities within the rocks and veneers the joint planes. Higher in the succession these tuffs contain large boulders of a glassy rhyolite, whereas the lava flows, which are sometimes finely laminated, become increasingly vitreous. The highest part of the succession, which is exposed near the survey cairn at the summit of Swine Hill, consists of coarse iron-stained tuffs and agglomerates interbedded with quartz-porphyry lava flows.

The dips in the southern part of Swine Hill are extremely variable but it appears that the outcrops are part of an asymmetric anticline which plunges at about 20° in a direction 270° (mag.) (Fig. 38). The lowest part of the succession, exposed in the southernmost cliff face, consists of grey-green rhyolite lava flows with slaggy iron-stained upper surfaces interbedded with tuffs. Green massive tuffaceous rocks containing angular fragments of brown rhyolite form the uppermost part of this succession, which is exposed at the western end of southern Swine Hill. Iron-stained volcanic breccias appear to be interbedded with these massive tuffs at the summit of Swine Hill and are underlain to the east by well-bedded green quartz-porphyries. These have been corrugated into alternate small anticlines and synclines on the southern limb of the major anticline, the axis of which trends at 270° (mag.). Crystalline calcite fills cavities and veneers the joint planes of these quartz-porphyries. This succession of southern Swine Hill may lie nearer the volcanic centre because of the greater content of agglomerates and coarse tuffs.

On the southern side of Norman Glacier, a similar succession of acid lavas and tuffs crops out at Bushell Bluff and also appears to crop out in the east–west-trending ridges farther south. Just below the summit at Bushell Bluff, quartz-porphyry lavas occur, although the summit itself is formed of iron-stained green tuffs which dip gently south-eastward and which contain angular fragments of rhyolite lavas (Fig. 14). These tuffs are similar to those at the summit of southern Swine Hill. Within the succession at Bushell Bluff, the regional dip, observed from Norman Glacier, is south-eastward at about 20°

At Horse Bluff, volcanic rocks crop out at the western ends of the ridges which trend east–west into George VI Sound. Quartz-porphyry lavas recorded from the western foot of Tindley Peaks may be related to the Swine Hill volcanic succession.

A vent agglomerate forms a small knoll (KG.209) in the middle of Norman Glacier. This agglomerate is composed of granodiorite, light-coloured glassy rhyolite and porphyritic flinty rhyolite boulders set in a fine-grained iron-stained rhyolitic matrix. A complex jointing pattern affects these rocks, which are

KG.215 near to the granodiorite/tuff contact (Fig. 19) and dip in the same direction as the well-developed joints which parallel this contact. To the south, in the south-western group of the Braddock Nunataks, similar minor intrusions of microgranodiorite occur: notably at station KG.218, where a 3 m wide dyke dipping north-westward at 70° cuts and bakes rhyolite lavas; at station KG.219, where a 6.5 m wide vertical dyke with associated pyrite mineralization strikes at 123° (mag.) and actually cuts the granodiorite intrusion (Fig. 33); and at stations KG.222 and 223 in the southern part of the south-western group of the Braddock Nunataks.

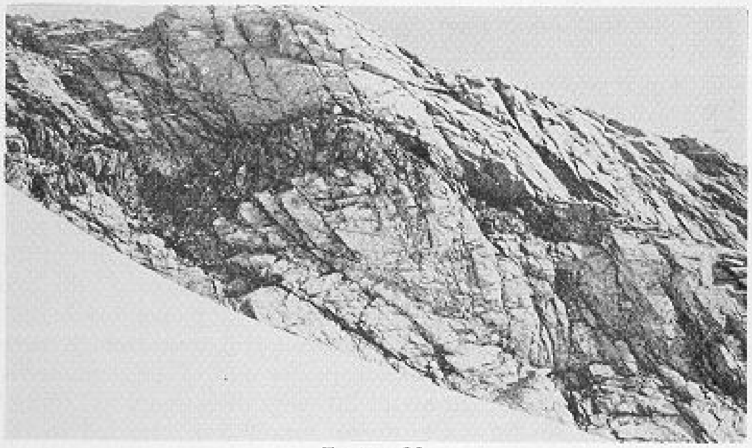


FIGURE 33
A 6 m wide dyke of porphyritic microgranodiorite which cuts the granodiorite at station KG.219 in the Braddock Nunataks.

These dykes of porphyritic microgranodiorite have a composition allied to that of the granodiorite, although some at least were definitely intruded after the granodiorite had solidified.

In the south-western group of the Braddock Nunataks, the granodiorite has either petered out or does not crop out. The most southerly outcrop of the granodiorite occurs at the extreme west of station KG.224 and acid dykes branch off into the volcanic rocks at this contact. To the south of this nunatak, the granodiorite is represented by a pattern of minor intrusions. At station KG.223, a broad porphyritic microgranodiorite sill with a chilled pitchstone margin cuts the volcanic rocks (Fig. 26). This sill, which dips south-westward at 22°, is impregnated with pyrite. Farther south, at station KG.222, this sill extends into a complicated pattern of minor intrusions of microgranodiorite which eventually form a 10 m wide dyke dipping south-westward at 75° at the extreme east of station KG.222 (Fig. 34). Pyrite mineralization is associated with this dyke, whereas the volcanic rocks immediately above it are impregnated with mobile acid material in the same way as at the discordant granodiorite/tuff contact at station KG.214.

At the extreme west of station KG.222, adjacent to the vent agglomerate, there is a 6.5 m wide dyke of metasomatized pink acid rock (Fig. 35). This dyke, which follows an earlier line of weakness (p. 15), dips south-eastward at 85°. A sill of similarly metasomatized acid rock, dipping southward at 38°, cuts the granodiorite at Cetus Hill (KG.230) and again this illustrates the conclusion that some if not all of these minor acid intrusions post-date the granodiorite.

FIGURE 34
A 10 m wide dyke of porphyritic microgranodiorite which cuts the volcanic rocks at station KG.222 in the Braddock Nunataks.

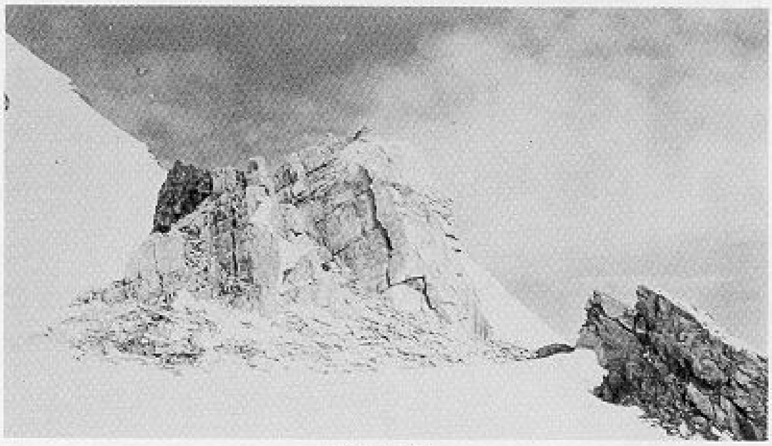


FIGURE 35
A 6 m wide acid dyke, which dips at 85° south-eastward, adjacent to the vent agglomerate at the western foot of station KG.222 in the Braddock Nunataks.

3. *Dyke swarm*

Basalt, andesite, augite-andesite and augite-microdiorite dykes with a predominant north-west to south-west trend cut both the volcanic rocks and the granodiorite in the Braddock Nunataks area. The texture and the degree of alteration of the minerals within a dyke are related to its width, although the composition of each dyke is also modified by the amount of material which has been derived from the country rock into which it has been injected.

These dykes, invariably with chilled margins, bake the country rocks into which they have been intruded and produce a set of joints parallel to the contact (Fig. 36). They also contaminate the country rocks. This feature is particularly evident in the granodiorite which may be impregnated with epidote, pyrite and chalcopyrite within a few feet of a dyke.

These dykes are not as resistant to weathering as the volcanic country rocks and several trenches in the outcrop at station KG.222 are occupied by vertical dykes striking at 345° (mag.) (Fig. 37). In the granodiorite outcrops the dykes are more resistant than the surrounding rocks and tend to weather out (Fig. 36).

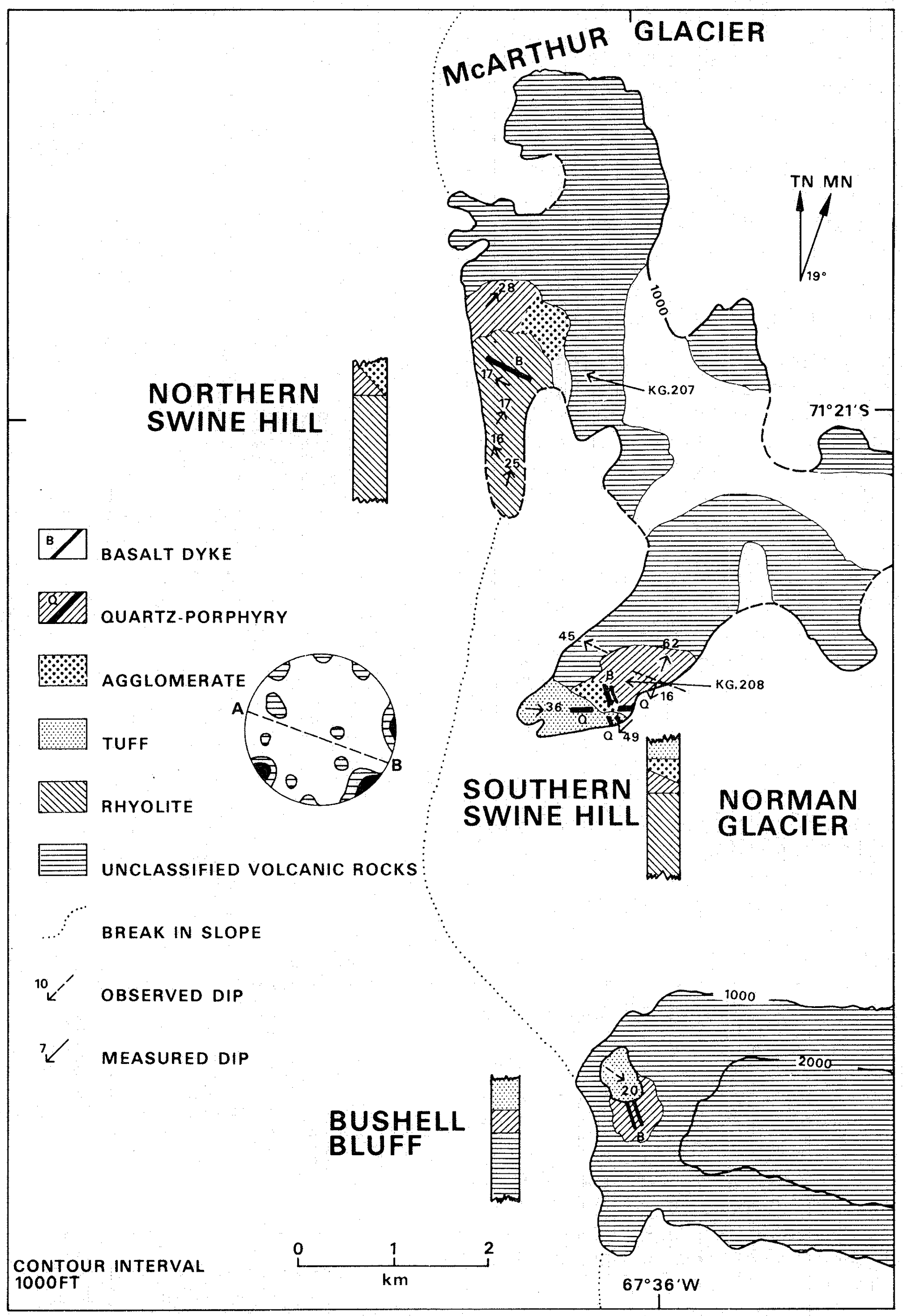


FIGURE 38
A geological sketch map of the Swine Hill area, showing the stratigraphical successions at the three outcrops which were visited. A contoured stereographic plot of the joint surfaces at Swine Hill (plotted on the lower hemisphere) indicates a degree of symmetry about the fold axis A–B. The extent of the volcanic rock outcrops is indicated by the horizontal shading.

contaminated with epidote. The granodirite boulders within the agglomerate pose the same problem as that in the Taurus and Braddock Nunataks area, since it may be that some explosive volcanic activity took place in the Batterbee Mountains after the granodiorite intrusion. However, since granitic rocks, unlike the granodiorite boulders in the vent agglomerates, occur in the western part of the Batterbee Mountains, it is probable that this granodiorite represents an earlier rock which is no longer exposed in this area.

Much farther to the east, on the plateau, R. R. Horne recorded a volcanic agglomerate at the nunatak 25 km north-east of Mount Cadbury; this contains many blocks of porphyritic andesite lava and nearby there are similar andesite lava flows.

2. *Andean intrusive rocks and associated minor intrusions*

A succession of Andean intrusive rocks, which ranges from gabbro to granodiorite and granite, has been established from the observations made in the Batterbee Mountains.

Gabbroic rocks are exposed 5 km east of Mount Bagshawe (KG.234), where they form three conspicuous north–south-trending arêtes, and at the peak 5 km south-west of Mount Ness (KG.237). The central part of the outcrop of gabbroic rocks is a coarse-grained troctolite, whereas the flanking parts are augite-microgabbros associated with lineated hornblende-gabbros and leucogabbros (Fig. 39). This lineation trends predominantly northward or slighty west of north and is almost vertical. Copper and iron staining of the gabbros often occurs, particularly near the granodiorite intrusions, the primary ores being chalcopyrite and pyrite, which are oxidized to malachite and limonite, respectively.

At station KG.237, the gabbro is intruded by granodiorite. This granodiorite is a medium-grained dark hybridized rock, which possesses a distinct mineral lineation and which also contains elongated xenoliths that have been derived from the adjacent gabbro. Marginal veins of a granite-pegmatite trending parallel to the contact at 310° (mag.) intrude the gabbro at the western end of this outcrop and pyrite occurs as narrow veins and disseminated crystals both in the granodiorite and in the gabbroic country rock. Within a zone about 30 m wide at the eastern contact, the gabbros are extensively stained with limonite and epidote as a result of the granodiorite intrusion.

On the eastern flanks of Mount Bagshawe, granite-pegmatite veins trending at 325° (mag.) cut the augite-leucogabbro, indicating that these gabbros have also been intruded subsequently by acid magma.

At Thomson Rock (KG.201) (Fig. 40), the granodiorite is a coarse-grained mesocratic rock in which the dark minerals and xenoliths are aligned in a direction 330° (mag.) and they dip north-eastward at approximately 70° (Fig. 41). Zones of dark medium-grained xenoliths up to 13 m long occur within the granodiorite (Fig. 42), which is also cut by many sub-horizontal pegmatite dykes and quartz stringers. Epidote and limonite veneering the open cross (*Q*) joints is infrequently associated with malachite.

Another outcrop of granodiorite recorded by R. R. Horne at Mount Cadbury possesses a mineral lineation which trends at 130° (mag.) and dips north-westward at 35°. At this locality, veins of the granodiorite intrude gabbroic rocks.

The acid rocks exposed north of Mount Bagshawe, and north and east of Horse Bluff, are also probably granodiorite. These outcrops are composed of pale grey and pink massive well-jointed rocks which become noticeably more orange-coloured towards the contact with volcanic rocks, and which are crossed by a network of basic dykes. They apparently intrude the earlier volcanic rocks (Fig. 43).

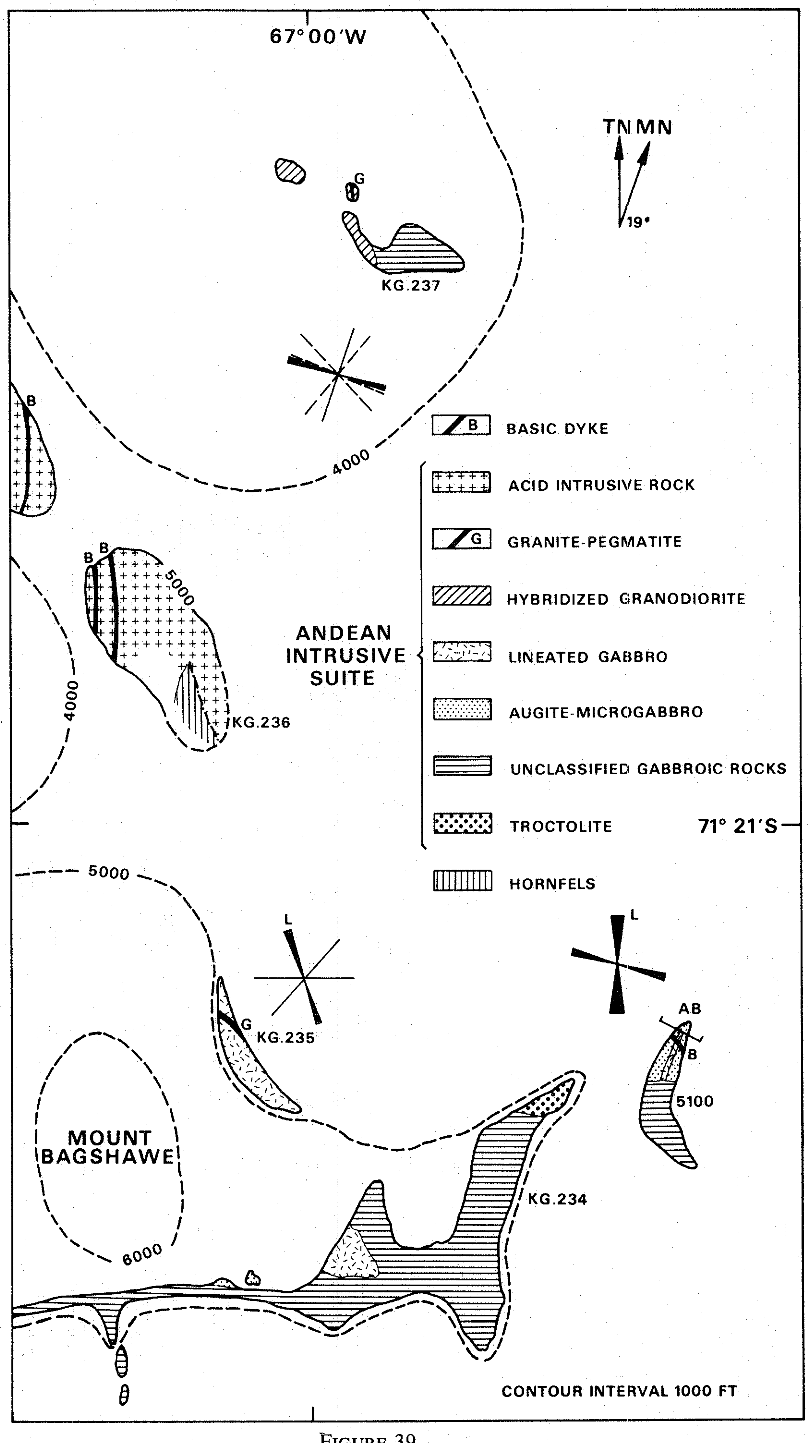


FIGURE 39
A geological sketch map showing the outcrop of gabbroic rocks north-east of Mount Bagshawe; also included are diagrams indicating the strikes of the predominant joint planes and the direction of mineral lineation, L. The unclassified outcrops of gabbroic rocks are indicated by horizontal shading.

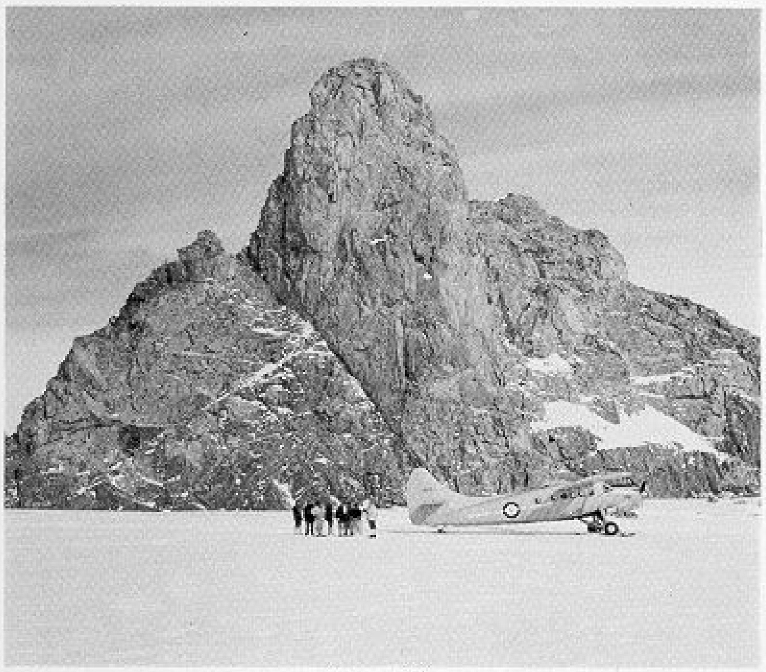


FIGURE 40
The granodiorite outcrop at Thomson Rock.

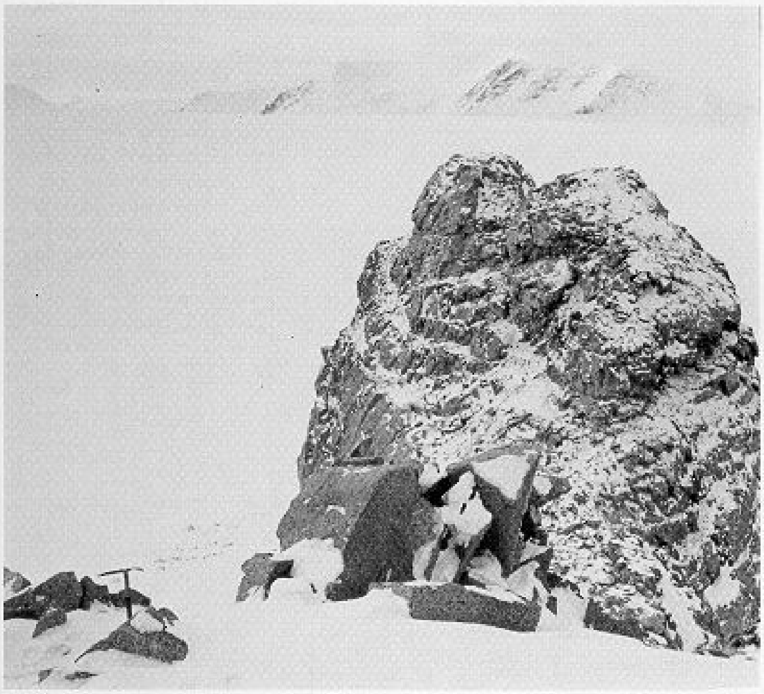


FIGURE 41
Granodiorite at the summit of Thomson Rock, showing the many small xenoliths enclosed by this well-jointed rock.

Pink granitic rocks crop out south of Armstrong Glacier and at Horse Bluff; they also occur as erratics on the summit of Swine Hill, to which they had presumably been carried from the east. It is uncertain whether these granites represent a later or a marginal phase of the main granodiorite intrusion but it is probable (Adie, 1954) that they are the last plutonic rocks to have been injected.

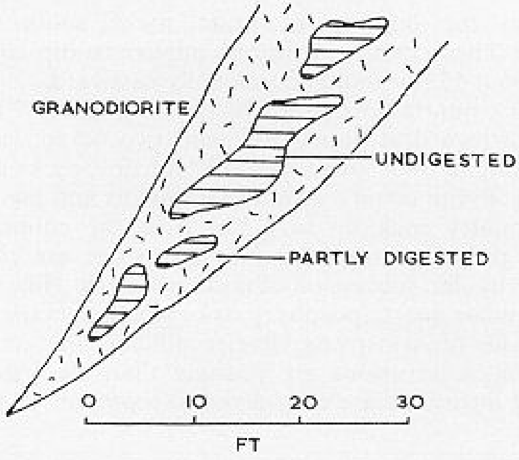


FIGURE 42
A field sketch showing the arrested process of assimilation of basic xenoliths by the granodiorite intrusion.

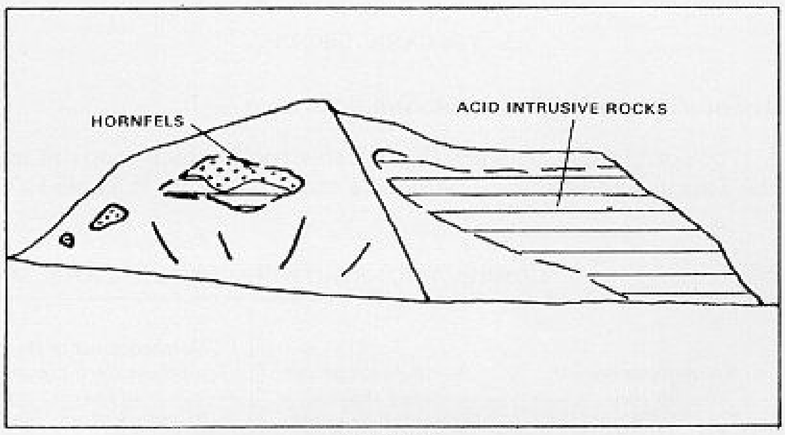


FIGURE 43
A contact exposed at station KG.236, north of Mount Bagshawe. Pink acid rocks intrude and hornfelsed darker fine-grained rocks. These hornfelses may have been derived from earlier basic volcanic rocks (p. 36). The face of the nunatak is about 230 m high.

On the south side of Armstrong Glacier a prominent ot outcrop of a medium-grained massive pink granite juts out into the glacier and has weathered to give a characteristic jagged ridge profile (Fig. 15). The joint planes within this granite are veneered with epidote and limonite, and the whole intrusion is cut by dolerite and quartz-porphyry dykes. The volcanic country rocks are baked at the contact with the granite intrusion. This contact continues in a north-westerly direction on the north side of Armstrong Glacier.

A small cupola of pink granitic rocks crops out at Horse Bluff, where it is cut by many basaltic dykes of the later swarm. This granite becomes increasingly fine-grained near the contact with the volcanic rocks and grades eventually into a grey porphyritic microgranite, which has a texture similar to that of the quartz-porphyry dykes within the volcanic rocks at Swine Hill.

Many minor intrusions related to the granite and granodiorite occur in the Batterbee Mountains. Thick irregular sills were observed within the volcanic rocks south of Bushell Bluff and within the outcrop of basic rocks south of Mount Bagshawe. These minor intrusions appear to dip either southward at about 45° or more occasionally eastward.

Two thick quartz-porphyry sills trending at 268° (mag.) and dipping northward at about 50°, and two 6.5 m wide vertical dykes striking at 340° (mag.), cut the volcanic rocks at southern Swine Hill. Pyrite occurs within these dykes and has impregnated the country rock up to 6.5 m from the contact. Several similar brightly iron-stained minor intrusions are conspicuous within the rhyolite succession of northern Swine Hill.

The irregular quartz-porphyry dyke which cuts the granite on the south side of Armstrong Glacier indicates that at least some of these minor intrusions are younger than the granite. These minor acid intrusions are considered to represent a late stage of the intrusive cycle, comparable to the phase of porphyritic microgranodiorite minor intrusions of the Taurus and Braddock Nunataks area.

3. *Dyke swarm*

A swarm of dolerite and andesite dykes cuts all the previous stratigraphical units, although the dykes are particularly conspicuous in the acid rocks north of Horse Bluff and Mount Bagshawe. The aspect of these dykes varies considerably but the predominant strike is north-west to south-east. The dykes have metasomatized the adjacent country rock, resulting in the formation of a narrow zone impregnated with epidote, limonite and less frequently with malachite.

IV. PETROLOGY

A. Volcanic Group

1. *The Taurus and Braddock Nunataks area*

The correlations between the volcanic rocks which crop out in the Taurus and Braddock Nunataks area are shown in Table I.

a. *Basaltic lavas and interbedded tuffs*. Andesitic lithic tuffs interbedded with andesine-basalt lava flows comprise the lowest stratigraphical horizon which is exposed at station KG.214. The number of lava flows increases at the expense of the tuff towards the summit of this nunatak, which is formed of successive lava flows, separated by rubble zones up to 0.3 m thick.

Table I

Correlations between the volcanic successions in the Braddock Nunataks area

North-westernmost of the Braddock Nunataks (KG.214)	*North-easternmost of the Braddock Nunataks (KG.213)*	*Northernmost of the south-western group of the Braddock Nunataks (KG.215)*	*Central ridge of the south-western group of the Braddock Nunataks (KG.221)*	*Stations KG.218, 219 and 224*	*Station KG.223 and southernmost of the south-western group of the Braddock Nunataks (KG.222)*
Vent agglomerate					Vent agglomerate
			Augite-andesite lava flow	Augite-andesite lava flow	
	Green well-bedded tuffs	Green well-bedded tuffs	Green well-bedded tuffs		
		Massive lava			
	Weathered consolidated ashes and tuffs			Weathered tuffs	
		Andesitic lithic tuffs with few interbedded lava flows		Layered andesitic tuffs and volcanic breccias	
	Andesitic lithic tuffs with infrequent interbedded lava flows	Flow-banded rhyolite lavas	Vitroclastic rhyolite	Spherulitic flow-banded rhyolite lavas and crystal tuffs	Andesitic lithic tuffs* containing accidental fragments of granodiorite
		Andesitic lithic tuffs with infrequent inter-bedded lava flows		Andesitic lithic tuffs	
Andesitic lithic tuffs inter-bedded with many andesine-basalt lava flows					

*These tuffs may be part of a parasitic cone derived from the vent at station KG.223.

The tuffs are dark green or black, massive but well-jointed rocks, which contain many tabular feldspar crystal fragments with their long axes orientated parallel to the bedding surfaces. Lithic fragments of essential basaltic scoria composed of an aggregate of magnetite and labradorite (An_{55}) crystals and less frequent lapilli of accessory rhyolitic tuff occur within the unsorted tuffaceous matrix. These rocks are irregularly iron-stained and the many joint planes are veneered with calcite and limonite due to late-stage deuteric alteration associated with the volcanism. The tuffaceous rocks and lava flows also contain disseminated crystals of pyrite which were produced by mineralization associated with the granodiorite intrusion.

Thin sections reveal that these tuffs are composed of large broken crystals of labradorite (An_{52}), infrequent corroded orthoclase crystals and uralite pseudomorphs of augite phenocrysts set in a cryptocrystalline felsic groundmass composed of randomly orientated andesine (An_{48}) microlites, granular magnetite and amorphous patches of uralite. The tuffaceous matrix is irregularly banded and vesicles within it are infilled by a radiating intergrowth of fibrous actinolite and penninite with a characteristic anomalous brown interference colour.

Near the granodiorite/tuff contact, these andesitic tuffs are propylitized to a bright green rock, in which the large feldspar crystals are stained pink and the pyrite crystals are oxidized to conspicuous pockets of red ochre. It appears that the original pyroxene within these tuffs has often been deuterically altered to uralite which is associated with some secondary granular quartz. However, the granodiorite intrusion has caused the pyroxene to be altered in a different manner. It is initially altered to actinolite, which is optically continuous with the pyroxene at the crystal edges, but gradually the core of the crystal also becomes completely pseudomorphed by a fibrous penninite–actinolite intergrowth.

The andesine-basalt lava flows, which crop out at the top of station KG.214, are dark grey or black aphanitic rocks containing orientated feldspar phenocrysts. Large labradorite (An_{50}) phenocrysts, which are zoned normally to An_{45} at the crystal edges, and phenocrysts of pale brown augite ($2V \simeq 55°$), twinned frequently on $\{100\}$, are set in an intergranular fine-grained matrix of andesine (An_{38}) microlites, subhedral magnetite grains and granular crystals of pale brown clinopyroxene. These are similar in composition to the phenocrysts and are associated with and to some extent pseudomorphed by uralite. Oval vesicles in the upper part of some of these flows are infilled by an intergrowth of crystalline quartz and epidote, and less frequent aggregates of fibrous actinolite and penninite (Fig. 44a). These amygdales tend to weather out of the surrounding lava. A modal analysis of a typical basalt is given in Table II (KG.214.27). The pyroxene within these basalts is also pseudomorphed in the two ways mentioned above: by uralite as a result of deuteric alteration associated with the volcanic activity, and by all stages of a complete penninite–actinolite intergrowth as a result of metasomatism caused by percolating alkaline solutions (Williams and others, 1954) derived from the granodiorite intrusion.

Of the several dolerite dykes cutting the basalt lava flows at least one is a feeder to the volcanic group of rocks (p. 11). These medium-grained porphyritic dolerites consist of unaltered phenocrysts of pale brown augite ($2V \simeq 50°$) and corroded labradorite (An_{61}) set in an intergranular groundmass of labradorite (An_{55}) laths, subhedral magnetite grains, euhedral augite granules and amorphous patches of uralite (Fig. 44b). Small crystals of an iron-rich biotite, which are pleochroic from deep brown to pale yellow, are associated with the uralite in one dyke (KG.214.26). Therefore, the amorphous patches of uralite in the basalts and tuffs may have been produced by the deuteric alteration of original biotite crystals which only appear in the unaltered doleritic rocks.

b. *Andesitic tuffs*. The andesine-basalts are succeeded by a considerable thickness of lithic andesitic tuffs, with which infrequent massive basic lava flows are interbedded. These tuffs are exposed in the ice cliff west of station KG.213, where they dip steeply northward, and in the cliff face of station KG.213 itself. The lower sequence of andesitic tuffs at station KG.215 is correlated with them and they are in turn correlated with the lower andesitic tuffs at station KG.224 in the south-western group of the Braddock Nunataks.

The tuffs west of station KG.213 contain many angular accessory fragments of porphyritic and spherulitic rhyolite together with fragments of rhyolitic tuff, trachytic andesite lava and holocrystalline epidote-impregnated porphyritic andesite. One atypical pumiceous lapillus of trachytic andesite contains sub-parallel oval vesicles filled with an intergrowth of secondary radiating chlorite associated with granular magnetite crystals. The long axes of these oval lapilli are approximately parallel to the bedding surfaces within the unsorted tuffaceous matrix, which is composed of sub-parallel crystal fragments of quartz, sericitized orthoclase, cloudy oligoclase (An_{28}) and penninite–actinolite pseudomorphs after augite. These crystal fragments are set in a cryptocrystalline felsic groundmass containing magnetite granules and local interstitial intergrowths of minute crystals of chlorite and actinolite. Euhedral basaltic hornblende (lamprobolite) microphenocrysts with a pleochroism scheme a = yellow, β = reddish brown and γ = red-brown are conspicuous in the groundmass (Fig. 44c).

At station KG.215, similar lithic tuffs contain sub-parallel angular lapilli of porphyritic and cryptocrystalline rhyolite lava and tuff, and porphyritic trachytic andesite lavas containing oligoclase (An_{27}) phenocrysts set in an unsorted matrix composed of fragments of orthoclase, quartz and andesine (An_{36}) crystals. The interstitial felsic groundmass, which is extremely fine-grained, is speckled with granules of magnetite, minute plagioclase microlites and amorphous intergrowths of chlorite and minute actinolite crystals (Fig. 44d). Both the lapilli and the tuffaceous matrix are cut by minute stringers of crystalline quartz and epidote derived from the granodiorite intrusion.

The lowest andesitic tuffs at station KG.224 contain similar lapilli of accessory fragments of rhyolitic tuff, and porphyritic andesite, trachytic andesite and rhyolite lavas, within an unsorted matrix of quartz and feldspar crystal fragments, with local aggregates of minute crystals of green biotite, actinolite and magnetite grains, which have also been produced by the granodiorite intrusion, weaving through lapilli and tuffaceous matrix alike.

c. *Rhyolitic lavas*. The andesitic lithic tuffs at station KG.215 are succeeded by about 30 m of rhyolite lava flows which are correlated with the rhyolite horizon at the summit of station KG.221 and at stations KG.218, 219 and 224 in the south-western group of the Braddock Nunataks. These rhyolites are also tentatively related to the rhyolites at station KG.232; all

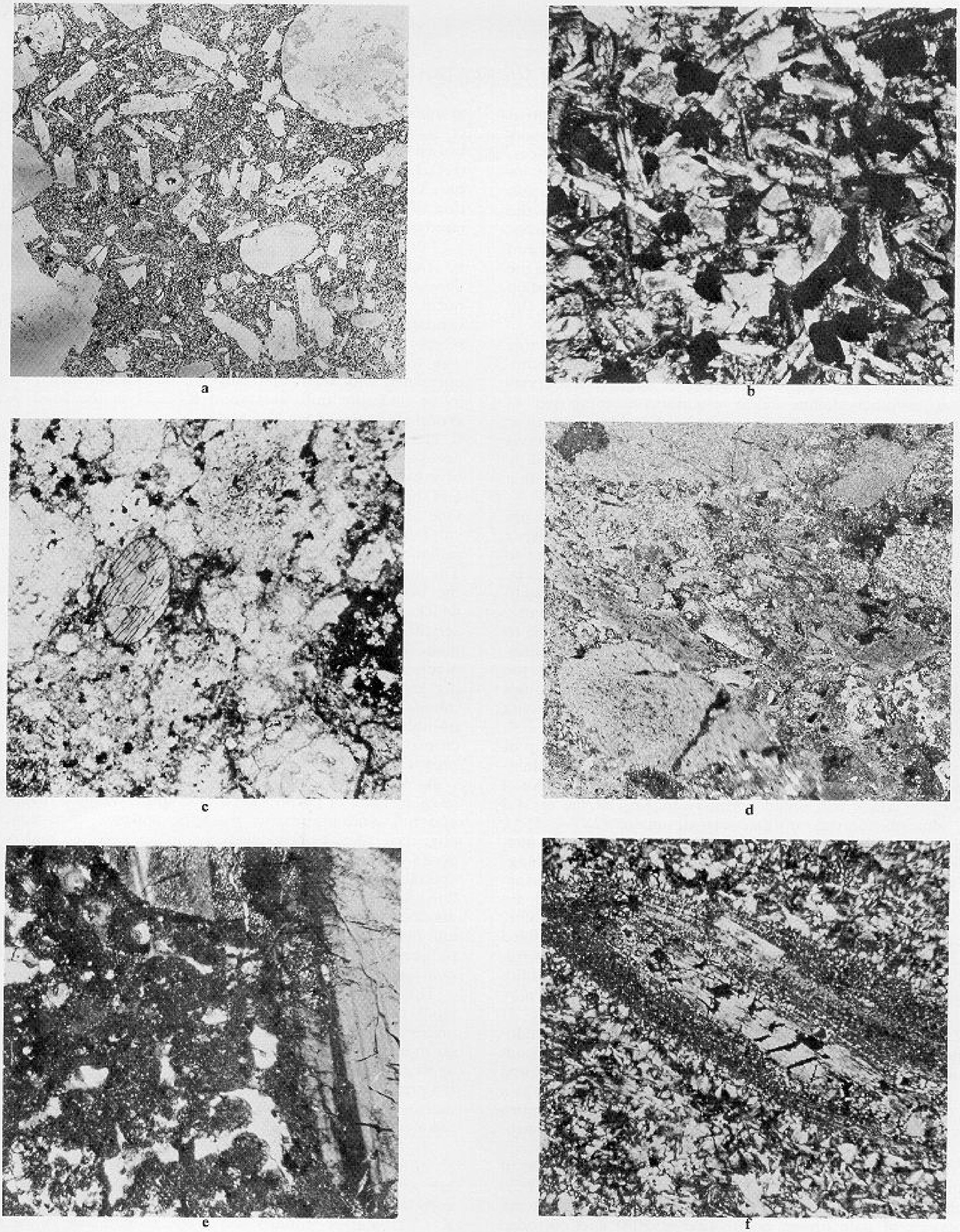


FIGURE 44

a. An andesine-basalt showing oval vesicles infilled with a quartz–epidote granular mosaic. (KG.214.25; ordinary light; × 5)

b. The intergranular groundmass of a dolerite dyke composed of subhedral magnetite grains (black), labradorite laths (twinned), euhedral augite crystals (high relief) and amorphous patches of interstitial uralite which are associated with iron-rich biotite. (KG.214.26; X-nicols; ×28)

c. A twinned microphenocryst of lamprobolite in a tuff, composed of sub-parallel orientated rhyolite and trachytic andesite lapilli in a cryptocrystalline felsic matrix speckled with magnetite granules. (KG.216.1; ordinary light; ×31)

d. Andesitic lithic tuff from the Braddock Nunataks showing many sub-parallel lapilli of rhyolitic lava and tuff set in a felsic matrix of crystal fragments, plagioclase microlites and granular magnetite. (KG.215.4; X-nicols; ×6)

e. The vitroclastic texture of the groundmass of a glassy spherulitic rhyolite from the summit of station KG.221 in the Braddock Nunataks. The original glass shards have been replaced by quartz. (KG.221.1; X-nicols; ×28)

f. An orientated biotite crystal contained within a band of cryptocrystalline devitrified glass in a crystallized rhyolite matrix. (KG.232.5; X-nicols; ×22)

TABLE II
MODAL ANALYSES OF VOLCANIC ROCKS FROM THE BRADDOCK NUNATAKS AREA, AND OF GRANODIORITE INCLUSIONS IN VENT AGGLOMERATES AND TUFFS FROM THE BRADDOCK NUNATAKS AREA AND THE BATTERBEE MOUNTAINS

	Volcanic rocks					*Granodiorite inclusions*		
	KG.214.27	KG.224.5	KG.213.2	KG.221.2	KG.214.17	KG.220.12	KG.223.2	KG.209.1
Quartz	*	†	*	*	—	11.2	19.9	10.9
Orthoclase: phenocrysts	–	13.1‡	10.9	4.7	1.4	25.0	34.0	43.0
Orthoclase: groundmass	—	—	—	—	—			
Plagioclase: phenocrysts	25	8.9	19.1	35.5	6.0	52.0	43.0	35.2
Plagioclase: groundmass	39	—	—	—	—			
Prehnite	—	—	—	tr	—	—	—	—
Unresolved predominantly quartz-feldspathic groundmass	9	70.1	47.5	47.6	64.0	—	—	—
Biotite	—	—	—	—	—	—	0.2	—
Penninite	*	tr†	3.0*	3.1	0.7	tr	2.3	10.7
Magnetite: phenocrysts	—	—	—	1.5	2.5	—	0.2	tr
Magnetite: groundmass	11	0.2	tr	3.2	6.7			
Epidote	tr*	tr†	tr*	tr*	—	8.0	0.4	0.2
Augite	5	—	1.5	2.7	—	—	—	—
Amphibole	7*	—	0.2§	—	—	—	—	—
Apatite	tr	tr	tr	—	—	—	tr	—
Vesicles*	4	—	5.8	1.6	—	—	—	—
Stringers	—	6.9	—	—	—	—	—	—
Lapilli: rhyolitic	—	0.8	5.0	0.1	—	—	—	—
Lapilli: andesitic	—	—	7.0	—	—			
Pyrite	tr	—	tr	—	tr	—	—	—
Sphene	—	—	—	—	—	3.8	tr	—
Calcite	—	—	tr	tr	18.7	tr	—	—
Plagioclase composition: phenocrysts	An_{50}	An_{25}	An_{30-44}	An_{27}	An_{36-49}	An_{34}	An_{32}	An_{36}
Plagioclase composition: groundmass	An_{38}	—	—	—	An_{28}			

tr Trace.
* Also occurs in vesicles.
† Also occurs in stringers.
‡ 1.1% forms spherulites.
§ Conspicuous microphenocrysts pseudomorphed by epidote, calcite and magnetite.

KG.214.27 Andesine-basalt lava flow; north westernmost of the Braddock Nunataks.
KG.224.5 Spherulitic rhyolite; south-western group of the Braddock Nunataks.
KG.213.2 Andesitic tuff; north-easternmost of the Braddock Nunataks.
KG.221.2 Augite-andesite lava flow; central ridge of the south-western group of the Braddock Nunataks.
KG.214.17 Matrix of vent agglomerate; north-westernmost of the Braddock Nunataks.
KG.220.12 Granodiorite inclusion from an andesitic tuff; south-eastern group of the Braddock Nunataks.
KG.232.2 Granodiorite inclusion from a vent agglomerate; south-western group of the Braddock Nunataks.
KG.209.1 Adamellite inclusion from a vent agglomerate; Norman Glacier.

these rhyolitic lavas and tuffs of the Taurus and Braddock Nunataks area are classified with the potash-rhyolites.

The rhyolites of station KG.215 are black porphyritic lavas containing orientated feldspar phenocrysts set in a flinty, aphanitic or glassy flow-banded matrix. A complex columnar jointing pattern causes them to weather into jagged rock pinnacles. These rhyolites are composed of deeply embayed quartz, sericitized orthoclase and oligoclase (An_{27}) phenocrysts in a cryptofelsitic groundmass. Both the orthoclase and oligoclase phenocrysts contain many inclusions of granular epidote and amorphous patches of calcite, and these secondary minerals are also widespread within the felsic groundmass. Original subhedral microphenocrysts of biotite are pseudomorphed by an aggregate of minute crystals of secondary biotite (pleochroic from olive-green to pale yellow) with associated bright green chlorite and granular magnetite. These rhyolites have, in general, undergone fairly extensive deuteric alteration due to the hydrothermal solutions which percolated through the lavas as they cooled.

At the summit of station KG.221, the rhyolites are both glassy and porphyritic. The groundmass of these rocks has a vitroclastic texture (Fig. 44e) due to the arcuate glass shards, which have subsequently been replaced by quartz, set in a banded iron-stained cryptocrystalline matrix containing some sub-parallel feldspar microlites. The feldspar spherulites which also occur at intervals within this cryptocrystalline matrix have often been formed around the nuclei of a quartz mosaic. Crystal lapilli of large corroded oligoclase (An_{27}) crystals, which are zoned normally to An_{23} at their rims, are quite common but they are usually dissociated from the large octahedral magnetite crystals, which include minute prisms of apatite, and the uralite pseudomorphs after original biotite phenocrysts. The groundmass also contains infrequent euhedral microphenocrysts of lamprobolite and small fresh euhedral crystals of sanidine, which are distinguished by their small 2V and clarity.

Flinty flow-banded porphyritic rhyolites, which are dissected by a columnar jointing pattern, crop out at stations KG.218 and 219, although they are extremely hornfelsed at the latter locality. At station KG.218 the flinty rhyolites are iron-stained but otherwise they possess a mineral assemblage similar to that of the rhyolites at station KG.215. As a result of deuteric alteration, the biotite microphenocrysts have been partly altered to penninite and calcite, and the andesine (An_{36}) and corroded orthoclase phenocrysts contain many inclusions of granular epidote. These flow-banded rhyolite lavas supersede an unusual horizon of banded green rhyolitic tuffs, which are rhythmically colour banded (Fig. 45). Each unit consists of a dark-coloured base, up to 5 mm thick, composed of euhedral magnetite grains and disseminated chlorite; this grades into a pale green zone (up to 10 mm thick), which is almost entirely composed of felsic minerals. Each unit represents an ash fall, in which the heavier mafic minerals are the first to separate from the atmosphere and are followed by the lighter felsic minerals. However, quartz-rich lapilli have broken through the layers at intervals, due to the force of their fall.

About 30 m of porphyritic flow-banded flinty rhyolites crop out at the summit of station KG.224 and are distinguished from the majority of the previous rhyolites by the feldspar spherulites, concentrated on nuclei of euhedral orthoclase crystals, which occur infrequently in the groundmass. This pale brown groundmass contains a greater proportion of granular iron ore

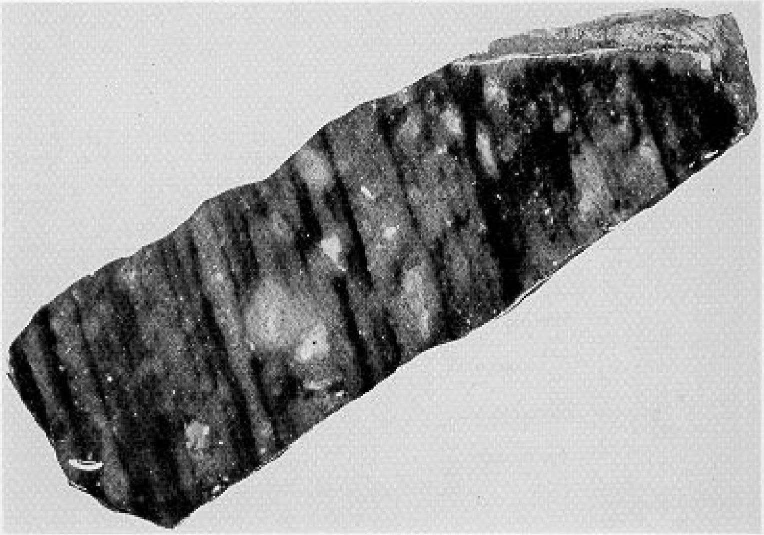


FIGURE 45
Rhythmic banding within an horizon of consolidated ashes showing the successive gradation within each ash fall from a dark magnetite-rich base to an upper zone rich in felsic minerals. Small lapilli break through the ash bands at irregular intervals. (KG.218; × 1.2)

than those rhyolites described above. A modal analysis of these rhyolites is given in Table II (KG.224.5). Deuteric alteration has given rise to many inclusions of granular epidote in the oligoclase (An_{25}) and orthoclase phenocrysts in these lavas, and many stringers and elongated vesicles filled with a granular mosaic of crystalline quartz cut the groundmass. These stringers represent zones in which the more volatile components of the lava were concentrated as it cooled. Discrete fragments of rhyolite lava, which occur at intervals within the main lava flow, may be lapilli of accessory rhyolite or they may have been caused by autobrecciation of the individual flows.

At station KG.232, flow-banded, predominantly glassy, porphyritic rhyolite lavas (Fig. 46), which dip steeply southward and south-westward, form the whole outcrop. Subsequent deuteric alteration associated with the volcanism has, however, caused many of the numerous joint planes to be veneered with limonite, epidote and calcite. Euhedral phenocrysts of oligoclase (An_{29}) and sericitized orthoclase are orientated with their long axes approximately parallel to the banding in these lavas and they occur in association with phenocrysts of an iron-rich biotite (pleochroic from deep brown to pale yellow) and octahedral magnetite crystals including small prismatic crystals of apatite. Extremely fine-grained bands with a cryptofelsitic texture and elongated lenses and irregular stringers composed of a granular quartz mosaic, with associated sphene, penninite and epidote, accentuate the fluidal banding and have been caused by the greater concentration of volatile constituents in these zones (Fig. 44f). Sub-angular fragments of rhyolitic tuff, composed of magnetite granules and angular quartz and feldspar crystal fragments set in a cryptofelsitic base, infrequently occur within the lavas.

At the extreme east of station KG.232, the rhyolite lavas grade into rhyolitic crystal tuffs, composed of sub-angular fragments of fresh andesine which are normally zoned from An_{38} to An_{25}, uralite–penninite–magnetite pseudomorphs after biotite, quartz, sanidine (distinguished by its small 2V) and octagonal

FIGURE 46
A porphyritic rhyolitic lava from the nunatak 6.5 km north-east of Cetus Hill showing the aligned euhedral phenocrysts of oligoclase set in a fine-grained flinty flow-banded matrix. A fragment of rhyolitic tuff is contained in the lava (bottom right).

FIGURE 47
A polished section of a tuffaceous rock showing the slumping which has occurred in an irregular light-coloured band of gravelly crystal tuff enclosed between the more competent dark green volcanic breccias. (KG.224.4; ×0.8)

magnetite crystals. These are set in a pale brown fine-grained felsic groundmass which is impregnated with parallel veins of sericite (Fig. 48a). It is probable that this horizon represents either the autobrecciated base or top of a flow and that the lithic fragments of dark porphyritic flinty rhyolite contained in this tuff have been derived in the same way.

d. *Andesitic breccias and tuffs.* At stations KG.215 and 224, lithic andesitic breccias and tuffs succeed the rhyolite horizon. At the first locality these tuffs have been subject to exceptionally severe deuteric hydrothermal mineralization and any zones of weakness within the rock have been coated with limonite, calcite and epidote. This mineralization may have been caused by late-stage volcanic activity around hot springs or fumaroles. The tuffs are composed of lapilli of holocrystalline porphyritic andesite, metasomatized rhyolitic tuff, and fine-grained rhyolite and trachytic andesite lavas set in a banded felsic matrix composed of magnetite grains and sericitized feldspar laths set in a cryptocrystalline matrix. Both the lithic fragments and the matrix are extensively impregnated with secondary calcite, epidote and chlorite, and the infrequent crystal fragments of oligoclase (An_{25}) and orthoclase are particularly altered.

At the summit of station KG.224, the tuffaceous rocks overlying the rhyolites are also less basic than the lower andesitic tuffs. They are composed of conspicuous irregular layers of light-coloured gravelly crystal tuffs interbedded between thicker, more massive, dark green volcanic breccias. A 1 cm thick ash band forms one consistent horizon (Fig. 22). The oval blocks in the volcanic breccias are all flattened in the plane of the bedding surfaces, for these tuffs may have accumulated on a shallow scree slope. The small slump structures (Fig. 47), which occur in some of the finer-grained less competent beds of gravelly tuff, support this postulated environment and may indicate that the unconsolidated tuffs tended to "slide" down-hill before they were consolidated. Alternatively, the unconsolidated tuffs may have been contorted by an over-riding lava flow.

The volcanic breccias contain orientated blocks of porphyritic rhyolite lavas and very fine-grained consolidated ashes together with less frequent lapilli of trachytic andesite lavas, composed essentially of aligned andesine (An_{46}) microlites. The tuffaceous matrix between the lithic fragments consists of crystal fragments of deeply embayed quartz, clear andesine (An_{39}) and sericitized orthoclase crystals, the smallest fragments of which form the interstitial cryptocrystalline groundmass of the tuff. Lenses and stringers, composed of a granular mosaic of recrystallized quartz, occur frequently throughout the whole groundmass, which is also impregnated with amorphous patches and well-defined veinlets of secondary green biotite, which is partly altered to penninite with associated chlorite, magnetite and sericite. This unusual combination of secondary minerals is the result of deuteric alteration that took place as the lavas cooled.

e. *Weathered horizons.* Two weathered horizons occur in the volcanic rocks of the Taurus and Braddock Nunataks area: at stations KG.213 and 224, respectively. On purely stratigraphical evidence, they occur at a comparable level in the succession, and the petrographic similarities between the horizons strengthens the contention that they may be correlated.

At station KG.213, the weathered horizon consists of about 6.5 m or iron-stained tuffs interbedded with very fine consolidated ash bands (porcellanite), which are more frequent towards the top of the horizon. The tuffs contain sub-angular lapilli of trachytic andesite and rhyolitic lavas set in an iron-stained gravelly matrix containing fragments of euhedral orthoclase and oligoclase (An_{38}) crystals and infrequent rectangular sanidine microphenocrysts. These are set in a fine-grained matrix, which contains many plagioclase microlites, granular magnetite largely oxidized to limonite and interstitial patches of granular quartz. Both the lapilli and the matrix are extensively impregnated with amorphous patches of calcite with some associated chlorite and re-distributed limonite, and the feldspar crystals are sericitized.

The consolidated ashes, which occur in the upper part of the weathered horizon, are purple, bright green or brown finely banded porcellanites. They were probably produced following a particularly violent explosive eruption of the volcano, which was followed by a quiescent period during which weathering of the earlier volcanic rocks took place. A thin section shows that the ashes are composed of a fine uniform aggregate of felsic minerals which have been sericitized, and granules of magnetite which have been subsequently oxidized to limonite, together with some minute grains of epidote and apatite.

At station KG.224 in the south-western group of the Braddock Nunataks, the weathered zone of tuffs is underlain by the crudely bedded volcanic breccias and tuffs, which are interbedded with a band of laminated, green, fine-grained consolidated ash (Fig. 22), very similar to the porcellanites at station KG.213.

The weathered horizon itself is iron-stained and contains subangular, accessory lapilli of porphyritic rhyolite lava, fine-grained rhyolitic ash and less frequent basaltic lapilli, which are composed of plagioclase laths set in an amorphous groundmass of partly oxidized magnetite. The cryptocrystalline felsic groundmass of these tuffs is impregnated with sericite, and the fragments of oligoclase (An_{29}) and orthoclase crystals are cloudy due to alteration (Fig. 48b). Fragments of quartz crystals and vesicles infilled with a granular quartz mosaic are scattered throughout the matrix, which also contains many patches of re-distributed limonite associated with small muscovite crystals.

The weathering process of these tuffs and ashes has, in general, resulted in alteration of the feldspars and oxidation of the iron ores, with the development of secondary calcite, sericite and limonite which is re-distributed throughout the matrix.

f. *Green andesitic tuffs and interbedded augite-andesite lavas.* A thin though consistent horizon of bright green well-bedded lapilli-tuffs exposed directly above the weathered zone at station KG.213 is correlated with a similar inaccessible horizon at the summit of station KG.215 and at station KG.221.

At station KG.213 these tuffs contain large angular accessory lapilli of flinty porphyritic rhyolite and essential scoria of medium-grained andesite set in a gravelly unsorted matrix of sub-parallel lithic and crystal fragments. It is significant that the majority of the lapilli in this horizon are rhyolitic, because, in the absence of a recorded rhyolite horizon at station KG.213, their presence adds weight to the contention that these green tuffs accumulated after the eruption of the rhyolite lavas in the south-western group of the Braddock Nunataks. Examination of thin sections reveals that the tuffs also contain lapilli of porphyritic trachytic andesite lavas, which are composed of phenocrysts of augite and andesine (An_{32}), and oval chlorite-filled vesicles set in a trachytic groundmass of aligned feldspar microlites. The other sub-parallel lapilli consist of fine-grained consolidated ashes, spherulitic and cryptocrystalline rhyolites, and porphyritic andesite lavas containing andesine (An_{36}) phenocrysts. These are set in a fine-grained groundmass composed of plagioclase microlites, grains of iron ore and interstitial patches of chlorite. As a result of deuteric alteration, many of these lapilli had been partly altered to a granular intergrowth of epidote and penninite before they were included in the tuff. The andesite scoria are composed of glomeroporphyritic aggregates of sheared andesine (An_{42}) and orthoclase phenocrysts contained in an intergranular matrix impregnated with secondary crystalline granular epidote and quartz. Deuteric alteration has caused the original microphenocrysts of amphibole to be pseudomorphed by epidote and magnetite which has been concentrated along the original cleavage planes.

The groundmass of this green tuff contains many embayed fragments of orthoclase and andesine (An_{33}) crystals, which contain epidote, penninite and calcite inclusions, together with euhedral crystals of magnetite including small prismatic apatite crystals, and derived augite phenocrysts which are altered at their rims to calcite (Fig. 48c). The many vesicles in the groundmass are filled with chlorite (with an anomalous blue birefringence colour) and this vesicular texture is a result of the large proportion of volatiles which were present in the accumulating tuffs. This factor probably accounts for the bright green colour of the propylitized rocks and has caused many of the joint planes to be veneered with epidote and pink feldspar.

The tuffs at station KG.213 are correlated with similar green tuffs at the summit of station KG.215 and at station KG.221. These lower outcrops are interbedded with augite-andesite lava flows, which were first encountered just below the summit on the east side of station KG.221. Similar lava flows crop out above the weathered horizon at station KG.224 and they probably form the thick lava flow which occurs directly beneath the green tuffs at the summit of station KG.215. This lava contains large aligned phenocrysts of feldspar and smaller black phenocrysts of augite set in a grey-green fine-grained matrix.

In thin section, the rock contains augite phenocrysts pleochroic from colourless to pale brown and containing magnetite inclusions; they are frequently twinned on {100} (Fig. 48d). Other mafic crystals are pseudomorphed in fibrous chlorite (with an anomalous blue birefringence colour), either representing a ferromagnesian mineral phase which became unstable in the conditions that prevailed as the magma was erupted, or alternatively, these pseudomorphs could be accidental xenocrysts which were caught up and altered by the magma as it penetrated the pre-existing country rock (Fig. 48e). The most frequent phenocrysts are euhedral oligoclase (An_{27}) containing inclusions of epidote and prehnite, but orthoclase phenocrysts and large sub-octahedral crystals of magnetite are also common. All the phenocrysts are corroded and are set in a pilotaxitic groundmass composed of feldspar microlites and granules of ore in an interstitial pale brown cryptocrystalline matrix. Vesicles within the lava are infilled with quartz and crystalline epidote which encloses some hexagonal β-quartz crystals. The volatile constituents of the original lava have been concentrated within these vesicles but, in general, very little deuteric alteration of the lavas at station KG.221 has occurred. The few tuff fragments contained in these lavas were probably incorporated in the advancing front of the flow. A modal analysis of this lava is given in Table II (KG.221.2).

Similar augite-andesite lava flows occur above the weathered horizon at station KG.224 and, although they are essentially alike, they have been more extensively hydrated. Augite phenocrysts have been partly pseudomorphed by actinolite, which has preserved the original crystal form and twinning, while the plagioclase phenocrysts in this outcrop are of basic andesine (An_{40}). Sheaves of secondary prehnite crystals occur in cavities in the lava and these are associated with the chloritic pseudomorphs of the mafic minerals (see above).

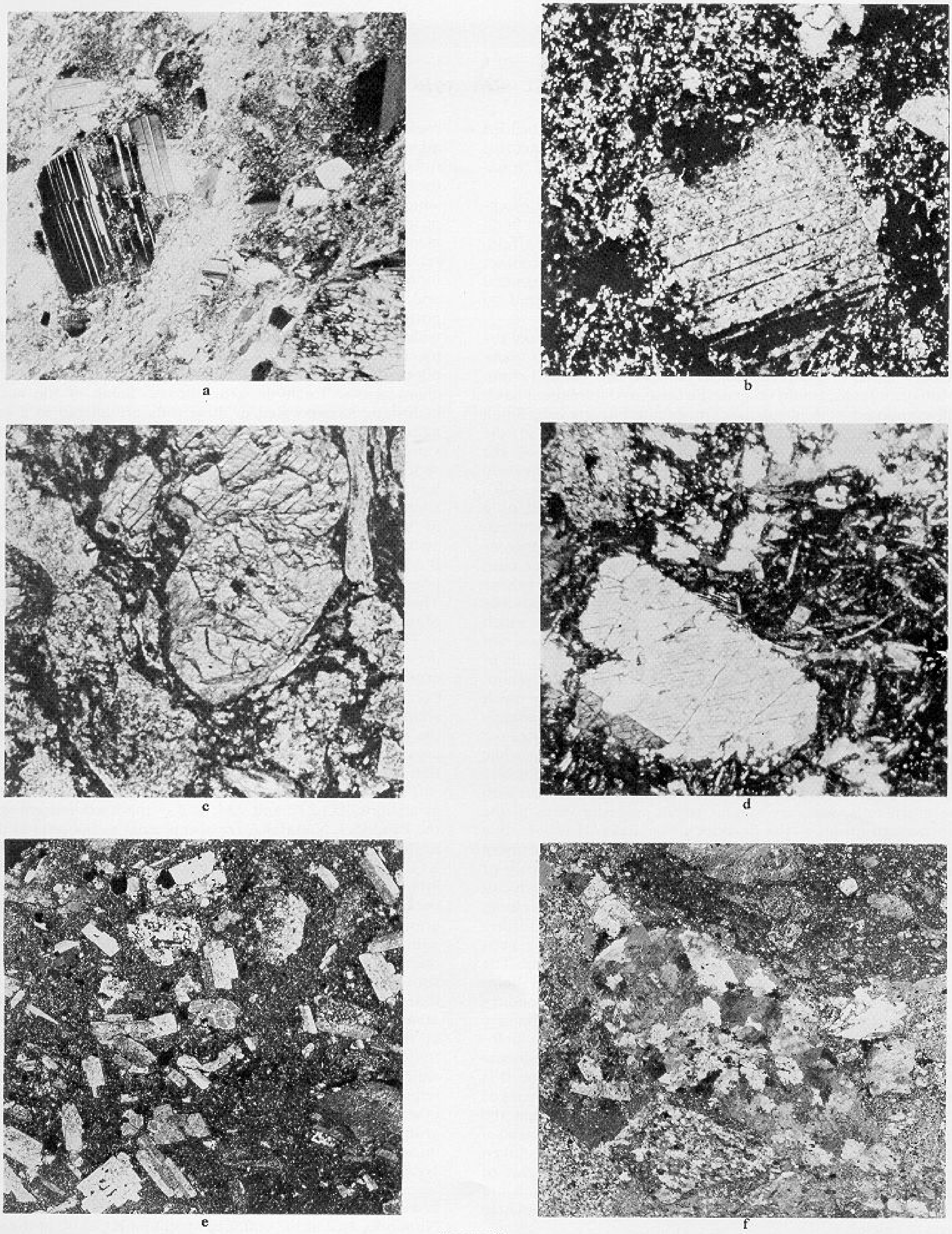


FIGURE 48

a. A crystal tuff from the east end of the nunatak 6.5 km north-east of Cetus Hill showing crystal fragments of andesine, quartz, magnetite and sanidine with less frequent large shattered crystals of normally zoned andesine (An_{17-25}) set in a sericite-impregnated cryptocrystalline matrix. (KG.232.6; X-nicols; x×22)

b. Impregnation of a weathered tuff by sericite. (KG.224.2; X-nicols; ×23)

c. Large crystals of augite (altered at their rims to calcite) which are contained in the bedded green tuffs of station KG.213 in the Braddock Nunataks. (KG.213.2; ordinary light; ×30)

d. An augite-andesite lava containing augite phenocrysts set in a pilotaxitic groundmass composed of small crystals of feldspar and grains of magnetite in a cryptocrystalline base. Part of a quartz-filled vesicle appears at the top of the photograph. (KG.221.1; X-nicols; ×32)

e. Phenocrysts of oligoclase (An_{27}), orthoclase and augite, quartz-filled vesicles and the chlorite pseudomorphs in an augite-andesite lava. (KG.221.1; X-nicols; ×4.5)

f. An andesitic tuff from the south-eastern group of the Braddock Nunataks, showing an oval lapillus of metasomatized granodiorite. Although the original quartz has remained unaltered, the original feldspars have been pseudomorphed by a mosaic of crystalline calcite. (KG.220.12; X-nicols; ×3)

A thin cap of green propylitized andesitic tuffs interbedded with similar augite-andesite lava flows covers the intrusive granodiorite in the south-eastern group of the Braddock Nunataks.

These tuffs contain many large grey and white angular essential lapilli of flinty, porphyritic and pumiceous rhyolites set in an unsorted pale green propylitized matrix containing many feldspar crystal fragments (Fig. 23). Near the concordant contact with the granodiorite, these tuffs are extensively impregnated with secondary calcite and pyrite subsequently oxidized to limonite.

Many of the lithic fragments in the tuffs were derived from the interbedded augite-andesite lava flows but there are also many accessory lapilli of granular, holocrystalline and banded rhyolitic tuffs and lavas, trachytic andesite lavas and infrequent basic lapilli composed of a plagioclase–magnetite intergrowth. Small sub-angular accidental lapilli of granodiorite occur in the easternmost nunataks of the south-eastern group of the Braddock Nunataks, although they were often extensively altered to calcite and epidote as they were erupted (Fig. 48f). These granodiorite inclusions were originally composed of a coarse-grained mosaic of quartz, large tabular crystals of microperthitic orthoclase, which poikilitically include sub-angular plagioclase crystals, and andesine (An_{37}) crystals that have been sheared during the eruption. A large euhedral crystal of sphene also occurs as an accessory mineral in one of the granodiorite lapilli. These lapilli are set in a green tuffaceous matrix, which contains derived fragments of orthoclase, plagioclase of compositions ranging from An_{27} to An_{39}, and cubic crystals of magnetite with apatite inclusions. Particularly near the granodiorite/tuff contact, both the feldspar constituents include much calcite and granular epidote. The pyroxene crystals in these tuffs were probably derived from the interbedded augite-andesite lava flows and they are often pseudomorphed by uralite, while vesicles in the tuffs are filled with radiating crystalline epidote.

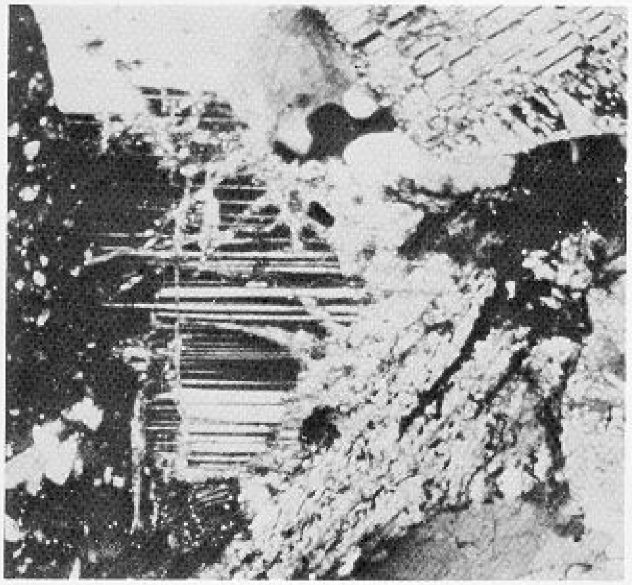
Several augite-andesite lava flows, which are interbedded with these green tuffs, are very similar to the andesite lavas in the south-western group of the Braddock Nunataks. However, due to the proximity of the intrusive granodiorite, they are more altered. The original pyroxene phenocrysts have been partly or wholly altered to a fibrous aggregate of actinolite with which calcite is associated; the chlorite pseudomorphs including prehnite sheaves in the original lavas have not undergone any further change but the zoned andesine (An_{42}) phenocrysts have been sericitized and contain many granular epidote inclusions. The original texture of the groundmass, which varies from holocrystalline to pilotaxitic, is largely obliterated by secondary patches of granular epidote and calcite, but in one relatively unaltered lava, hornblende is the mafic mineral in the holocrystalline groundmass and is associated with cubic magnetite crystals, andesine (An_{37}) laths and some interstitial quartz. It is significant that the ferromagnesian mineral in the groundmass of this lava is hornblende rather than augite, indicating that the magma was more hydrous than the augite-andesite lava of station KG.221. In cases where extreme alteration has taken place, augite is completely pseudomorphed by an aggregate of calcite and epidote, and the andesine phenocrysts, which are more liable to alteration than the groundmass, are completely altered to calcite.

g. *Parasitic cone*. It is uncertain what relationship the volcanic rocks of station KG.222 bear to the successions in the other adjacent nunataks. These outcrops are of green andesitic lithic tuffs, characterized by the accidental granodiorite inclusions they contain. These sub-angular fragments of granodiorite, which possess a hypidiomorphic granular texture, are composed of euhedral biotite crystals pseudomorphed by strongly pleochroic (green to colourless) penninite and granular epidote, set in a mosaic of sheared euhedral andesine (An_{34}) crystals, more poorly formed sercitized microperthitic orthoclase crystals and interstitial clear quartz (Fig. 49a). Accessory lapilli of porphyritic and holocrystalline rhyolitic lavas and tuffs are also widespread in these tuffs and they occur with less frequent fragments of porphyritic andesite lavas possessing a characteristic pilotaxitic groundmass, and trachytic andesite lavas with a characteristic trachytic groundmass. Some of the accidental inclusions incorporated in these tuffs are altered to a granular aggregate of epidote and calcite but the degree of this alteration varies considerably. One unusual fragment, which is completely sericitized, may have been derived from an earlier weathered horizon. All the lavas recorded from the northern part of the south-western group of the Braddock Nunataks occur as lapilli in these andesitic tuffs. It is therefore probable that they accumulated after the main volcanic cone had been formed and it is also possible that they were erupted from the prominent isolated vent at station KG.223, 0.8 km north of station KG.222. These tuffs may be part of a parasitic cone formed on the flanks of the main volcano.

The fine-grained groundmass of these tuffs contains much disseminated granular magnetite and epidote together with large crystal fragments derived from the granodiorite lapilli. However, the andesites are propylitized near the vents in an iron-stained zone impregnated with secondary calcite, whereas near the summit of station KG.222 they are cut by many veins of crystalline quartz and epidote associated with the mineralization caused by a large microgranodiorite dyke.

The granodiorite inclusions, which occur in the andesitic tuffs at stations KG.222 and 224, and in the south-eastern group of the Braddock Nunataks, are also present as boulders in the vent agglomerate at station KG.223. Modal analyses (Table II, KG.220.12 and 223.2) of these accidental granodiorite xenoliths do not clarify the relationship they bear to the granodiorite outcrops to the south and west, but it is significant that the granodiorite fragments show none of the textures associated with the marginal intrusive granodiorite (p. 50), which should be found if this intrusive granodiorite had been incorporated into subsequent volcanic rocks. The most satisfactory explanation is that boulders of an earlier granodiorite no longer exposed in this area were incorporated in these tuffaceous rocks, which are part of the Braddock Nunataks volcanic group. The alternative is that the granodiorite boulders were derived from the intrusion which crops out to the west and south. This explanation would require that the volcanic rocks at station KG.222 and at the other relevant outcrops were erupted after the intrusion of the granodiorite; in the absence of any substantial evidence of an unconformity within the volcanic succession in the Braddock Nunataks area, this explanation is considered unlikely.

h. *Vent agglomerates*. Vent agglomerates occur in the Braddock Nunataks area in the cliff face at station KG.214, at the western foot of station KG.222 and at station KG.223. where they form the major part of that knoll. In all cases, the agglomerate and



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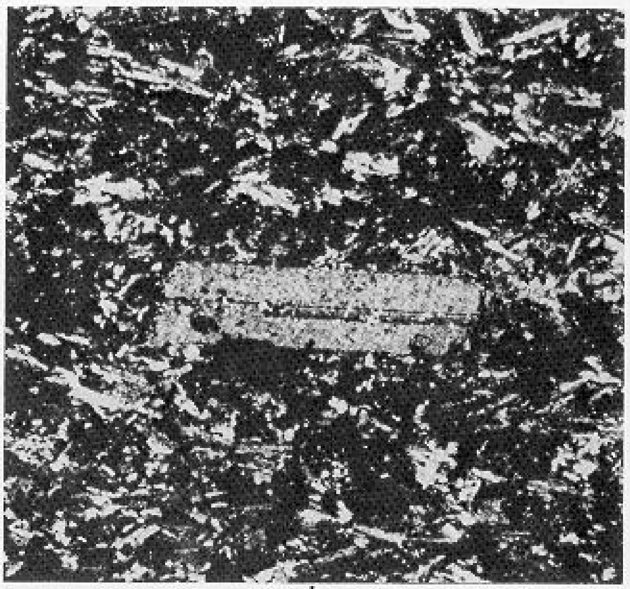

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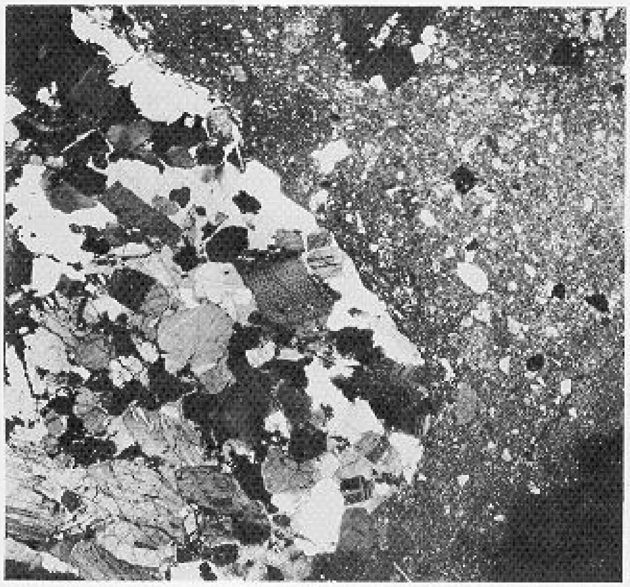

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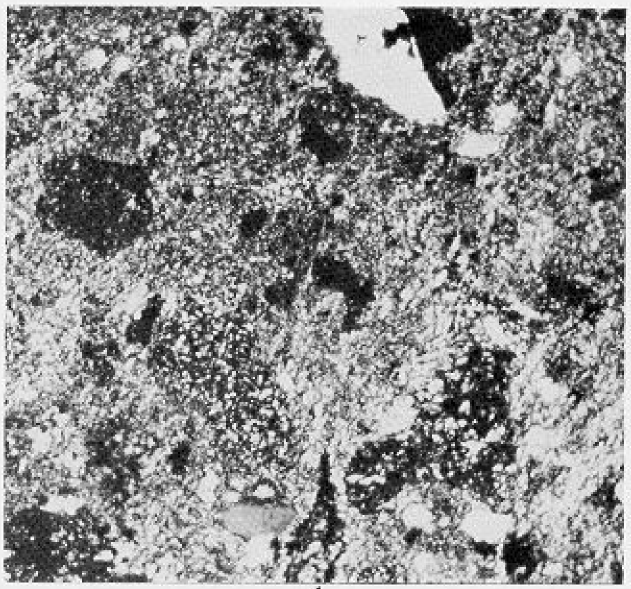

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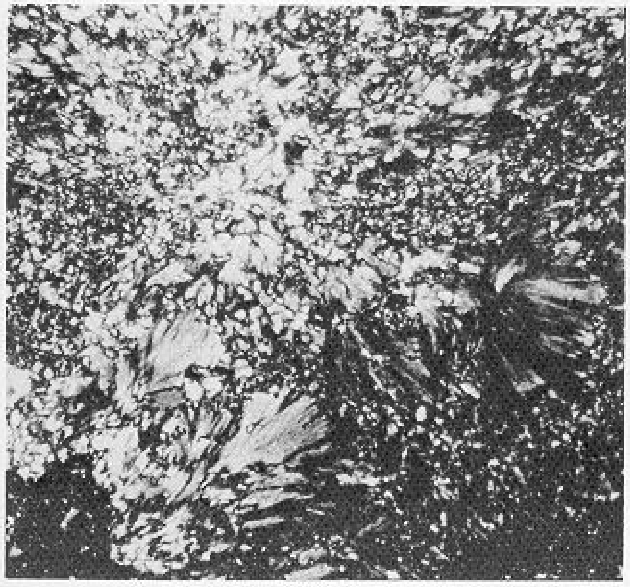

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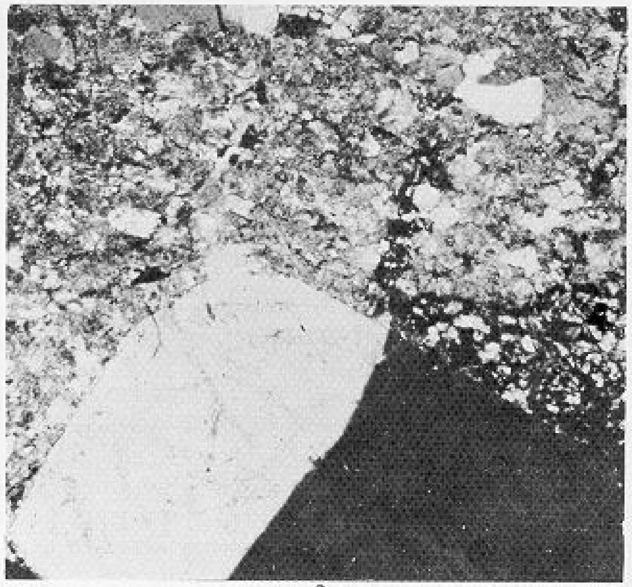

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FIGURE 49

a. A granodiorite lapillus in the andesitic tuff of station KG.222 in the Braddock Nunataks. This granodiorite is composed of an hypidiomorphic granular aggregate of euhedral biotite, andesite (An_{34}), microperthitic orthoclase and interstitial quartz. (KG.222.11; X-nicols; ×24)

b. The texture of the groundmass of the vent agglomerate with an euhedral andesine phenocryst set in a fine-grained matrix of feldspar microlites, magnetite grains and a cryptocrystalline interstitial base. (KG.214.17; X-nicols; ×27)

c. A fragment of granodiorite in a vent agglomerate. Subhedral andesine (An_{32}) crystals are often poikilitically included in large orthoclase plates and there is a little anhedral interstitial quartz. (KG.223.2; X-nicols; ×4.5)

d. The gravelly tuffs, which are composed of crystal fragments of quartz, orthoclase and andesine (An_{39}), and rhyolite lapilli, set in a sericite-impregnated fine-grained matrix. (KG.207.6; X-nicols; ×24)

e. A lapillus of spherulitic rhyolite which is contained in the tuff south-east of the summit of northern Swine Hill. The spherulites are composed of radiating intergrowths of alkali-feldspar. (KG.207.12; X-nicols; ×20)

f. A quartz-plagioclase-porphyry showing Carlsbad twinning in a corroded feldspar phenocryst contained in a microcrystalline groundmass of feldspar, small biotite crystals and patches of anhedral quartz. (KG.207.14; X-nicols; ×19) surrounding volcanic rocks are extensively impregnated with calcite and limonite.

The vent at station KG.214 is about 6.5 m across and it is composed of many large boulders of the earlier volcanic rocks set in a fine-grained andesitic matrix. The matrix is formed of feldspar microlites and magnetite grains set in a cryptocrystalline base impregnated by amorphous patches of secondary calcite. A modal analysis of the matrix is given in Table II (KG.214.17). Larger crystals of orthoclase, basic andesine (ranging in composition from An_{36} to An_{49}), penninite pseudomorphs and larger corroded magnetite grains have been derived from the boulders in the agglomerate (Fig. 49b). This vent probably represents a late explosive stage of the Braddock Nunataks volcanic activity which caused much hydrothermal mineralization of the surrounding volcanic rocks. No boulders of granodiorite were recorded from this vent.

The vent agglomerate at station KG.223 is about 15 m across and has extensively baked the adjacent earlier volcanic rocks (Fig. 26). It is also distinguished from the vent at station KG.214 by the fact that it contains many boulders of the granodiorite which also appear in the tuffs of nearby station KG.222. This granodiorite, which possesses a hypidiomorphic granular texture, is composed of euhedral biotite crystals largely pseudomorphed by penninite and epidote, broken euhedral crystals of andesine (An_{32}), large tabular orthoclase crystals, which poikilitically include all the previous minerals, interstitial quartz, some accessory sphene and magnetite containing apatite inclusions (Fig. 49c). A modal analysis is given in Table II (KG.223.2).

The groundmass of the agglomerate is composed of crystal fragments of quartz and sericitized orthoclase and oligoclase set in a cryptocrystalline matrix, impregnated by granular epidote. Also contained are lithic fragments of the earlier volcanic rocks—trachytic andesites, composed of aligned oligoclase (An_{28}) microlites, and microcrystalline and cryptocrystalline rhyolites. Many large cubic crystals of pyrite, largely oxidized to limonite, are disseminated through the groundmass.

The vent agglomerate which occurs at the western foot of station KG.222 is far less significant than the previous agglomerate. However, granodiorite boulders are contained in it, and the agglomerate and surrounding rocks are impregnated with secondary limonite and calcite.

i. *Summary,* The volcanic rocks of the Taurus and Braddock Nunataks area are part of an original composite cone centred north-west of station KG.215. It is probable that the original walls of the volcano are preserved in the escarpments of the south-western group of the Braddock Nunataks and in the cliff line from station KG.213 to station KG.214, and that the dips of the volcanic rocks have not been drastically altered by the subsequent granodiorite intrusion.

It appears that the eruptions began with the outpouring of basaltic lava flows with a certain amount of associated explosive activity, which produced the interbedded tuffs at station KG.214. As time passed, the explosive activity increased at the expense of the eruption of lava, so that a steep-sided composite cone was built up. Pyroclastic debris continued to accumulate on this cone but a transition in the activity occurred midway through the history of the volcano, which then began to erupt a sequence of potash rhyolite lava flows with some associated pyroclastic debris. This rhyolite horizon is restricted to the south-western group of the Braddock Nunataks and becomes thinner southward away from station KG.215.

As the eruption of rhyolite lavas decreased, explosive activity increased, producing a succession of andesitic and rhyolitic breccias and tuffs. This activity gradually gave way to a period of quiescence during which the uppermost ash and tuff horizons were weathered.

In a short time, there was renewed activity of a quite different character to the rhyolite eruptions. The opening stages of this activity produced the augite-bearing andesitic tuffs, which form the thin but consistent horizon on the outer walls of the cone, preserved at stations KG.213, 215 and 221, and the south-eastern group of the Braddock Nunataks. The explosive activity responsible for these tuffs accompanied the eruption of several augite-andesite lava flows, some of which swept down the sides of the volcano from station KG.221 as far as the south-eastern group of the Braddock Nunataks.

It is probable that the tuffs at station KG.222 were derived from a parasitic cone at station KG.223, on the southern flank of the main volcano, at a fairly late stage in the volcanic activity. However, in the final stages of activity, fumaroles and hot springs were active, particularly around the choked volcanic vents at stations KG.214 and 222.

This course of eruption is very similar to that in the Lassen group of volcanic rocks forming the volcanic province of the Cascade Range in the north-western United States. Many of the peaks of the High Cascades are composite cones of andesite, dacite and rhyolite, and have been formed by a rapid inconsistent alternation of basalt, andesite and rhyolite eruptions (Turner and Verhoogen, 1960, p. 287). In the Braddock Nunataks area there is a general trend from basic to more acid eruptions up to the close of the rhyolite eruptions but in the renewed volcanic activity this trend is upset by the eruption of the augite-andesite lavas. The trend of these eruptions cannot be attributed to a straight-forward differentiation series but is considered to be due to the differential fusion of deep-seated crustal rocks accompanying an orogeny in the Antarctic Peninsula. When this folding was active, filter pressing and segregation of the deep-seated magmas, subsequent blending of these magmas on their way to the surface, and further modification by differentiation whenever the magmas were held in a closed chamber, could cause the variations recorded in the eruptive rocks in the Braddock Nunataks and similar areas.

2. *Batterbee Mountains*

Outcrops of volcanic rocks were visited in the Batterbee Mountains at northern Swine Hill, southern Swine Hill and at Bushell Bluff. Although the successions at these localities are fundamentally similar, it is considered inadvisable to inter-relate them because so little of the ground was covered. The petrographic characteristics of each of the three outcrops are therefore considered in turn.

a. *Northern Swine Hill.* The succession at northern Swine Hill (Fig. 50) is drawn from a traverse made from the foot of the southern ridge to the summit cairn.

The lowest recorded beds are gravelly tuffs which contain pillows of rhyolitic lava. These pillows of fine-grained flinty grey-green rhyolite are colour zoned and not only indicate that the succession is younging upwards but also that the eruptions

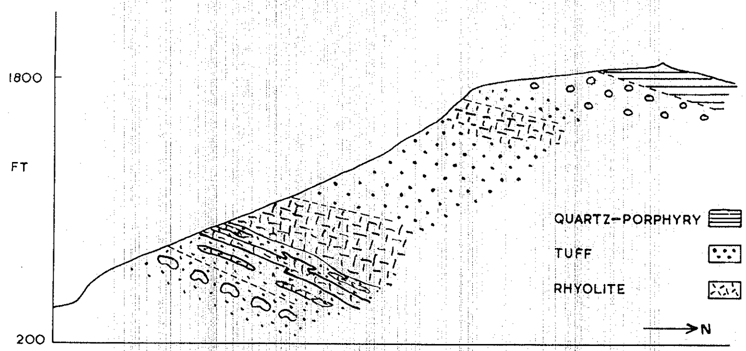


FIGURE 50
A diagrammatic section at northern Swine Hill, showing pillow lavas, rhyolite lava flows and interbedded tuffs, and volcanic breccias (open pattern). The vertical exaggeration is ×3.

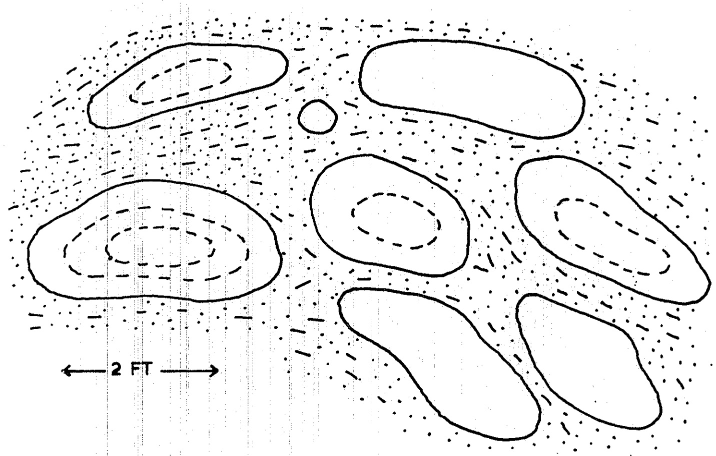


FIGURE 51
A field sketch showing the form of the colour-zoned pillows contained in a banded matrix of gravelly tuff, indicating that the section is younging upwards.

were submarine (Fig. 51). Thin sections reveal that the rhyolite pillows are composed of angular fragments of quartz, sericitized orthoclase and occasional relatively unaltered phenocrysts of oligoclase (An_{15}) set in a banded cryptocrystalline felsic matrix. Amorphous green chlorite pseudomorphs of an original ferromagnesian mineral (probable biotite) are rare but conspicuous and partly oxidized magnetite grains are evenly scattered thoughout the groundmass. Some sub-parallel quartz lenses and stringers in the groundmass represent zones along which the volatile constituents in the lava were concentrated. However, deuteric alteration, which probably occurred at the time of the submarine eruptions, has produced the many epidote inclusions in the groundmass feldspar and in the sericitized feldspar phenocrysts. Amorphous patches of secondary calcite and sub-parallel stringers of crystalline calcite in the groundmass were caused in the same way. Some small lithic fragments of holocrystalline and spherulitic rhyolite are contained in the rhyolite pillows, indicating that explosive activity occurred at the same time as the eruption of the lavas.

The gravelly banded matrix enclosing these pillows is an iron-stained, poorly consolidated, equigranular lithic crystal tuff, composed of small sub-angular fragments of quartz and feldspar crystals, infrequent chlorite and epidote pseudomorphs after biotite, and fragments of rhyolite, set in a fine-grained felsic matrix impregnated by sericite. It is probable that this sericite indicates the aqueous environment in which the gravels accumulated but the angularity of the grains indicates that they had not been abraded and that they were probably produced during the explosive activity accompanying these eruptions.

6.5 m higher in the succession, irregular but continuous layers of these grey-green flinty banded rhyolites are separated by less resistant layers and lenses of a similar grey-green gravelly tuff (Fig. 52). These gravelly tuffs are composed of equigranular andesine (An_{39}), orthoclase, quartz and green rhyolite fragments set in a grey-green sericite-impregnated matrix. The succession is cut by pipe armygdales, 15 cm long, filled with calcite (Fig. 52). These pipe amygdales typically occur at the base of a flow and have resulted from the uprising of steam from the moist surfaces over which the lava flowed. Since they commonly occur when lava is erupted over wet sediment (Du Toit, 1907), it is probable that the lenses and irregular beds of gravel were caught up in the lava flow from the floor of the area of water into which these rhyolites were erupted.

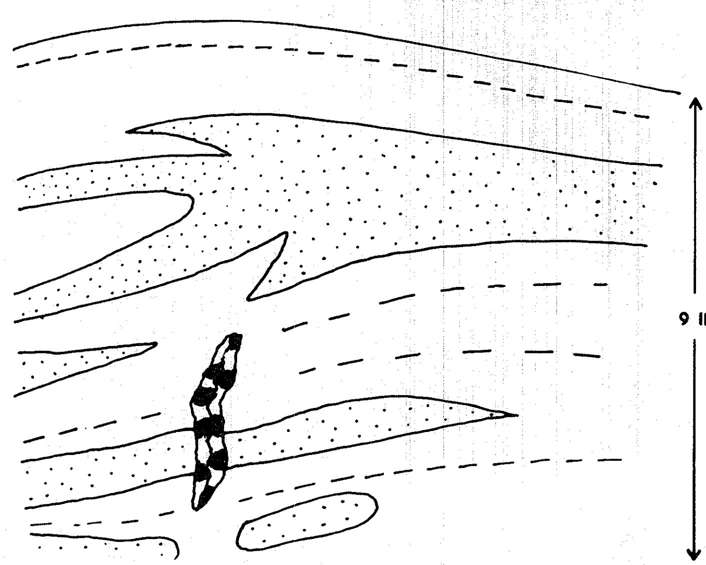


FIGURE 52
A field sketch showing the lenses and bands of gravelly tuff (stippled) which are interbedded with banded rhyolite layers. A pipe amygdale filled with crystalline calcite (black) cuts the succession.

About 15 m higher in the succession, the rhyolites at the top of a flow become slaggy and vesicular, and are dissected by many haphazardly orientated joints which are frequently veneered with a black cindery deposit. Iron-stained gravelly tuffs containing many large angular fragments of glassy rhyolite separate this from the subsequent rhyolite lava flow and they are also composed of sub-angular lithic fragments of cryptocrystalline, spherulitic and porphyritic rhyolites, and crystal fragments of oligoclase (An_{29}) and quartz set in a fine-grained sericite-impregnated felsic matrix (Fig. 49d). The sericite laths are often sub-parallel to the outlines of the lithic fragments.

Another lava flow crops out at the top of the ridge extending to the summit of northern Swine Hill. This is composed of vesicular and finely banded rhyolites dissected by innumerable joints. The banded rhyolites are composed of slightly corroded phenocrysts of andesine (An_{33}) and orthoclase, which are contained in a fine-grained felsic groundmass with disseminated grains of oxidized magnetite concentrated in the darker bands.

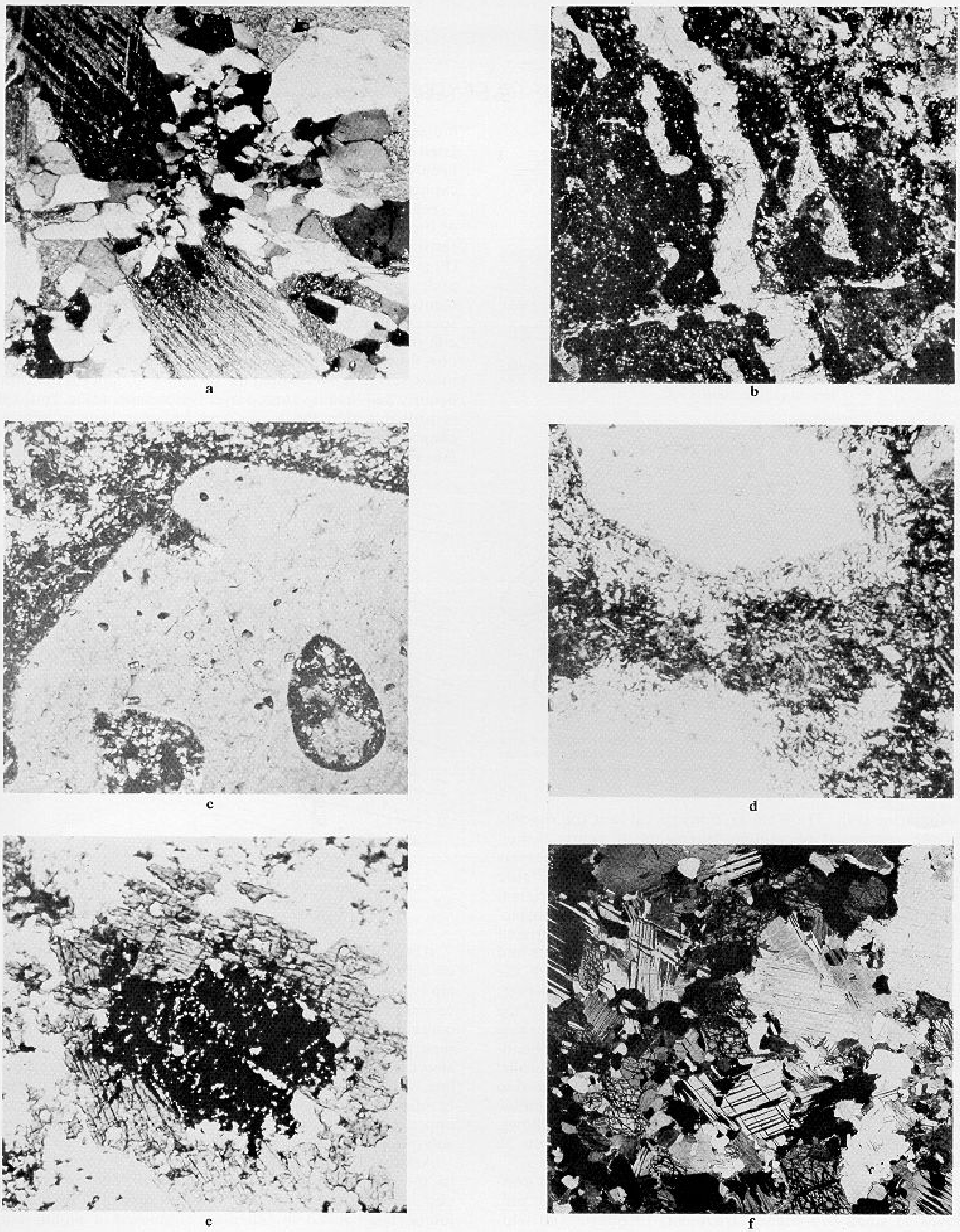


FIGURE 53

a. Crystalline calcite associated with a granular quartz mosaic infilling a cavity in bedded quartz-porphyry lava flows. The twin lamellae are curved due to subsequent deformation. (KG.208.8; X-nicols; ×19)

b. Detail of the replacement by calcite of a plagioclase phenocryst in the massive green tuffs at the summit of southern Swine Hill. (KG.208.1; X-nicols; ×28)

c. Inclusions of the fine-grained groundmass in quartz phenocrysts in a quartz-porphyry lava flow at Horse Bluff. (KG.210.9; X-nicols; ×21)

d. The cryptocrystalline corona of feldspar and interstitial quartz which occurs around the quartz crystals in a quartz-porphyry lava at Horse Bluff. (KG.210.9; X-nicols; ×21)

e. The detail of an aggregate of secondary magnetite and green hornblende in a hornfels. (KG.236.1; ordinary light; ×30)

f. A troctolite showing olivine crystals, which are crossed by alteration cracks containing magnetite and serpentine, surrounded by a reaction rim grading from diopsidic augite to fibrous amphibole. The olivine crystals are contained in an hypidiomorphic granular aggregate of clear bytownite crystals exhibiting pericline and albite twinning. (KG.234.6; X-nicols; ×3.5)

Many of the porphyritic rhyolites in the upper part of this flow are glassy and iron-stained due to weathering which occurred soon after the eruption.

At the summit of northern Swine Hill, the rhyolites are superseded by coarse tuffs and quartz-porphyry lavas. The coarse tuffs, which crop out south-east of the summit (Fig. 38), are composed of angular fragments of porphyritic and banded spherulitic rhyolites, and crystal fragments of quartz and orthoclase, set in a fine-grained felsic groundmass impregnated with bright green chloritic patches and partly oxidized magnetite grains (Fig. 49e).

At the summit cairn, the uppermost stratum recorded is a yellow quartz-plagioclase-porphyry that appears to constitute a lava flow. This rock is composed of hexagonal quartz and euhedral feldspar crystals set in a pale yellow fine-grained groundmass. Thin sections reveal that it contains corroded quartz and euhedral andesine (An_{33}) phenocrysts together with smaller biotite microphenocrysts set in a holocrystalline groundmass composed of a mosaic of quartz, feldspar and small biotite crystals (Fig. 49f). This biotite, which is pleochroic from green to pale yellow, may well be the original ferromagnesian mineral that has been pseudomorphed by green chlorite in the lower rhyolites. In a quartz-porphyry lava flow, beneath the survey cairn at Swine Hill, green chlorite with associated granular epidote does, in fact, partly pseudomorph the biotite.

b. *Southern Swine Hill.* At southern Swine Hill the volcanic rocks are folded about an east–west-trending anticlinal axis, the northern limb of which dips more steeply than the southern one (Fig. 38). The tentative stratigraphical succession illustrated in Fig. 38 is based on the limited number of observations which were made.

The lowest exposed outcrops consist of a succession of grey-green rhyolitic lava flows interbedded with massive dark green tuffs, and cut by basaltic and quartz-porphyry dykes. Each flow is iron-stained and slaggy towards its top and is generally inconsistent in thickness and direction. At the summit of southern Swine Hill, the sequence in the folded succession appears to be from bedded metasomatized quartz-porphyry lavas to iron-stained volcanic breccias and massive green tuffs.

Well-bedded green quartz-porphyry lavas exposed east of the summit of southern Swine Hill are extensively impregnated with crystalline calcite, which is particularly conspicuous along the open joints trending parallel to the fold axis. In thin section, these rocks are evidently composed of large, corroded euhedral quartz crystals, and many almost entirely sericitized feldspar phenocrysts, some of which are identified as oligoclase (An_{26}), set in a microcrystalline felsic groundmass impregnated by many sub-parallel zones of granular quartz. Calcite pseudomorphs some of the original euhedral amphibole microphenocrysts, stringers of crystalline calcite cut all the constituents of the rock and large crystals of calcite are associated with granular quartz which infills large cavities at the apex of the anticline. The cleavage planes of this calcite are markedly curved (Fig. 53a), indicating that the crystals were probably deformed at the same time as the rocks were folded.

At the summit of southern Swine Hill, the volcanic breccias are composed of sub-angular blocks of quartz-porphyry, spherulitic and cryptocrystalline rhyolite lavas set in a gravelly iron-stained tuffaceous matrix. These breccias, which appear to be interbedded with the succeeding tuffs, are dissected by a complex but well-developed joint pattern. One quartz-porphyry block in this volcanic breccia is composed of sub-angular fragments of quartz, containing many cryptocrystalline inclusions of the groundmass that invaded it, sericitized orthoclase crystals, unaltered oligoclase (An_{28}) phenocrysts, and chloritic pseudomorphs of an original ferromagnesian mineral contained in a microcrystalline felsic mosaic of quartz, feldspar and interstitial secondary chlorite. Vesicles in this groundmass are filled with granular quartz, with which crystalline siderite is associated, and pyrite crystals characteristically altered to limonite are disseminated throughout this rock.

The massive green tuffs exposed west of the summit of southern Swine Hill are composed of lapilli of green and brown porphyritic rhyolite set in a green flinty matrix containing feldspar crystal fragments. The bedding surfaces of some of these compact well-jointed rocks are iron-stained as a result of contemporaneous weathering but deuteric alteration has resulted in a calcite veneer on some joint planes and crystalline calcite infills many of the cavities in these rocks. In thin section, they are evidently composed of lapilli of fine-grained porphyritic and holocrystalline rhyolites set in a fine-grained felsic matrix containing magnetite grains, sub-parallel quartzose lenses and amorphous patches of calcite, and secondary green chlorite. Large crystals of orthoclase and oligoclase (An_{22}), containing calcite and quartz inclusions (Fig. 53b), are also widespread in this groundmass.

c. *Bushell Bluff.* The outcrops at the summit of Bushell Bluff are iron-stained, bedded, well-jointed green lithic tuffs cut by basalt dykes, which are underlain by quartz-porphyry lavas. These green tuffs are composed of crystal fragments of quartz, orthoclase, oligoclase (An_{16}) and less frequent muscovite set in a fine-grained groundmass impregnated with secondary green chlorite. This green chlorite also partly pseudomorphs original biotite phenocrysts. Grains of magnetite are concentrated in patches of altered rock and occasional lapilli and blocks of dark green holocrystalline and cryptocrystalline porphyritic rhyolite lavas containing zoned feldspar phenocrysts are embedded in the tuffaceous matrix. However, there is no trace of secondary calcite in these rocks.

d. *Summary.* This succession represents the remains of a volcano, the active centre of which may have been situated near southern Swine Hill. This conclusion has been reached because most of the coarse-grained pyroclastic rocks occur at southern Swine Hill and because deuteric alteration of the volcanic succession is most intense there. Dominantly rhyolitic lavas and tuffs were erupted from it, the basal flows being erupted in a subaqueous environment. The higher flows do not appear to have been erupted under water, since the contemporaneous iron staining associated with them leads to the conclusion that they were erupted and weathered above the water level. The trend in these eruptions was for explosive activity to increase with time and for quartz-porphyry lavas to be included in the later activity.

e. *Other outcrops of volcanic rocks in the Batterbee Mountains.* At the western end of Horse Bluff quartz-porphyry lavas crop out. These contain conspicuous corroded quartz phenocrysts containing many inclusions of the groundmass by which they had been invaded (Fig. 53c). These phenocrysts are also surrounded by a fine-grained reaction rim composed of anhedral quartz and microlites of feldspar (Fig. 53d). Andesine (An_{37}) phenocrysts, infrequent penninite pseudomorphs after biotite and occasional orthoclase crystals, sometimes surrounded by a graphic intergrowth of quartz and feldspar, are set in the microcrystalline felsic groundmass composed of feldspar microlites, chlorite and interstitial quartz. The vesicles in this lava are filled with crystalline epidote but, in another more altered quartz-porphyry lava, epidote inclusions occur in the feldspar phenocrysts and in the penninite–calcite–magnetite pseudomorphs after biotite. These quartz-porphyries may be related to those of Swine Hill.

In the middle of lower Norman Glacier a small knoll is composed of agglomeratic rocks, which mark the site of a former vent. These agglomerates contain blocks of porphyritic and flinty rhyolite and granodiorite, and feldspar and mafic crystal fragments set in a well-jointed, glassy, iron-stained rhyolitic tuffaceous matrix. The rhyolite blocks are similar to the lavas of Swine Hill, perhaps indicating that this vent agglomerate was formed after the Swine Hill eruptions. Although the granodiorite blocks are somewhat similar to the granodiorites of the plateau (Table II, KG.209.1), it is probable that the explosive activity at this locality was a late phase of the Swine Hill activity and that, as in the Braddock Nunataks area, the granodiorite blocks were derived from an earlier intrusion.

Although volcanic rocks appear to be widespread in the Batterbee Mountains, they were only sampled at two other localities. At station KG.236, north of Mount Bagshawe (Fig. 39), hornfelsed dark-coloured rocks crop out above a pink acid intrusion (Fig. 43). This hornfels is composed of a fine-grained granoblastic mosaic of quartz, magnetite, green amphibole and feldspar, in which are set euhedral phenocrysts of basic andesine (An_{49}), anhedral sericitized orthoclase crystals and composite aggregates of mafic minerals. These mafic aggregates grade from a core of small biotite crystals (pleochroic from olive-green to pale yellow), with associated quartz and granular magnetite, to a rim composed of crystalline deep green amphibole (α = pale brown; β = green; γ = dark green) (Fig. 53e). It is possible that the hornfels was derived from a porphyritic basic volcanic rock.

R. R. Horne, who visited the nunatak 25 km north-east of Mount Cadbury, described a vent agglomerate and nearby black cryptocrystalline andesitic lava flows of indeterminate age. This nunatak (lat. 71° 15′S, long. 66° 02′W) is sharp and conical, composed of a vent agglomerate, and formed of blocks of andesitic lava up to 2.5 m across cemented by grey tuff with lithic crystal and vitric components.

The lava blocks contain euhedral andesine (An_{32}) and infrequent orthoclase phenocrysts, more or less pseudomorphed by a crystalline aggregate of epidote, with which a little secondary chlorite is associated. These discrete or aggregate phenocrysts are embedded in a pilotaxitic groundmass composed of feldspar microlites and magnetite grains in a cryptocrystalline matrix.

Infrequent cubic pyrite crystals are disseminated throughout the groundmass of the agglomerate, which is a compact grey andesite containing large crystal fragments of feldspar and lithic fragments of andesitic tuff and lava.

Actual lava flows, which are very similar to the blocks in the agglomerate, were recorded in a small nunatak 0.4 km south-east of the main nunatak.

B. Andean Intrusive Rocks

1. *Gabbroic rocks*

These occur in the Batterbee Mountains on the eastern side of Mount Bagshawe, at stations KG.234 and 237 (Fig. 39), and range from augite-microgabbro and lineated amphibole-gabbro, which form the majority of the exposures, to an equigranular troctolite differentiate.

The troctolite, which occurs in the centre of the outcrops of gabbroic rocks, is a coarse-grained equigranular rock composed of a mosaic of glassy feldspar and olivine (Fig. 54). Thin

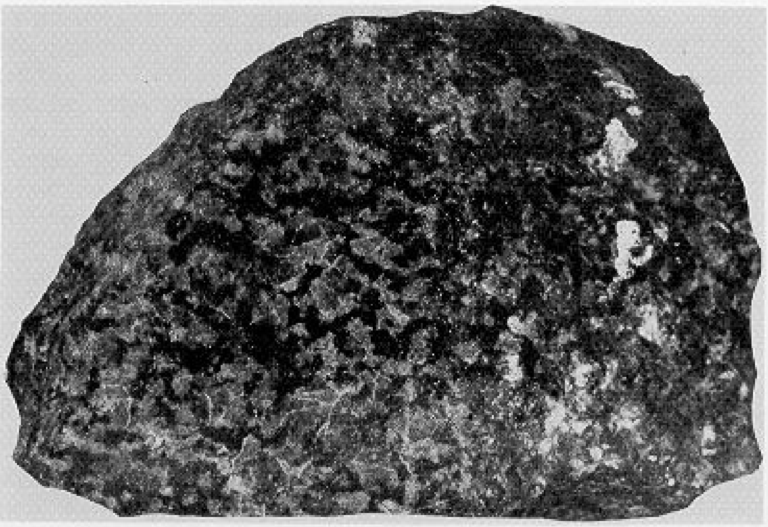


Figure 54

A polished section of troctolite showing the equigranular mosaic of large glassy bytownite crystals, dark-coloured olivine and accessory pyroxene, which form the rock. The white mineral, which emphasizes the sutured contacts between the component crystals, is composed of small triturated grains of bytownite. (KG.234.6; ×0.6)

sections reveal that it contains large, rounded, optically negative olivine crystals ($2V \simeq 80°$) crossed by a network of alteration cracks filled with magnetite grains and fibrous chlorite. The olivine crystals are sometimes partly altered to patches of yellow-green antigorite and are frequently surrounded by a narrow reaction rim of diopsidic augite, in turn fringed by hornblende (pleochroic from pale green to pale brown). Infrequent large crystals of diopsidic augite are associated with the olivine crystals and are altered initially to diallage with many inclusions of tremolite along a parting parallel to {100}, and subsequently, at the crystal edges, to crystallized hornblende and clinochlore. At the extreme edges of these composite crystals, the hornblende merges into a fibrous aggregate of tremolite, in which there are some ragged grains of green spinel (pleonaste). The ferromagnesian minerals usually occur in aggregates of crystals representing a continuous reaction series from olivine to tremolite. Some of the smaller olivine crystals are poikilitically included in plates of fresh bytownite, which ranges in composition from An_{72} to An_{85}, but some small grains of this bytownite are also poikilitically included in the larger subhedral bytownite plates and in the larger olivine crystals (Fig. 53f). This restricted poikilitic texture has probably arisen because the bytownite and olivine were crystallizing slowly and simultaneously, and it is probable that this rock is formed of a cumulate of early crystallizing minerals, which separated out from the magma and were

TABLE III
MODAL ANALYSES OF ANDEAN INTRUSIVE ROCKS

	KG.234.6	KG.235.2	KG.237.10	KG.225.1	KG.201.1	KG.215.2	KG.211.1	KG.228.7	KG.227.1	KG.210.3	KG.219.5
Unresolved quartzo-feldspathic groundmass	—	—	—	—	—	—	—	—	—	—	60.6
Quartz	—	—	—	30.2	13.8	38.1	11.8	8.9	12.3	46.6	0.8
Orthoclase	—	—	—	17.7	5.3	20.5†	62.8†	9.7	9.2	27.3†	2.0
Plagioclase	69.9	49.7	28.3	37.2	66.1	30.7	17.8	39.7	60.0	22.4	16.8
Sericite	—	—	tr	tr	tr	tr	tr	—	tr	tr	tr
Olivine	25.7	—	18.1	—	—	—	—	—	—	—	—
Antigorite	0.7	—	0.1	—	—	1.0	—	—	—	—	—
Magnetite	0.2	3.5‡	3.1	0.9	tr	1.0	1.1	0.7	0.3	tr	2.2
Pyroxene	2.8	45.1	3.2	—	—	1.7	0.2	—	—	—	—
Hornblende	0.7	0.2	34.2	5.9	3.2	1.0	4.1	27.9	9.2	—	—
Actinolite-tremolite	tr	1.5*	12.9*	—	—	0.6	—	—	—	—	—
Clinochlore	—	—	—	tr	1.7	2.5	0.3	3.9	0.9	—	—
Biotite	—	—	—	7.5	9.7	2.0	1.9	7.5	—	—	—
Penninite	—	—	—	0.4	0.2	—	tr	tr	7.6	1.3	14.4
Prehnite	—	—	—	tr	tr	tr	tr	tr	0.1	—	—
Pleonaste	tr	—	0.1	—	—	—	—	—	—	—	—
Epidote	—	—	—	tr	tr	—	tr	0.4	0.1	2.4	0.8
Calcite	—	—	—	—	—	—	—	—	—	—	1.8
Apatite	—	—	—	0.2	tr	tr	tr	tr	0.3	—	0.4
Sphene	—	—	—	tr	—	—	—	1.3	tr	—	tr
Plagioclase composition	An_{85}	An_{68}	An_{68}	An_{44-38}	An_{53-32}	An_{58-22}	An_{38-25}	An_{46-27}	An_{48}	An_{34}	An_{36}

tr Trace.
* Some of this occurs in secondary veins.
† Microperthitic.
‡ Partly oxidized to limonite.

KG.234.6 Trocolite; main north-south ridges 5 km east of Mount Bagshawe.
KG.235.2 Augite-microgabbro; north-eastern side of Mount Bagshawe.
KG.237.10 Olivine-gabbro; peak 5 km south-west of Mount Ness.
KG.225.1 Granodiorite; depot site, central member of the Taurus Nunataks.
KG.201.1 Granodiorite; Thomson Rock.
KG.215.2 Marginal hybridized granodiorite; northernmost of the south-western group of the Braddock Nunataks.
KG.211.1 Basic inclusion in granodiorite; westernmost of the Taurus Nunataks.
KG.228.7 Basic inclusion in granodiorite; main peak in nunatak group 10 km north-west of Cetus Hill.
KG.227.1 Leucocratic raft in granodiorite; north-westernmost of nunatak group 10 km north-west of Cetus Hill.
KG.210.3 Granitic rock; Horse Bluff.
KG.219.5 Microgranodiorite dyke cutting granodiorite; south-western group of the Braddock Nunataks.

consolidated into an allotriomorphic mosaic by the pressure exerted by the remaining crystallizing magma. A modal analysis is given in Table III (KG.234.6).

In contrast, the other gabbroic rocks from Mount Bagshawe and station KG.234 are either augite-microgabbros or lineated coarse-grained amphibole-gabbros and pyroxene-leucogabbros, which vary in grain-size and composition according to the rapidity of their crystallization and the extent of subsequent deuteric hydration.

A traverse A–B (Fig. 39) across the strike of the mineral lineation in the easternmost of the ridges at station KG.234 shows that the coarse-grained lineated hornblende-gabbros occur as an irregular layer in the equigranular augite-microgabbros (Fig. 55). This augite-microgabbro is composed of a hypidiomorphic granular mosaic of pale brown augite and

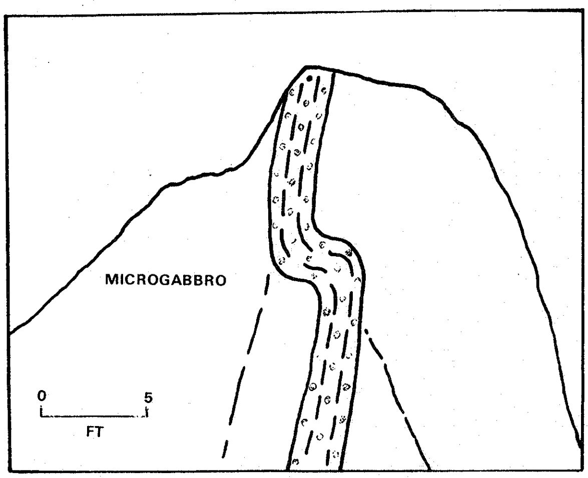


FIGURE 55
A field sketch showing how the layer of lineated, coarse-grained, deuterically altered amphibole-gabbros is related to the augite-microgabbros at the north-western end of the eastern of the main north–south ridges 5 km east of Mount Bagshawe.

bytownite (An_{75}) crystals in the approximate proportions of 1 : 2. The augite crystals contain small inclusions and a kelyphitic fringe of hornblende (pleochroic from green to brown); the clear plagioclase crystals often show albite and pericline twinning (Fig. 56a). Stringers of fibrous tremolite cut the granular groundmass and veneer some of the joint planes of these iron-stained rocks, and aggregates of large diallage crystals are also scattered irregularly through the microgabbro.

A layer of coarse-grained lineated altered gabbro is interleaved with the equigranular more widespread microgabbro. This lineated gabbro is composed of sub-parallel elongated anhedral crystals of glassy feldspar and dark green mafic minerals. Therefore, the lineation shows up most strikingly on the weathered rock surfaces. In thin section, the rock is composed of ragged phenocrysts of diopsidic augite, from which minute grains of magnetite have exsolved, surrounded by kelyphitic rims of optically continuous actinolite, merging at the crystal edges into a feathery aggregate of fibrous tremolite crystals. This secondary tremolite sometimes completely absorbs the pyroxene. The original bytownite (An_{70}) remains as isolated ragged phenocrysts but it has been largely granulated by deuteric alteration to form a fine mosaic of relatively unaltered grains often impregnated by calcite.

A coarse-grained pegmatitic gabbro in the scree at the foot of this outcrop is composed of aggregates of large interlocking crystals of pale brown hornblende, in the cores of which grains of the original pyroxene remain. In some cases, these pseudomorphs consist of aggregates of small randomly orientated tremolite–actinolite crystals but, more frequently, the amphibole crystals are optically continuous with the pyroxene crystals. Large interlocking bytownite (An_{73}) crystals occur between the mafic crystals and are slightly sericitized and granulated. Accessory crystals of euhedral apatite and a little granular epidote are associated with the amphibole pseudomorphs in this altered pegmatitic gabbro (Fig. 56b).

On the north-eastern flank of Mount Bagshawe the gabbroic rocks are lineated pyroxene-leucogabbros in which the lineation trends at 145° (mag.). These gabbros consist of finer- and coarser-grained layers, and contain irregular more leucocratic inclusions. The pyroxene in these rocks is pale green diopsidic augite, which occurs as ragged crystals or crystal aggregates that are slightly altered to antigorite and include small grains of magnetite. However, about 80% of the rock is composed of a granular aggregate of subhedral interlocking bytownite crystals (An_{71}) of varying sizes with associated anhedral patches of magnetite.

The outcrops of gabbroic rocks high on the eastern side of Mount Bagshawe are also augite-microgabbros and altered lineated coarse-grained amphibole-gabbros. The coarser-grained lineated varieties are identical to those at the eastern of the ridges at station KG.234 and have been subjected to deuteric alteration. This has produced amphibole pseudomorphs after the original pyroxene crystals and has caused some copper staining. A little farther east (Fig. 39), iron-stained augite-microgabbros crop out; these are also essentially similar to those of the eastern of the ridges at station KG.234, although limonite is concentrated along the sutures between the constituent minerals and infrequent magnetite-rich bands occur. A modal analysis of this augite-microgabbro is given in Table III (KG.235.2).

At station KG.237, there are gabbros similar to both the coarse-grained lineated amphibole-gabbros and the augite-microgabbros of station KG.234. The gabbros south-west of a small intrusive boss of granodiorite (Fig. 39) are extremely iron-stained and impregnated with malachite and epidote due to metasomatism associated with the intrusion. In one such altered coarse-grained gabbroic rock, the original ferromagnesian mineral has been altered either to large pale green amphibole crystals with associated clinochlore or to a felted aggregate of actinolite and penninite crystals containing amorphous inclusions of calcite. The original feldspar has been altered to large irregular crystals of epidote, with which are associated radiating sheaves of prehnite.

North-west of the granodiorite intrusion the gabbroic rocks are not so extensively metasomatized. They consist of olivine-gabbros and microgabbros, which contain all members of the reaction series from olivine to tremolite. Infrequent corroded olivine crystals with patches of olive-green antigorite are crossed by typical alteration cracks containing exsolved magnetite. Surrounding the olivine crystals is a corona structure composed of a reaction rim of diopsidic augite, which is in turn altered to amphibole (pleochroic from pale green to colourless) forming large, optically continuous partial pseudomorphs after the pyroxene. The crystallized amphibole grades at the edge of the reaction rim into an aggregate of disorientated feathery actino-

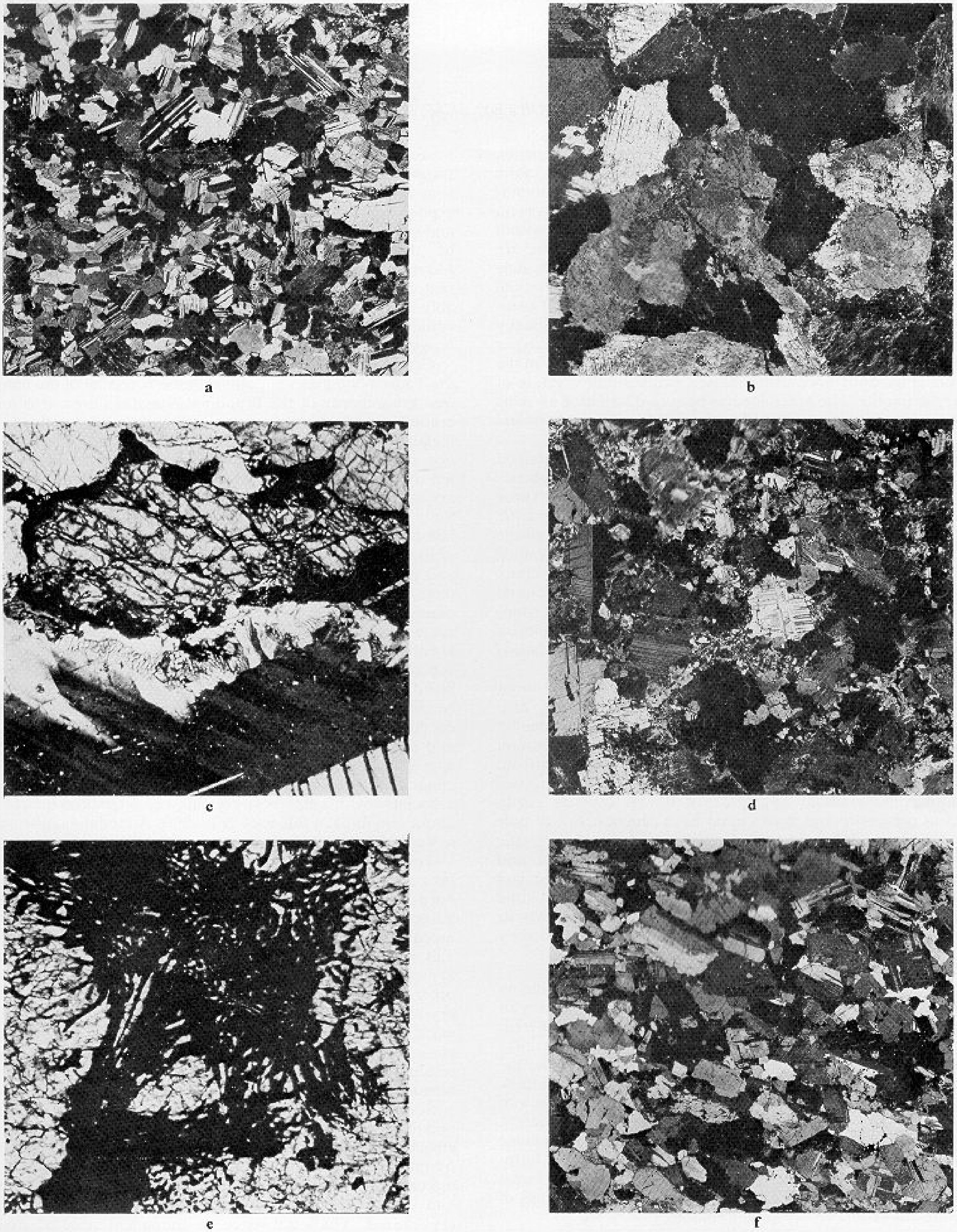


FIGURE 56

a. An augite-microgabbro composed of an hypidiomorphic granular aggregate of bytownite (An_{75}) and pale brown augite surrounded by a kelyphitic fringe of hornblende. (KG.234.1; X-nicols; ×3.5)

b. A gabbro-pegmatite composed of a mosaic of large interlocking, optically continuous, near-complete hornblende pseudomorphs after pyroxene and slightly sericitized bytownite (An_{73}) crystals. In places the crystallized hornblende is replaced by a fibrous aggregate of feathery tremolite-actinolite crystals. (KG.234.5; X-nicols; ×2.5)

c. The corona of magnetite and fibrous tremolite which has developed around an olivine crystal in an olivine-gabbro. The interstitial feldspar is labradorite (An_{68}). (KG.237.10; X-nicols; ×31)

d. An olivine-gabbro showing the deuteric alteration which has taken place. The original labradorite (An_{68}) crystals are slightly granulated and include feathery crystals of tremolite; the original pyroxene crystals are altered either to a felted mass of tremolite crystals or to optically continuous amphibole; the intermediate zones are composed of aggregates of re-distributed feathery actinolite-tremolite crystals. (KG.237.10; X-nicols; ×3.5)

e. A characteristic radiating growth of dendritic iron ore which has developed as diopside replaced the original olivine in an olivine-microgabbro. (KG.237.11; ordinary light; ×30)

f. A typical granodiorite from the depot site in the central part of the Taurus Nunataks. Large anhedral orthoclase crystals poikilitically include some of the rounded slightly sericitized andesine crystals. Quartz is interstitial and euhedral crystals of hornblende, biotite and magnetite occur frequently. (KG.225.1; X-nicols, ×3.5) lite crystals with dendritic growths of granular magnetite, whereas the actual contact between plagioclase and the mafic minerals is marked by an outer shell of fibrous tremolite containing many vermicular feldspar inclusions (Fig. 56c). This corona is idealized and is preserved in all stages of completion within the gabbro. The large original crystals of diopsidic augite are also largely pseudomorphed by either optically continuous pale green hornblende or by an aggregate of feathery actinolite crystals, which frequently contain amorphous patches of pleonaste. These large composite mafic crystals subophitically enclose rounded grains of labradorite (An_{68}). This feldspar forms the allotriomorphic granular mosaic between the mafic minerals (Fig. 56d) and also encloses many small crystals of feathery actinolite. The actinolite has been re-distributed as veins and stringers and is associated with a little calcite. A modal analysis of this rock is given in Table III (KG.237.10).

The microgabbros, which occur near the coarse-grained olivine-gabbros, also contain infrequent corroded olivine phenocrysts almost completely pseudomorphed by antigorite. These phenocrysts are surrounded by coronas of radiating dendritic iron ore (Fig. 56e) and reaction rims of pale brown diopsidic augite with some associated hornblende. The medium-grained groundmass of the microgabbros is formed by many interpenetrating labradorite (An_{63}) laths subophitically enclosed by diopsidic augite. This mineral also occurs as interstitial rounded grains between the plagioclase laths and is usually associated with granular magnetite. Some ragged bytownite (An_{72}) phenocrysts also occur in the matrix.

Similar microgabbros crop out in the small nunatak about 1.6 km north-west of station KG.237 (Fig. 39). R. R. Horne also recorded gabbros at Mount Cadbury where they are intruded by granodiorite; gabbros with a similar mineralogical composition to those of Mount Bagshawe were collected by D. Nash from Gurney Point. These gabbros are composed of a coarse-grained hypidiomorphic granular aggregate of olivine crystals partly altered to antigorite and surrounded by a reaction rim of pale brown augite and hornblende. Original crystals of diopsidic augite have been largely pseudomorphed by hornblende and chlorite, and the bytownite (An_{76}) crystals are sericitized and contain many inclusions of crystalline epidote. In a pegmatitic rock associated with these gabbros, the large plates of feldspar are normally zoned to An_{22} at their rims and are surrounded by a corona of orthoclase.

Summary. The outcrops of gabbro are derived from a magma which produced mainly olivine-gabbros composed essentially of bytownite or labradorite and olivine. The troctolite is a differentiate from this magma, whereas the remaining outcrops have resulted from the crystallization of the original magma under the variable conditions which prevailed throughout the intrusion(s). The ratio of mafic to felsic minerals varies from one place to another as does the degree of hydration of the mafic minerals. This reaction and deuteric hydration of the original olivine crystals has given rise to diopsidic augite, followed by hornblende and fibrous actinolite–tremolite, which in extreme cases is partly altered to calcite, whereas the infrequent alteration of bytownite has produced crystalline epidote.

2. *Granodiorites*

Granodiorites are widespread in the Braddock Nunataks area, forming all the nunataks west and south of the south-western group of the Braddock Nunataks with the exception of station KG.232. Marginal variations of this granodiorite intrusion also appear where the granodiorite/volcanic contact is exposed in the south-western group of the Braddock Nunataks and surrounding outcrops (Fig. 16); granodiorite also appears to be the most widespread plutonic rock in the Batterbee Mountains (Fig. 1). It is not certain whether the outcrops represent cupolas of the same granodiorite intrusion but more probably several phases of similar granodiorite intrusion took place within the period of time broadly associated with the Andean orogeny.

Granodiorite was first encountered at the main depot site in the Taurus Nunataks and this outcrop is typical of the unhybridized granodiorite of the Braddock Nunataks area. It is a mesocratic coarse-grained rock containing finer-grained more melanocratic basic inclusions, which are elongated in the direction of a pronounced mineral lineation. This outcrop is dissected by an igneous jointing system, in which the cross (*Q*) joints are open and are veneered with epidote and limonite; the longitudinal joints trend in the same direction as the linear orientation of the constituent minerals.

In thin section it possesses a hypidiomorphic granular texture and is composed of euhedral andesine crystals normally zoned from An_{44} to An_{38}, slightly sericitized orthoclase crystals with a patchy extinction and containing poikilitic inclusions of the more sericitized andesine crystals, and aggregates of ragged hornblende crystals twinned on {100} and with a pleochroism scheme α = yellow-green, β = yellow and γ = brown. The hornblende contains inclusions of euhedral apatite crystals and rounded magnetite grains, and it is frequently associated with euhedral crystals of biotite pleochroic from brown to pale yellow and altered along the cleavage to penninite or, more rarely, to aggregates of minute secondary green biotite crystals. Flakes of clinochlore and amorphous crystals of sphene are usually associated with amphibole crystals and interstitial quartz forms about one-third of this rock (Fig. 56f). A modal analysis is given in Table III (KG.225.1).

The granodiorite outcrops in the Taurus and Braddock Nunataks area are consistent but there are some variations from the norm. In cases where the granodiorite has been metasomatized adjacent to later dyke intrusions, the mafic minerals are pseudomorphed by an aggregate of penninite, calcite, granular epidote and magnetite. When biotite is pseudomorphed, these minerals are concentrated along the original cleavage planes. In some other granodiorite outcrops, not only andesine but subhedral crystals of hornblende, orthoclase and a graphic quartz–orthoclase intergrowth are poikilitically included in the large orthoclase plates (Fig. 57a); in one granodiorite at station KG.228, a residual core of pyroxene occurs within the more typical hornblende crystals.

Several features of these granodiorites are significant; first, the poikilitic inclusions of andesine are more sericitized than the enveloping orthoclase crystals and the amphibole inclusions are frequently pseudomorphed by calcite–magnetite–penninite. This indicates that some deuteric alteration of the included minerals had occurred before most of the more acid residuum had crystallized. The occurrence of infrequent residual pyroxene cores in the mafic minerals and the consistent occurrence of normally zoned andesine crystals also means that these rocks had been formed by the assimilation of relatively basic rocks by a more acid magma.

a

b

FIGURE 57

a. A granodiorite from the main peak in the nunatak group 10 km north-west of Cetus Hill, showing the poikilitic inclusions of the mafic minerals and plagioclase in the large euhedral crystals of orthoclase. (KG.228.3; X-nicols; ×4)

b. The sharp contact and textural and compositional differences between a basic inclusion and granodiorite. (KG.228.8; X-nicols; ×3.5)

The granodiorite outcrops are uniform in the Braddock Nunataks area but the outcrop at Thomson Rock is significantly different. This granodiorite is composed of euhedral crystals of hornblende, biotite, quartz and feldspar which are clearly aligned. The proportion of mafic to felsic constituents is about 1 : 4 in most of the granodiorite but zones and discrete finer-grained basic inclusions are more melanocratic. In thin section, this rock is composed of euhedral biotite crystals, pleochroic from brown to pale yellow and very slightly altered to prehnite and penninite. This biotite is usually associated with ragged green hornblende crystals with a pleochroism scheme α = pale brown, β = greenish and γ = dark green, and infrequently altered to flakes of clinochlore. Many rounded grains of magnetite and euhedral crystals of apatite are contained within the mafic minerals. The felsic minerals of this rock are interstitial quartz, euhedral crystals of slightly sericitized labradorite (An_{53}) zoned normally to An_{34} at the crystal rims, and infrequent interstitial patches of orthoclase.

The Thomson Rock granodiorite is significantly different from that of the Taurus and Braddock Nunataks in several respects (Table III, KG.201.1). The plagioclase is both more abundant and more calcic; orthoclase is an interstitial mineral at Thomson Rock but it poikilitically includes the earlier crystallizing minerals in the Taurus and Braddock Nunataks area; the proportion of biotite in the Thomson Rock granodiorite is greater, apparently at the expense of hornblende. It is probable, in view of the fact that there are many more basic inclusions and zones of inclusions in the Thomson Rock granodiorite, that the more basic composition of this granodiorite is due to the greater proportion of basic material that has been assimilated.

a. *Basic inclusions.* These are widespread in the granodiorite and in the cases where they occur in the marginal granodiorite they are clearly xenoliths (Fig. 29). However, in the majority of cases, it is not certain whether these inclusions are genuine reconstituted xenoliths, or autoliths, formed of segregations of early formed minerals in the granodiorite. These inclusions are composed of the same minerals as the enclosing granodiorite but they occur in different proportions (Table III, KG.228.7). In particular, the content of mafic minerals, strongly zoned plagioclase, apatite, sphene and magnetite is greater in the inclusions.

At Thomson Rock, zones of fine-grained basic inclusions and schlieren up to 10 m long occur in the granodiorite, by which they have been more or less assimilated (Fig. 42).

Similar, though less frequent basic inclusions, occur in the granodiorites of the Taurus and Braddock Nunataks area. At

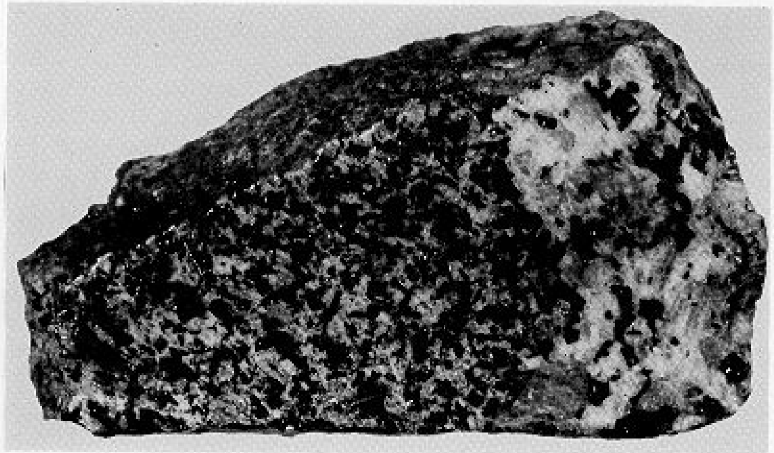


FIGURE 58

A polished section showing the difference in texture and composition between a basic inclusion and granodiorite. (KG.228.8; ×2.5) station KG.228, a basic inclusion in the granodiorite (Fig. 58) has a medium-grained hypidiomorphic granular texture. It contains euhedral hornblende crystals, with a pleochroism scheme α = pale brown, β = pale green and γ = dark green, which include many magnetite grains and which are partly altered to flakes of clinochlore. Associated with these are large grains of magnetite, euhedral sphene crystals and infrequent large biotite crystals pleochroic from dark brown to pale yellow. These biotite flakes include lenses of prehnite and have been partly altered to penninite and granular epidote. The mafic crystals or crystal aggregates are enclosed by a mosaic of large clear euhedral andesine (An_{46}) crystals, which may have been introduced from the enveloping magma and which are normally zoned to An_{27} at their rims, interstitial orthoclase crystals with a patchy extinction and some infrequent interstitial quartz. Both the plagioclase and particularly the orthoclase crystals are extensively sericitized. The main difference between this basic inclusion and the granodioritic matrix is the smaller grain-size, the smaller quartz content and the fact that orthoclase is interstitial in the basic inclusion (Fig. 57b).

The basic inclusions vary considerably in composition and appearance, depending presumably upon how much they have been assimilated. The more they have been assimilated, the closer their mineralogical composition approaches that of the enveloping granodiorite, and the more inclusions of large feldspar crystals and interstitial quartz are introduced from granodioritic magma into the more basic xenoliths.

Some stages of this transition are shown by the modal analysis of a basic inclusion from the western-most of the Taurus Nunataks (Table III, KG.211.1). The basic inclusions at this locality are as much as 1 m long and are composed of a hypidiomorphic granular aggregate of large clear normally zoned andesine (An_{38}) crystals derived from the magma. These large crystals are sharply zoned to oligoclase (An_{25}), which forms a narrow distinct optically continuous rim. In some cases, the microperthitic orthoclase, which constitutes the major part of the groundmass of this inclusion, has also grown in optical continuity on to the outer edges of the zoned plagioclase crystals.

The hornblende crystals in this basic inclusion possess a pleochroism scheme α = pale brown, β = green and γ = deep green, and they frequently contain a residual pyroxene core. Magnetite grains are associated with these mafic aggregates, which grade at their extremes into a mass of disorientated biotite crystals with associated flakes of clinochlore replacing the hornblende. The interstitial finer-grained matrix is composed of an allotriomorphic granular mosaic of quartz, small crystals of sericitized microperthitic orthoclase and cloudy plagioclase (An_{32}) together with small ragged crystals of the mafic minerals. Both apatite and sphene occur as accessory minerals within the mafic crystals.

b. *Leucocratic raft*. A further indication that the granodiorite is not homogenous is provided by a small rock outcrop between stations KG.227 and 228 (Fig. 79). This outcrop contains a raft of leucocratic igneous rock which appears to have been in the process of being assimilated by the surrounding granodiorite (Fig. 59). In thin section, the rock comprising this raft contains euhedral crystals of green hornblende each with a residual core of pyroxene, and which include magnetite grains, apatite prisms and sphene crystals. These hornblende crystals are partly altered

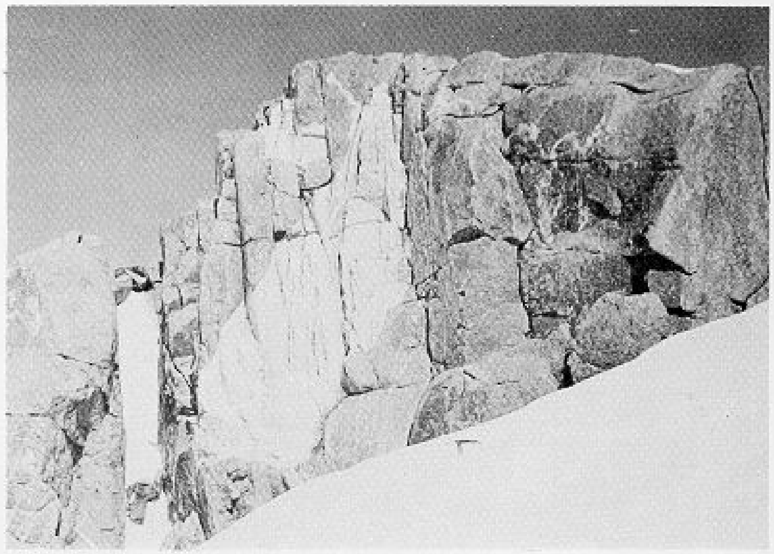


FIGURE 59
A raft of coarse-grained leucocratic rock contained in the granodiorite at the east end of station KG.227. This raft has been partly assimilated by the surrounding granodiorite.

to flakes of clinochlore and are associated with penninite pseudomorphing crumpled biotite crystals. These include lenses of prehnite, granular epidote and ragged sphene crystals. Much of the rock is composed of idiomorphic unzoned andesine (An_{48}) crystals fairly extensively sericitized and granulated; some of them are ophitically included in the amphibole crystals. Both the orthoclase, showing patchy extinction, and the quartz are fresh and interstitial, and include corroded grains of plagioclase and mafic minerals. This indicates that the quartz and potash feldspar were the last constituents to crystallize.

This raft has a sharp contact with the surrounding granodiorite and may represent a large plagioclase-rich segregation, which formed early in the course of crystallization and which was subsequently partly assimilated by the magma. A modal analysis (Table III, KG.227.1) confirms that the interstitial quartz and orthoclase are less abundant in the raft than in the granodiorite and it is probable that these minerals were introduced into the aggregate of euhedral plagioclase crystals late in the course of crystallization. This would cause the distortion and shearing in the plagioclase crystals, and the characteristic poikilitic inclusions of plagioclase in orthoclase. This explanation accounts for the differential sericitization of the plagioclase and orthoclase, and for the deuteric alteration of the original pyroxene to amphibole and clinochlore before the magma completely solidified. However, this raft is apparently unique in the granodiorites of the Taurus Nunataks.

c. *Orthoclase-rich bands*. In the granodiorites at station KG.228, consistent pink bands up to 1 m across, which are finer-grained than the surrounding granodiorite, more or less follow the mineral lineation. They owe their colour to the predominance of large euhedral pink orthoclase crystals (Fig. 60). In thin section, these crystals are fresh, euhedral and twinned according to the Carlsbad law. They appear to have grown around nuclei of corroded plagioclase crystals and also include small grains of the mafic minerals (Fig. 61a). Biotite, pleochroic from yellow to dark brown, and hornblende with a pleochroism

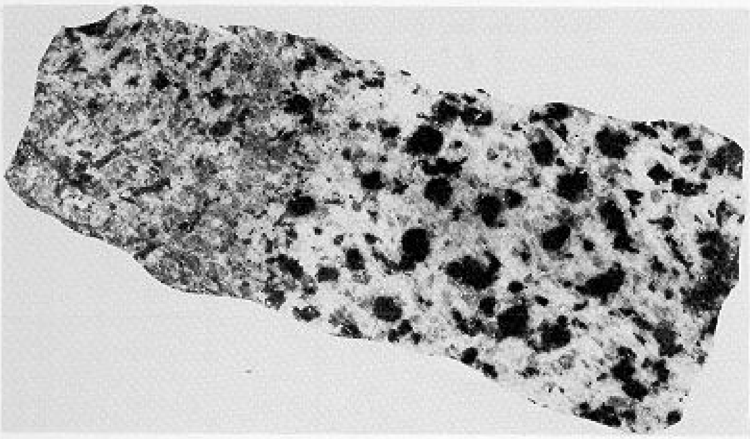
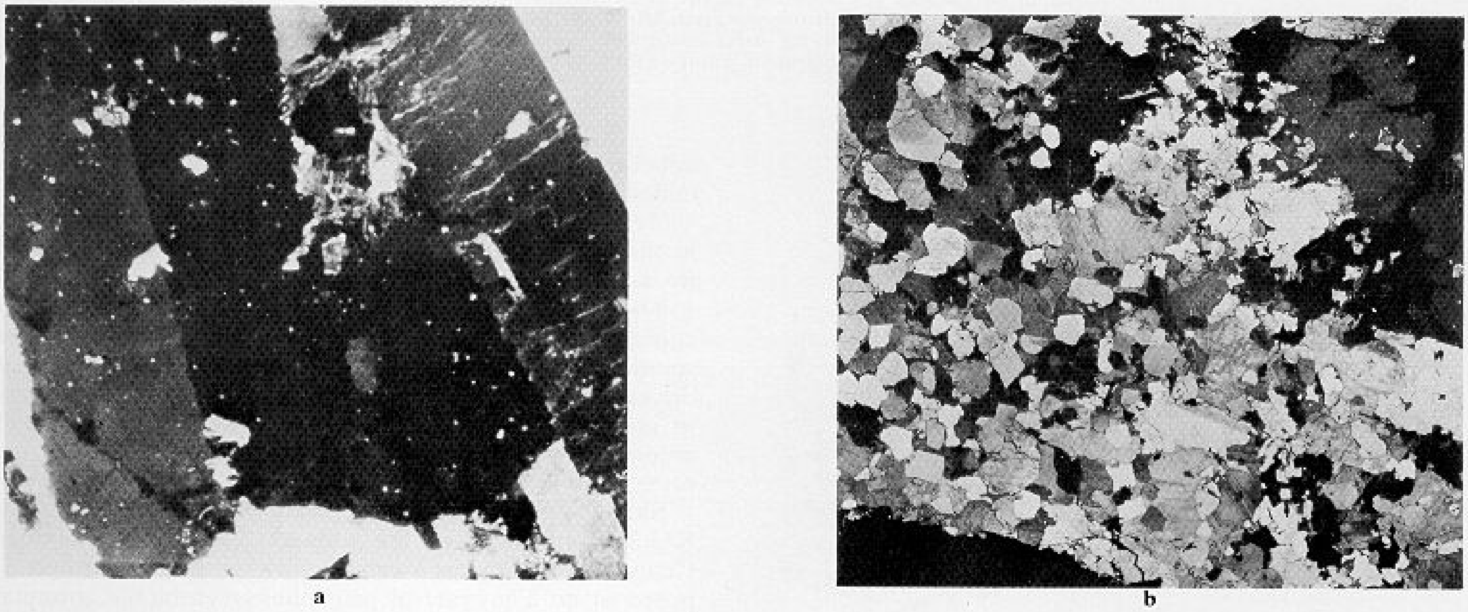


FIGURE 60
A polished section showing the difference in texture and composition between orthoclase-rich bands and the surrounding granodiorite. (KG.228.6; ×0.4)

scheme α = pale yellow, β = pale green and γ = dark green are associated with the felsic minerals. This amphibole is partly altered to flakes of clinochlore and contains euhedral sphene lozenges, magnetite grains and apatite crystals, while the remainder of the rock is composed of sericitized unzoned plagioclase (An_{42}) crystals. These bands probably represent zones in which the last acid residuum crystallized, since both the euhedral orthoclase crystals and the interstitial areas of quartz contain many poikilitic inclusions of the earlier crystallized minerals. Since these bands are almost as coarse-grained as the granodiorite, it would appear they crystallized while the surrounding rock was still hot. Similar orthoclase-rich zones occur in the granodiorite at Cetus Hill (KG.230).

d. *Gneissose zones.* Mineralized gneissose zones in the granodiorite outcrops are characterized by the intense brecciation caused in the surrounding rocks. These zones are particularly conspicuous at station KG.212, where they are impregnated with secondary epidote, in association with iron and copper sulphide ores. These near-vertical zones trend at 105–115° (mag.) and reach a maximum width of 1 m but irregular stringers impregnated with similar secondary material cut the surrounding granodioritic rocks and become more frequent as the gneissose zones are approached. The mineralized zones trend in a direction parallel to the longitudinal joints in the granodiorite but they also appear to be cut by this igneous jointing system (Fig. 62).

The first indication of these gneissose zones is provided by the many randomly orientated epidote-impregnated stringers which cut the surrounding granodiorite (Fig. 63). In these granodiorites, penninite pseudomorphs the original biotite, sericite and granular epidote have partly replaced the sheared feldspar crystals and the original quartz has an undulose extinction. Many sub-parallel stringers of re-distributed epidote with associated granulated quartz cut these rocks and, in the more intensely altered zones associated with these stringers, a felted aggregate of secondary green biotite crystals has completely replaced the original mafic minerals. In the actual gneissose zones, the plagioclase crystals of the original granodiorite are completely replaced by granular epidote, which has been re-distributed, together with secondary green biotite, throughout the mineralized zone. In these most intensely altered zones the only remaining constituents of the granodiorite are the abraded quartz crystals. Chalcopyrite and pyrite are disseminated throughout the gneissose zones but they have been oxidized to malachite and limonite, respectively. These secondary ores have then been re-distributed along the joint planes in the granodiorite. In some of the most intensely brecciated zones very little



a b

FIGURE 61
a. Large euhedral orthoclase crystals, which are Carlsbad twinned and contain plagioclase and mafic inclusions. (KG.228.6; X-nicols; ×15)
b. The aplitic texture of the margin of a pegmatite dyke at the westernmost of the Taurus Nunataks. The marginal aplitic zone grades rapidly into a coarser-grained garnet-pegmatite. (KG.211.5; X-nicols; ×4)

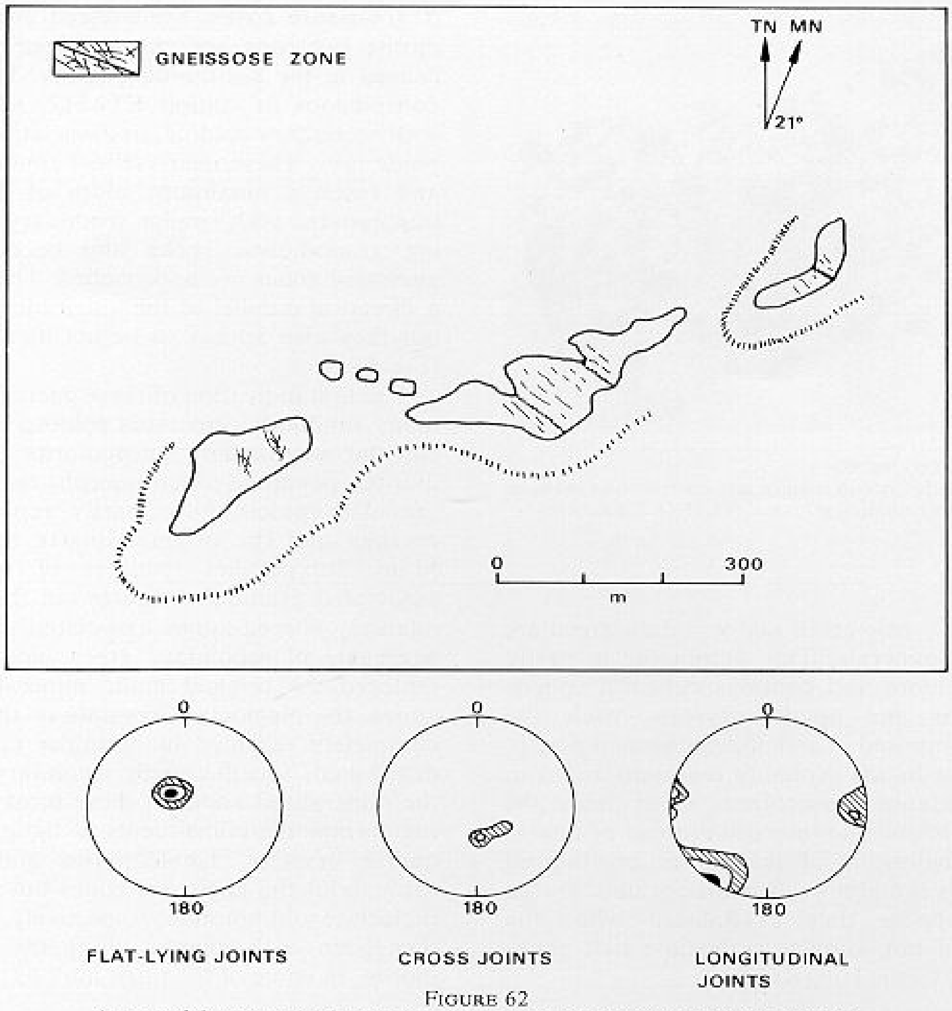


FIGURE 62
A map of the nunatak 12 km west of the Braddock Nunataks showing how the strike of the mineralized gneissose veins parallels the strike of the longitudinal joints and is perpendicular to the strike of the flat-lying and cross (*Q*) joints. The contoured stereographic plot is on the lower hemisphere.

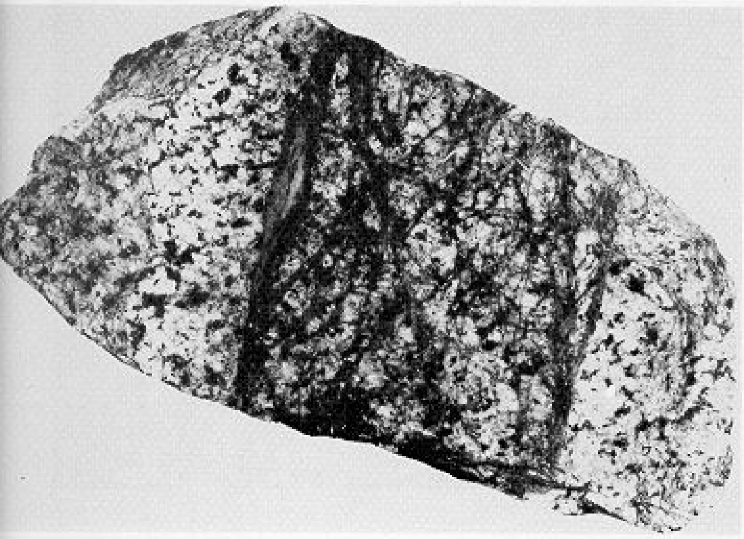


FIGURE 63
A polished section of granodiorite from the nunatak 12 km west of the Braddock Nunataks showing many stringers of epidote and secondary green biotite. These stringers trend predominantly in the direction of the gneissose zones. (KG.212.2; ×0.5)

mineralization is evident but augen of granodiorite are contained within a brecciated matrix of quartz, feldspar and magnetite fragments (Fig. 64). Pockets of recrystallized quartz occur in these zones with associated pyrite, partly oxidized to limonite, and small muscovite crystals.

These gneissose zones have been formed, at a late stage in the cooling cycle of the granodiorite, by percolating hydrothermal solutions, which brecciated and mineralized the rock and altered the original feldspar to epidote, and the original mafic minerals to green biotite with associated epidote and magnetite. These secondary minerals were then re-distributed with the metallic ores.

Similar zones occur in the granodiorite outcrops at stations KG.211 and 228, and the nunatak 2.5 km south-south-east of Cetus Hill. At the last locality many sub-parallel stringers, composed of an aggregate of penninite, green biotite, granular epidote, minute tremolite and recrystallized quartz crystals cut the granodiorite. This granodiorite is not homogeneous but the variations in grain-size are most probably due to the different rates of cooling that occurred rather than to brecciation of the constituent minerals. The many xenoliths in this rock are not

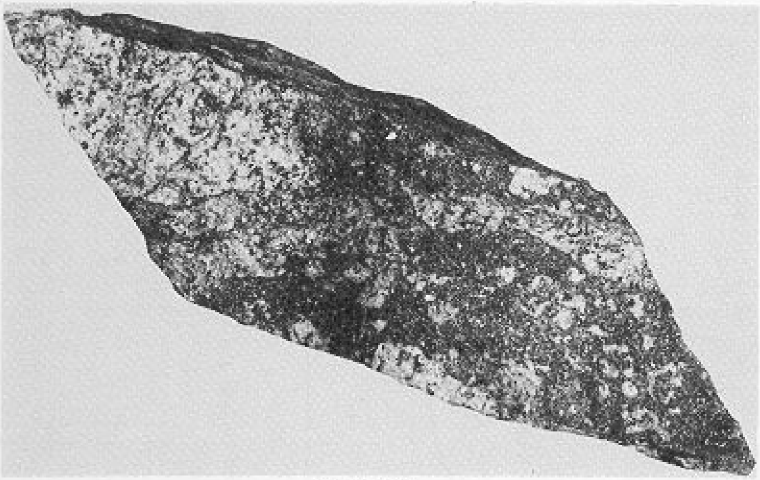


FIGURE 64
A specimen from a gneissose zone showing augen of granodiorite included in a brecciated mineralized dark matrix. (KG.212.7; ×2.7)

well digested and it appears that this granodiorite possesses textures that could occur near the edge of the intrusion. There is very little evidence of granulation of the constituent minerals of the granodiorite at this locality, although the original biotite is pseudomorphed either by penninite or by aggregates of secondary green biotite, and the original feldspars contain many inclusions of granular epidote. Many fine-grained felsitic stringers cut the granodiorite.

At station KG.211, conspicuous sub-horizontal veins cutting the granodiorite are filled with a central zone of recrystallized quartz and outer zones of granular epidote with a little associated green biotite and tremolite. These zones are considered to have a similar hydrothermal origin to the gneissose zones at station KG.212 but the constituent minerals are more crystalline at station KG.211. Copper and iron mineralization is conspicuous at station KG.211 and also appears to be concentrated along the longitudinal joints but, as at station KG.212, the original chalcopyrite and pyrite have been oxidized and redistributed along the other joint planes.

e. *Pegmatites*. Many sub-horizontal felsitic and pegmatitic dykes and stringers cut the granodiorite at Thomson Rock. They also occur in the Taurus Nunataks granodiorites. At station KG.211, where the pegmatite dykes are as much as 1 m wide, they strike at about 340° (mag.) and dip either sub-parallel to the flat-lying or longitudinal joints of the granodiorite. The larger dykes, however, parallel the longitudinal joints and impose on the adjacent granodiorite a local jointing pattern parallel to their edges. In thin section, these pegmatite veins are composed of a graphic intergrowth of quartz, with an undulose extinction, and perthitic orthoclase, in which are disseminated euhedral muscovite and oligoclase (An_{22}) crystals, and penninite pseudomorphs of biotite (Fig. 61b). The marginal texture of these dykes is aplitic but towards the centre they become coarser-grained and contain euhedral almandine and more frequent muscovite crystals. The pegmatites were intruded after the granodiorite had solidified and partly cooled, because the margins of these dykes are finer-grained and the contacts with the surrounding rock are sharp.

At station KG.212, similar narrow pegmatite and quartz veins, up to 10 cm across, trend in a direction 232° (mag.) approximately parallel to the cross (*Q*) joints.

f. *Marginal features of the granodiorite intrusion*. The marginal granodiorites, which crop out at station KG.214, along the western edge of the south-western group of the Braddock Nunataks and in the south-eastern group of the Braddock Nunataks, are unusual because they have crystallized adjacent to the volcanic country rocks.

At station KG.214, a small granodiorite boss has intruded the volcanic succession which is domed over it. At the top of this boss, *lit-par-lit* intrusion has taken place as layers of granodioritic magma were injected along the bedding planes of the andesitic tuffs and basaltic lava flows. The volatile constituents of the magma have been concentrated at the top of this boss, resulting in intense metasomatism of the interleaved layers of volcanic rock.

A traverse was made across the summit of station KG.214 to record the variations in the contact rocks and the results are summarized in Fig. 65. The marginal iron-stained granodioritic rocks are extremely fine-grained and are frequently laminated parallel to the contact. They are composed of lenses of crystalline granular quartz contained in a cryptofelsitic banded groundmass of devitrified glass. This is impregnated with calcite and sericite, and contains many partly hydrated magnetite grains.

This glassy marginal zone, which seldom exceeds 1 m in width, merges into more widespread pink fine-grained felsitic rocks containing many xenocrysts derived from the original phenocrysts in the adjacent volcanic rocks and many fine-grained semi-digested hornfelsed xenoliths of the original groundmass of these volcanic rocks. These relict basaltic and andesitic fragments are more assimilated away from the immediate contact. Adjacent to the basaltic rocks, the marginal granodiorites contain derived crystals or crystal aggregates of almost unaltered augite, labradorite and penninite set in a cryptofelsitic matrix in which there are quartzose segregations. Stringers of secondary quartz and epidote cut both the groundmass and the xenocrysts. Adjacent to the andesitic tuffs, however, the cryptofelsitic matrix of these marginal granodiorites contains many corroded xenocrysts of penninite and pink andesine (An_{30}) including much granular epidote and calcite. The fine-grained matrix of the andesitic tuffs is apparently more liable to assimilation than that of the basalts.

The layers of fine-grained marginal granodiorite, which are interleaved with the metasomatized volcanic rocks at the summit of station KG.214 (Fig. 65, inset), are characterized by their porphyritic texture and red colour. The phenocrysts, which have also apparently been derived from the adjacent volcanic rocks, consist of acicular mafic crystals that are always pseudomorphed by a calcite–magnetite–epidote–penninite intergrowth and large feldspar crystals partly or wholly pseudomorphed by calcite and sericite. These phenocrysts are set in a microcrystalline groundmass of feldspar microlites, amorphous patches of calcite and oxidized magnetite grains. Hydrothermal oxidation of the original iron ores has caused the red colour of these rocks. Many of these marginal granodioritic rocks contain zones of sub-parallel oval vesicles filled with secondary sericite, quartz, calcite and limonite (Fig. 66).

The iron-stained residual layers of metasomatized volcanic rock contain much secondary calcite, limonite and sericite produced by the hydrothermal mineralization that occurred at the top of the intrusive boss. These altered rocks frequently contain many large vesicles, up to 5 mm across, which are filled with radiating growths of alkali feldspar (Fig. 67) that have grown on

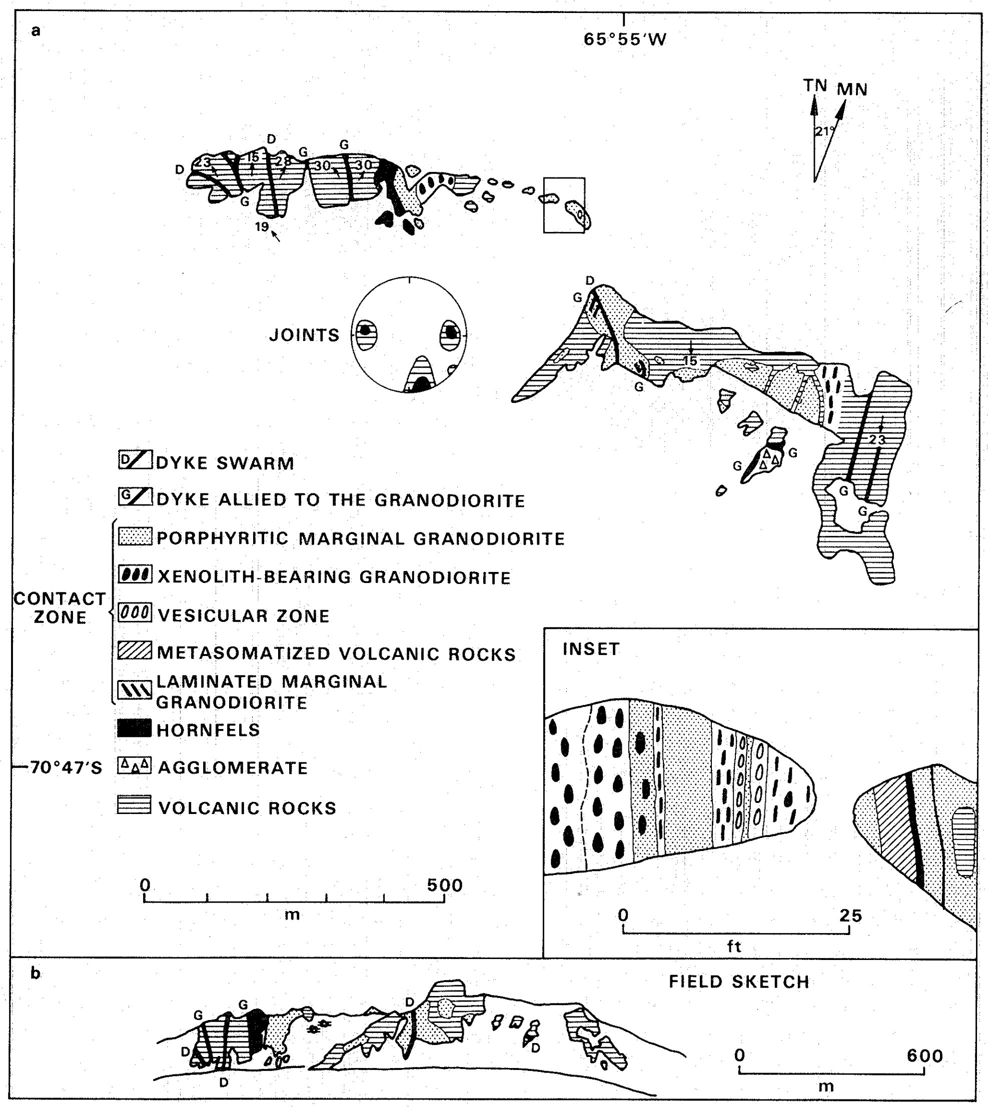


FIGURE 65
a. A geological sketch map of station KG.214 in the Braddock Nunataks showing the marginal features of the granodiorite intrusion at this locality. The location of the inset is shown on the map.
b. A field sketch of station KG.214.

nuclei of euhedral quartz or feldspar crystals. The vesicles themselves are cut by many radiating granular quartz veins. The groundmass, in which these vesicles are set, is composed of stringers and lenses of granular quartz in a laminated cryptofelsitic matrix. Some large relatively unaltered inclusions of volcanic rock in these marginal granodioritic rocks are rimmed by pitchstone.

West of the centre of the boss, this zone of *lit-par-lit* intrusion grades into coarser-grained extensively hybridized marginal rocks, largely composed of brecciated aggregates of slightly altered crystals derived from the adjacent volcanic rocks and set in a graphic quartzo-feldspathic matrix with some associated crystalline epidote and sphene. The large plagioclase xenocrysts are partly altered to an aggregate of sericite, epidote and calcite. Secondary actinolite–tremolite, produced from the original chloritic groundmass of the volcanic rocks, has been redistributed throughout the hybridized marginal rocks of the intrusion.

At the steep western contact of this boss, a network of steeply dipping interweaving dykes and veins has impregnated and partly assimilated the marginal volcanic rocks. These hornfelsed volcanic rocks are iron-stained and cut by a well-developed set of joints parallel to the contact. They are impregnated with pegmatitic veins and quartz blebs (which become more abundant towards the contact) composed of a graphic intergrowth of quartz and microperthite, with which some crystalline epidote is associated (Fig. 68a).

The marginal volcanic rocks are hornblende-biotite-plagioclase-hornfelses of the amphibolite facies. They are composed of a granoblastic mosaic of quartz, feldspar and mafic minerals, and exhibit a blastoporphyritic texture due to the relict feldspar phenocrysts which contain many granular quartz inclusions.

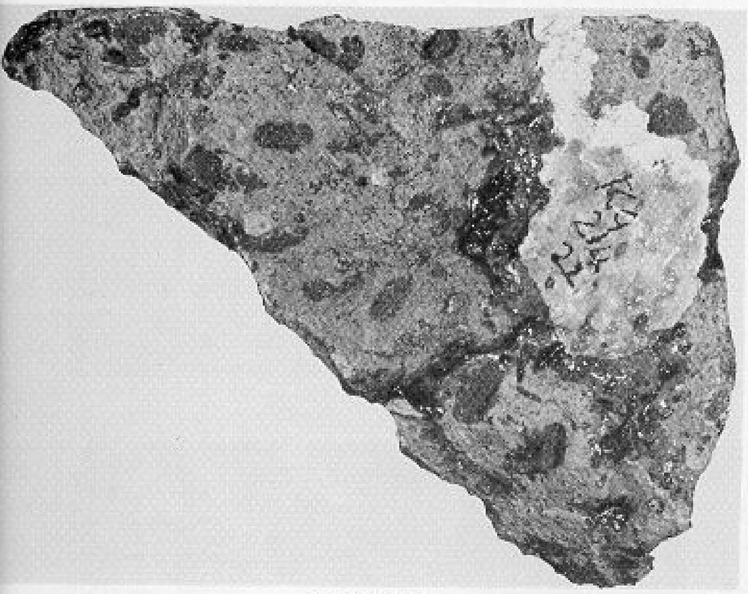


FIGURE 66
\ marginal, hydrothermally altered granodioritic rock from station KG.214 ontaining many sub-parallel vesicles filled with crystalline quartz, calcite, sericite and limonite. (KG.214.22; ×1.3)

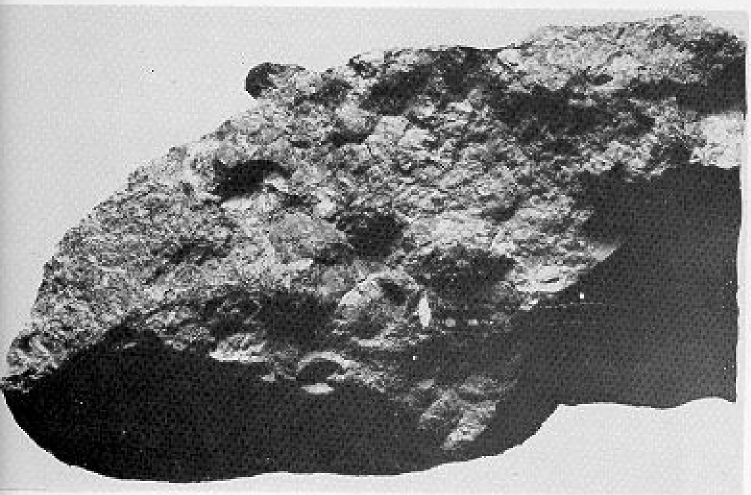


FIGURE 67
'he many spherical vesicles in the marginal metasomatized volcanic rock at tation KG.214. These vesicles are filled with a radiating feldspar aggregate which grows from nuclei of quartz or feldspar crystals. (KG.214.44; ×1)

Chlorite in the original groundmass of the volcanic rocks has artly recrystallized to form aggregates of small, brown biotite rystals (Fig. 68b), which are evenly disseminated throughout he most severely hornfelsed rocks, and apatite is a frequent ccessory mineral.

Pockets of red ochre in the volcanic rocks near the intrusion ave been derived from original pyrite which impregnated these ocks at the time of the intrusion. Some chalcopyrite associated vith the pyrite has been oxidized to malachite.

Along the western edge of the escarpment of the southvestern group of the Braddock Nunataks, the contact between he granodiorite and volcanic rocks is discordant and dips eastvard at moderate angles. It is exposed at stations KG.215, 219, 21 and 224 (Fig. 16).

At station KG.215, the volcanic country rocks are baked and impregnated with secondary quartz–epidote veins. The marginal hybridized granodioritic rocks contain many large, dark grey, anhedral feldspar xenocrysts set in a finer-grained interstitial felsic matrix. This granodiorite therefore appears to be more melanocratic than its composition justifies.

In thin section this rock contains large subhedral labradorite xenocrysts, which are sharply and normally zoned from An_{58} in the cores to An_{22} at the rims. These crystals are frequently enveloped by a rim of perthitic cloudy orthoclase, which is also widespread in the hypidiomorphic granular groundmass of this rock. The composite mafic xenocrysts in this rock are composed of a residual core of pyroxene, often altered to yellow-green fibrous chlorite surrounded by an optically continuous rim of hornblende (with a pleochroism scheme α = yellow-green, β = yellow and γ = brown) which has itself been partly altered to clinochlore. However, some of the mafic minerals have been pseudomorphed by an aggregate of fibrous actinolite. Biotite frequently occurs in the rims surrounding the composite mafic crystals and it is also present in the groundmass of the rock. This biotite is pleochroic from light to dark brown and appears to be the final stable alteration product of the mafic minerals. Anhedral inclusions of magnetite and apatite are frequently contained in these mafic aggregates, but large ragged patches of magnetite, with associated antigorite and apatite prisms, are also widespread in the groundmass of this rock. The groundmass is composed of a sub-graphic intergrowth of quartz and microperthitic cloudy orthoclase (Fig. 68c). This texture is the most characteristic feature of the hybridized marginal granodioritic rocks, of which a modal analysis is given in Table III (KG.215.2).

These marginal rocks contain disseminated pyrite crystals which, when oxidized, cause the iron-staining of the outcrops. They are also cut by finer-grained felsitic veins and stringers. One zone of hydrothermally altered granodiorite, which dips at 73° in a direction 310° (mag.) sub-parallel to the contact, is impregnated by secondary epidote, limonite and calcite. The original andesine (An_{47}) crystals in these zones are sheared and largely altered to granular epidote and calcite, and the original quartz crystals have an undulose extinction. The original mafic minerals have been pseudomorphed by a penninite–epidote–magnetite assemblage and the secondary epidote and calcite have been somewhat re-distributed, together with some recrystallized quartz, along the sutures between the original minerals.

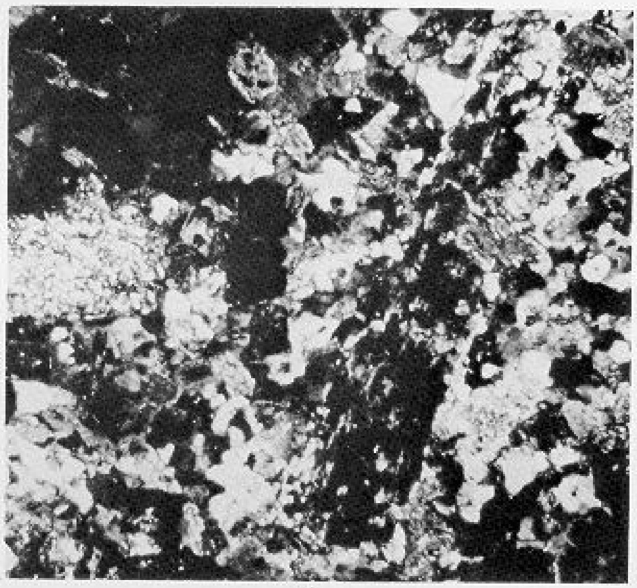
At the foot of station KG.221, a fine-grained acid porphyritic dyke intrudes a more widespread, coarse-grained, melanocratic hybridized granodiorite similar to the marginal outcrop at station KG.215. This dyke encloses many xenoliths of the hybridized marginal rocks and has imposed a set of joints on to the hybrid rocks parallel to the edge of the dyke. The margin of the dyke is composed of about 10 mm of fine-grained felsitic rock (Fig. 69) formed of a graphic intergrowth of perthitic orthoclase and quartz with a little associated oligoclase (An_{34}) and brown biotite.

The perthitic orthoclase and graphic quartz–perthite intergrowth, which occur in the melanocratic hybrid and in this marginal felsitic zone of the dyke, do not appear in the greater part of the dyke. This may indicate that both the groundmass of the melanocratic hybridized granodiorite and the marginal felsitic zone of the dyke cooled more rapidly than the centre of the

a

b

c



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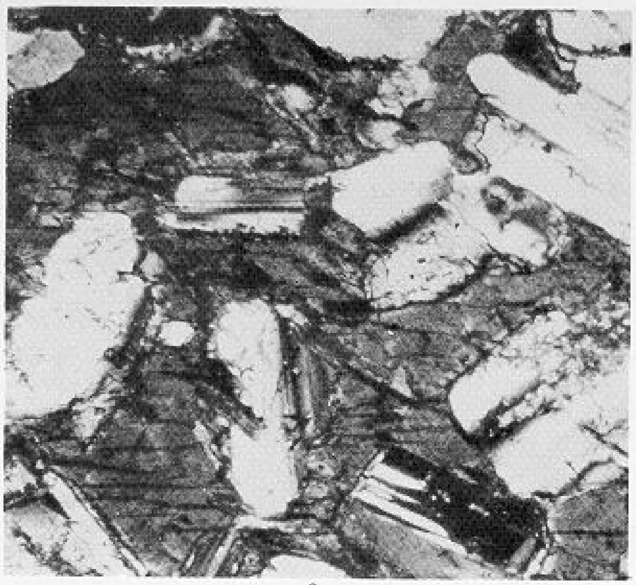

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FIGURE 68

a. The process of assimilation of hornfelsed xenoliths of volcanic rock by a granodioritic magma. This has crystallized to a graphic quartz-microperthite intergrowth. (KG.214.33; X-nicols; ×8.5)
b. Many crystals of secondary brown biotite which form in the marginal hornfelsed volcanic rocks of station KG.214. (KG.214.34; X-nicols; ×200)
c. The texture of the marginal granodioritic rocks at station KG.215 in the Braddock Nunataks. Euhedral crystals of labradorite (An_{58}) are normally zoned to oligoclase at their rims and are enveloped by microperthitic orthoclase. This mineral occurs in a sub-graphic intergrowth with quartz in the matrix of the rock. (KG.215.2; X-nicols; ×5)
d. The large crystals of dark brown hornblende in a hornfelsed andesitic tuff. (KG.224.7; X-nicols; ×33)
e. The marginal granodiorites at station KG.220 in the Braddock Nunataks. Xenoliths and xenocrysts from the original volcanic rocks are contained in a sub-graphic intergrowth of quartz and microperthitic orthoclase. (KG.220.8; X-nicols; ×5)
f. Ophitic inclusions of plagioclase in hornblende retained in the marginal granodiorite of the peak 5 km south-west of Mount Ness. (KG.237.12; X-nicols; ×41)

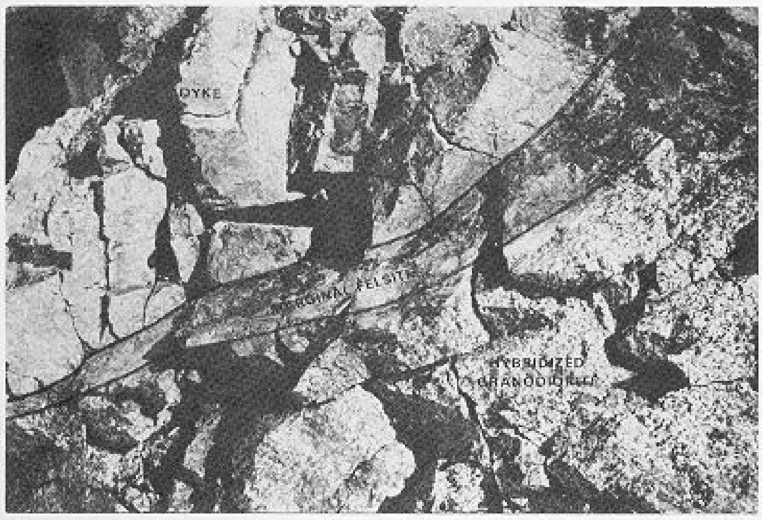


FIGURE 69
The contact between a later dyke of porphyritic fine-grained microgranodiorite and the hybridized coarse-grained marginal granodiorite at the foot of station KG.221 in the Braddock Nunataks.

dyke. Much of the dyke is composed of xenocrysts of labradorite (An_{62}) containing many quartz inclusions, set in a granular mosaic of euhedral brown biotite crystals partly altered to penninite, euhedral green hornblende crystals (with a pleochroism scheme α = pale brown, β = green and γ = dark green, and partly altered to clinochlore), granular quartz and clear orthoclase with a patchy extinction. Apatite and magnetite inclusions occur in the mafic crystals, which are more abundant in this dyke than in the normal granodiorite.

It appears that this dyke was intruded after the initial assimilation of the basic country rocks and it is therefore possible that the granodiorite intrusion was composite.

Similar hybrid rocks occur at station KG.219. The volcanic country rocks are baked and extensively iron-stained in a contact zone about 15 m wide. The hornfelses produced from the rhyolitic country rocks are composed of a granoblastic mosaic of brown biotite, strongly pleochroic green hornblende, quartz, feldspar and magnetite. The blastoporphyritic texture of these hornfelses is caused by large corroded orthoclase and strongly zoned plagioclase (An_{25}) relict phenocrysts that contain many mafic inclusions.

North-west of this contact zone the marginal granodioritic rocks are similar pink and grey hybridized rocks cut by many sub-vertical hydrothermally altered zones. Finer-grained felsitic dykes also cut the coarser-grained typical hybridized granodiorites at this locality.

In thin section, these marginal hybridized granodioritic rocks are identical to the marginal outcrops at station KG.215, although the euhedral plagioclase xenocrysts are zoned from An_{36} to An_{30} and the mafic minerals are less frequent. The dearth of ferromagnesian minerals in this hybridized rock is probably due to the rhyolitic nature of the volcanic country rock into which the granodiorite has been intruded.

In the most southerly of the south-western group of the Braddock Nunataks, where the granodiorite/volcanic contact is exposed (Fig. 16), the volcanic rocks are extensively hornfelsed in a narrow zone near the contact and both the volcanic and marginal granodioritic rocks are impregnated with epidote in association with some iron and copper mineralization.

The hornfelsed andesitic tuffs at this locality are composed of a granoblastic mosaic of quartz, feldspar, magnetite, brown biotite and green amphibole. Relict phenocrysts of euhedral andesine (An_{38}), containing many quartz inclusions, and augite crystals rimmed with strongly pleochroic hornblende are common. Much of the original augite has been transformed to diallage and there are large crystals of dark brown hornblende, with which are associated some faintly pleochroic (purple to pale yellow) apatite prisms and brown biotite crystals (Fig. 68d).

Farther from the contact, the less altered volcanic country rocks are cut by many quartz stringers containing epidote, sphene, penninite and pyrite, and the groundmass of these tuffs is impregnated with minute crystals of green biotite associated with aggregates of green amphibole, magnetite and quartz. This may be a deuteric feature of the original rock or, alternatively, it may have been caused by thermal metamorphism.

Fine-grained dykes and stringers of the intrusive granodiorite finger into the volcanic rocks (Fig. 31) and the near-contact granodiorites are iron-stained. The hybridized granodioritic rocks are similar to those of the other outcrops but they contain a higher proportion of mafic minerals and accessory sphene. Both the major intrusion and dykes contain small xenoliths of hornfelsed volcanic rocks, in which green hornblende is concentrated.

Father east, in the south-eastern group of the Braddock Nunataks, similar coarse-grained, pink, well-laminated, xenolithic, epidote-impregnated hybridized granodiorites crop out. This intrusion appears to have domed the volcanic country rocks, because the dips are anomalous adjacent to the steep western contact between the granodiorite and volcanic rocks.

These marginal granodiorites contain many xenocrysts of fibrous chlorite and augite, and hornfelsed xenoliths derived from the volcanic country rock. The microscopic characteristics of these rocks are similar to those of the marginal granodiorites in the south-western group of the Braddock Nunataks, although the composition of the plagioclase (An_{33}) xenocrysts is the same as that in the green andesitic tuffs of the south-eastern group of the Braddock Nunataks (Fig. 68e). There is very little biotite in these marginal granodioritic rocks but crystalline epidote frequently occurs in interstices of the rock fabric.

At the westward-dipping contact exposed in the south-eastern group of the Braddock Nunataks (Fig. 16), the marginal metasomatized volcanic rocks are cut by stringers of epidote and calcite, and by pegmatitic veins composed of a graphic quartz–microperthite intergrowth. These marginal granodioritic rocks are similar to those in the exposures of the western contact at station KG.214 and they are composed of brecciated fragments of the volcanic rocks set in a matrix of more finely granulated fragments. Epidote stringers cut the rock and radiating crystalline epidote fills the interstices; there is some copper and iron mineralization. However, the original pyrite is frequently oxidized to pockets of red ochre and calcite veneers many of the joint planes of this brecciated contact zone.

Farther west in the south-eastern group of the Braddock Nunataks, sub-parallel fine-grained granodioritic dykes have intruded the volcanic country rocks and have caused hydrothermal mineralization similar to that in the *lit-par-lit* intrusion at station KG.214.

In the Batterbee Mountains, a small granodiorite boss intrudes the gabbroic country rock at station KG.237. The marginal gabbros are extensively iron-stained in a zone about 30 m wide and are metasomatized near the contact, resulting in the production of epidote from the original feldspar and secondary tremolite–actinolite, penninite and calcite associations from the original mafic minerals (p. 38). The marginal rocks are impregnated with pyrite and some chalcopyrite. The hybridized marginal granodioritic rocks contain many xenocrysts of sharply zoned sericitized euhedral feldspar crystals, which are often granulated and contain frequent inclusions of recrystallized granular feldspar. These xenocrysts may be as basic as An_{50} when they are not significantly zoned but the majority of crystals, which appear to have been more altered by the contaminating magma, are strongly and normally zoned from An_{39} to An_{21} and are frequently surrounded by a rim of clear orthoclase. In the most marginal granodioritic rocks, the mafic minerals occur as aggregates of small ragged olive-green biotite crystals and green amphibole crystals with much associated magnetite, sphene and apatite. Towards the centre of the boss, however, the crystal aggregates become fused to form large composite hornblende and biotite crystals, in which biotite has apparently formed at the expense of hornblende. The numerous mafic xenocrysts are either strongly pleochroic hornblende (α = pale brown, β = greenish and γ = dark green), clinochlore or biotite. Relict ophitic textures of plagioclase included in the mafic crystals are sometimes retained in these xenocrysts (Fig. 68f).

These xenocrysts are set in a groundmass of abundant granular quartz with some associated orthoclase. Graphic textures in this groundmass are rare but epidote frequently veneers the joint planes of these rocks, disseminated pyrite crystals and veins are frequently found and the many dark inclusions of the adjacent gabbros are aligned in the direction of a mineral lineation which is evident in the centre of this boss.

Similar rocks occur in a small nunatak north-west of station KG.237 adjacent to fine-grained microgabbros (Fig. 39). In these marginal granodiorites the mafic xenocrysts have also been transformed to strongly pleochroic hornblende surrounded by brown biotite crystals and the strongly zoned plagioclase xenocrysts are set in a quartzose groundmass.

Summarizing the marginal features caused by the granodiorite intrusion, the volcanic rocks near the contact contain veins and vesicles infilled with crystalline quartz and epidote with associated copper and iron mineralization. The marginal hornfelsed volcanic rocks are impregnated by pegmatitic veins and inclusions composed of a graphic quartz–microperthite intergrowth, with which are associated some epidote, actinolite and sphene. The hornfelses contain brown biotite and green hornblende resulting from the thermal metamorphism. Occasionally, the extreme edges of the granodiorite intrusion are glassy and laminated parallel to the contact but, more typically and particularly where the contacts are discordant, the marginal volcanic rocks have been brecciated and assimilated by the intrusive granodioritic rocks. The sharpness of this contact is probably related to the original composition of the volcanic country rock. Marginally, the granodioritic rocks contain many xenocrysts and xenoliths derived from the volcanic rocks and these are enveloped in a graphic groundmass composed essentially of quartz and microperthite. Farther from the contact, as the material derived from the country rocks becomes more digested, the plagioclase crystals become strongly zoned and are rimmed with microperthitic orthoclase, the groundmass texture becomes sub-graphic and any original augite is transformed first to amphibole and then frequently to biotite. Sphene and apatite are abundant accessory minerals in the marginal granodioritic rocks but they become less frequent away from the contact.

It is clear that the composition of these marginal granodioritic rocks will have been modified by the type of volcanic rocks into which they have been intruded, and it is also apparent that the features of these marginal granodiorites occur on a smaller scale in the basic inclusions in the main granodiorite outcrops.

g. *Minor intrusions allied to the granodiorite.* Minor intrusions trending sub-parallel to the contact between the volcanic rocks and the granodiorite cut both the volcanic and the marginal intrusive rocks. In miniature, these dykes and sills repeat some of the variations which appear in the marginal granodioritic rocks.

The mineralogical compositions of these minor intrusions and the granodioritic rocks are similar (Table III, KG.219.5) but frequently large crystals derived from the country rock are contained in the fine-grained matrix of these intrusions. A section across a dyke at station KG.214 (Fig. 70), which dips north-eastward at 61°, illustrates some of the textural variations that

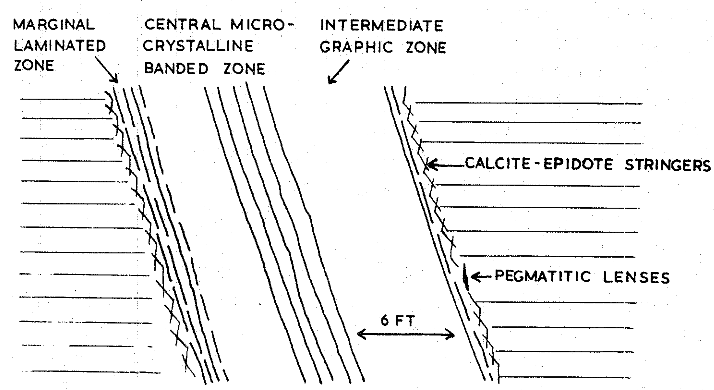
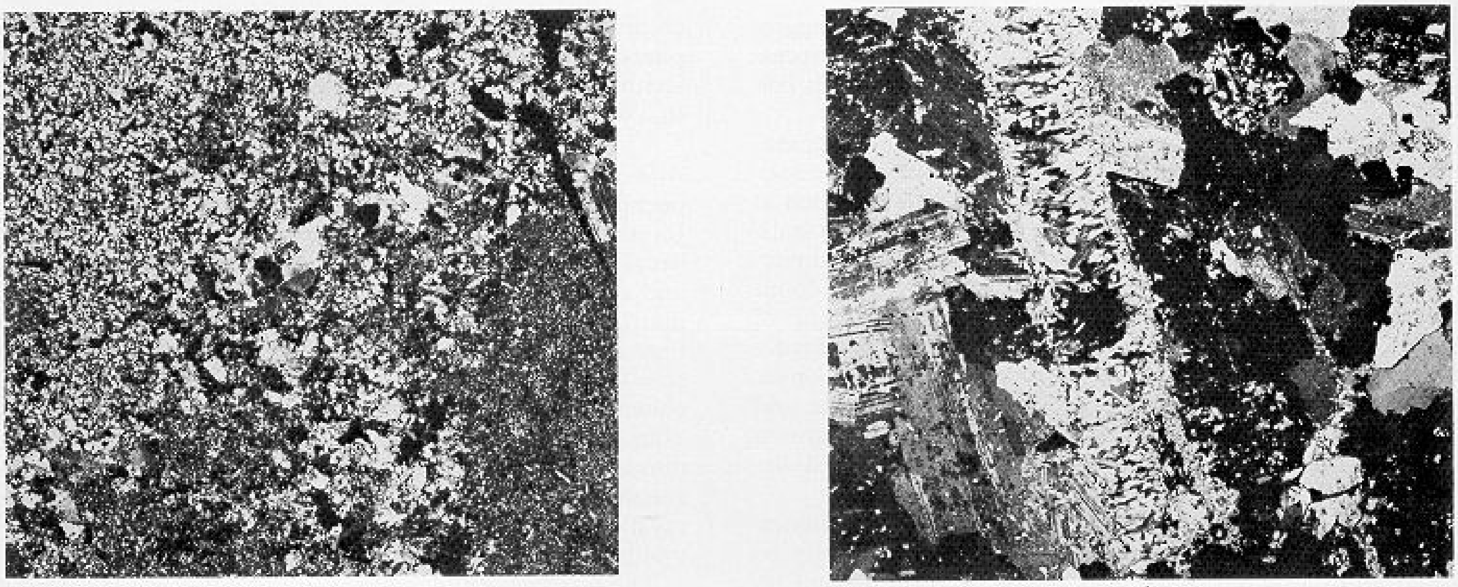


FIGURE 70
A section across a dyke allied to the granodiorite, which intrudes the volcanic rocks at station KG.214, showing the textural variations across its width.

occur. The central part of the dyke is banded parallel to the dyke edges and is composed of a microcrystalline aggregate of euhedral andesine (An_{34}) laths set in an interstitial groundmass of orthoclase and quartz. Infrequent ragged penninite crystals, magnetite grains and disseminated grains of epidote and sphene occur in this groundmass. Large acicular mafic crystals, which have been extensively altered to a penninite–calcite–magnetite aggregate, and large feldspar crystals containing many epidote inclusions have been incorporated from the volcanic country rocks into which the dyke was intruded. In the zones adjacent to the dyke centre, small rounded hornfelsed xenoliths and xenocrysts of the adjacent country rock are contained in a graphic quartzo-feldspathic groundmass containing disseminated epidote grains (Fig. 71a). The iron-stained margins of these dykes are extremely fine-grained and are laminated parallel to the contact with the volcanic country rocks. Many parallel stringers of quartz, epidote, penninite and sphene cut both the dyke



a b

FIGURE 71

a. The intermediate zone of the dyke shown in Fig. 70, illustrating the graphic texture of the groundmass of this dyke and the hornfelsed xenoliths of volcanic country rock which are contained in it. (KG.214; X-nicols; ×10)

b. Quartz–epidote veins which cut the hydrothermally altered granodiorite at the margins of a minor acid intrusion. (KG.219.6; X-nicols; ×6)

margins and the adjacent volcanic country rock. Copper- and iron-staining frequently occurs in these marginal zones.

Several similar minor intrusions cut and bake the volcanic rocks near the contact with the granodiorite at station KG.214 and similar dykes occur at stations KG.215, 218, 222, 223 and 232 in the Braddock Nunataks. In some cases the intrusions dip at relatively shallow angles but they usually strike sub-parallel to the granodiorite/volcanic contact (Fig. 72). The edges of the dykes and the marginal volcanic rocks have frequently been hydrothermally altered at the time of the dyke intrusion, producing much secondary calcite and sericite from the original feldspar, as opposed to secondary calcite and epidote derived from feldspar at the dyke centres. These dykes and the adjacent volcanic rocks are always brightly iron-stained due occasionally to the hydration of the original magnetite grains but more frequently to pyrite mineralization associated with the dyke intrusion.

A few of these minor intrusions, which appear to have undergone more extensive hydrothermal alteration, contain a different assemblage of secondary minerals. The acid dyke cutting the volcanic rocks at the western foot of station KG.222 is composed of recrystallized aggregates of quartz, calcite and muscovite set in a fine-grained quartzo-feldspathic groundmass, in which all the original magnetite has been oxidized to limonite. Several other dykes from this locality and one at Cetus Hill contain the same secondary mineral assemblage.

The 6.5 m wide intrusion at Cetus Hill, which dips south-eastward at 38°, is unusual in that it penetrates the granodiorite. A similar 6.5 m broad dyke of fine-grained granodioritic rock cuts the marginal granodiorite at station KG.219 in the Braddock Nunataks and contains large crystal fragments from this granodiorite set in a calcite-impregnated microcrystalline felsic groundmass. The crystals, which have been derived from the adjacent granodiorite, are feldspar containing many inclusions of sericite, calcite and epidote, penninite–magnetite–calcite–epidote pseudomorphs of the original mafic crystals, occasional sphene lozenges and corroded quartz crystals. In many of these xenocrysts, poikilitic inclusions of plagioclase remain in the large plates of orthoclase. The mafic minerals in the adjacent hydrothermally altered granodiorite are impregnated with epidote, whereas sericite has impregnated the feldspar crystals. Quartz–epidote veins also cut these rocks (Fig. 71b).

Similar, though more coarsely crystalline rocks form the 6.5 m high rock knoll of the Friedmann Nunataks. The fine-grained pink rock forming this outcrop is composed of many interlocking andesine (An_{39}) laths and some similar microphenocrysts set in an interstitial matrix of orthoclase and quartz.

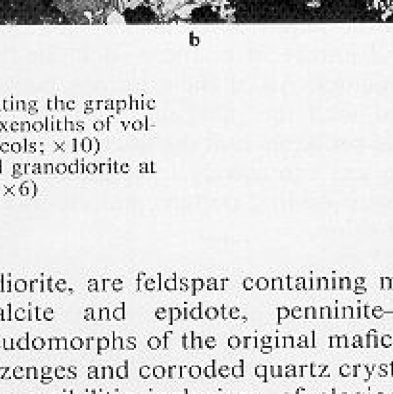


FIGURE 72

A contoured stereographic plot on the lower hemisphere showing how the strikes of the majority of the minor acid intrusions parallel the contact between the granodiorite and volcanic rocks in the Braddock Nunataks area. The dip directions of these dykes are referred to true north.

The ferromagnesian minerals are pseudomorphed by aggregates of epidote, penninite and magnetite with associated accessory sphene and apatite. The feldspars are speckled with epidote.

In the Batterbee Mountains, coarse-grained granite-pegmatite dykes cut the gabbro outcrops near the contact with granodiorite. One such dyke, striking at 310° (mag.), was recorded at station KG.237 and this contained orientated biotite crystals. Several similar narrow veins of granite-pegmatite cut the augite-leucogabbros, which crop out on the east side of Mount Bagshawe; these are composed of a coarse-grained mosaic of sericitized orthoclase, euhedral andesine (An_{42}) and haphazardly orientated euhedral brown biotite crystals. These include lenses of prehnite and are frequently pseudomorphed by calcite and penninite, speckled with tiny needles of a secondary dark brown biotite. A little copper mineralization is associated with the dyke.

h. *Summary*. The granodioritic rocks exposed in the Braddock Nunataks area and in the Batterbee Mountains are similar to each other and the minor differences in composition depend on the amount and nature of country rock (or the autoliths) that has been assimilated. All of the outcrops possess features typically associated with the marginal outcrops of a granodiorite intrusion(s); it is probable that the intrusive rocks farther east on the plateau are less extensively hybridized, possess a less well-developed igneous jointing pattern and are more uniform in texture and composition.

3. *Granitic rocks*

Pink granitic rocks occur in the Batterbee Mountains, west and south-west of Mount Bagshawe and at Horse Bluff; the pink acid intrusive rocks which are visible in the western Batterbee Mountains may well be similar (Fig. 1). To the west of Mount Bagshawe, granitic rocks intrude and bake the adjacent volcanic rocks. The near-vertical contact trends slightly west of north. However, erratics of these granites are found in the coastal mountains, notably at Swine Hill.

These rocks are composed of a coarse-grained hypidiomorphic granular assemblage of euhedral andesine (An_{34}), anhedral microperthitic sericitized orthoclase and abundant interstitial quartz. Plagioclase is rare and is frequently poikilitically included in the large orthoclase crystals. Some ragged crystals of biotite, largely pseudomorphed by green chlorite, occur in the felsic matrix with associated magnetite grains and infrequent euhedral zoned allanite crystals (pleochroic from pale to dark brown).

Similar rocks occur at Horse Bluff intruding the volcanic rocks that are exposed at the western end of this locality. These granites are finer-grained and are cut by many veins containing secondary epidote, resulting from hydrothermal alteration associated with the many basalt dyke intrusions. Secondary green chlorite, which pseudomorphs the mafic minerals at this locality, occurs in aggregates of small crystals. Near the contact, the marginal granitic rocks grade into fine-grained hybridized porphyritic microgranites, which are frequently stained by malachite and limonite. They contain corroded quartz phenocrysts that have been invaded by the felsic groundmass, sericitized orthoclase and andesine phenocrysts (An_{34}), and less frequent brown hornblende xenocrysts pleochroic from yellow-green to brown. These mafic crystals have been partly altered to green chlorite and include large rounded grains of magnetite. The phenocrysts are set in a microcrystalline flinty quartzo-feldspathic matrix containing many small crystals of hornblende that have been partly altered to chlorite and clinochlore.

Allied quartz-porphyry minor intrusions. Several quartz-porphyry dykes cut the granite outcrop south-west of Mount Bagshawe and the volcanic succession at Swine Hill. The former irregular sub-vertical minor intrusions contain rounded quartz and euhedral feldspar phenocrysts in a grey-green fine-grained matrix. The quartz-porphyry dykes at Swine Hill are similar but they are brightly iron-stained due to pyrite mineralization. Large corroded quartz crystals with kelyphitic rims and sheared euhedral cloudy andesine (An_{34}) crystals are set in the fine-grained, cryptocrystalline or microcrystalline banded groundmass of these dykes. Towards the centres of the dykes, areas of graphic intergrowth of quartz and orthoclase occur in the microcrystalline groundmass and aggregates of secondary green biotite crystals are also present.

The quartz-porphyry dykes in the Batterbee Mountains probably represent a later stage of the granite intrusions. However, in view of the fact that quartz-porphyry lavas occur in the volcanic successions at Swine Hill and at Bushell Bluff, this conclusion is not definite.

C. Dyke Swarm

Many dykes cut all the stratigraphical units in the Braddock Nunataks area and in the Batterbee Mountains. They form part of a swarm striking slightly west of north (Fig. 73) but their dips and widths vary considerably.

It is probable that all the dykes are fundamentally basaltic but they have been contaminated by the rocks into which they have been injected. All possess severely chilled margins and the majority contain many xenocrysts derived from the country rock in addition to the original phenocrysts.

In the vicinity of station KG.228, the widest dykes, which are

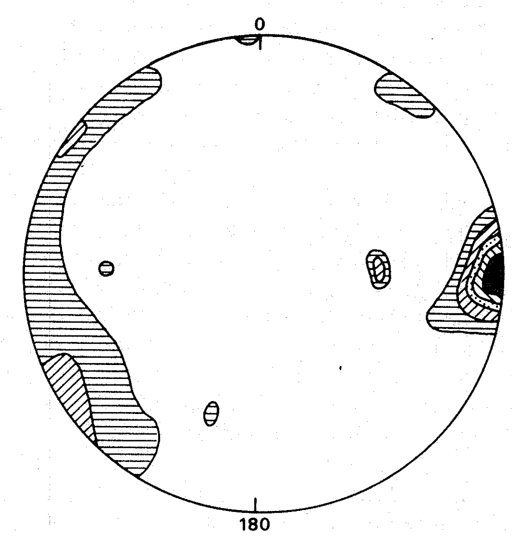


FIGURE 73
A contoured stereographic plot on the lower hemisphere illustrating the predominant trend of the dyke swarm in the Braddock Nunataks area. The dip directions of these dykes are referred to true north.

FIGURE 74
A dolerite dyke from Cetus Hill. This shows the phenocrysts of augite and labradorite contained in an intergranular matrix in which quartz is an interstitial accessory constituent. (KG.230.3; X-nicols; ×5.5)

up to 6.5 m wide, are dolerites composed of large clear corroded phenocrysts of augite and labradorite (An_{54}), contained in an intergranular groundmass of labradorite (An_{50}) microlites, augite crystals, magnetite grains and interstitial chlorite (Fig. 74). Many of the augite phenocrysts are associated with fibrous chlorite pseudomorphs possessing an anomalous blue birefringence colour. The chilled margins of the dykes are finer-grained basalts, which contain acicular amphibole phenocrysts and groundmass crystals in place of the sugite and many quartz, sphene, andesine and penninite xenocrysts derived from the country rock. The quartz xenocrysts have been corroded, the andesine xenocrysts contain many inclusions of calcite, prehnite and epidote, and the penninite pseudomorphs original biotite. These penninite pseudomorphs contain epidote, calcite and magnetite inclusions and lenses of prehnite. The marginal zones of these dykes are frequently cut by quartz stringers containing crystalline epidote and calcite.

Many of the narrower dykes are andesitic. This is probably because they have assimilated a large amount of the surrounding granodiorite, since quartz is a frequent interstitial mineral. The textures of these contaminated dykes range from pilotaxitic at their edges to holocrystalline at their centres. The plagioclase in these rocks is andesine (An_{40}) and the acicular mafic phenocrysts are typically brown hornblende, sometimes colour zoned to pale green at their edges. This hornblende is partly altered to magnetite, calcite and epidote, and contains apatite inclusions.

The granodiorite adjacent to these minor intrusions is hydrothermally altered. Original biotite is altered to muscovite and penninite, containing prehnite lenses, and the original feldspar is altered to sericite and calcite, and is occasionally replaced by complete euhedral muscovite pseudomorphs. The surfaces of the joints, which are imposed upon the adjacent granodiorite by the dyke intrusions, are frequently veneered by crystalline calcite and epidote, and copper- and iron-staining of the adjacent granodiorite frequently occurs.

Similar dykes cut the volcanic rocks of the Braddock Nunataks area and, although they are not so conspicuous in these rocks, they frequently occupy deep trenches in the more resistant country rock. Although these dykes cutting the volcanic rocks do not appear to be extensively hybridized, they do contain many semi-digested xenocrysts and xenoliths of the adjacent country rock (Fig. 75). Frequent vesicle trains filled with crystalline calcite and quartz are present in the finer-grained marginal zones of the dykes, which also contain brown hornblende and penninite mafic aggregates instead of the pyroxene–antigorite associations that occur in the dyke centres. This variation in the mafic mineral content reflects the more extensive hydration that has taken place in the margins of these dykes. Similar dykes, which also trend predominantly northwestward, occur in the Batterbee Mountains, cutting the granodiorite, granite, gabbro and volcanic rocks.

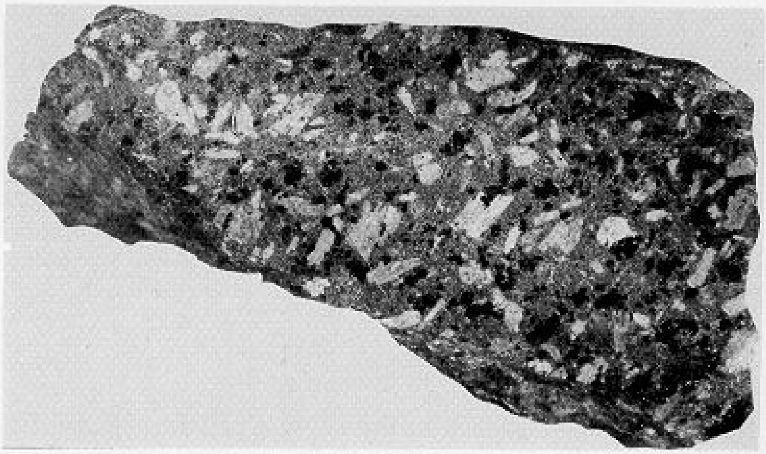


FIGURE 75
A polished section of a porphyritic baslat dyke from station KG.224 in the Braddock Nunataks. This contains sericitized phenocrysts of labradorite (An_{52}) and smaller crystals of augite which are partly or wholly pseudomorphed by penninite and epidote. These are contained in a grey intergranular matrix which is extensively impregnated with secondary epidote. (KG.224.6; ×1.3)

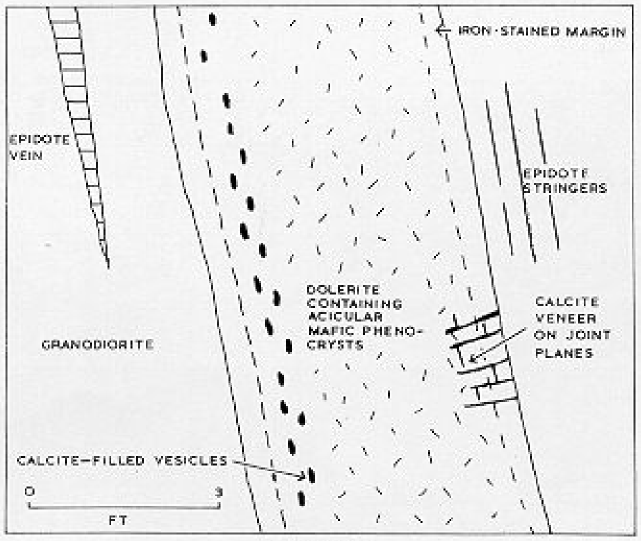


FIGURE 76
A field sketch of a cross-section across a basaltic dyke which cuts the granodiorite at Thomson Rock. This illustrates the characteristic variations which occur across its width.

The dolerites intruding the granitic country rock at Horse Bluff are fine-grained iron-stained rocks composed of brecciated augite crystals, sericite pseudomorphs after feldspar (An_{50}) and penninite–epidote–magnetite pseudomorphs set in an intersertal matrix containing interstitial quartz and calcite. The marginal basalts and granite are extensively impregnated with granular epidote.

Similar dykes cut the gabbros at stations KG.234 and 237, and they also contain accessory interstitial quartz in their composition.

At Thomson Rock, a similar dyke cuts the granodiorite outcrop (Fig. 76), causing intense epidote impregnation of the adjacent granodiorite. In this dyke, augite, acicular corroded brown hornblende and sheared labradorite (An_{54}) phenocrysts are set in an intersertal matrix of normally zoned andesine (An_{42}) microlites, augite and magnetite grains, and brown hornblende crystals (with a pleochroism scheme α = greenish brown, β = reddish brown and γ = red-brown); throughout the cryptocrystalline matrix grains of secondary calcite are disseminated.

Summary

These dykes cut and occasionally offset the late-stage dykes allied to the granodiorites in the Braddock Nunataks area. This phase of hypabyssal intrusion is consequently the latest geological episode in this area but the dykes are apparently unconnected with the superficial extrusion of volcanic rocks.

V. STRUCTURE

THE observations on the structure are largely confined to measurements of the linear flow structures and primary igneous jointing pattern in the granodiorites of the Taurus and Braddock Nunataks area. However, measurements of the dykes and of the joints in the volcanic rocks in the Taurus and Braddock Nunataks area and the Batterbee Mountains are also significant.

A. STRUCTURAL PATTERN IN THE GRANODIORITE AND OTHER ANDEAN INTRUSIVE ROCKS

The interpretation applied to the jointing pattern and the flow structures in the granodiorites of the Taurus and Braddock Nunataks area is that of Cloos and Balk (Hatch and others, 1949, p. 159–62). It is probable that these granodiorite outcrops represent a cupola(s) of the Andean intrusive rocks which comprise much of the core of the Antarctic Peninsula in these latitudes, and the linear flow structures and the primary joint patterns of the otherwise unconnected exposures substantiate their petrological affinities.

The primary joints in the granodiorite outcrops follow Balk's interpretation (Fig. 77). The cross (*Q*) joints are always open and are frequently veneered with epidote and calcite, whereas the feldspars in the adjacent country rock are stained pink. These open joints appear to have been fractures along which hydrothermal mineralization was able to take place at a late stage in the cooling cycle of the granodiorite. The strike of the longitudinal joints is sub-parallel to the linear flow structures and the elongated basic inclusions in the granodiorite, and, like the cross joints, these joints usually dip steeply. The linear flow structure is caused by the alignment of the long axes of the mafic minerals. Little evidence of a platy flow structure was recorded, although basic inclusions and segregations of dark minerals at stations KG.211 and 227 occur in vertical zones.

In several outcrops, the typically sub-horizontal flat-lying joints appear to be folded. At station KG.211 they are folded about a north-west to south-east-trending anticlinal axis extending along the length of the outcrop (Fig. 78). The contoured stereographic plot for station KG.211 (Fig. 79) indicates this division of the flat-lying joints about the fold axis. Major corrugations about a similar trending axis were observed in the

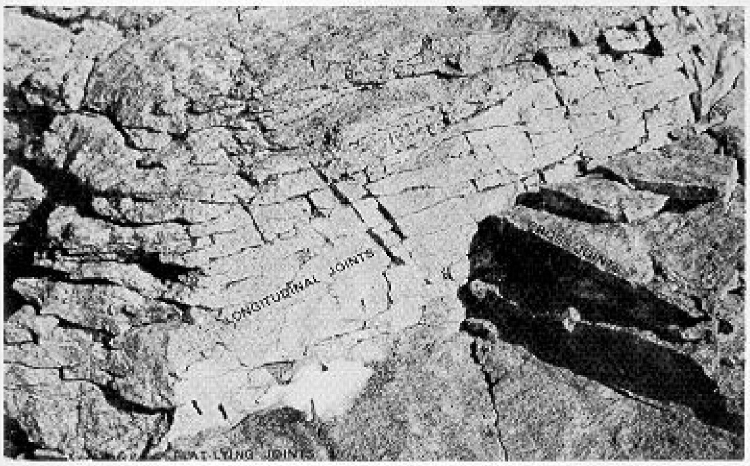


FIGURE 77
Flat-lying, cross (*Q*) and longitudinal joints in the granodiorite outcrop at station KG.212, 12 km west of the Braddock Nunataks. The vertical face of the longitudinal joint is 1 m high.

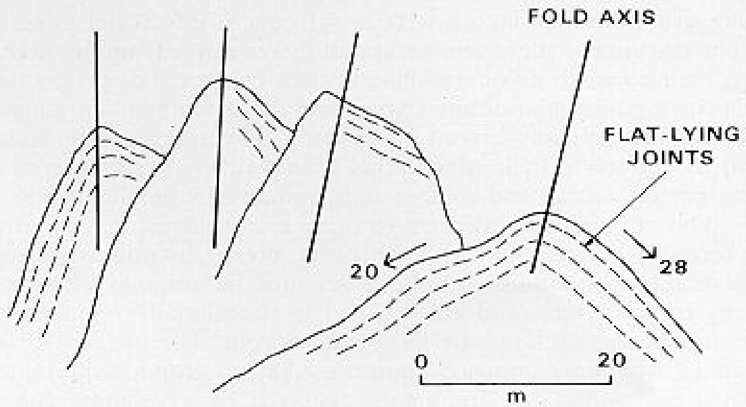


FIGURE 78
A field sketch showing the apparent anticlinal axis which extends along the summit of the westernmost of the Taurus Nunataks (looking eastward).

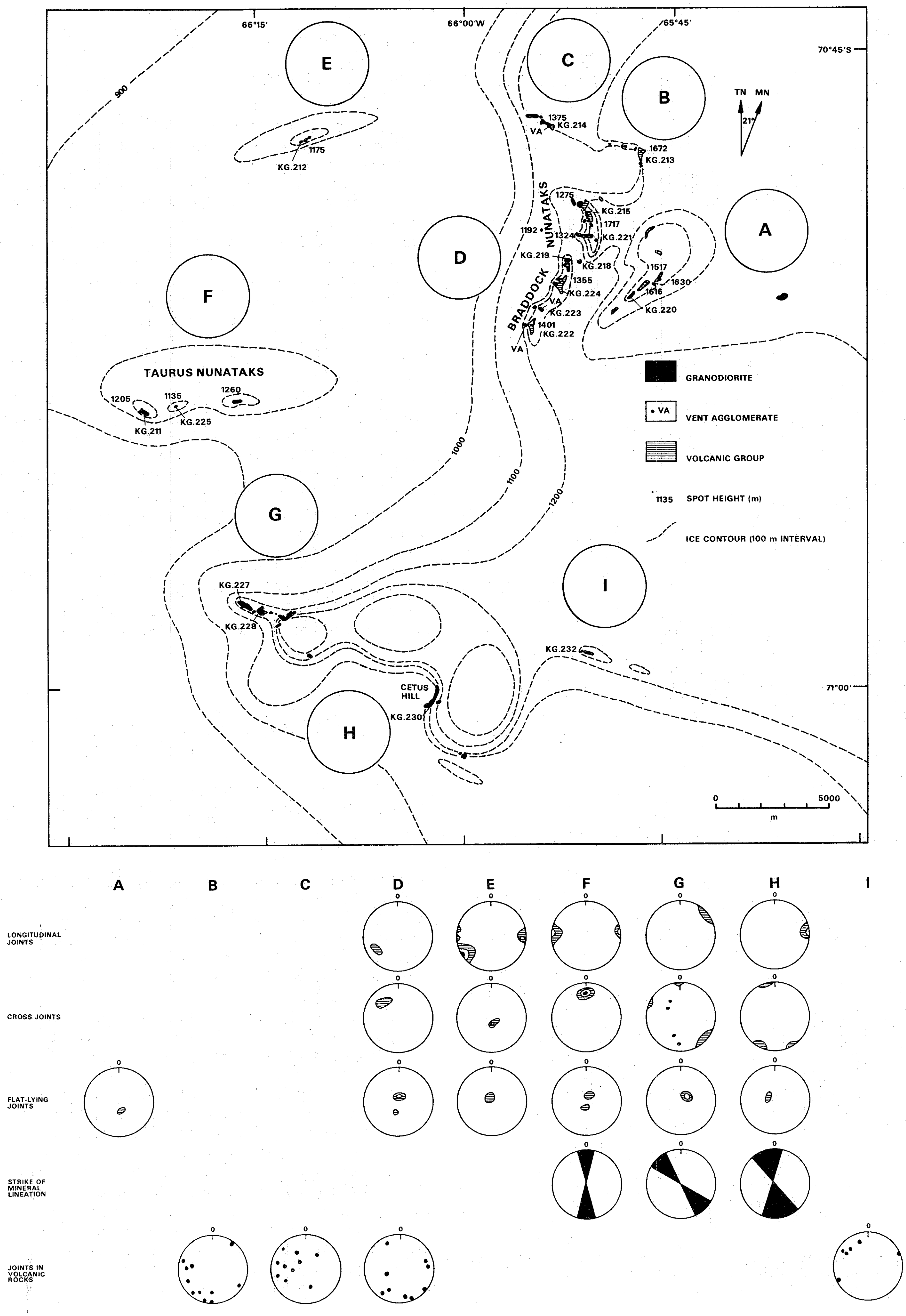


FIGURE 79
A structural map of the Taurus Nunataks–Braddock Nunataks area which shows the linear flow structure in the granodiorite in relation to the igneous jointing pattern. The joints in the volcanic rocks are also plotted (solid black sectors or dots). The plots are on the lower hemisphere.

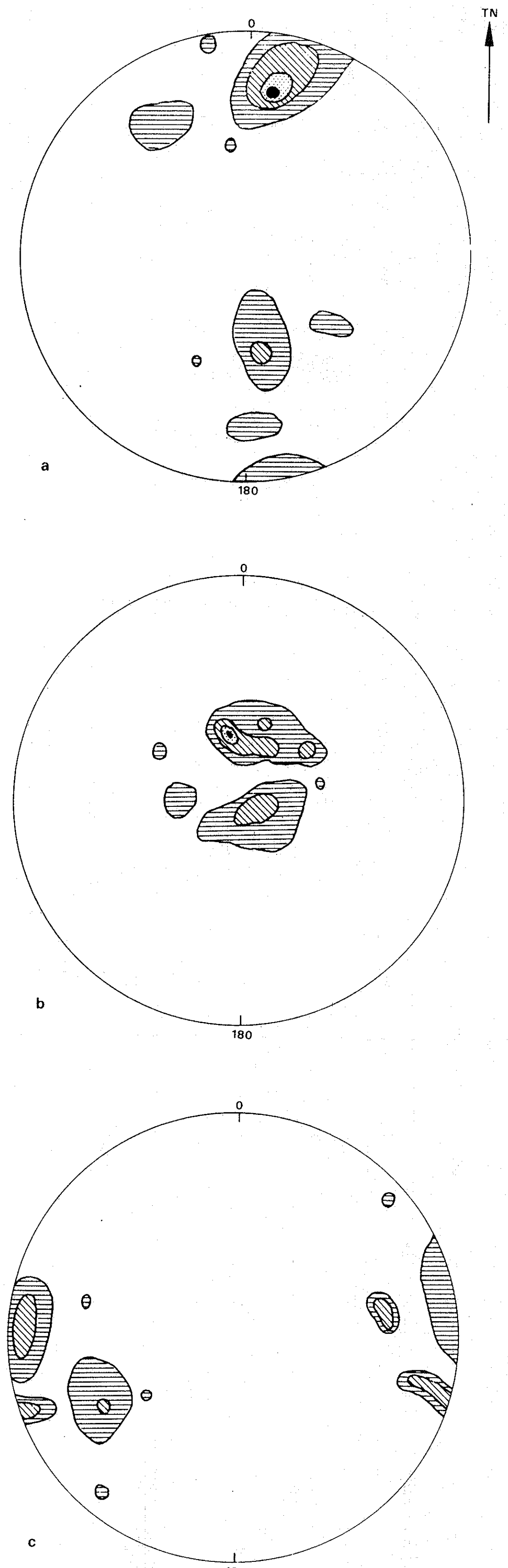


FIGURE 80
A contoured stereographic plot on the lower hemisphere of the primary jointing pattern in the granodiorites of the Braddock Nunataks area.
a. Cross joints; b. Flat-lying joints; c. Longitudinal joints.

flat-lying joints at station KG.228, while the flat-lying joints dip northward at station KG.219 in the south-western group of the Braddock Nunataks but southward at the adjacent station KG.224. In general, the flat-lying joints on the contoured stereographic plot of the primary igneous joints in the Taurus and Braddock Nunataks area (Fig. 80) shows a marked symmetry about an approximately east–west-trending axis. It is possible, however, that these flat-lying joints do not always represent primary igneous joints but exfoliation surfaces caused by recent weathering of the granodiorite outcrops. Consequently, the most important factors that have been used to provide structural information about the granodiorite outcrops are the measurements of the cross (*Q*) joints, the longitudinal joints and of the linear flow structures.

These linear flow structures trend in a direction varying between northerly and north-westerly (Fig. 79). Their trends vary from north-westward in the group of nunataks 10 km north-west of Cetus Hill to northward in the Taurus and Braddock Nunataks. The cross (*Q*) joints strike predominantly east–west but their dip varies in magnitude and direction. They dip gently south-south-eastward at station KG.212, steeply north-north-westward in the Taurus and Braddock Nunataks, and are vertical or sub-vertical in the group of nunataks 10 km north-west of Cetus Hill, where they strike slightly north of east. If the cross (*Q*) joints are considered to be perpendicular to the contact of the granodiorite intrusion, a possible form of the upper surface of this intrusion is represented in Fig. 81.

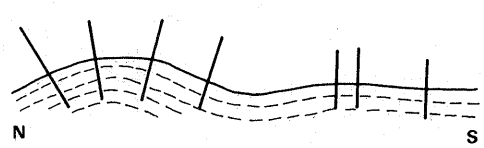


FIGURE 81
A section from station KG.212 to the nunatak group at station KG.228 showing how the aspects of the cross (*Q*) joints may be related to the form of the intrusion(s).

In the Batterbee Mountains, the linear flow structures in the similar granodiorite outcrops at Thomson Rock and station KG.237 also trend at about 10° west of north. However, zones of basic inclusions in the outcrop at Thomson Rock dip north-westward at about 70°. The foliation in the gabbros at station KG.234 also strikes slightly west of north and dips vertically or sub-vertically (Fig. 39).

The minor intrusions allied to the granodiorite, which cut both the granodiorite and the volcanic rocks, reflect this predominant structural trend, slightly west of north. The principal pegmatite dykes at station KG.211 trend north–south and dip westward at about 45°. The minor intrusions allied to the granodiorite also strike in a predominantly north-north-west direction parallel to the granodiorite/volcanic contacts (Fig. 72) but dip steeply both east-north-eastward and west-south-westward. One of the minor acid intrusions, at station KG.218, is offset 2 m by a small normal fault, the plane of which dips at 73° in a direction 220° (mag.). Several small parallel reverse faults each offset the volcanic rocks by about 0.7 m near the contact with the granodiorite at the foot of station KG.215. The planes of these reverse faults, which resulted from the granodiorite intrusion, dip at 70° in a direction 145° (mag.).

B. Other Indications of a Structural Pattern

The volcanic rocks of the Taurus and Braddock Nunataks area are dissected by many joints which have been plotted at the individual nunataks (Fig. 79). Although there are local maxima both in the individual stereographic plots on this map and in the complete stereographic plot (Fig. 82), it is not considered possible with the available evidence to relate the jointing pattern to structural controls. However, some of the joints clearly parallel the contacts between the granodiorite and volcanic rocks, and locally others follow the trends of dykes (Fig. 36).

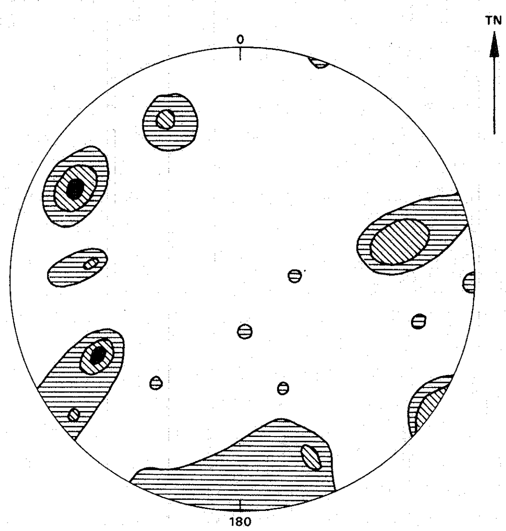


Figure 82
A contoured stereographic plot on the lower hemisphere of the joints cutting the volcanic rocks of the Braddock Nunataks area.

It appears that the volcanic rocks have been slightly distorted by the intrusion of the granodiorite. Anomalous dips were recorded in the volcanic rocks at station KG.214, which appear to have been folded about an axis trending slightly north of west, whereas steep and sometimes anomalous dips were recorded in the volcanic succession adjacent to the granodiorite intrusion in the south-western and south-eastern groups of the Braddock Nunataks (Fig. 16). It is probable that the distortion caused by the granodiorite intrusion was restricted to the volcanic rocks near the actual contact.

In the Batterbee Mountains, the volcanic succession at the summit of southern Swine Hill has been asymmetrically folded about an anticlinal axis trending slightly north of west (Fig. 38). The dips of the volcanic rocks forming the northern limb are about 60° but those of the southern limb are about 15°. Congruous drag folding of the layered strata in the southern limb of this major fold is accompanied by minor reverse faulting along calcite-filled joints dipping at 81° in a direction 130° (mag.), the strike of which follows the axial trends of the drag folds. This offsets strata by 1–3 cm. The anticlinal drag folds plunge at $22\frac{1}{2}$° in a direction 220° (mag.) and the many transverse joints cutting the major fold dip eastward at 35–70°.

The dykes of a swarm cutting all the rock types also strike slightly west of north and are usually sub-vertical (Fig. 73). These dykes trend in a direction perpendicular to the Andean compressional stress system. By analogy with the Hercynian and Alpine dyke swarms of the Scottish Highlands, which trend at right-angles to the orogenic compressional stress (de Sitter, 1964, p. 114), it is considered that this dyke injection was due to an elastic release of the regional compression after the main Andean period of folding and intrusion. Some of the dykes are offset along relatively shallow planes in both the granodiorite outcrop at station KG.228 and the granite outcrop south-west of Mount Bagshawe. This offsetting, which seldom exceeds 6.5 m may have been caused by movement along the original flat-lying joints in the plutonic rocks or it may have been caused by minor faulting independent of these joints.

Summary

It appears that the emplacement of the gabbros and granodiorites in the Taurus and Braddock Nunataks area and the Batterbee Mountains was controlled by a principal compressional stress which acted in an east-north-east to west-south-west plane. From the limited evidence of the sub-vertical zones of basic inclusions and of the dominantly vertical dykes of the swarm, this stress may have acted in a sub-horizontal plane in these areas.

The folding about axes trending slightly north of west may be related to the release of the Andean compressional stress but, without more widespread observations, the extent and significance of the structural trend cannot be determined.

VI. SUMMARY AND CONCLUSIONS

In its broadest context, the Taurus and Braddock Nunataks area and the Batterbee Mountains are part of the Antarctic continuation of the circum-Pacific orogenic belt, which includes the Antarctic Peninsula and extends into Marie Byrd Land. Consequently, those areas in which the geology is most closely related to the present reconnaissance are in the explored areas to the north in the Antarctic Peninsula, although there are some geological similarities in the mountain ranges of Marie Byrd Land, in the Ellsworth Mountains, the Eights Coast and the cordillera of the Andes. The andesite–basalt–rhyolite volcanic rocks, which have been erupted from discrete vents in the Taurus and Braddock Nunataks area, and the rhyolites of the Batterbee Mountains, are typical volcanic associations of this orogenic belt; as such, they have many counterparts in the more northerly parts of the Antarctic Peninsula.

Since these volcanic rocks are almost unaltered and are also intruded by Andean gabbros and granodiorites, they are assigned to the Upper Jurassic Volcanic Group. Tuffaceous and agglomeratic representatives of this group were first described in 1905 by Nordenskjöld from Hope Bay, where they overlie

Middle Jurassic lacustrine sediments. Predominantly andesitic volcanic rocks of a similar age have subsequently been found along much of the coast and on the offshore islands of western Graham Land as far south as Marguerite Bay (Adie, 1964*a*). On the east coast of Graham Land, however, the representatives of this group are less abundant and more rhyolitic. South of Marguerite Bay, the extent and character of the Upper Jurassic volcanic rocks is not so well known. However, andesitic and rhyolitic rocks have been described from the Fallières Coast and the east coast of George VI Sound (Adie, 1953) and from the Mount Edgell area (Procter, 1959).

The volcanic successions of both the Taurus and Braddock Nunataks area and the Batterbee Mountains include rounded fragments of granodiorite and more acid plutonic rocks which are not found *in situ*. Perfectly rounded boulders, up to 1.3 m across, which are predominantly granodioritic and less frequently granitic or gneissose rocks of the Basement Complex, have been recorded in conglomeratic beds in the stratified rocks of Adelaide Island (Dewar, 1970) but they have also not been found *in situ*. Similar boulders of acid plutonic rocks have been found in the volcanic conglomerates of Pourquoi Pas Island (Adie, 1953) and it is probable that they have been derived from pre-Jurassic plutonic intrusions into Basement Complex rocks. Adie (1954) has recorded several prominent boss-like intrusions of unfoliated coarse "pink and white granites", to which he assigned an early Palaeozoic age, cutting the Basement Complex of Marguerite Bay. Not only are these considered to be more widespread in southern Graham Land but they have also been considered (Adie, 1964*b*) to represent the acid phase of a gabbro–granite suite which is similar to but older than the Andean Intrusive Suite. Consequently, it is possible that the rounded granodiorite and granite boulders in the Taurus and Braddock Nunataks and Batterbee Mountains volcanic rocks have been derived from this older intrusive sequence. American geologists working in the Jones Mountains (Craddock and others, 1964) have recorded a granitic "Basement Complex" of at least Triassic age, which may be important in this context.

Dewar (1970) considered that the well-rounded boulders contained in the volcanic rocks of Adelaide Island had been transported rapidly over short distances and he suggested that they accumulated in either fanglomerates or coastal sediments at the foot of a mountain range. In contrast, Adie (1953) suggested that the boulders in the Pourquoi Pas Island conglomerates may have been incorporated in the lowest volcanic rocks which overrode boulder-filled valleys in a pre-volcanic erosion surface. However, in the Taurus and Braddock Nunataks area and the Batterbee Mountains, the large rounded boulders most frequently occur in or near circular volcanic vents together with similarly rounded boulders of earlier volcanic rocks. It appears that the boulders had been rounded during their passage through the vents, unless they had been derived from an original unexposed conglomerate horizon, and that they have been incorporated in the surrounding tuffs after explosive ejection from these active centres.

Although no boulders of Basement Complex rocks have yet been recorded from the Taurus and Braddock Nunataks area, J. F. Pagella (personal communication) recorded these rocks about 160 km to the south-east, and Adie (1953) observed that stratified flow rhyolites of the Upper Jurassic Volcanic Group overlie the Basement Complex rocks north of the Batterbee Mountains where both stratigraphical units are cut by acid plutonic rocks of presumed Andean age. Procter (1959) also recorded gneisses and schists from Mount Guernsey and the Mica and Rhyolite Islands, and an older sequence of volcanic rocks on the mainland coast north-east of the Rhyolite Islands.

Taylor (1966), in his discussion on the source area of the Aptian sediments of Alexander Island, has postulated a high rapidly eroded Aptian landmass east of George VI Sound composed of older intrusive rocks and subordinate metamorphic and sedimentary rocks on which active volcanoes were erupting predominantly andesitic lavas. The exact origin of the plutonic, metamorphic and sedimentary rocks in the Aptian sediments cannot be defined by the present work. However, oscillatorily zoned allanite crystals in the Andean intrusive rocks of Horse Bluff also occur in the Aptian greywackes and arkoses, and granodiorites are widespread on the Antarctic Peninsula plateau in these latitudes. The existence of predominantly andesitic volcanic fragments in the sediments may have been the result of the andesitic volcanic eruptions in the Braddock Nunataks area. If this volcano provided some of the debris included in the Aptian sediments, the Upper Jurassic volcanic eruptions in the Braddock Nunataks area will have extended into Aptian times. This would mean that the age of the intrusive granodiorite in this area is post-Aptian. Since Taylor recorded few rhyolites in the Aptian sediments of Alexander Island, the Swine Hill volcano(es) was probably already extinct.

A sub-tropical flora has been recorded from the Middle Jurassic volcanic rocks of the Hope Bay area (Halle, 1913), while the flora of the Aptian rocks of Alexander Island indicates a warm-temperate if not sub-tropical climate (Taylor, 1966). These climatic conditions, which presumably extended throughout Upper Jurassic times, could have resulted in the red bole horizons that are present in the Braddock Nunataks volcanic succession and also the iron-stained agglomeratic horizons in the Swine Hill successions. Although no fossil remains or definite sedimentary rocks have yet been discovered in the Batterbee Mountains or the Taurus and Braddock Nunataks area, it is significant that some of the lower rhyolite flows of northern Swine Hill are pillow lavas and are consequently considered to have been erupted in a sub-aqueous environment. It also seems that the outcrops on the northern side of Bertram Glacier in the longitude of the Taurus Nunataks depot are well stratified, possibly indicating that in the southern part of the Antarctic Peninsula sedimentary rocks of a Mesozoic age are not only confined to Alexander Island. In this context, Knowles (1945) recorded a hornfels in lat. 70° 25′S, long. 67° 15′W, which he considered may have been the metamorphic product of a greywacke; also Jurassic sedimentary rocks have been discovered in the Antarctic Peninsula in eastern Ellsworth Land in lat. 70°S, long. 72°W (Halpern, 1966).

The nearest described outcrops of Upper Jurassic volcanic rocks occur at Mushroom Island, Cape Jeremy and on some islands in the north of George VI Sound. Mushroom Island is a small volcanic vent composed of rocks grading from acid trachytic andesites to rhyolites, the most acid of which are the innermost and youngest. It may be questioned whether the rhyolites of the Braddock Nunataks area are intrusive rather than extrusive but from field and laboratory evidence this alternative is considered unlikely.

The most acid rhyolites of the Mushroom Island vent are impregnated with iron pyrites of hydrothermal origin. This phenomenon could be compared with that of the pyrite impregnation of the quartz-porphyry dykes cutting the southern Swine Hill volcanic succession. Although these dykes have been tentatively correlated with the acid intrusive rocks of the Batterbee Mountains, they could well represent a late stage of the volcanic activity.

The consistent trend of eruption from more basic to more acid lavas, which has been observed at Mushrrom Island, has been applied in general terms (Adie, 1964*b*) to the Upper Jurassic volcanic rocks, in which several basic to acid cycles of eruption have been postulated. In the 366 m thick Braddock Nunataks succession, one such cycle does exist and the uppermost sequence of andesitic tuffs and interbedded augite-andesite lava flows could be considered to represent the early stages of a second cycle. However, the upward gradation in the volcanic rocks from agglomerate to flow lavas postulated by Adie is not borne out in the Braddock Nunataks area, where explosive activity appears to have become more widespread as the acidity of the extruded lavas increased.

Rhyolites and rhyodacites similar to those of Mushroom Island have been recorded from the north coast of Cape Jeremy, on the groups of small islands off the east coast of George VI Sound and from the west coast of the mainland and the Batterbee Mountains (Adie, 1953). The epidotization of the more basic andesites in these areas can be compared with the present observations but no lithophysae were found in the Swine Hill rhyolites, although spherulitic rhyolites were recorded.

Procter (1959) also recorded agglomeratic rocks containing rhyolite fragments from Cape Jeremy; quartz-porphyry lavas and minor intrusions on the east coast of George VI Sound north-east of the Rhyolite Islands and in the Mount Edgell area; and rhyolites from the Rhyolite Islands. These volcanic rocks appear to be similar to the rhyolites, agglomerates and quartz-porphyries of the Swine Hill and Horse Bluff areas.

Dewar (1970) found that the earliest dykes of Adelaide Island pre-date the emplacement of the Andean intrusive rocks. Although he only recorded one definite instance of this, he considered that many of the mafic dykes cutting the volcanic rocks may have been feeders through which the higher members of the volcanic pile were erupted. In the Braddock Nunataks area one dyke, baked by an adjacent felsitic dyke related to the granodiorites, has also been classified as a feeder. Although this dyke follows the trend of the later dyke swarm, many of the dykes in the Braddock Nunataks volcanic group may be feeders to the upper extrusive rocks rather than members of the later dyke swarm.

Modal analyses of the intrusive plutonic rocks of the Taurus and Braddock Nunataks area and Batterbee Mountains are comparable with those of the most widespread plutonic rocks elsewhere in the Antarctic Peninsula, assigned to the Andean Intrusive Suite. Stelzner (1885) first applied the name "Andean" to comparable rocks of the South American cordillera system, the age of which has subsequently been bracketed, by a comparison with Patagonian stratigraphy (Adie, 1955), between the late Cretaceous and early Jurassic. K-Ar dating of Andean rocks from the Antarctic Peninsula has subsequently shown that they range from 100 ($\pm$20) to 45 ($\pm$5) Ma (Halpern, 1964; Scott, 1965), indicating that the Andean Intrusive Suite was emplaced between mid-Cretaceous and Eocene times. However, Adie (1962) considered that the main intrusions are Aptian in age.

Throughout the Andean Intrusive Suite a basic to acid sequence of intrusion has been observed. The primary members of this suite are considered to have the same parentage and to follow a line of liquid descent by a process of crystallization differentiation (Adie, 1964*b*). However, the pre-existing country rocks and earlier intrusions will have been subject to assimilation by the later members, giving rise to hybrid rock types.

The evidence from both the Taurus and Braddock Nunataks area and the Batterbee Mountains does not contradict these statements, since there is definite evidence that the gabbro intrusions pre-date the granodiorites, although no evidence has yet been found regarding the relative ages of the granite and granodiorite outcrops, particularly of those occurring near the contact with the volcanic rocks in the Braddock Nunataks area.

Granitization has not taken place in the Taurus and Braddock Nunataks area and Dewar's observations that all facies of the plutonic rocks appear to have been gently intruded into the country rocks applies here. As in Adelaide Island, the volcanic country rocks are no more than slightly thermally metamorphosed at the always sharp contacts. Assimilation appears to have been the principal process involved in the displacement of the country rocks by plutonic rocks, although the rounded forms of the xenoliths in the intrusive rocks indicate that some dissolution has taken place.

Both Dewar (1970) and Procter (1959) recorded intrusion breccias at some of the contacts between the plutonic and volcanic country rocks, comparable to the brecciated contact between the granodiorite and volcanic country rocks at station KG.214 and in the south-western group of the Braddock Nunataks. Those described by Procter from the Mount Edgell area represent "a continuous gradation from dark grey volcanics to medium- or coarse-grained granites". The matrix of these brecciated rocks frequently contains diffuse dark grey patches representing relic xenoliths which have been altered to such an extent that they approach the composition of the pink acid matrix. In the Taurus and Braddock Nunataks area it may be significant that the intrusion breccias occur at the steep western contacts between the granodiorite and volcanic rocks, whereas at the less steeply dipping eastern contacts the intrusive igneous rock has been injected into the adjacent volcanic succession. Dewar (1970, p. 176) recorded many large zoned calcic plagioclase xenocrysts in the Adelaide Island acid plutonic rocks and these are remnants of assimilated xenoliths. This feature is evident in the hybridized Taurus Nunataks granodiorite.

The nearest recorded outcrops of granodiorite and quartz-diorite were described by Knowles (1945). His description of these rocks, the related pegmatites and felsites, and the later dyke swarm appears to correspond to the observations in the area described here. However, the one example described from the Eternity Range appears to be a deeper-seated plutonic rock.

Gabbroic intrusions are also widespread in Adelaide Island and are always more heterogeneous than the granodioritic or granitic rocks. The gabbroic rocks of the Batterbee Mountains are somewhat similar to the olivine-gabbros at the Terra Firma Islands (Adie, 1953) which are uralitized and layered but which have produced a 12 m wide metamorphic aureole in the adjacent andesitic rocks. The outer zones of the aureole are comparable to the narrow thermal aureoles around the granodiorite intrusions of the Taurus and Braddock Nunataks area but the ultimate plagioclase-pyroxene-hornfels resulting from the volcanic rocks of the Terra Firma Islands is of a higher metamorphic grade than the plagioclase-amphibole-hornfelses of the amphibolite facies in the Braddock Nunataks area. The latter contain strongly pleochroic amphibole whereas the former contain pale green diopsidic augite. However, the faintly pleochroic pale blue or pink apatite crystals recorded in the Terra Firma Islands hornfelses also occur in the hornfelses of the Braddock Nunataks area. Adie (1953) recorded a marked difference between the low-grade metamorphism of lavas and tuffs which is not so pronounced in the higher metamorphic grades. Some evidence to support this statement has been found in the Braddock Nunataks area.

The structural trends in the Taurus and Braddock Nunataks granodiorites have been briefly recorded on p. 54. Procter (1959) has also recorded a predominant vertical set of joints striking parallel to the Antarctic Peninsula but Dewar (1970) considered that the intrusion of rocks of the Andean Intrusive Suite has not caused the formation of additional strong jointing in the country rocks.

In the Taurus and Braddock Nunataks area and in the Batterbee Mountains, the trends of the linear flow structures in the intrusive rocks parallel the length of the Antarctic Peninsula and, where there are any platy flow structures, they dip steeply to the east or west. The longitudinal joints in the granodiorite are also sub-vertical and strike parallel to the length of the Antarctic Peninsula but insufficient observations of the jointing pattern in the volcanic rocks have been made to extend Dewar's conclusions. However, the infrequent presence of folds, the axes of which strike approximately east–west, may be significant.

VII. ACKNOWLEDGEMENTS

I WISH to thank Sir Vivian Fuchs, former Director of the British Antarctic Survey, for his encouragement to prepare this work for publication; Professor F. W. Shotton for making available the facilities of the Department of Geological Sciences, University of Birmingham; Dr R. J. Adie for his advice on the presentation of this work and Dr A. G. Fraser for his criticism of the content. I should also like to thank those members of the British Antarctic Survey and the University of Birmingham with whom I worked.

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