THE STRATIGRAPHY AND STRUCTURE OF THE LAGRANGE NUNATAKS, NORTHERN FUCHS DOME AND HERBERT MOUNTAINS OF THE SHACKLETON RANGE

P. D. MARSH

British Antarctic Survey, Natural Environment Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK

ABSTRACT. Amphibolite grade supracrustal rocks within the Shackleton Range Metamorphic Complex in the northern part of the range can be correlated with units recognized farther west. They are assigned to two new stratigraphic groups: the Schimper Group, which includes the Nostoc Lake and Mount Gass Formations of the Haskard Highlands; and the Haskard Group, which includes the Williams Ridge Formation. These rocks overlie higher grade gneisses correlated with the Read Complex of the Read Mountains to the south. The two supracrustal groups are not found in contact with each other and it is suggested that they form parts of different large-scale tectonic units. Both groups and the Read Complex were interleaved and attenuated during deformation associated with the formation of the first of two, nearly coaxial, east–west trending fold generations. The metamorphic fabric in the Haskard Group suggests that they did not suffer an early metamorphism detected in the Schimper Group.

INTRODUCTION

The Shackleton Range (80°–81° S, 19°–31° W) is composed mainly of amphibolite facies rocks of the Shackleton Range Metamorphic Complex, which have been divided into two broad groups: (i) older migmatitic gneisses intruded by granite stocks and (ii) younger metasedimentary schists, marbles and amphibolites, (Clarkson, 1972, 1982*b*). The 'older gneisses' crop out mainly in the south of the range, where they are overlain by late Precambrian quartzites and carbonates of the Watts Needle Formation, (Clarkson, 1972; Golovanov and others, 1980; Marsh, 1983*b*) and are in tectonic contact with greenschist facies arenites and argillites of the Turnpike Bluff Group (Clarkson, 1972, 1984). The metasediments of the metamorphic complex crop out mainly in the north. In the Haskard Highlands they have been resolved into three formations (Mount Gass Formation, Nostoc Lake Formation, Williams Ridge Formation) which overlie and are interleaved with the gneisses (Marsh, 1983*a*). They are unconformably overlain by unmetamorphosed arenaceous strata of the Blaiklock Glacier Group (Clarkson, 1972; Clarkson and Wyeth, 1984). Throughout most of the range, the foliation strikes 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*).

A geochronological investigation of the range has been reported by Pankhurst and others (1983) who reviewed earlier radiometric studies. The 'older gneisses' originated in the early Proterozoic or late Archaean and underwent major thermal activity in the mid Proterozoic. Subsequent sedimentation began in the late Proterozoic and the Nostoc Lake Formation probably underwent its main metamorphism in the Vendian. The Turnpike Bluff Group and Williams Ridge Formation could post-date this metamorphism but were deposited before a final metamorphism at about the time of the Cambro–Ordovician boundary. A slightly

Br. Antarct. Surv. Bull. No. 63, 1984, pp. 19–40

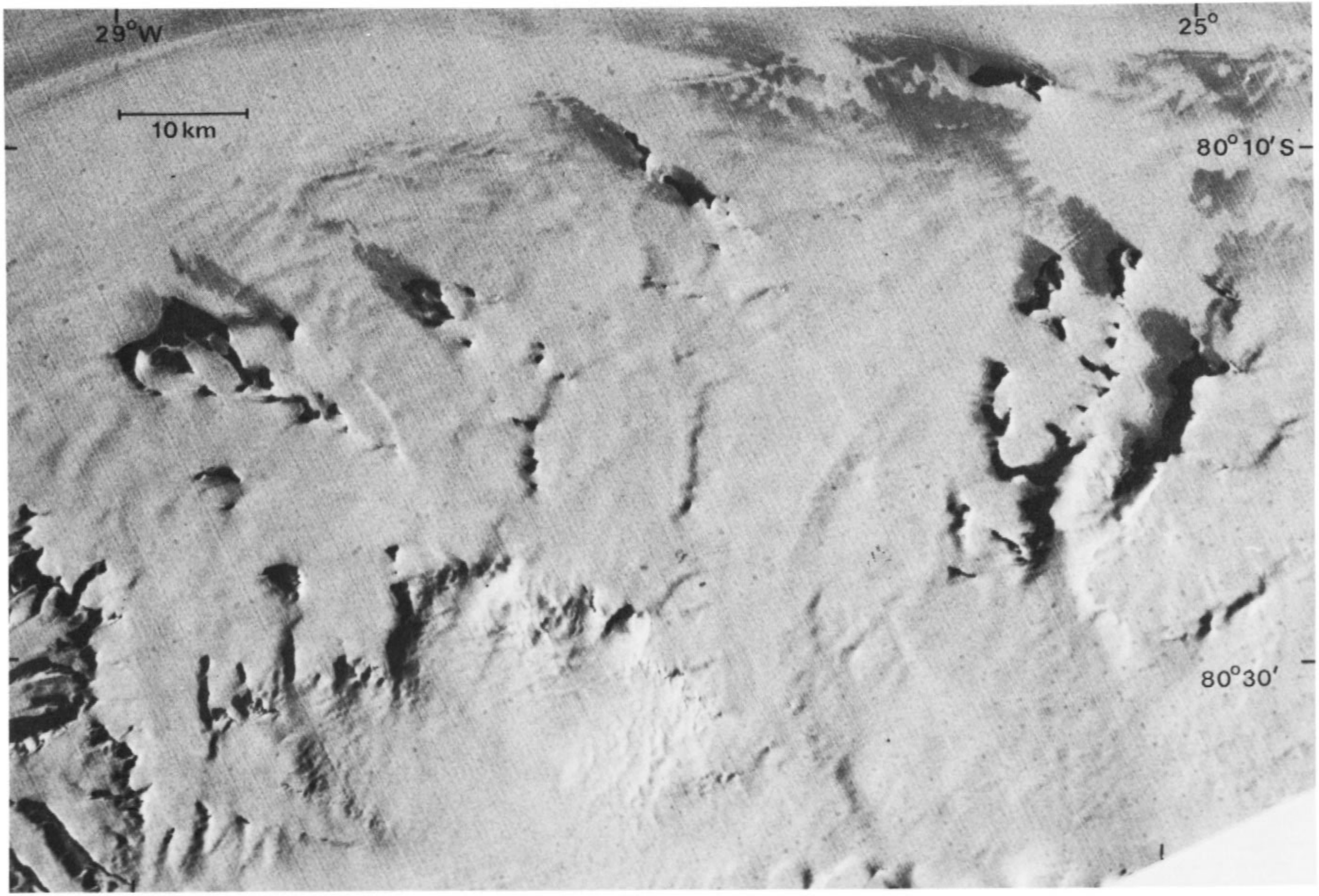


Fig. 1. [illegible]dsat image of the area described (part of E-1548-07151-701, 2[illegible]anuary 1974).

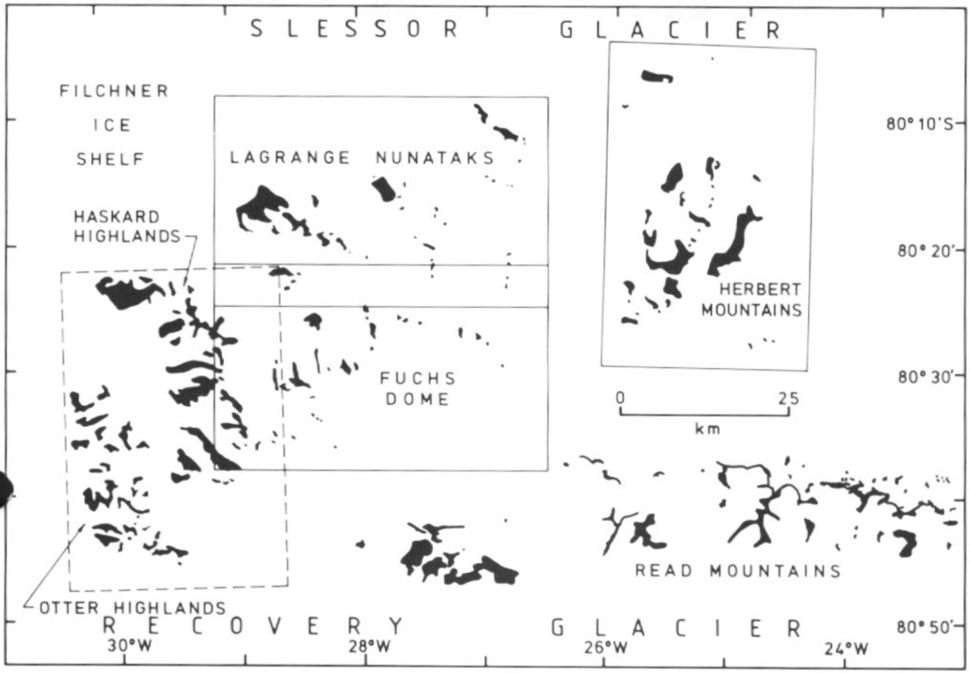


Fig. 2. Location within the Shackleton Range of areas referred to in the text. Broken outline shows the area described by Marsh (1983*a*).

younger age from the Blaiklock Glacier Group probably represents diagenesis in the early Ordovician.

This paper presents a description of the stratigraphy and structures in the metamorphic complex in the northern part of the range, extending eastward the stratigraphy recognized in the Haskard Highlands. The morphology of the area and distribution of rock outcrop are the best seen from Landsat imagery (Fig. 1); except on some WNW facing slopes (in shadow), the darkest tones are ice-free areas. Fig. 2 shows the areas covered by the geological maps (Figs. 3–5), and also the area described by Marsh (1983*a*).

The area was included in the reconnaissance mapping of Clarkson (1972, 1982*a*,*b*) who described middle and upper amphibolite facies mineral assemblages from the metasediments and showed that the foliation was in general subhorizontal, striking east–west, with some folding about east–west trending axes. Hofmann and Paech (1980) named the metasediments in the Herbert Mountains the Herbert Group. They recognized an overall northward dip of the foliation and the main structures, reported mineral assemblages similar to those described by Clarkson and recognized the presence of blastomylonitic fabrics. Kamenev and Semenov (1980) refer to the supracrustal rocks in the area as the Skidmore Complex, but give no stratigraphic details.

Stratigraphy

All the rock units identified in Figs. 3–5 are of formation rank in the sense of Gary and others (1972) but, as in many metamorphic terrains, it is not possible to follow

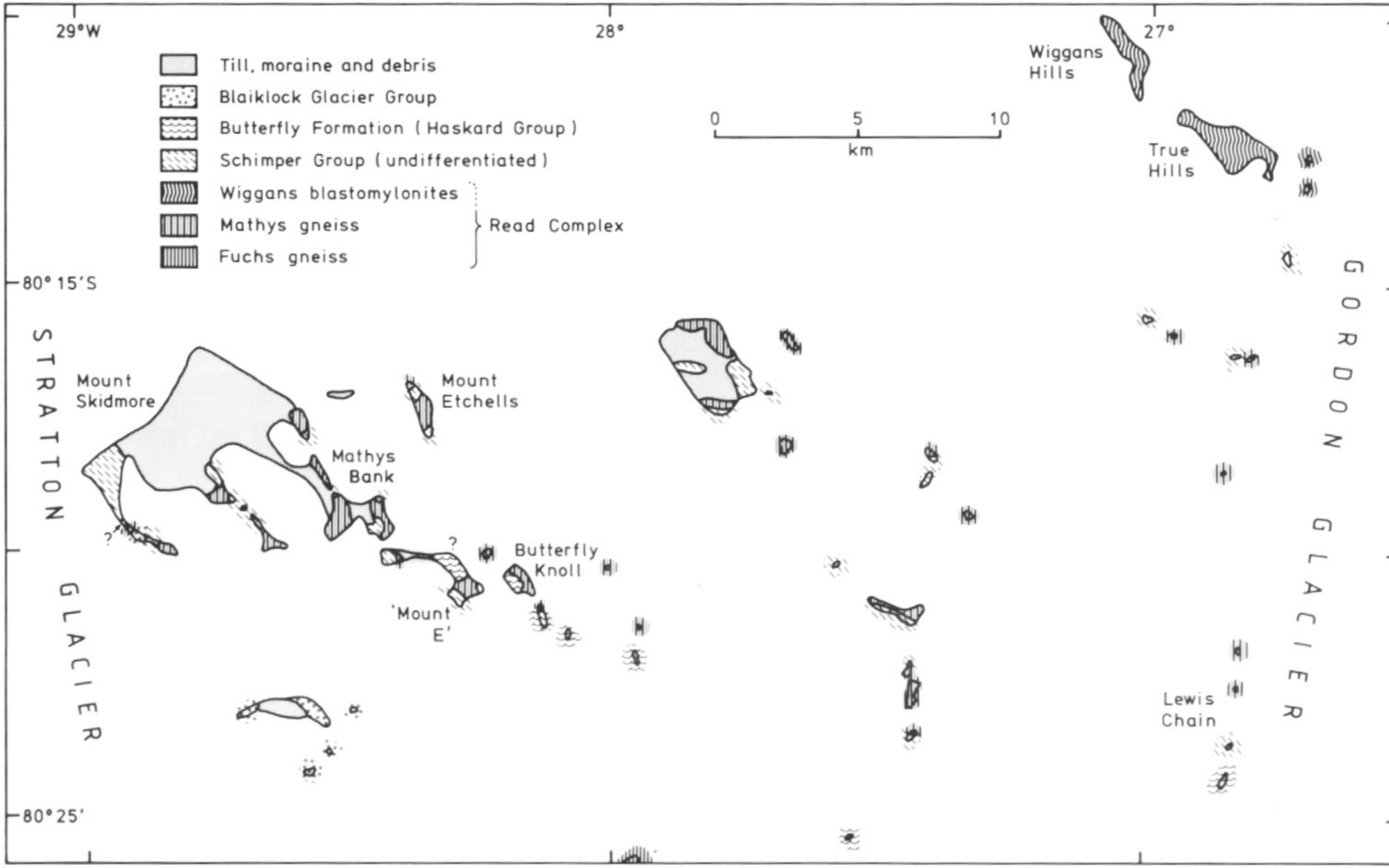


Fig. 3. Geological sketch map of the Lagrange Nunataks.

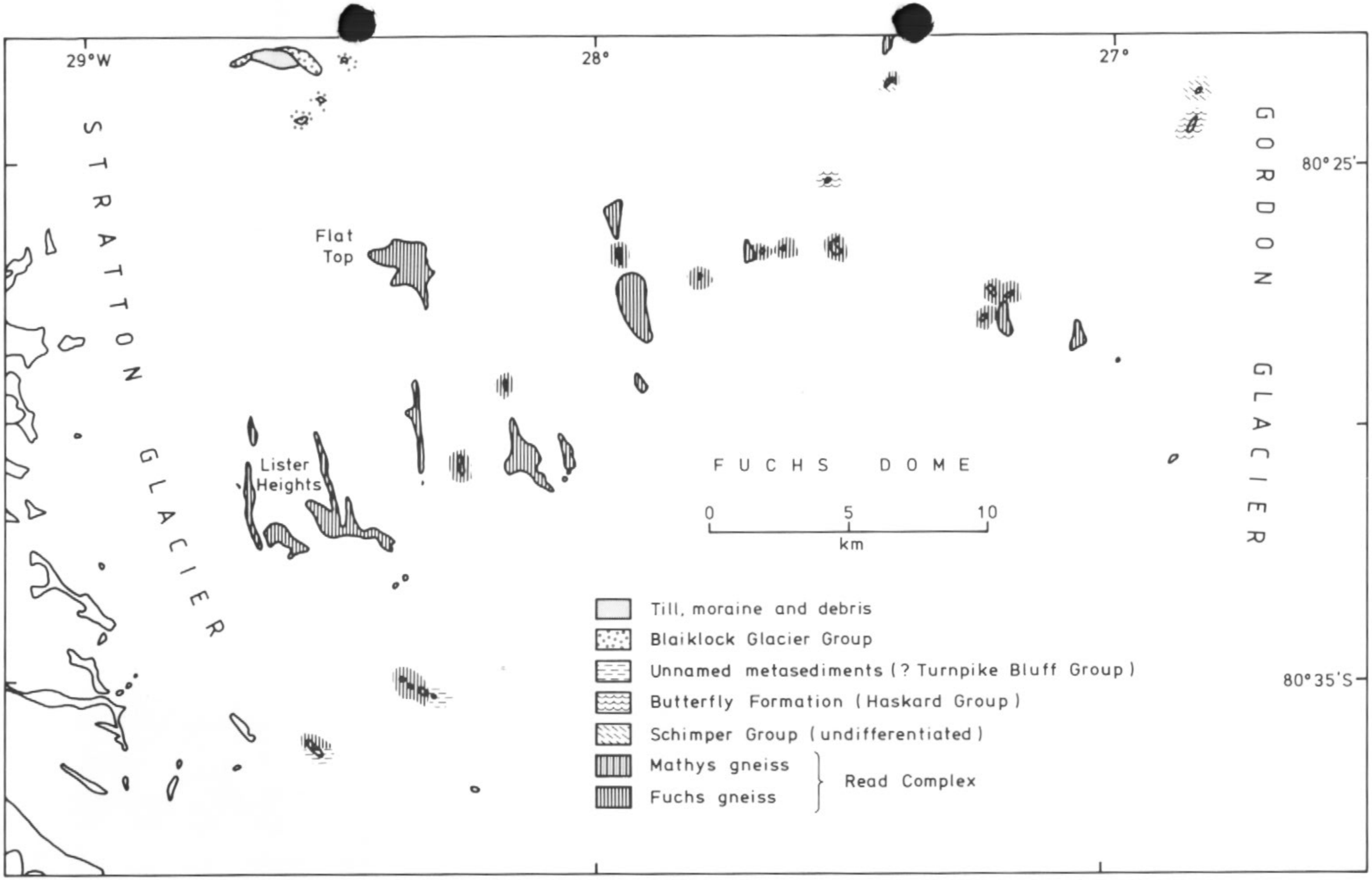


Fig. 4. Geological sketch map of the Fuchs Dome area.

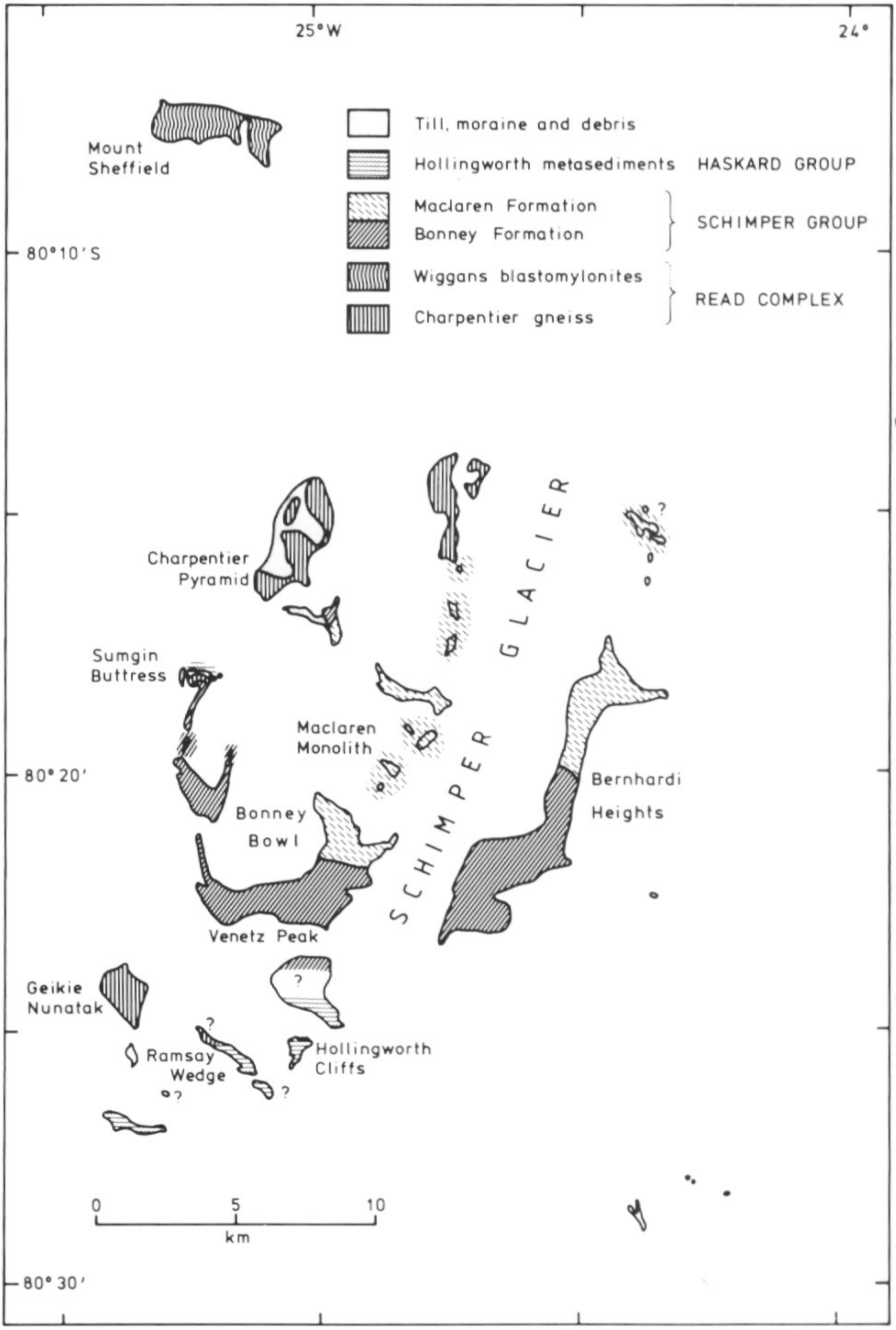


Fig. 5. Geological sketch map of the Herbert Mountains and Mount Sheffield.

formal codes of stratigraphic nomenclature when defining units. Nevertheless, those units of metasediments that retain relics of original boundaries and internal stratigraphy and have consistent features over large areas are named 'Formation'. Mappable units of metasediments that are poorly understood or of uncertain status and areas of gneiss with tectonic or geographic boundaries unrelated to the genesis of their internal structures are named informally for convenience in discussion. The descriptions given here are ordered within the framework of the proposed correlations. Two higher rank stratigraphic units are proposed: the Schimper Group (for Schimper Glacier, which divides the Herbert Mountains), to include equivalents of the Mount Gass and Nostoc Lake Formations, and the Haskard Group, to include equivalents of the Williams Ridge Formation and the Haskard Highlands. The Schimper Group may be synonymous with the Herbert Group of Hofmann and Paech (1980) and possibly with the Skidmore Complex of Kamenev and Semenov (1980) but the equivalence of these units is uncertain. These groups and the Turnpike Bluff Group are supracrustal rocks relative to the 'older gneisses' of Clarkson (1982*b*). The latter have been named the Read Complex by geologists with Soviet Antarctic Expeditions (see Hofmann and Paech (1980) and Hofmann and other (1981) for summaries) and this name is adopted here.

Read Complex

Fuchs Dome gneiss. Mainly coarse grained, mesocratic migmatitic gneiss.

In many outcrops the high grade fabric has suffered flattening and cataclasis, with the local development of mylonite schists. Some of the gneisses were probably derived from metasediments but no recognizable stratigraphic sequences remain.

Large-scale partial melting features are best seen on the ridge 6 km SSE of Flat Top (Fig. 4), where the effects of the later deformation are slight. Grey gneiss (plagioclase + K-feldspar + quartz + biotite ± amphibole ± garnet ± sillimanite) with millimetre- and centimetre-scale layering and feldspathic segregations grades into sheets and irregular bodies of granitic material with disrupted layers and schlieren derived from the palaeosome (Fig. 6a). On a larger scale, blocks of gneiss with few segregations are surrounded by more leucocratic migmatite (Fig. 6b). Sheets of more homogeneous granite (to 10 m thick) with sharp boundaries are also present. Garnet (to 20 mm in diameter, usually chloritized) is a typical feature of the leucosomes in many outcrops. Cross-cutting garnet-bearing veins or diffuse patches of garnetiferous quartzo-feldspathic material, are present locally in biotite gneiss. The migmatites have upper amphibolite facies mineral assemblages. Sillimanite is present and muscovite has only been identified in deformed and retrogressed samples. Dark feldspars and 'milky' quartz in some samples and the conspicuous garnet in the leucosomes combine to give the rocks a charnockitic aspect in places but no rocks can be identified as granulite facies relics. Evidence of later deformation, where present, varies from localized cataclasis at the margins of granite sheets to outcrops composed entirely of phyllitic muscovite-bearing schist with few fragments of larger crystals. Severely flattened rocks are often strongly lineated, a conspicuous ribbon lineation being produced in garnetiferous leucosomes. These mylonitic rocks have planar medium- or fine-grained biotite–muscovite–quartz fabrics. Relict feldspars are cracked and broken and garnet is drawn out into trails of finer crystals. Garnet and oligoclase were stable during recrystallization.

Mathys gneiss. Mesocratic and leucocratic medium-grained granoblastic gneiss (quartz + K-feldspar + plagioclase + amphibole and/or biotite ± garnet) with diffuse centimetre-scale layering.

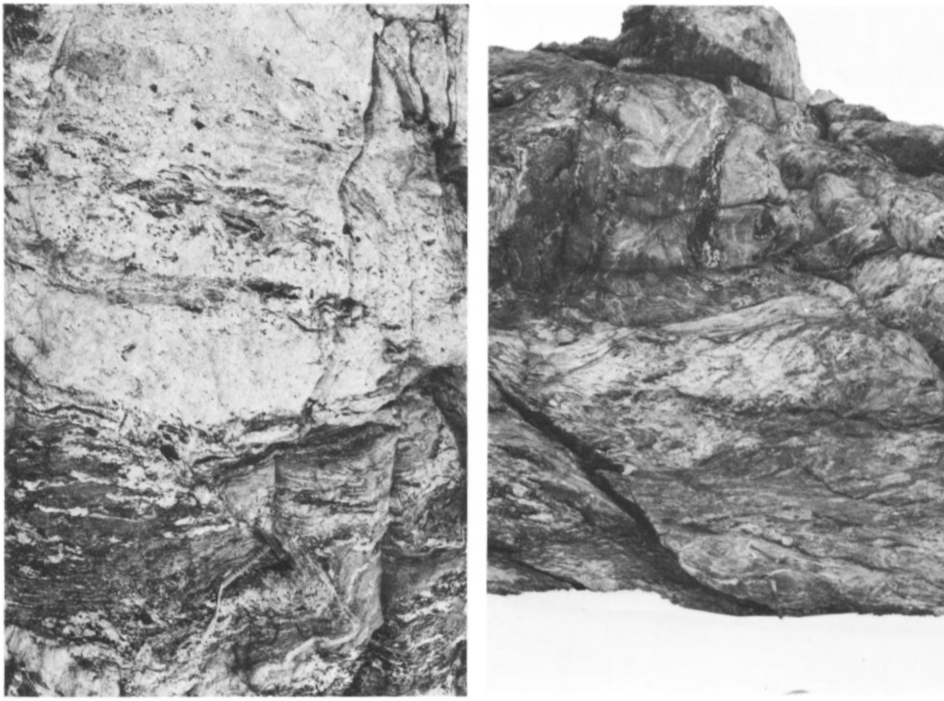


Fig. 6a, b. The Fuchs gneiss: migmatitic gneisses on the ridge 6 km south-south-east of Flat Top.

Feldspathic veins and pegmatites are normally present. They vary in thickness from metre-scale layers and boudins to strings of augen composed of single crystals a few millimetres in diameter: veins about one centimetre thick are the most common. Basic layers from 1 cm to several metres in thickness are typical and locally abundant; the thicker layers are commonly net veined by feldspathic material (Fig. 7). At nearly all localities the rocks have an attenuated appearance and they are often strongly lineated. All basic and feldspathic layers and veins have been flattened into near parallelism with the compositional layering and the thicker basic layers are boudinaged. Less common lithologies include rocks with alternating centimetre-scale siliceous and mafic layers, small areas of leucocratic gneiss with 'spots' of mafic minerals (probably chloritized garnet crystals) and flattened granite with feldspar crystals up to 2 cm in length (nunatak at 80° 20′ S, 28° 38′W). However, such rock types are rare and the most striking feature of the gneiss, when compared with the Fuchs gneiss and the basement rocks of the Haskard and Otter highlands (Marsh, 1983*a*), is its lithological uniformity. The proportion of garnet does not normally exceed about 5% but locally the typical lithologies grade into more garnetiferous schists and gneisses. It is uncertain whether these are tectonic inclusions of Schimper Group rocks or relics of older supracrustal rocks incorporated in the gneiss. Both garnet and amphibole suffered partial replacement by biotite during recrystallization following attenuation but amphibole, garnet and plagioclase were components of the new medium-grained fabric. Epidote-bearing assemblages are present in some rocks.

Charpentier gneiss. Leucocratic medium-grained granoblastic gneiss (quartz +

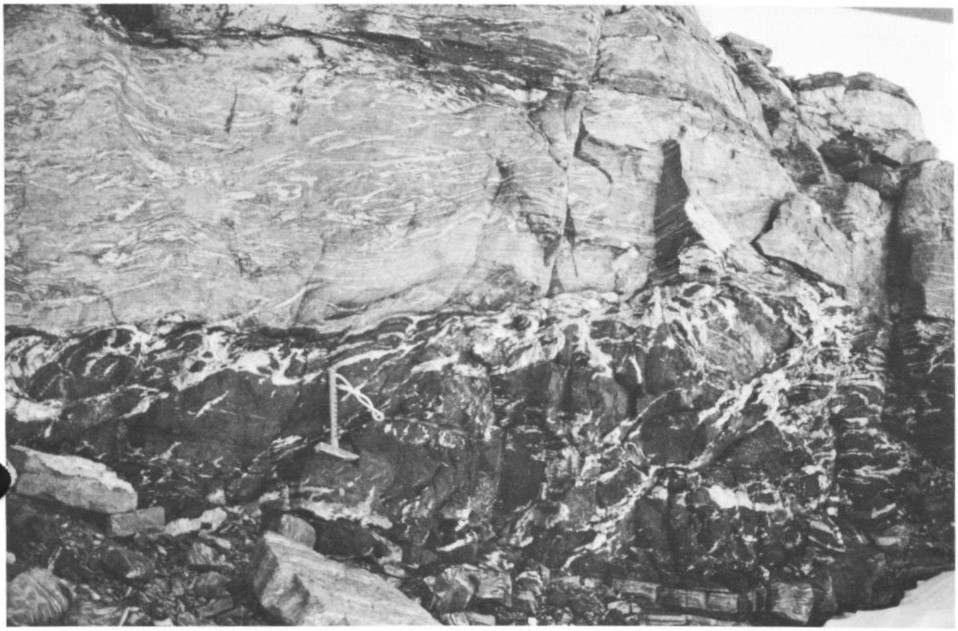


Fig. 7. The Mathys gneiss: a net veined basic layer in typical feldspathic gneiss. Peak 4 km east of Mount Skidmore.

plagioclase + K-feldspar + amphibole ± biotite ± garnet ± retrograde epidote) with centimetre-scale layering (often defined by amphibole rich laminae).

This unit resembles the typical rocks of the Mathys gneiss but is generally paler in colour and usually has amphibole as the dominant mafic mineral. Flattened layers and lenses of feldspar pegmatite are abundant (see Clarkson, 1982*b*, fig 4). The mineralogy and fabric are similar to those of the Mathys gneiss; assemblages bearing albite + epidote are found in flattened rocks on Sumgin Buttress but this low-grade mineralogy is atypical. Charpentier Pyramid and the peaks to the north provide the best outcrops of Read Complex rocks in the Lagrange Nunataks–Herbert Mountains area.

Wiggans blastomylonites. In the northern-most areas of outcrop (Wiggans Hills, True Hills, Mount Sheffield) the dominant lithology is a mesocratic, hornblende bearing quartzo-feldspathic rock with a well-defined parallel foliation. Lenses of basic material (up to 250 mm across) and abundant isolated coarse-grained feldspar crystals lie in the foliation, which commonly includes intrafolial folds. Feldspathic veins (typically 1 cm thick) are strongly flattened but cross cut the foliation at low angles. Evidence of cataclasis is ubiquitous but the present medium-grained mineral fabric is a result of recrystallization following the deformation. Layers of carbonate rock, 1–5 m thick, on True Hills, provide the only evidence that these rocks are in part of sedimentary origin, possibly including Schimper Group material. For the most part they are probably derived from rocks similar to the Mathys and Charpentier gneisses. No boundaries with other units have been identified but, in the nunataks south of True Hills, blastomylonitic zones resembling these rocks pass through outcrops of Mathys gneiss and metasediments, suggesting that the change in tectonic fabric could be gradational.

Schimper Group

Schimper Group rocks of the Lagrange Nunataks. Schistose metasediments ascribed to the Schimper Group crop out throughout the Langrange Nunataks but only in the area around 'Mount E' (Fig. 3) and on Mount Skidmore are cross-strike sections more than a few tens of metres thick exposed. On 'Mount E' and the nunatak to the west the Mathys Bank gneiss is overlain by quartzite (to 5 m thick, locally pale green) succeeded by muscovite-rich schists with grey metalimestone layers (200 mm thick). These are overlain by garnetiferous schists and gneisses of varied mineralogy (muscovite and/or biotite + quartz + garnet + plagioclase ± kyanite ± staurolite), kyanite schist, garnetiferous quartz-rich layers and amphibolites (to 15 mm thick). Grey garnetiferous layers resembling the Mathys gneiss are present in the upper part of the sequence. Some of these may be metasedimentary but on 'Mount E' the highest rocks in the section are attenuated and strongly lineated Mathys gneiss-like lithologies, and it is probable that the metasediments are in thrust contact with the gneiss, possibly with some interleaving.

On the south ridge of Mount Skidmore a 20-m-thick sequence of quartzite, muscovite schist and white metalimestone, of uncertain affinities (see below), appear to overlie the Mathys gneiss. It is separated by 50 m of unexposed ground with loose blocks of strongly lineated Mathys gneiss from a thicker sequence of metasediments forming the upper part of the ridge. The lower part of the main sequence is dominated by garnetiferous muscovite-rich schist and quartzite, with subordinate layers of amphibolite. In the upper part garnetiferous amphibolite is dominant, with common interlayers of garnetiferous biotite schist (locally with amphibole), grey metalimestone (*c*. 250 mm thick) and cream metalimestone (1–2 m thick). Magnetite and sulphide ore-rich layers, probably of sedimentary origin, are present locally. In the highest outcrops mesocratic garnetiferous biotite–hornblende schists are locally dominant.

Most of the smaller outcrops of metasediments in the Lagrange Nunataks can be referred to parts of these sequences. The presence of quartzite and/or metalimestone associated with muscovite schists close to these boundaries is repeatedly observed and at many localities the quartzite is markedly green due to the presence of fuchsite. The schists are mainly medium grained and have middle amphibolite facies mineral assemblages. Fibrolite is present in a minority of kyanite and/or staurolite bearing samples. The compositional layering often appears attenuated and, although blastomylonitic fabrics are uncommon, cracked and broken crystals of garnet, kyanite and staurolite, drawn out along the schistosity, provide evidence of an earlier medium- or coarse-grained amphibolite facies fabric.

Bonney Formation. In the upper part of Sumgin Buttress, gneisses are overlain by a sequence comprising green quartzite, muscovite schist, metalimestone and garnetiferous amphibolite that is strikingly similar to the Mount Gass Formation of the Haskard Highland (Marsh, 1983*a*). The amphibolites estimated at 300 m in thickness by Clarkson (1982b), dip gently on the west side of Bonney Bowl but gain a steep dip to the north-east in the south and form the prominent east–west ridge of Venetz Peak. In structurally higher rocks on the east side of Bonney Bowl, metalimestone and garnetiferous schist are interlayed with the amphibolites and the sequence appears to grade upwards into typical rocks of the Maclaren Monolith Formation. The rocks are mineralogically similar to comparable lithologies in the Lagrange Nunataks. Kyanite is present in aluminous schists. Little detail is known of the geology east of the Schimper Glacier but the characteristic green quartzite–grey metalimestone–amphibolite association is found at almost all sample localities in the southern Bernhardi Heights.

Maclaren Monolith Formation. The dominant lithologies in the central and north-eastern Herbert Mountains are medium- and coarse-grained, richly garnetiferous schists and gneisses. Typical lithologies are well exposed on the ridge 4 km north of Maclaren Monolith. Mica (biotite ± muscovite) schists often with kyanite are most common but mesocratic amphibole- and pyroxene-bearing schists are present. Subordinate lithologies include kyanite schists (mica poor), metalimestone layers (to *c.* 5 m thick), siliceous schists and amphibolites. Fibrolite and rare laths of sillimanite are present in a few samples. This formation appears to be structurally above the Bonney Formation in the Bonney Bowl area but the relationship with adjacent Charpentier gneiss to the nort-west is unknown. The formation has strong lithological similarities with the Nostoc Lake Formation in the Haskard Highlands (Marsh, 1983*a*) but the less pelitic, amphibole- and pyroxene-bearing, schists appear less abundant and (possibly for that reason) evidence of partial melting is less conspicuous.

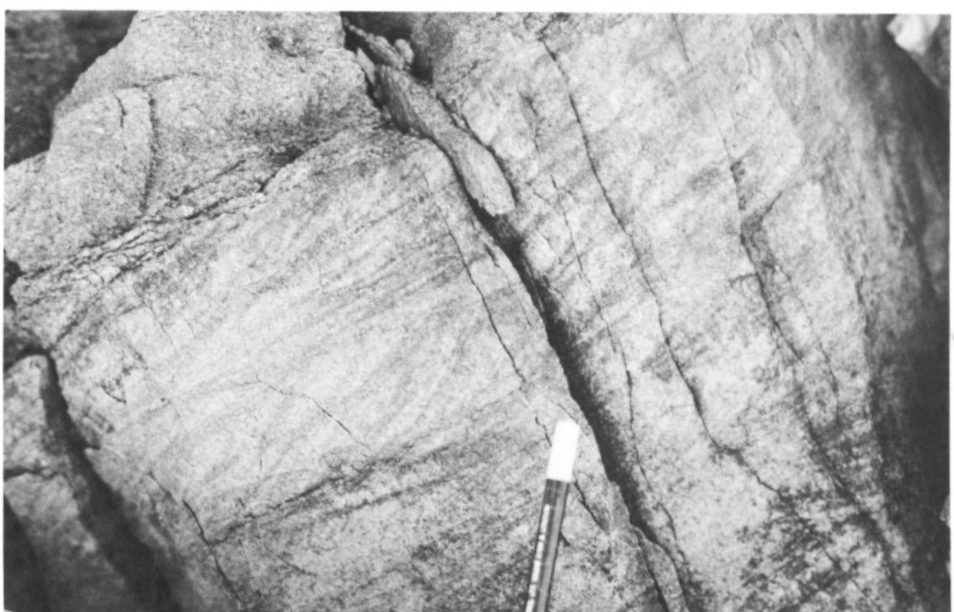
Haskard Group

Butterfly Formation. On Butterfly Knoll in the Lagrange Nunataks a well-exposed metasedimentary sequence overlies granitic gneiss (Fig. 8a). Calcareous schist (12 m total thickness), with varying proportions of white mica and biotite, and locally with tremolite, is overlain by calcareous biotite schists (2–3 m) and cream calcareous metasandstone with right-way-up cross-bedding (1 m) (Fig. 8b). This is succeeded by several tens of metres of muscovite-bearing quartzite, calcareous in its lower part, followed by white saccharoidal metalimestone with radiating clusters of tremolite crystals. On the nunatak to the south-east, gneiss is overlain by quartzite (*c.* 15 m), succeeded by white metalimestone (locally with centimetre-scale quartzite layers), which passes into grey metalimestone with subordinate cream-coloured layers. On the nunatak 1 km to the south-east the same sequence of quartzite-white metalimestone-grey metalimestone is exposed. Tremolite is conspicuous in most outcrops. Metalimestones, calcareous schists and kyanite-bearing mica-schists forming the southern nunatak of Lewis Chain are referred to this formation. Petrographic descriptions of several samples from this area are given by Clarkson (1982*b*).

Other metalimestone- and/or quartzite-dominated exposures in the Lagrange Nunataks may be referred to the Butterfly Formation with varying degrees of certainty. Quartzites and metalimestone structurally overlain by gneiss on the eastern ridge of 'Mount E' are identical in lithology to the upper part of the sequence on Butterly Knoll; the same unit possibly forms the north ridge of 'Mount E', which is composed almost entirely of quartzite, but structural evidence is inconclusive. The 20-m-thick sequence on the south ridge of Mount Skidmore referred to above includes no lithologies specific to either the Butterfly Formation or the Schimper Group but the metamorphic fabric resembles that of the Butterfly Formation.

Hollingworth metasediments. The southern outcrops of the Herbert Mountains are composed of metalimestone, calcareous mica schist, mica schist (often with kyanite), quartzite and amphibolite. A petrographic description of a diopside chrysotile marble forming Hollingworth Cliffs has been given by Clarkson (1982*b*). These rocks have none of the characteristic features of the Schimper Group and are broadly similar in lithology to the Butterfly Formation, but possibly of slightly higher metamorphic grade. Little is known of the relationships in this area but they probably overlie the gneiss of Geikie Nunatak. Metasediments structurally overlain by gneiss on Sumgin Buttress are similar in lithology.

(a)



(b)

Fig. 8. The Butterfly Formation at Butterfly Knoll: a. gently dipping metasediments overlying sheared gneiss. b. cross-bedding in calcareous arenite.

Metasediments of uncertain affinities. A small area of muscovite schist and cross-bedded quartzite, 8 km south-east of Lister Heights, and phyllitic schists at a nearby locality (Fig. 4) may represent supracrustal rocks younger than the migmatites of the Fuchs Dome gneiss. The quartzite is probably structurally above the gneiss of adjacent exposures but the contact is unexposed. The contact of the phyllite with gneiss is poorly exposed, parallel to the foliation, and probably tectonic. There is little evidence on which to base correlations of these metasediments but their lithology and geographic positions suggest that they could be part of the Turnpike Bluff Group.

Structure

Variations in the orientation of the locally dominant S-surfaces and minor structures are shown in Figs. 9–11. Structures in the Fuchs gneiss (Fig. 10) the Lagrange Nunatak (Fig. 9) and the Herbert Mountains (Fig. 11) are described separately.

Fuchs gneiss

The foliation shown in Fig. 10 is the relatively late mylonitic fabric associated with amphibolite grade retrogression. Where this fabric is not present the gneisses rarely show a well-defined planar fabric or laterally continuous compositional layering. No major folds older than or associated with the foliation forming event were recognized. However, minor isoclinal folds within the foliation have axes parallel to a north-east plunging extension lineation, which is part of the mylonitic fabric. The foliation dips generally to the north-east but is deformed by open folds about north-east plunging axes with wavelengths of *c*. 3 km; no minor folds or crenulations with the same orientation were observed. Some of the dispersion of poles to the foliation is due to major and minor open folds and kinks with axes plunging gently to near north or south, which typically crenulate the schistosity. The axial surfaces of these folds commonly dip at moderate angles to the east or west but they have no consistent orientation throughout the area and probably represent more than one set of post-foliation structures.

Lagrange Nunataks

The foliation shown in Fig. 9 is the dominant planar mineral fabric which, with few exceptions, is parallel to the compositional layering. Except on Mount Etchells (planes dipping steeply to the south-east in stereogram 2) most observed fold axes and lineations plunge gently to near east or west.

The variation in foliation attitude appears to be due mainly to close folds, with gently plunging hinges and axial surfaces dipping at about 45° to the south. Poorly developed minima in the pole densities coincide with the axial surfaces of minor folds of this orientation and a pair of major folds, of wavelength about 3 km, are seen on the eastern side of the nunatak at 80° 19′ S, 28° 21′ W. Despite the presence of well-defined lithological boundaries it is difficult to interpolate between nunataks as they are smaller and more widely separated than the main structures. However, the folds seem to have comparatively short steep limbs and longer limbs with the dominant northerly dip. A new amphibolite facies planar fabric and an intersection lineation are often present at the hinges of minor folds of this generation. However, the folds deform the dominant schistose fabric in the metasediments, the attenuated compositional layering in the gneisses, a locally strong east or west plunging lineation, and at least one set of major isoclinal folds. The only large areas

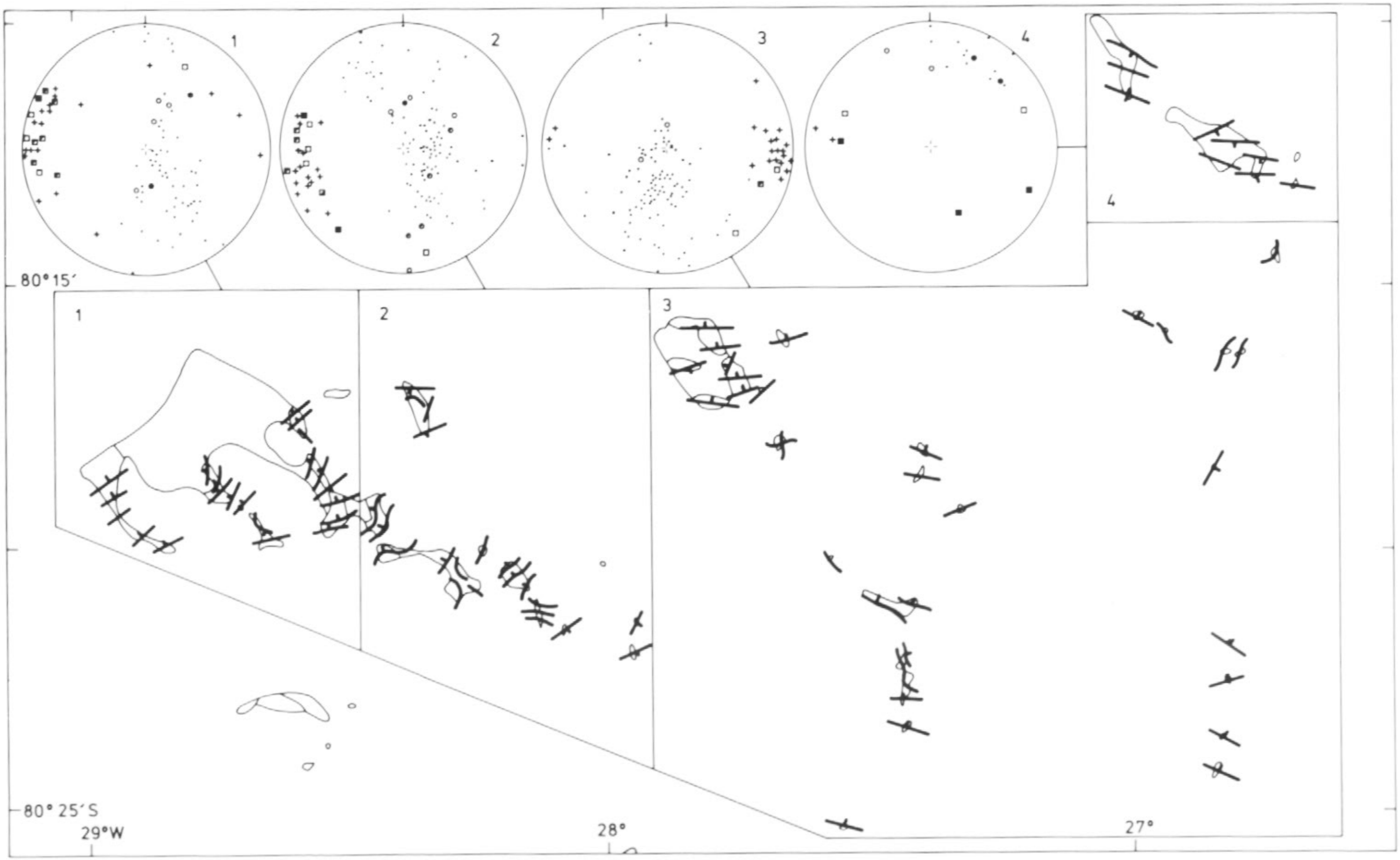


Fig. 9. Orientation of the foliation (locally youngest S-surface) and minor structures in the Lagrange Nunataks. See Fig. 10 for key.

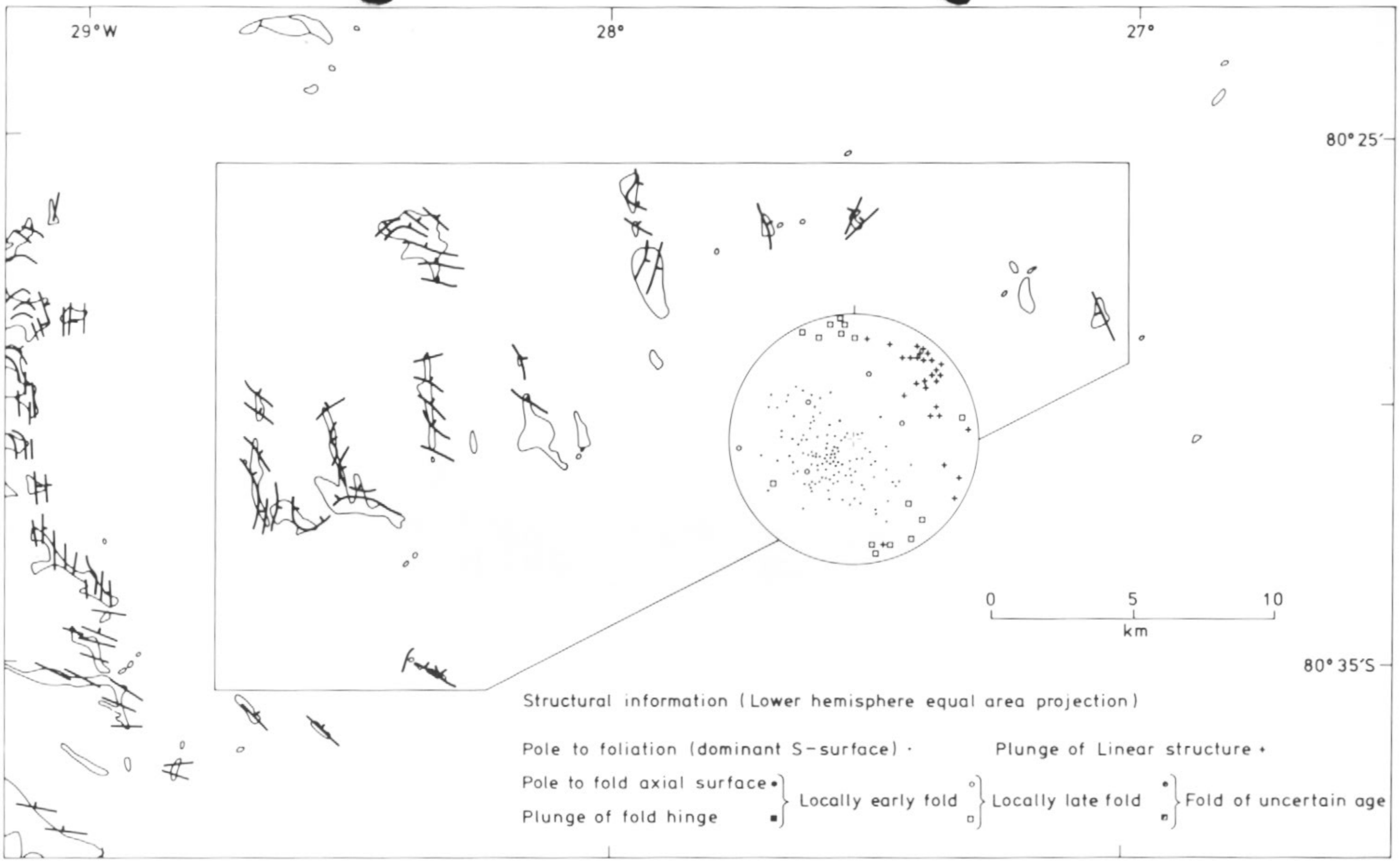


Fig. 10. Orientation of the foliation (locally youngest S-surface) and minor structures in the Fuchs Dome area. Strike data west of the Stratton Glacier are from Marsh (1983*a*).

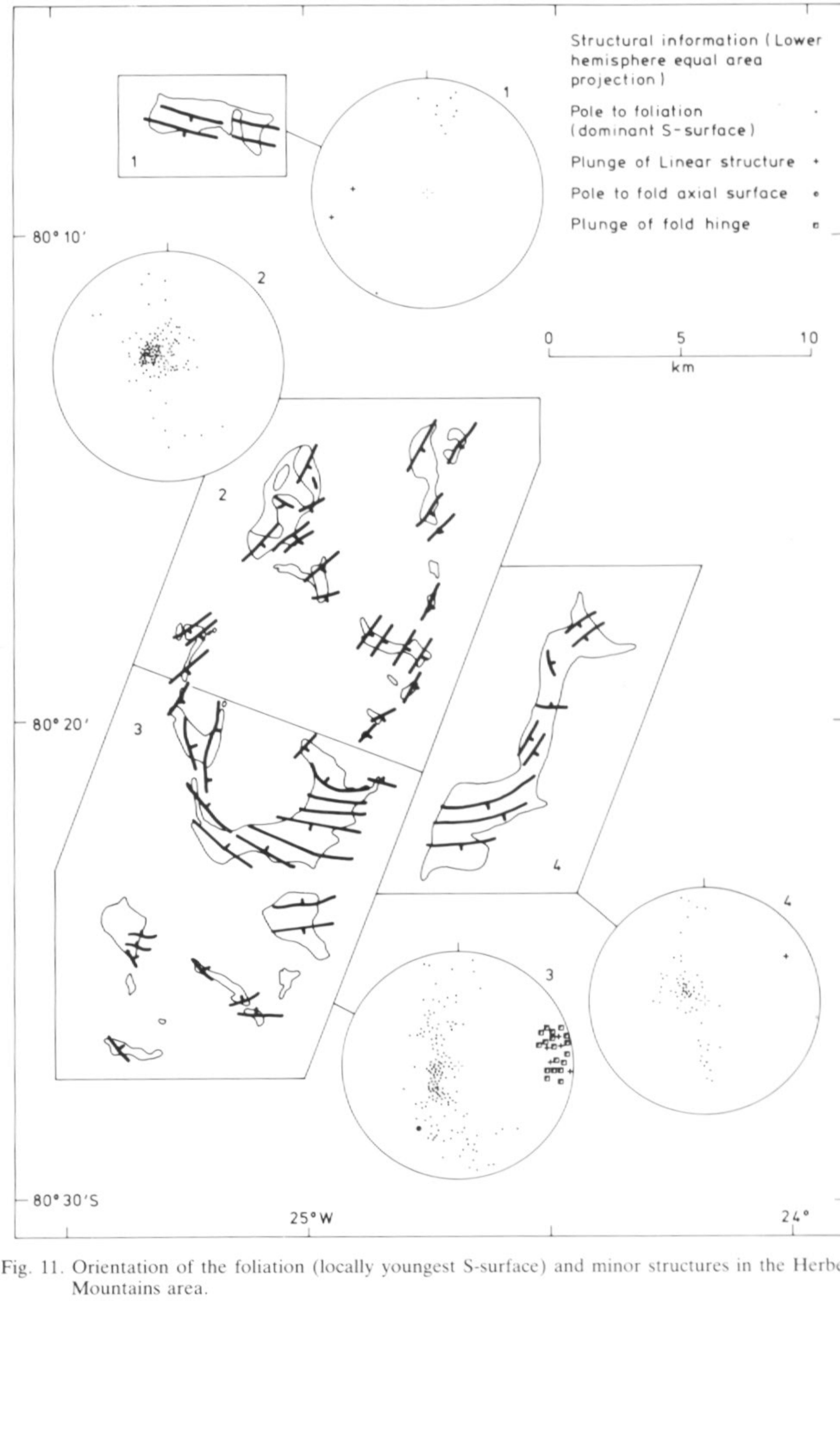


Fig. 11. Orientation of the foliation (locally youngest S-surface) and minor structures in the Herbert Mountains area.

of exposure with consistently steep dips are at Wiggans Hills and True Hills. This could indicate a different pattern of deformation associated with the blastomylonitic rocks but the orientation is consistent with the steep limbs of the major folds.

More conspicuous at outcrop than the above structures are older isoclinal folds about subhorizontal axes with axial surfaces parallel to the foliation. These deform the layering and the contacts between stratigraphic units but were not seen to deform highly attenuated layering. Mineral lineations, where present, are parallel to the axes of these folds. The isoclinal form of these early folds probably results from the deformation which produced the attenuated layering and the dominant mineral fabric. Thrusts hinted at by the stratigraphy may also be of this age.

The Butterfly Formation strata on Butterfly Knoll have been regarded above as the base of the sequence. However the rocks on both sides of the boundary are strained. The underlying porphyroblastic gneiss becomes progressively flattened as the contact is approached but cross-cutting aplitic veins, though deformed, retain their integrity. The fabric of the lower few metres of the overlying calcareous schist is probably entirely tectonic but the intensity of deformation decreases rapidly upwards. It is possible that there has been displacement at this contact. However, the metasediments must have originally had an unconformable contact with older rocks and there is no indication of any truncation or omission of strata. The contact is thus interpreted as an unconformity that became a locus of higher strain. The strained rocks have a lower amphibolite facies mineralogy, which, in the Butterfly Formation, includes undeformed coarse tremolite laths typical of the unit. There is no indication of the nature of any earlier metamorphic fabric in the metasediments. Later narrow (30 mm) shears with greenschist facies mineral assemblages cut the deformed gneiss.

On the hillside to the west of Butterfly Knoll, metasediments of the same lithology are overlain by gneiss, which is itself overlain unconformably by a Schimper Group sequence. The gneiss is highly attenuated at the lower contact, which truncates bedding passing round isoclinal folds in the metasediments. The dip of the axial surfaces of the folds differs only by a few degree from that of the contact and the foliation in the gneiss. Deformed rocks at the contact have amphibolite facies mineral fabrics.

Herbert mountains

The structural investigation of this area reported here was mainly of a reconnaissance nature but confirms the impression gained from lithological mapping and air photography that the area is dominated by a single major fold of the foliation. The northern outcrops west of the Schimper Glacier (Fig. 11 area 2) lie on the structurally lower limb of the fold whilst those to the south (area 3) form the hinge zone. The Bernhardi Heights (area 4) probably lie mainly on the upper limb and there a major early isocline may be present. The main fold plunges gently towards the east and, so far as can be ascertained from the partial exposure and mapping, is tight in form with the axial surface dipping a little east of south at about 45°. The wavelength is large, possibly greater than 10 km. The schistosity and blastomylonitic fabrics are folded around Bonney Bowl but strong planar fabrics and eastward plunging lineation in the south may be related to the fold. The most significant structural interpretation made in this area is that an upward sequence metalimestone – gneiss – Bonney Formation, seen in Sumgin Buttress, follows the strike round the major fold and reappears in a northward traverse from Hollingworth Cliffs to Venetz Peak. Gneiss was not encountered in this area but the basal quartzite of the Bonney Formation is present. Relationships on Ramsay Wedge are uncertain but if no large faults are present the Hollingworth metasediments would overlie the gneisses of Geikie Nunatak. The orientation of the foliation in the blastomylonites of Mount Sheffield is the same as in those at Wiggans and True Hills and its interpretation is equally ambiguous.

Structural History

The fragmentary evidence gives a broad but clear picture of the structural history. Supracrustal rocks (Schimper Group) deposited on older gneisses (Mathys gneiss, Charpentier gneiss) were metamorphosed to middle or upper amphibolite facies ('M1'), folded about E–W trending axes (early isoclinal folds) and attenuated ('D1'), and the now dominant mineral fabrics established by further amphibolite grade metamorphism ('M2'). Deformation of this fabric to give major folds with southward dipping axial surfaces and E–W trending axes ('D2') was also accompanied or followed by amphibolite grade metamorphism ('M3'). It is probable that D1 represents several phases of deformaion, which may have commenced before M1. No textural evidence was found to indicate whether M1, M2, and M3 represent continued metamorphism or separate thermal events.

The Butterfly Formation and the Hollingworth metasediments were interleaved with the other units during D1 but the fabrics in the Butterfly Formation suggest that they did not suffer an earlier metamorphism at amphibolite grade. There is no direct evidence for correlation of the main fabrics in the Wiggans blastomylonites or the Fuchs gneiss with this sequence. The simplest correlation is with the dominant D1–M2 fabrics elsewhere. The orientation of the fabric in the Wiggans blastomylonites is consistent with a pre-D2 age, and the north-eastward plunging folds in the Fuchs gneiss may also be D1 in age. However, in both areas the fabrics are morphologically distinct from those in the intervening ground, suggesting different structural environments and it is possible that the fabrics are a manifestation of D2. The variation in plunge of the east–west trending structures in the north (Fig. 9 stereograms 1–3) may be due to the deformation that produced the north–south trending folds in the Fuchs gneiss.

The D2 folds are in general not associated with strong penetrative fabrics and it is probable that the overall east–west trend of the nearly coaxial D1 linear structures is close to the original trend. The overall dip of the planar fabrics and stratigraphic units folded by D2 is towards the north, suggesting that before D2 the foliation had an east–west strike and northerly dip. In the Herbert Mountains, near Butterfly Knoll and possibly on Mount Skidmore, gneiss, which is overlain by basal Schimper Group rocks, structurally overlie rocks of the Haskard Group. Haskard Group rocks have not been identified at higher structural levels in the Herbert Mountains nor within areas of interfolded gneiss and Schimper Group rocks in the Lagrange Nunataks. The main outcrops of the group are along the south of the area with metasediments, where the lowest structural levels relative to D1 would be expected and underlying gneiss is not seen in contact with other units. These observations lead to the suggestion that a lower tectonic unit, composed of gneiss overlain by Haskard Group rocks, is separated by a major D1 thrust from higher units composed of gneiss and Schimper Group rocks. This higher unit has been termed the Lagrange Nappe (Marsh, 1983*b*).

Stratigraphic and Structural Correlations within the Range

The 'older gneisses' throughout the range are correlated with each other and the Read Complex of the Read Mountains (Fig. 2) on the basis of geochronological studies (Pankhurst and others, 1983), relationships to younger metasediments and local lithological similarities. Gneisses in the Haskard Highlands included in this category by Clarkson (1982*a*,*b*) have been shown by later work to be younger high grade metasediments (Grew and Halpern, 1979). Though unlikely it is possible that other small areas of younger high grade rocks have been erroneously included here. If, for example, the Haskard Group does post-date the first metamorphism of the Schimper Group then the gneisses underlying the Butterfly Formation could be younger than the Read Complex.

The characteristic lithologies of the Schimper Group crop out throughout the northern part of the range and basal sequences in the Haskard Highlands, western Lagrange Nunataks and Herbert Mountains are identical. However, there is some uncertainty as to the internal stratigraphy of the group. Where the upper parts of the distinctive basal sequence are exposed they pass upwards into garnetiferous schists and gneisses. In several places similar garnetiferous rocks have quartzites, metalimestones and schists, but not amphibolites and fuchsite-bearing quartzite, at contacts with gneiss. It is thus uncertain whether a single sedimentary sequence with a variable basal facies or two similar (possibly overlapping) sequences are present.

The units forming the Haskard Group are correlated mainly on the basis of lithology. Evidence supporting that they are part of the same stratigraphic and structural unit, distinct from the Schimper Group, is provided by their similar structural positions relative to gneisses overlain by Schimper Group rocks and by the comparatively simple, prograde, fabrics in the better-known areas.

The structural history compares favourably with that found farther west (Marsh, 1983*a*). In the Schimper Group rocks of the Haskard Highlands, early coarse-grained amphibolite facies fabrics are replaced by blastomylonitic fabrics parallel to the formation boundaries and to the axial surfaces of isoclinal folds. The associated deformation can be equated with D1 of the Lagrange Nanataks and the metamorphic events forming the two fabrics to M1 and M2. Major neutral folds of the blastomylonitic fabric in the northern Haskard Highlands (Mount Gass generation folds), which locally have amphibolite facies fabrics at their hinges, can probably be correlated with D2 and the associated metamorphism with M3. The different attitude of these folds to the D2 structures of the Lagrange Nunataks can be ascribed to the effects of the later, post-metamorphic, north–south-trending Mount Weston generation folds. The latter are probably equivalent to the north–south trending folds in the Fuchs gneiss but folds of this generation appear to be well developed only in the central Haskard Highlands.

Table I. Correlations between named units in the metamorphic complex.

	Haskard Highlands	*Fuchs Dome*	*Lagrange Nunataks*	*Herbert Mountains*
Haskard Group	Williams Ridge Formation		Butterfly Formation	Hollingworth metasediments
Schimper Group	Nostoc Lake Formation		Units not differentiated	Maclaren Formation
	Mount Gass Formation			Bonney Formation
Read Complex	Mount Weston gneiss Wedge Ridge gneiss	Fuchs gneiss	Mathys gneiss ?Wiggans blastomylonites	Charpentier gneiss
	? Stratton gneiss			

Table II. Geological history of the Shackleton Range.

Sequence of events (Marsh, 1983b)	*Rb-Sr chronology (Pankhurst and others, 1983)*
Diagenesis of Blaiklock Glacier Group	475 ± 40 Ma
Deposition of Blaiklock Glacier Group	
? north–south trending folds	
Close of metamorphism	500 ± 5 Ma
East–west trending deformation and metamorphism (M2) of Haskard Group	505 ± 18 Ma
Diagenesis (or M2 metamorphism) of Turnpike Bluff Group	526 ± 6 Ma
? Deposition of Turnpike Bluff and Haskard Groups	
Dating event in Schimper Group – ?high-grade M1 metamorphism	580 ± 10 Ma
? Deposition of Turnpike Bluff and Haskard Groups	<c.720 Ma
Deposition of Watts Needle Formation (late Precambrian)	
Source of immature sediment in Schimper Group	<*c*.850 Ma
Deposition of basal Schimper Group	?<*c*.900 Ma
Metamorphic resetting of isotope systems in Read Complex	*c*.1600 Ma
Granitic intrusions in Read Complex	1763 ± 21 Ma
Minimum age of Read Complex	2300 ± 130 Ma
? Pegmatites	2700 ± 100 Ma
Derivation of Read Complex material from the mantle	2700–2800 Ma

Correlation with structures in the southern part of the range is less specific. As in the Haskard and Otter highlands (Marsh, 1983*a*) the most probable correlation of the cleavage in the Turnpike Bluff Group (Clarkson, 1984) is with the blastomylonitic fabrics in the Read Compex. However, in neither the Fuchs gneiss nor the Wedge Ridge gneiss to its south-west (Marsh, 1983*a*) is it clear whether the blastomylonitic fabrics were produced mainly during late D1 flattening or were associated with the D2-Mount Gass folds.

A model for the overall structure of the range, based on the work of Clarkson (1972, 1982*a*,*b*, 1984), Marsh (1983*a*) and that described here has been proposed by Marsh (1983*b*). The Lagrange Nunataks and Herbert Mountains form part of a zone of outcrop of Haskard Group and Schimper Group metasediments and associated gneisses that extends across the northern part of the range. The Fuchs Dome gneiss is part of a less well-defined zone of outcrops of gneiss and Turnpike Bluff Group rocks in the centre of the range. The two zones are probably separated by a major fault. The range as a whole is interpreted as a complex of northward-dipping nappes brought together in an event or events that produced the retrograde fabrics in the Read Complex and Schimper Group and the prograde fabrics in the Haskard Group and Turnpike Bluff Group. The grade of metamorphism associated with the locally youngest fabrics decreased from middle amphibolite facies in the north to lower greenschist facies in the south. However, inferred or observed high angle faults make it difficult to determine relative levels of exposure or to correlate structural and stratigraphic units between the east–west trending 'zones'.

Discussion

The account given here complements the description of the area to the west given by Marsh (1983*a*). It is found that the stratigraphy recognized in the Haskard Highlands (Fig. 2) is applicable to the northern part of the range as a whole. The structural history in the two areas also seems to be the same but, due mainly to the comparatively poor exposure in the Lagrange Nunataks, little further detail is revealed.

A recent discussion of the geological history of the range has been given by Marsh (1983*b*) and will not be repeated here. The history proposed is summarized in Table II. It is based on the geochronological investigation of Pankhurst and others (1983) and the main uncertainties concern the relationships between the three sedimentary groups and the Vendian dating event. The Rb-Sr systematics suggests a greater maximum age for the Schimper Group, which bears evidence of this early event, than for the Haskard and Turnpike Bluff groups, which do not. The greater chemical maturity of the sediments forming the Haskard and Turnpike Bluff groups is consistent with their containing recycled material from the Schimper Group or its source. However, at the opposite extreme, it is possible that all the metasediments were geographically remote parts of the same sedimentary system and were brought together by tectonic transport.

Despite the uncertainties the main elements of the history and stratigraphy seem clear. Mid Proterozoic and older basement rocks are overlain by late Precambrian and possible Cambrian sediments which underwent a major tectono-thermal event at about the time of the Cambrian–Ordovician boundary, before being overlain by Ordovician post-orogenic sediment.

Acknowledgements

I wish to thank the BAS Air Unit and personnel from Halley, General Belgrano and Druzhnaya stations for logistical support during the 1977-78 field season and G. A. Holden for assistance in the field. My field work followed reconnaissance traverses by P. D. Clarkson, whose notes, collections and advice were invaluable. The loan of colour air photographs by the United States Geological Survey is gratefully acknowledged.

Received 19 October 1983; accepted 7 November 1983

References

Clarkson, P. D. 1972. Geology of the Shackleton Range: a preliminary report. *British Antarctic Survey Bulletin,* No. 31, 1–15.

Clarkson, P. D. 1982*a*. Tectonic significance of the Shackleton Range. (*In* Craddock, C. *ed. Antarctic Geoscience*. University of Wisconsin Press, Madison, 835–9.)

Clarkson, P. D. 1982*b*. Geology of the Shackleton Range: I. The Shackleton Range Metamorphic Complex. *British Antarctic Survey Bulletin,* No. 51, 257–83.

Clarkson, P. D. 1984. Geology of the Shackleton Range: II. The Turnpike Bluff Group. *British Antarctic Survey Bulletin,* No. 52, 109-24.

Clarkson, P. D. *and* Wyeth, R. B. 1984. Geology of the Shackleton Range: III. The Blaiklock Glacier Group. *British Antarctic Survey Bulletin,* No. 52.

Gary, M., McAfee, R. *and* Wolf, C. L. (*eds.*) 1972. *Glossary of geology*. Washington, DC, American Geological Institute, 857 pp.

Golovanov, N. P., Mikhailov, B. M. *and* Stuliatin, O. G. 1980. Pervyye diagnostiruemye stromatolite Antarktidy i ikh biostratigraficheskoe znachenie. [First diagnostic stromatolites from Antarctica and their biostratigraphical significance (in Russian).] *Antarktika, doklady komissii,* No. 19, 152–9.

Grew, E. S. *and* Halpern, M. 1979. Rubidium–strontium dates from the Shackleton Range Metamorphic Complex in the Mount Provender area, Shackleton Range, Antarctica. *Journal of Geology,* **87**, 325–32.

Hofmann, J. *and* Paech, H. J. 1980. Zum strukturgeolischen Bau am Westrand de Ostantarktischen Tafel. [On the geological structure of the western part of the East Antarctic platform.] *Zeitschrift fur geologische Wissenschaften,* **8**, 425–37.

HOFMANN, J., PILOT, J. *and* SCHLICHTING, M. 1981. Das Rb/Sr-Alter von Metamorphiten der Herbert Mountains, Shackleton Range, Antarktica. [The Rb-Sr age of metamorphic rocks of the Herbert Mountains, Shackleton Range, Antarctica.] *Zeitschrift für geologische Wissenschaften*, **9**, 835-42.

KAMENEV, E. N. *and* SEMENOV, V. S. 1980. Regional metamorphism in Antarctica. (*In* CRESSWELL, M. M. *and* VELLA, P. *eds. Gondwana Five.* Rotterdam, A. A. Balkema, 209-15.)

MARSH, P. D. 1983*a*. The stratigraphy and structure of the Haskard Highlands and Otter Highlands of the Shackleton Range. *British Antarctic Survey Bulletin*, No. 60, 23–43.

MARSH, P. D. 1983*b*. The late Precambrian and early Palaeozoic history of the Shackleton Range, Coats Land. (*In* OLIVER, R. L., JAMES, P. R. *and* JAGO, J. B. *eds. Antaractic earth science.* Canberra, Australian Academy of Sciences and Cambridge University Press, 190–3.)

PANKHURST, R. J., MARSH, P. D. *and* Clarkson, P. D. 1983. A geochronological investigation of the Shackleton Range. (*In* OLIVER, R. L., JAMES, P. R. *and* JAGO, J. B. *eds. Antarctic earth science.* Canberra, Australian Academy of Sciences and Cambridge University Press, 176–82.)