THE STRATIGRAPHY AND STRUCTURE OF THE METAMORPHIC ROCKS OF THE HASKARD HIGHLANDS AND OTTER HIGHLANDS OF THE SHACKLETON RANGE

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Abstract. Within the Shackleton Range Metamorphic Complex, three formations of metamorphosed supracrustal rocks overlie and are interleaved with higher grade basement gneisses. The basement, and two formations of supracrustal rocks cropping out in the north (Nostoc Lake Formation and Mount Gass Formation), have coarse-grained metamorphic fabrics cut by lower grade grain size reduction fabrics. The formation cropping out to the south (Williams Ridge Formation) and the Wyeth Heights Formation of the Turnpike Bluff Group have simpler prograde fabrics. The grain size reduction fabrics and the prograde fabrics in the south are of similar age and were probably produced during the interleaving of the 'cover' and 'basement'. The grade of metamorphism associated with the youngest planar fabrics decreases from middle amphibolite grade in the north to greenschist grade in the south. The youngest folds have northerly striking axial surfaces, crenulate the mica fabrics and are associated with little metamorphic recrystallization; before this folding the strike of the foliation was probably east–west.

The supracrustal rocks of the north had an active source providing a high proportion of first cycle sediment and were deposited under ensialic shelf or basin conditions. Those of the south are dominated by more mature sediment, suggesting a more stable environment; either they post-date the early metamorphism shown in the supracrustal rocks of the north or suffered only low grade metamorphism at that time.

The Shackleton Range (80° 07′–80° 50′ S, 19°–31°W) is composed mainly of medium and high grade rocks of the Shackleton Range Metamorphic Complex (Clarkson, 1972, 1982*b*), which include mid-Proterozoic granitoids (Rex, 1972; Pankhurst and others, in press) and suffered late Proterozoic–early Palaeozoic metamorphism (Grew and Halpern, 1979; Grew and Manton, 1980; Hofmann and others, 1980, 1981). In the south the complex has tectonic boundaries with low grade metasediments of the Turnpike Bluff Group (Clarkson, 1972, 1983) and is unconformably overlain by a late Proterozoic quartzite–carbonate sequence (Clarkson, 1972; Golovanov and others, 1980). In the north-west the complex is overlain by the unmetamorphosed, arenaceous Blaiklock Glacier Group for which ages between Cambro-Ordovician (Stephenson, 1966; Clarkson and others, 1979) and Permian (Grikurov and Dibner, 1979) have been suggested. Throughout most of the range the foliation in the metamorphic complex and the cleavage in the Turnpike Bluff Group strike predominantly east–west but in the north-west folding about north–south striking axial surfaces is present in the metamorphic complex and, possibly, in the Blaiklock Glacier Group (Clarkson, 1982*a*). Skidmore and Clarkson (1972) interpreted the range as a horst bounded by faults parallel to its long axis. It is separated by major westward-flowing glaciers from outcrops of undeformed Permo-Carboniferous sediments of the Beacon Supergroup (Plumstead, 1962; Stephenson, 1966); a conspicuous peneplain could be an exhumed pre-Beacon erosion surface.

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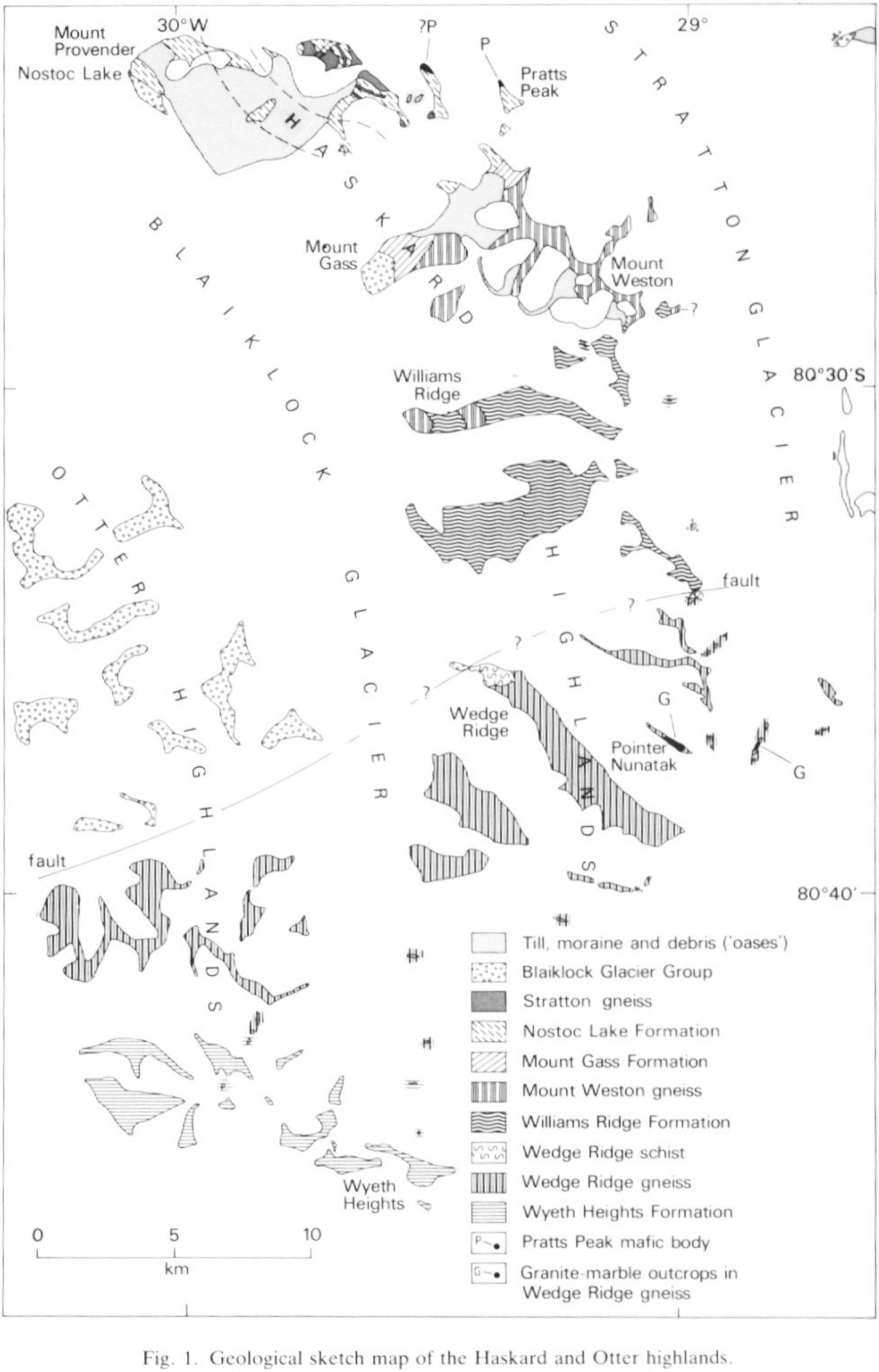


Fig. 1. Geological sketch map of the Haskard and Otter highlands.

This paper is a mainly descriptive account of the geology of the western part of the range and includes a subdivision of the stratigraphy within the metamorphic complex which Clarkson (1972) suggested would be possible as work progressed. The area described is that covered by the reconnaissance mapping of Stephenson (1966) and includes the ground with north–south trending structures. Stephenson recognized the juxtaposition across mylonite zones of belts of rocks of contrasted lithology and, in some cases, metamorphic grade. He suggested that large scale thrust movements had affected two groups of metamorphic rocks, one of much lower grade than the other, but did not trace structural units over any distance. More detailed mapping of the metamorphic complex has allowed structural and lithological units of the type recognized by Stephenson to be mapped out (Fig. 1). Seven new stratigraphic units are described here, their relationships discussed and a preliminary account of their metamorphism given. Many typical lithologies and outcrops were described in detail and/or figured by Stephenson and reference to these descriptions is made where appropriate. The area around Mount Provender has been described by Grew and Halpern (1979). A Landsat image of the area covered by Figures 1 and 2 is shown in Figure 3; except on some west-north-west facing slopes (in shadow) dark tones are ice free areas.

Stratigraphy

Eight mappable units of metamorphic rocks, and one minor igneous body, have been recognized in the area (Fig. 1). One unit, the Wyeth Heights Formation, has been formally defined by Clarkson (1972). Three further formations of metasediments (the Nostoc Lake Formation, the Mount Gass Formation and the Williams Ridge Formation) are defined here. The remaining units, also of formation rank, are named informally pending further studies.

Stratton gneiss

Migmatitic, medium-grained, pink and grey, leucocratic granoblastite (K-feldspar + plagioclase (An_{25-28}) + quartz + amphibole ± biotite (finer grained)), usually with faint, often irregular and discontinuous compositional layering defined mainly by variation in biotite content.

Disrupted layers and schlieren (10–150 mm wide) of darker, finer grained, biotite and/or amphibole-rich material are present locally (Fig. 4a). Mafic material (amphibole+clinopyroxene) occurs locally as agmatite (Fig. 4b) and net-veined bodies (to 5 m across); the felsic material of the agmatites and veins is of similar mineralogy to the dominant lithology of the formation but is generally coarser grained. The migmatites in 'unit a' of Grew and Halpern (1979, fig. 2) belong to this formation.

Nostoc Lake Formation

This formation is locally divisible into three belts (Fig. 1) with distinctive lithological associations (units a, b and c, of Grew and Halpern, 1979, fig. 2).

(i) *Adjacent to and interleaved with the Stratton gneiss.* A variety of metasedimentary lithologies, mainly marble, quartzo-feldspathic granoblastite, garnetiferous gneiss and schists (including kyanite schists), interlayered on scales of 1–10 m.

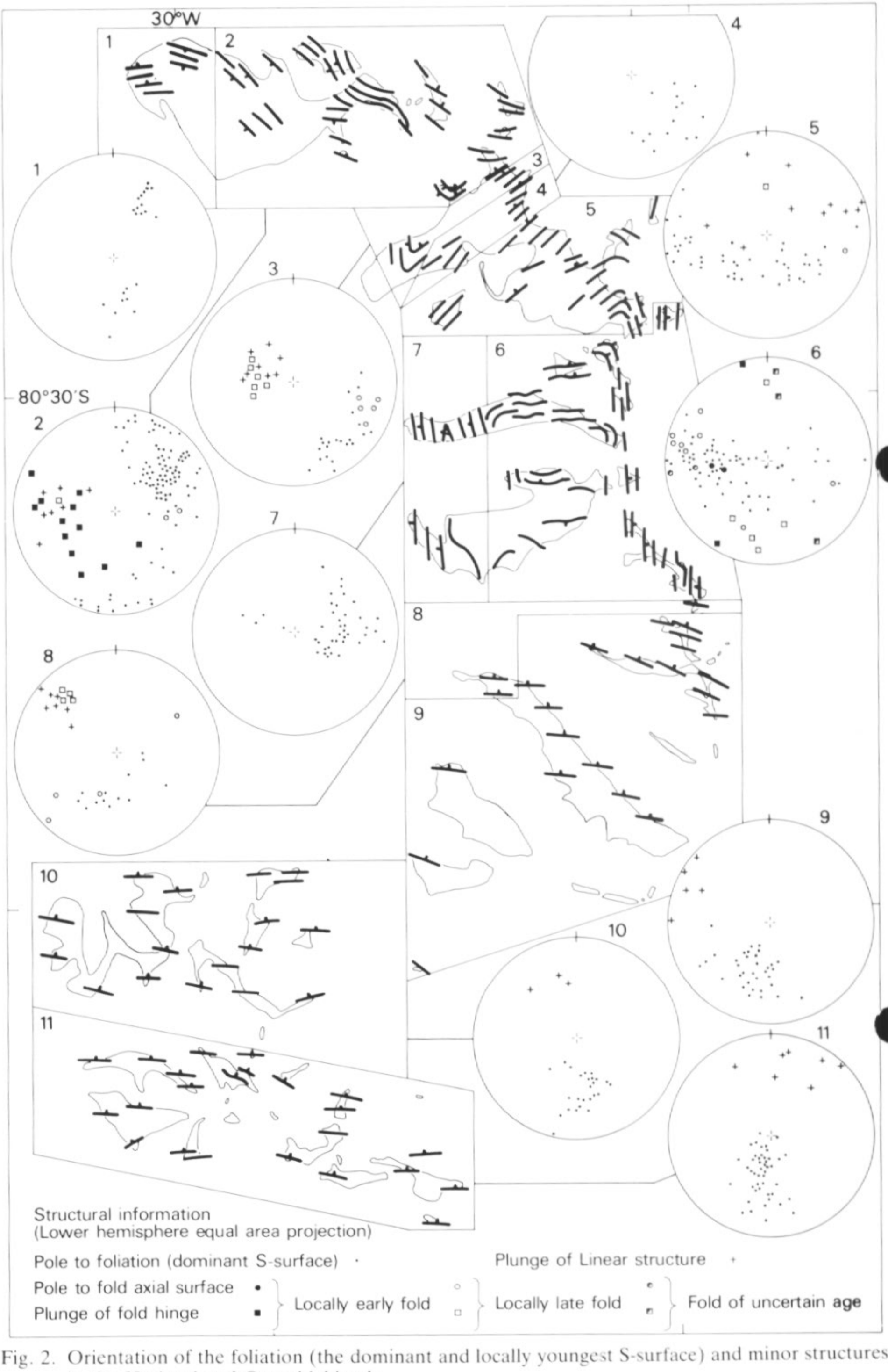
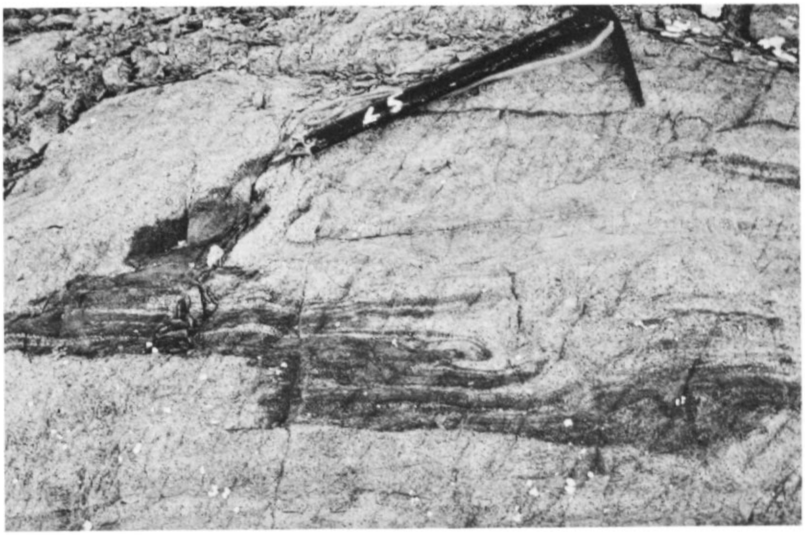


Fig. 2. Orientation of the foliation (the dominant and locally youngest S-surface) and minor structures in the Haskard and Otter highlands.

Fig. 3. Landsat image of the area shown in Figures 1 and 2 (part of E-1548-07151-701, 22 Jan. 1974).



a

b

Fig. 4. The Stratton gneiss: a, biotite bearing schlieren in typical migmatitic gneiss; b, agmatite.

The marbles are white and cream, pink or grey striped, or grey (the last mainly forming thinner layers) and occur in layers up to 8 m thick. They are composed of coarse-grained calcite, calcite with dolomite, or dolomite, generally with calcsilicate minerals; amphibole schists and siliceous calcsilicate layers are typically present. The quartzo-feldspathic granoblastites are medium-grained, sometimes clinopyroxene-bearing, and locally have carious weathering layers and calcsilicates; quartzites occur locally. The garnetiferous schists and gneisses are medium- to coarse-grained rocks (andesine + biotite + garnet ± horblende + quartz ± K-feldspar ± clinopyroxene) occurring as layers 1–2 m thick. The kyanite schists are medium-grained schists (kyanite + garnet + plagioclase + quartz) in layers 2 m thick; the association kyanite + K-feldspar was not observed in this study but is reported by Grew and Halpern (1979). Basic and ultrabasic rocks occur locally as lenses and groups of boudins; pegmatites are rare and conspicuous only when cutting marble layers.

(*ii*) *Central belt.* Richly garnetiferous coarse- and medium-grained gneisses (Fig. 5). There is less compositional variation than in (i), mainly gradations between amphibole-bearing gneiss (andesine + garnet + quartz

a

b

c

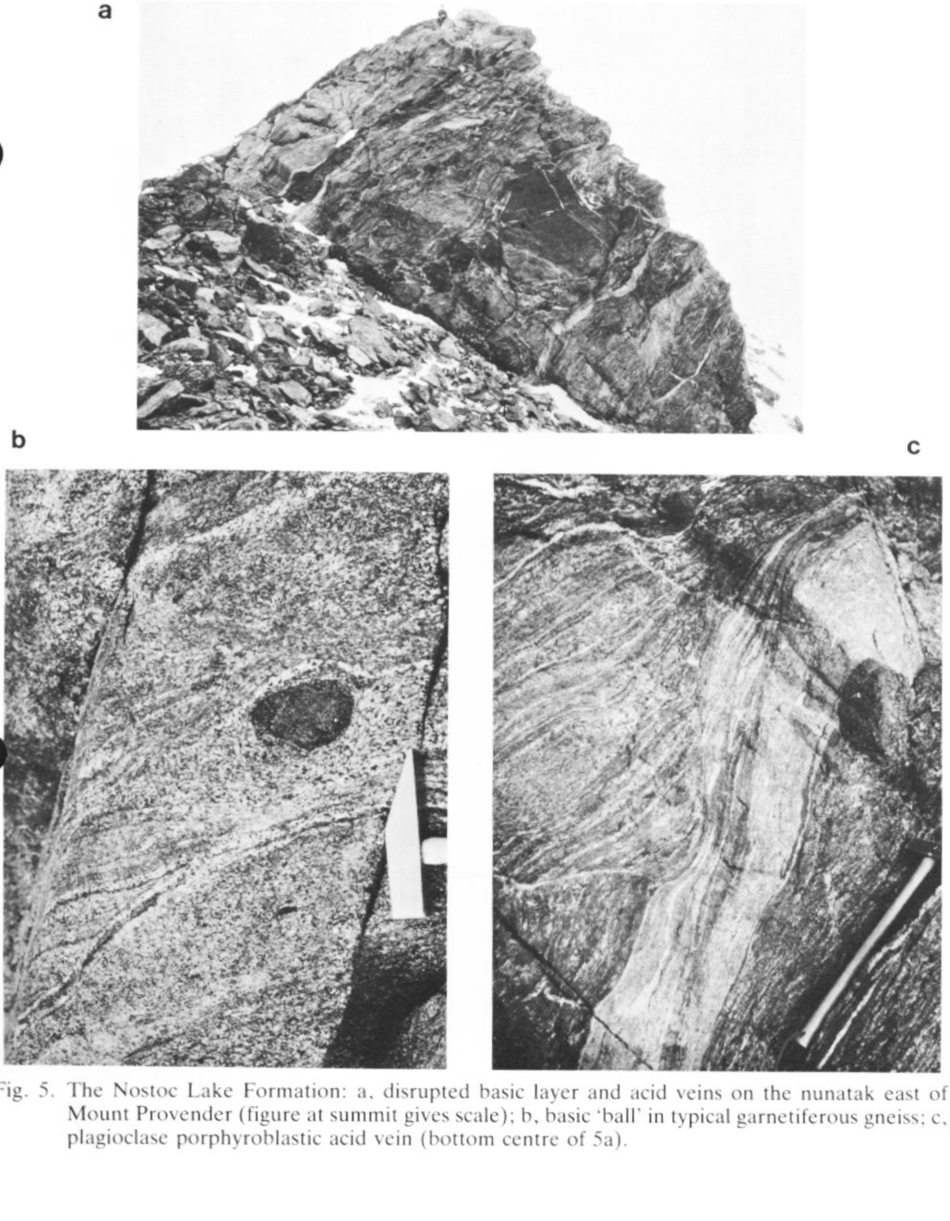


Fig. 5. The Nostoc Lake Formation: a, disrupted basic layer and acid veins on the nunatak east of Mount Provender (figure at summit gives scale); b, basic 'ball' in typical garnetiferous gneiss; c, plagioclase porphyroblastic acid vein (bottom centre of 5a).

+hornblende±K-feldspar±clinopyroxene) and biotite-bearing gneiss (andesine+garnet+quartz+biotite±K-feldspar±clinopyroxene) and variations in the proportions of the mafic and felsic phases (Fig. 5b). Stephenson (1966, p. 25–6) gave a petrographic description of a typical sample. Biotite-bearing lithologies generally have better defined compositional layering, are less coarse grained and commonly have calcsilicate layers. Plagioclase is commonly in the form of porphyroblasts to 10 mm in length. Acid veins (from 10 mm thick) and sheets (to 25 m thick, usually plagioclase porphyroblastic) follow and cut the compositional layering (Fig. 5c) but have the same mineral fabric as the gneiss. A larger area (approximately 0.5 km^2) of foliated garnetiferous granitic rock with plagioclase prophyroblasts to 20 mm in length and abundant layers and schlieren of metasedimentary material occurs on Pratts Peak. (The threefold subdivision of the formation is unclear in this area.) Flattened pegmatite layers (with a mineral fabric different to that of the gneiss) occur locally. Clinopyroxene-bearing basic material occurs as isolated centimetre-scale schlieren and balls in the hornblende-bearing gneiss and as boudinaged layers (to 7 m thick) in all lithologies. Typical lithologies were illustrated by Stephenson (1966, Pl. VIIa).

(iii) *South-western belt.* The main lithologies are as in (ii) but marble and subordinate layers of more variable composition as in (i) are present.

Further petrographic details of lithologies in the Mount Provender area are given by Grew and Halpern (1979). The three lithological belts cannot be traced across the area of little exposure north of Mount Gass but the rocks in this area are similar to those of the south-western belt.

Pratts Peak Intrusion

The northern 70 m of the north ridge of Pratts Peak is composed of unfoliated biotite pyroxenite. The mineralogy is clinopyroxene+biotite+apatite±hornblende (replacing pyroxene), with accessory carbonate, and sphene. The grain size varies from medium (2 mm) to very coarse (biotite up to 120 mm diam., clinopyroxene to 50 mm). The proportion of biotite varies between approximately 5 and 60%; apatite, present as individual crystals or radiating clusters of stout needles up to 30 mm in length, locally accounts for 20% of the rock. The grain size and mineralogy vary irregularly over the outcrop, with patches of similar lithology on scales of 100 mm to several metres having rapidly gradational boundaries. Sharp-sided dark veins (60–100 mm thick), mainly of amphibole with a little plagioclase, are present and a medium grained leucocratic vein (plagioclase+K-feldspar+quartz +clinopyroxene) traverses the outcrop, varying from a single 1-m-thick vein to a 3-m-wide zone of veins following the joints.

The margin of the body against the adjacent gneiss is unexposed but can be traced through frost-heaved debris. The gneiss is strongly foliated but no foliated mafic rocks were recognized at the margin and the distribution of the debris suggests that veins of mafic rock cut the foliation in the gneiss within a few metres of the boundary. However, biotite in the pyroxenite is crenulated in places, and the leucocratic vein and adjacent pyroxenite are affected by a shear zone within which mixed rocks have recrystallized to a medium-grained hornblende–biotite–plagioclase-bearing assemblage. The mafic body thus appears to post-date most of the deformation in the surrounding rocks but has suffered local shearing and medium grade metamorphism.

Mount Gass Formation

A sequence of muscovite-bearing quartzite (locally pale green in colour), white metalimestone (up to 7 m thick), mica-schist (biotite + muscovite + quartz + andesine ± staurolite ± kyanite ± K-feldspar (not with kyanite or staurolite)), grey metadolomite (typically less than 0.2 m thick), amphibole schist (hornblende + garnet ± clinozoisite ± clinopyroxene (rare, relict)) and feldspathic granoblastite (K-feldspar + quartz + andesine + biotite + garnet), interlayered on centimetre and metre scales. On a traverse away from the Mount Weston gneiss each lithology reaches its maximum abundance in the order quoted (Fig. 6). The amphibole schist occurs in layers rather than as lenses or boudins (cf. Nostoc Lake Formation). No pegmatite layers or feldspathic segregations were observed.

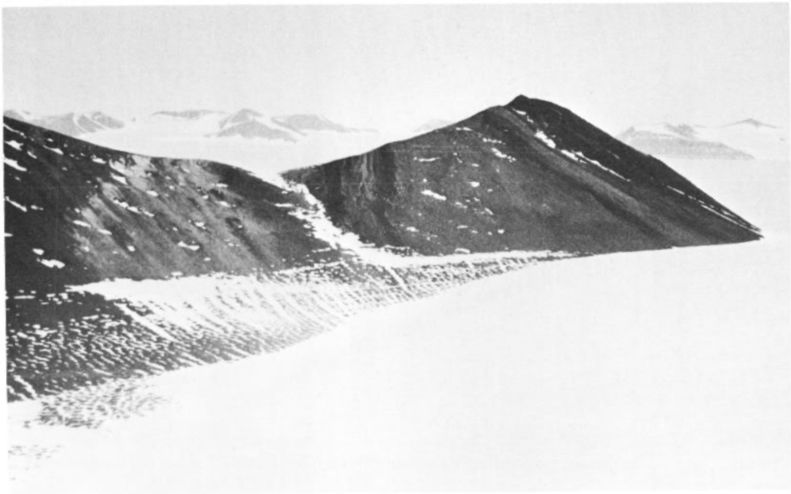


Fig. 6. The Mount Gass Formation and Mount Gass fold on Mount Gass, viewed from the north-east. Dark outcrops at left are Mount Weston gneiss, pale band is limestone near base of formation and dark layers are amphibolites.

Mount Weston gneiss

Areas of gneiss, each 10–100 m in cross-strike thickness, alternate with similar thicknesses of strongly foliated rocks, mainly mylonitic schists with relics of gneissose precursors on all scales. Gneiss dominates within *c*.3 km of the Mount Gass Formation and in the area of the summit of Mount Weston (Fig. 7a). Between these areas (Fig. 7b) schist and gneiss occur in approximately equal proportions. Schist dominates south-east of Mount Weston, with a southward decrease in the number and size of gneiss lenses.

The gneisses are mainly coarse- or medium-grained leucocratic gneiss (quartz + plagioclase + K-feldspar ± garnet ± hornblende ± biotite), locally with layers and boudins of basic rocks (to 2 m thick) and calcsilicate layers (to 150 mm thick). Abundant unfoliated feldspar pegmatites (to 3 m thick, commonly 50–150 mm) cross-cut each other and the gneissose foliation. In the north-west sillimanite and K-feldspar coexist and quartz is milky blue in colour. Small (10–20 m across) bodies of granitic rock with abundant garnets to 20 mm in diameter occur and appear to

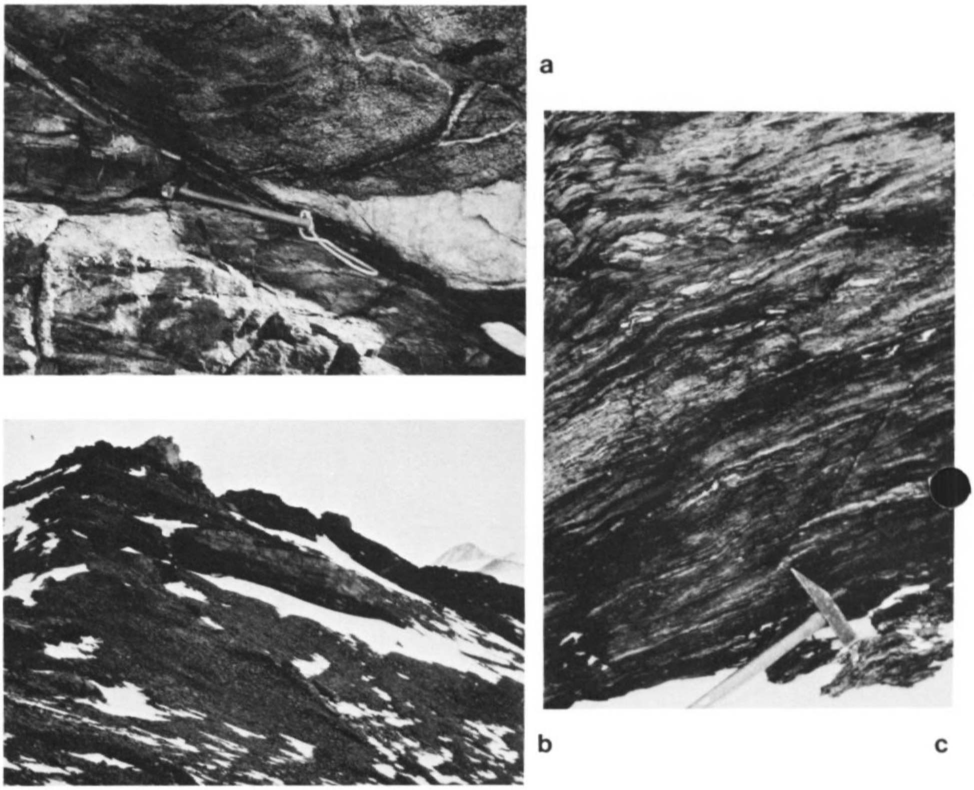


Fig. 7. The Mount Weston gneiss: a, late shear in slightly deformed gneiss on the south ridge of Mount Weston; b, gneiss lenses in mylonitic schists north of Mount Weston; c, mylonitic schists north of Mount Weston.

post date the gneissose layering. Interlayered quartzite and amphibole schist occur on Mount Gass. Typical lithologies were illustrated by Stephenson (1966, Plates VId and VIIb), who gave petrographic descriptions of two typical samples (*op. cit.* p. 26–8, 'garnetiferous granitic gneiss' and 'garnet-sillimanite gneiss').

The schists (quartz + oligoclase + biotite ± muscovite ± K-feldspar ± garnet ± clinozoisite) are medium- and fine-grained, generally with abundant augen and lenses of lithologies typical of the gneisses (mainly pegmatite), lenses of basic rocks, and fragments of coarse grained crystals (Fig. 7c; see also Stephenson, 1966, P1. VIb). Quartz schist occurs locally.

Williams Ridge Formation

Cream or grey, medium- and fine-grained metalimestones (10 mm–10 m layers), typically with a few percent of quartz and occasionally of dolomite, metadolomites (rare), calcareous schists (ferroan calcite + white mica + biotite + quartz ± oligoclase ± clinozoisite/epidote), mica schists (biotite + muscovite + quartz + oligoclase + epidote ± calcite), white and yellow quartzites, and phyllites (chlorite + muscovite + quartz).

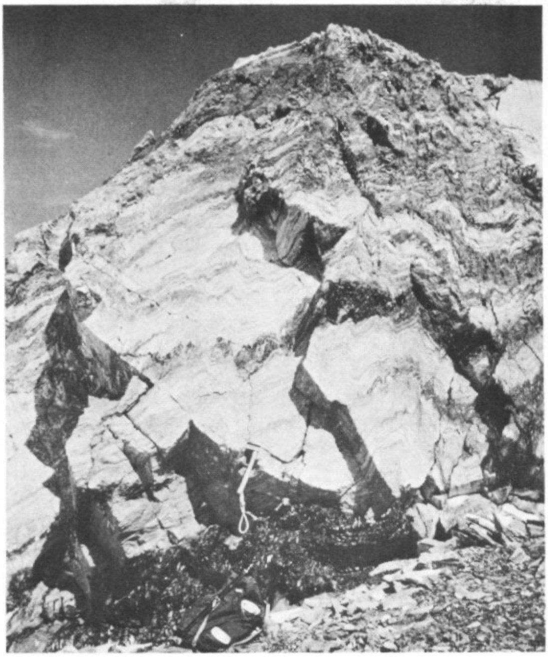


Fig. 8. The Williams Ridge Formation. Typical calcareous metasediments and mica schists (dark) on the ridge north-east of Williams Ridge.

Metalimestone with subordinate calcareous schist, centimetre-scale alternations of calcareous schist and metalimestone, and mica schist are interlayered on scales of 10–100 m (Fig. 8). Quartzite is found only in association with metalimestone, mainly at the contact with the Mount Weston gneiss. Phyllite is found only in the southernmost outcrops. No pegmatites, amphibolites or feldspathic segregations are present. Mica schists typically have flattened centimetre-scale quartz veins and lenticles.

Wedge Ridge schist

Mica schist (biotite+muscovite+quartz+oligoclase±garnet) with flattened quartz veins and lenticles. Cream metalimestone layers to 1 m in thickness occur locally.

The schists are similar in lithology to both the mica schists of the Williams Ridge Formation and to the slates of the Wyeth Heights Formation. No pegmatites, feldspathic segregations or amphibolites are present. The quartz-mica schists described by Stephenson (1966, p. 31) are from this unit.

Wedge Ridge gneiss

Dominantly grey and pink, mesocratic, medium- and coarse-grained gneiss (K-feldspar + quartz + albite/sodic oligoclase + biotite ± epidote/clinozoisite (fine-grained)) with flattened pink feldspathic segregations (Fig. 9).

Compositional layering is typically indistinct. Abundant cross-cutting feldspar pegmatites (see Clarkson, 1972, fig. 2) (to 3 m thick) are foliated only in the outer 50–100 m. Micaceous (often muscovite-bearing) schist and siliceous schist are

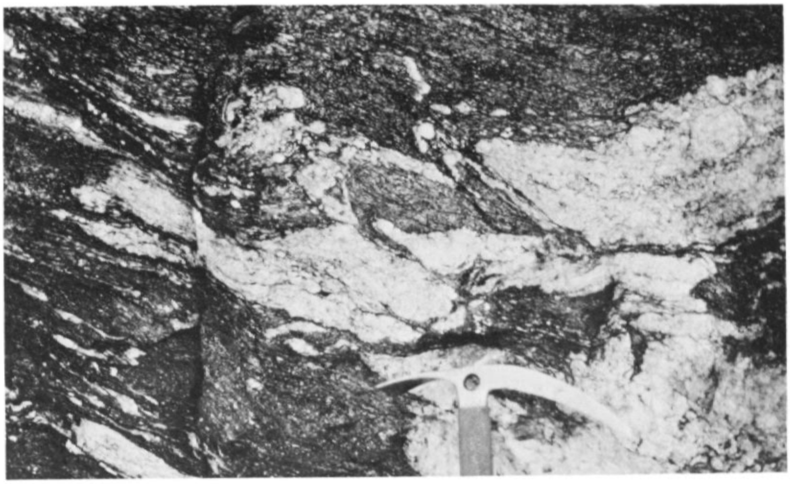


Fig. 9. The Wedge Ridge gneiss. Deformed feldspathic segregations in a typical outcrop north-east of Pointer Nunatak.

locally interlayered with flattened gneiss. Amphibole schist is uncommon. Granite sheets to 30 m thick are abundant locally. At Pointer Nunatak and the nunatak at 80°37′S, 28°51′W marble intruded by weakly foliated granite occurs. Typical lithologies from the Otter Highlands are described and illustrated by Stephenson (1966, p. 28, fig. 9 and P1. VIIc).

Wyeth Heights Formation (of the Turnpike Bluff Group)

Interlayered slate or phyllite (millimetre- and centimetre-scale layering) and cleaved siliceous meta-arenite, locally quartzite (centimetre- and metre-scale layering), each locally dominant.

The mineralogy is mainly white mica + quartz ± chlorite ± K-feldspar ± albite ± carbonate ± biotite (uncommon), in various proportions. White mica + quartz + chloritoid + andalusite occurs in meta-arenite at one locality. No carbonate rocks, amphibolites, pegmatites or feldspathic segregations occur. Quartz veins are abundant in slates and phyllites. Petrographic descriptions of several samples are given by Stephenson (1966, p. 36–8).

Boundaries between adjacent units

The boundaries between the formations of metamorphic rocks are zones of high strain, with attenuation and destruction of compositional layering and the development of mylonitic rocks. However some inferences as to the original relationships may be made.

West of Mount Provender discrete belts of Stratton gneiss alternate with similar belts of Nostoc Lake Formation, the latter show isoclinal folding and the former become more attenuated as the thickness of the belts decreases. No evidence was found to suggest that the Stratton gneiss was formed by partial melting of the Nostoc Lake Formation as was suggested by Grew and Halpern (1979). It is considered here to be either a pretectonic intrusion with its boundary parallel to the crude stratigraphy within the Nostoc Lake Formation or, more likely, to be the basement upon which the sediments of the Nostoc Lake Formation were deposited, the two formations having been tectonically interleaved.

The boundary between the Nostoc Lake Formation and the Mount Gass Formation is gradational over a few metres. Lenses and disrupted layers of andesine–garnet–hornblende–quartz–biotite gneiss appear in sheared and attenuated feldspathic granoblastite before this lithology (assigned to the Mount Gass Formation because it occurs amongst more typical lithologies in the western part of the formation) disappears westwards. Attenuation is more pronounced at the boundary than in the central parts of either formation but there is no specific evidence of a major structural break. It is possible that the two formations are part of the same sedimentary sequence since the superimposition of a north-westward increase in metamorphic grade and a change in lithology (from chemically mature sediments in the south-east to less mature types in the north-west) might produce the abrupt change from gneiss with feldspathic segregations to schist without such segregations. The subdivisions of the Nostoc Lake Formation cannot be traced across the area of little exposure north of Mount Gass but the gneisses in contact with the Mount Gass Formation are similar to those of the south-western belt, suggesting that the cross-strike sequence is Stratton gneiss–Nostoc Lake Formation–Mount Gass Formation.

At the Mount Gass Formation–Mount Weston gneiss boundary several metres of extremely attenuated quartzite and muscovite schist, and mylonitic schists derived from these, are in contact with alternations of gneiss with little pervasive deformation and mylonitic rocks derived from gneiss, occasional muscovite schist layers (to 4 m in thickness) within the gneisses near the boundary may represent interleaved material of the Mount Gass Formation. The boundary was illustrated by Stephenson (1966, Plates VIc, VIIIa and VIIIb). The gneiss has clearly suffered a higher grade of metamorphism than has the Mount Gass Formation and the presence of quartzites along the boundary suggests that it was originally an uncomformity.

The Mount Weston gneiss shows a progressive increase in the amount of pervasive deformation as the boundary with the Williams Ridge Formation is approached. This is particularly well seen at the western end of Williams Ridge. Except at the easternmost boundary on Williams Ridge (probably a minor fault) the lithology in contact with the gneiss is quartzite, followed after a few metres by metalimestone. The boundary is probably either a strain modified (and overturned) unconformity or a thrust following a particular lithological horizon in the metasediments.

The boundary between the Williams Ridge Formation and the Wedge Ridge schist is not exposed. The main lithological difference between the two formations is the low proportion of carbonate rocks in the Wedge Ridge schist but there are also differences in the structures within them (see below) and some indication that the Wedge Ridge schist suffered a higher grade of metamorphism than the phyllites in the southern part of the Williams Ridge Formation. It is suggested that the boundary is formed by a major fault or fault system, possibly related to that which produced a downthrow to the north of several hundred metres between the Blaiklock Glacier Group and the Wedge Ridge gneiss in the Otter Highlands (Clarkson, 1972).

Near the (poorly exposed) boundary between the Wedge Ridge schist and the Wedge Ridge gneiss the foliation in both formations is parallel to the boundary and the rocks are usually attenuated, mylonitic rocks being present locally. There is no lithological change in the schists as the boundary is approached. On Wedge Ridge pegmatites with only marginal foliation are present in the gneiss close to the boundary and some of these include material similar to that of the schists; there is, however, no intrusion of pegmatites into the metasediments. The evidence as to the nature of this boundary is thus ambiguous but there is clear evidence of high strain.

There is incomplete exposure between outcrops of typical Wyeth Heights Formation and typical Wedge Ridge gneiss but small outcrops of mylonitic schist derived from gneiss crop out a few tens of metres from slate with atypically fine layering; the attitude of the foliation in both is the same. The boundary is therefore interpreted as a thrust associated with the foliation-forming event rather than a fault as shown by Stephenson (1966) and Clarkson (1972).

Metamorphic Fabric

Except in the Williams Ridge Formation, Wedge Ridge schist and Wyeth Heights Formation coarse-grained high- and medium-grade metamorphic fabrics are cut by planar fabrics produced by recrystallization during or after cataclastic deformation. The quartz crystals in the earlier fabric are deformed and have become multigranular aggregates, feldspars are cracked and broken and have bent twin lamellae, and kyanite (where present) is kinked; garnet is often not deformed or broken but the new fabric is deflected round the grains. Where the deformation was more intense spaced zones with this grain size reduction fabric coalesce and the rocks grade into mylonitic schists (Fig. 10) in which garnet, and to a lesser extent plagioclase, are the main relict grains. Garnet, however, is often reduced to traces of smaller crystals, sometimes enclosed in micaceous laminae.

Although referred to as a 'mild cataclasis' by Grew and Halpern (1979) evidence of this deformation is ubiquitous in the coarse-grained metamorphic rocks and the new fabric defines the main parting direction. It is best developed adjacent to formation contacts and in broad zones in the Mount Weston gneiss. It is poorly developed only in the central parts of the larger belts of Stratton gneiss and in parts

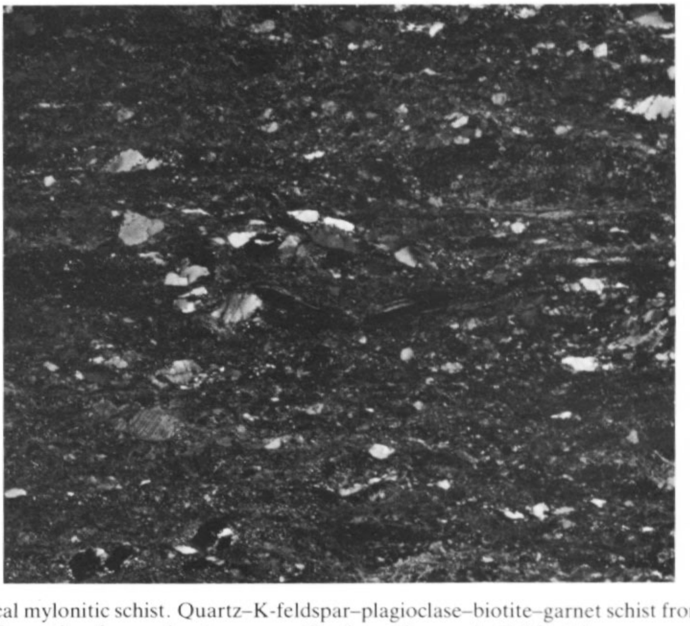


Fig. 10. A typical mylonitic schist. Quartz–K-feldspar–plagioclase–biotite–garnet schist from the Nostoc Lake Formation (crossed polars, magnification ×5, sample Z1056.11).

of the Mount Weston gneiss; except in these areas the compositional layering is parallel or subparallel to the cataclastic fabric.

In the Williams Ridge Formation, the Wedge Ridge schist and the Wyeth Heights Formation the main parting direction is defined by the orientation of micas in the latest, coarsest-grained and the highest-grade fabrics recognized. These fabrics appear to be the result of prograde recrystallization and the grain growth rather than grain size reduction. No earlier, coarse metamorphic fabric is evident. The foliation is generally parallel to the compositional layering or to the axial surfaces of tight and isoclinal folds of the layering but where micaceous laminae parallel to the bedding are only a few grains thick they usually remain parallel to the layering and are crenulated at isoclinal fold hinges.

Structure

Variations in the orientation of the foliation (dominant parting direction) and minor structures are shown in Fig. 2. Four areas with different styles and orientations of structures may be distinguished:

(i) The Mount Provender–Mount Gass area (areas 1–4 of Fig. 2)
(ii) The Mount Weston–Mount Rodgers area (areas 5–7)
(iii) The Wedge Ridge gneiss and the Wedge Ridge schist (areas 8–10)
(iv) The Wyeth Heights Formation (area 11).

The Mount Provender–Mount Gass area

The foliation (the later, finer fabric), the layering and the boundaries of all formations except the Mount Weston gneiss are deformed by neutral folds with north-north-easterly striking axial surfaces (Fig. 2 stereograms 1–3). A major fold of this orientation, the Mount Gass fold (Fig. 6), produces the main change in strike from north-westerly to north-easterly. Towards the south-east the dip of the axial surfaces of these folds and the plunge of their hinges becomes progressively steeper, the geometrical effect being that of a rotation of approximately 50° about an axis plunging gently to the north-north-east. This change is accompanied by a reduction of the interlimb angle of major and minor folds from 90° at Mount Provender to 35° at Mount Gass. A similar change in interlimb angle is observed as the Mount Gass fold is followed southwards towards Mount Gass. These folds will be referred to as the Mount Gass generation folds. Some of the scatter about the girdle of poles to the foliation from area 2 is due to later outcrop-scale flexures about northerly plunging axes.

In the west (areas 1 and 2) there is no strong mineral fabric associated with the Mount Gass generation folds but in the nunatak to the north-east of Mount Gass, where mylonitic schists are folded, crenulations are formed on minor fold limbs and a pervasive axial planar biotite schistosity is present at the hinges. This fabric is similar in morphology to the earlier grain size reduction fabric but is finer-grained and produces a more friable rock. A pronounced crenulation is present in the hinge zone of the Mount Gass fold on Mount Gass but in the highly deformed rocks at the boundary with the Mount Weston gneiss on the eastern limb there is a mylonitic fabric and a strong lineation, rodding being produced both by intersection of surfaces and by elongation. The lineation has a similar plunge to the hinges of Mount Gass generation folds but it is unclear whether this strong fabric is the same age as that deformed by these folds or was produced during their development; the increase in the intensity of this deformation towards the Mount Weston gneiss might indicate the latter possibility.

In the west (areas 1 and 2), earlier folds (including those at the boundaries between the Stratton gneiss and the Nostoc Lake Formation) have axial surfaces lying in the foliation and hinges apparently dispersed in a plane dipping to the south-west (Fig. 2 stereogram 2). In these areas, particularly at the margins of the Stratton gneiss, a strong elongation lineation is locally present. This has a similar orientation to the Mount Gass generation fold hinges but is best developed where the attenuation associated with the earlier mylonitic fabric is most intense. In contrast there is no lineation in the attenuated rocks at the Nostoc Lake Formation–Mount Gass Formation boundary.

There is thus some uncertainty as to the age relations of the folds and some fabric elements, however, the Mount Gass generation folds are observed to deform mylonitic rocks, including those at folded contacts between formations, and also to produce a similar pervasive fabric at some localities. The main uncertainty is in the age of the attenuation at the boundary of the Mount Weston gneiss.

The Mount Weston–Mount Rogers area

In the mylonitic rocks in the southern part of the Mount Weston gneiss and in the Williams Ridge Formation the foliation is deformed by folds with north-north-east striking axial surfaces and northward plunging hinges (Fig. 2, stereograms 5 and 6). A major antiform, the Mount Weston antiform, is present in the Mount Weston gneiss and the metasediments to the south but its hinge cannot be traced precisely in the latter as the hinge zone becomes broad and is offset across breaks in exposure by minor faults. These folds produce open or tight crenulations of the schistosity with wavelengths of the order of one centimetre; the micas affected commonly have bent cleavages and no new schistosity was observed. These folds will be referred to as the Mount Weston generation folds.

In the Mount Weston gneiss earlier folds, with and without axial-planar schistosity, lie in the mylonitic foliation. In the Williams Ridge Formation the schistosity is in general parallel to the axial surfaces of isoclinal folds with wavelengths of up to several hundred metres which interfold the main lithologies of the formation. However, thin micaceous laminae parallel to the layering are sometimes folded by minor isoclinal folds. On the western limb of the Mount Weston antiform (area 7 of Fig. 2) there is some indication of earlier folding about westerly plunging axes; an antiformal hinge in the metasediments which crop out between areas of gneiss on Williams Ridge is probably of this age. The relationships between these early folds in the west and those producing the schistosity in the metasediments is not known.

The Wedge Ridge schist and Wedge Ridge gneiss

The Wedge Ridge schist and the Wedge Ridge gneiss contrast sharply with the formations to the north by the absence of major folds of the foliation. Only in one outcrop (east of Wedge Ridge) were open flexures similar in orientation to the Mount Weston fold recorded (this outcrop yields the few poles to foliation which fall outside the main group from area 9 of Fig. 2). Mesoscopic and minor folds in the Wedge Ridge schist have north-westerly striking axial surfaces and crenulate the schistosity (including that of mylonite-schists) to produce a north-westerly plunging lineation. A strong north-westerly plunging lineation is also present in most parts of the Wedge Ridge gneiss but there it is defined by an elongation of feldspathic segregations and is part of the grain size reduction fabric. The finer-grained fabric is more uniformly developed than in the Mount Weston gneiss, being absent or weakly developed only in the thicker granite sheets and in the areas of granite which intruded marble. Within these latter areas the fabric becomes progressively stronger towards the margins of the areas of granite. The strong lineation is not present in the mylonitic rocks adjacent to the Wyeth Heights Formation.

Wyeth Heights Formation

The cleavage in the Wyeth Heights Formation has a uniform east–west strike but a variable, generally northerly, dip due to open flexures (to outcrop-scale) about east–west trending axes. These folds are accompanied by a fine (millimetre wavelength) crenulation of the cleavage which gives a lineation plunging gently to the east or west. Earlier isoclinal minor folds in the slates and phyllites, to which the cleavage is axial planar, have hinges plunging to the north-east, as do most of the recorded bedding/cleavage intersections in the meta-arenites. Variations in bedding/cleavage relationships indicate the presence of major folds of the layering with this orientation and a wavelenth of *c*. 1 km.

STRUCTURAL HISTORY

The boundaries between formations are everywhere parallel to the locally dominant planar fabrics which in all but the Williams Ridge Formation, the Wedge Ridge schist and the Wyeth Heights Formation are mylonitic. The fold sets which have been recognized are contemporaneous with or younger than these fabrics. Evidence of events associated with the earlier coarse-grained fabrics is preserved mainly in the form of relict lithological and metamorphic, rather than tectonic, features and will be discussed below together with the orogenic and depositional history of the area.

The similar orientations of the cleavage in the Wyeth Heights Formation and the late planar fabric in the Wedge Ridge gneiss invites their correlation and it is possible that the same deformation episode produced both the isoclinal folding about north-easterly plunging axes in the Wyeth Heights Formation and a north-westerly plunging extension lineation in the Wedge Ridge gneiss. This deformation can be assumed with some certainty to predate the Mount Weston generation folds but no direct correlation of structures north and south of the postulated major fault may be made.

The Mount Weston generation folds are the youngest in the central part of the area and the associated deformation ceased after the rocks had cooled to such a degree that the micas were unable to completely anneal. In the north the dominant late folds are of the Mount Gass generation and were followed by recrystallization of the quartz–feldspar–mica fabric. It could be suggested that these fold generations were approximately coeval, the difference in the degree of recrystallization being due to the temperature remaining higher in the north. However the presence in the Mount Provender area of late, weakly developed, folds of similar orientation to the Mount Weston generation folds and the presence on the western limb of the Mount Weston fold of earlier structures with similar orientations to the Mount Gass generation folds supports the conclusion made here that the Mount Weston folds are younger.

In terms of the long history of the metamorphic complex the mylonitic fabrics throughout the area are assumed to be of broadly similar age. However there is evidence for more than one phase of cataclasis. In the Mount Weston area, shears a few centimetres thick, with a greenschist facies mineral assemblage, cut gneiss with a weak amphibolite facies mylonitic fabric (Fig. 7c) and the evidence (above) from the Mount Gass area shows that, at least locally, penetrative fine-grained fabrics were produced by deformation that folded mylonitic fabrics. Present evidence is insufficient to determine whether the mylonitic rocks deformed by the Mount Weston fold are of the same age as those deformed by the Mount Gass fold or were produced during the formation of the latter. The similar orientation of the strong lineations in the Wedge Ridge gneiss and the Mount Provender–Mount Gass area suggests correlation of the foliation in these areas.

Whatever the age relations of these planar fabrics the east–west trend in the remainder of the Shackleton Range (Clarkson, 1982*a*) and widespread occurrence of grain size reduction fabrics (Grikurov and Dibner, 1979) strongly suggest that before the north–south trending folds the general strike of the foliation throughout the area was east–west, as it is at present south of the postulated major fault (areas 8–11 of Fig. 2). The poor development of north–south striking late structures in the south may be due to their having formed only at the higher structural level (implied by a downthrow to the north on this fault) of the rocks in the north; décollement in or at the base of the Williams Ridge Formation would provide a mechanism for this.

The unmetamorphosed Blaiklock Glacier Group also appears to be deformed about a southward plunging axis (Clarkson, 1982*a*). However no folds have been observed at outcrop (Clarkson and Wyeth, 1983), and in the main areas in which outcrop occurs the strata are homoclinal. These rocks may thus be tilted rather than folded. If they are folded, then the interlimb angle (*c.* 90°) is considerably less than that of the Mount Weston fold suggesting either that some of the deformation on the Mount Weston fold took place before the deposition of the Blaiklock Glacier Group or that, as already speculated above, considerable décollement has taken place. However an absence of evidence of strain at the unconformable base suggests that this was not the locus of any décollement which did occur.

A more detailed account of the events following the formation of the earliest recognized mylonitic fabric may be possible after more precise study of the fabrics and associated mineral assemblages. However, it can be concluded that, before the folding about axes striking nearly north–south, the area consisted of belts of rocks of contrasting lithologies having boundaries parallel to east–west striking, mainly northerly dipping planar fabrics developed during a period or periods of deformation involving cataclasis, there having been some interleaving or interfolding of adjacent formations at their boundaries. The metamorphism associated with the latest planar fabrics decreases from middle amphibolite grade in the north to greenschist grade in the south. The descending structural order of the formations was probably that in which they are described above and listed in the key to Fig. 1. Whilst there may be omissions from the sequence due to the major fault it is possible that there are none and that the Wedge Ridge schist and the Williams Ridge Formation are parts of the same sedimentary sequence. Major tectonic discontinuities may, however, be present between some formations.

Orogenic and Depositional History

The results of a geochronological investigation of the range have been presented by Pankhurst and others (in press) who review earlier radiometric studies and show that the structural history described above represents only the Phanerozoic (Cambro-Ordovician) part of a long tectonic and thermal history, during which the formations described here originated at various times by the addition to and reworking of an early-Proterozoic or Archaean crust. The formations may be classified into three types :-

(a) Two formations (the Mount Weston gneiss and the Wedge Ridge gneiss), or possibly three formations (including the Stratton gneiss), of high grade gneisses of igneous, or igneous and sedimentary, origin which either on structural/stratigraphic or radiometric evidence can be considered to have been incorporated into the crystalline basement in or before the mid-Proterozoic.

(b) Two formations (Nostoc Lake Formation and the Mount Gass Formation) of medium and high grade metasediments with gneissose or coarsely schistose fabrics, which may be regarded as supracrustal rocks relative to the above. These formations are of late-Precambrian age on radiometric evidence and their main metamorphism is Vendian or Cambrian in age.

(c) Three formations (Williams Ridge Formation, the Wedge Ridge schist and the Wyeth Heights Formation) of metasediments possessing schistose, phyllitic or slaty fabrics and lacking evidence of earlier coarser fabrics. Either these formations are younger than the metamorphism which produced the coarse fabrics in the Nostoc Lake Formation and were affected only by the Cambro-Ordovician event, or they predate it but were situated such as to suffer a lower grade metamorphism, which was more thoroughly overprinted by the later event.

The history leading to the production of the mid-Proterozoic basement is unclear. The three formations representing these rocks are lithologically distinct, possibly due to the juxtaposition of rocks from widely separated regions by thrusting associated with the cataclasis. There is evidence of anatexis and high grade metamorphism, possibly to granulite facies, affecting rocks of sedimentary origin and gneisses of generally intermediate to acid igneous composition, and of widespread acid and intermediate plutonic activity. Rocks of basic igneous composition are uncommon. A more representative view of these older rocks should be possible following work in progress in the remainder of the range.

In the Nostoc Lake Formation carbonate rocks and lithologies which were originally aluminous argillites and siliceous arenites are interlayered with rocks formed from extremely immature sediments, some of which were probably volcanogenic greywackes or tuffs, and the possibility of acid and intermediate lavas being present cannot be ruled out. A marine shelf or basin with a volcanic provenance is indicated. The Mount Gass Formation has a higher proportion of chemically mature sediments interlayered with amphibolites, which may represent volcaniclastic sediments or lavas, suggesting that the sediments were deposited on a shelf in or near a volcanic terrain. Less mature sediments become dominant higher in the formation. It is at present unclear whether these two formations are part of the same sedimentary sequence, the Mount Gass Formation being the lower part, or are two separate sequences brought together by thrusting. The base of the Mount Gass Formation has a prominent siliciclastic layer and the more mature sediments of the Nostoc Lake Formation are more common near its argueable base against the Stratton gneiss suggesting that, on either interpretation, deposition of these formations began with shelf facies sedimentation on a sialic basement.

The William Ridge Formation is almost entirely formed from limestone (often sandy) and argillites (often calcareous) representing prolonged stable conditions. Quartzites are present locally, particularly at the contact with the Mount Weston gneiss, suggesting that this formation was also laid down on a shelf floored by the basement now seen in the range. The Wyeth Heights Formation was formed from relatively mature terriginous clastic material without a volcanogenic component, an assemblage most commonly associated with a passive continental margin. Carbonate rocks are absent. The base is not seen.

The formations of sedimentary origin are sufficiently distinct in lithology to prevent direct correlations being made between them. Various palaeogeographies might be suggested which would allow the formations to be parts of the same sedimentary system prior to their having been brought together by tectonic transport but there is at present no evidence that these supracrustal rocks were formed during the same orogenic cycle. The main uncertainty is over the possibility of a break in the metamorphic activity after the high grade metamorphism of the Nostoc Lake Formation and before the final Cambro-Ordovician metamorphism, since the Wyeth Heights Formation and/or the Williams Ridge Formation could have been deposited in this period.

Discussion

The range has geological similarities with the Transantarctic Mountains in that it is a faulted block, with a late Precambrian–early Palaeozoic sedimentary and thermal history, within the zone of outcrop of Beacon sediments adjacent to the rifted Pacific–Weddell Sea margin of eastern Antarctica. However, the low grade rocks were relatively mature, non-volcanogenic, sediments, unlike the low grade turbidite-greywackes of the Beardmore–Ross belt (Hofmann and Paech, 1980; Clarkson, 1983), and the rocks yielding late Precambrian ages for their main metamorphism are of higher grade than those associated with the near contemporaneous Beardmore orogeny (Grew and Halpern, 1979). The range lies east of the extrapolated trend of the Beardmore and Ross orogenic belts and the dominant structural trend is at right angles to that in these belts (Clarkson, 1982*a*) and similar to that within the craton in Dronning Maud Land (Craddock, 1970*b*), where latest Precambrian and early Palaeozoic ages are also recorded from metamorphic rocks and high grade rocks suffered retrogression and cataclasis (e.g. Craddock, 1970*a*; Van Autenboer and Loy, 1972; Juckes, 1972). An intracratonic setting is envisaged by Kamenev and Semenov (1981), who interpret the range as a Proterozoic–early Palaeozoic fold system developed in an aulacogen, the Turnpike Bluff Group representing part of an intracratonic branch of the Ross system

The improved stratigraphy presented here will allow more detailed comparison of the sedimentary and tectonic history of the range with that of adjacent areas of eastern Antarctica. However further discussion of regional correlations and their tectonic significance will be postponed pending eastward extension of the stratigraphy recognized in the west.

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