GEOLOGY OF THE SHACKLETON RANGE: II. THE TURNPIKE BLUFF GROUP

By PETER D. CLARKSON

ABSTRACT. The Turnpike Bluff Group comprises four formations exposed along the south side of the Shackleton Range. In the east, quartzites and metalimestones rest unconformably on the metamorphic basement and are overlain by tightly folded and cleaved siltstones with minor conglomerates. The group youngs westward and becomes increasingly argillaceous apart from a thick sequence of quartzites. An east–west fold trend, usually plunging gently westward, is consistent throughout the group forming large open folds in quartzite and tight, isoclinal and chevron folds in slates. The age of the group is unknown but it is presumed to be late Precambrian. Regional correlation with similar rocks in the Transantarctic Mountains is discussed.

THE Shackleton Range (lat. 80° 07′–80° 50′ S, long. 31°–19° W) lies east of the Filchner Ice Shelf at the head of the Weddell Sea. The greater part of the range is formed of basement rocks of the Shackleton Range Metamorphic Complex (Clarkson, 1982) unconformably overlain by the Turnpike Bluff Group in the south and by the Cambro-Ordovician Blaiklock Glacier Group in the north-west (Clarkson and Wyeth, 1983).

The Turnpike Bluff Group was first described by Stephenson (1966) as the "Turnpike Metamorphics". He visited exposures at Turnpike Bluff and examined specimens collected from Mount Greenfield and Stephenson Bastion. Since then the group has been mapped farther east (Fig. 1), has been re-named and subdivided into four formations (Clarkson, 1972). This subdivision of the group (Table I) is based on the geographical separation of the four main areas

TABLE I. STRATIGRAPHY OF THE TURNPIKE BLUFF GROUP IN THE SOUTHERN SHACKLETON RANGE

Age	*Group*	*Formation*	*Lithologies*	*Thickness* (m)
Late Precambrian	**Turnpike Bluff Group**	Wyeth Heights Formation	Slates and quartzites	(?)
		Stephenson Bastion Formation	A thick sequence of quartzite overlying slates and a pebble-conglomerate	(?) > 2 000
		Flett Crags Formation	Mainly slates, with minor quartzites and some pebble-conglomerates	(?) > 1 500
		Mount Wegener Formation	Slate, quartzite and minor conglomerate overlying a basal sequence of quartzite and metalimestone resting unconformably on the metamorphic basement	(?) > 2 500
Middle Precambrian	**Shackleton Range Metamorphic Complex**		Gneisses, schists and amphibolites	

of outcrop and on the different amounts of the main lithologies in each area. The rocks comprising the group are essentially sandstones and siltstones with some conglomeratic horizons and some thin limestones near the base of the group, which have been tightly folded and cleaved and regionally metamorphosed to a low grade.

Fig. 2. Horizontal quartzites of the Mount Wegener Formation resting unconformably on gneisses of the Shackleton Range Metamorphic Complex at Nicol Crags, Read Mountains. The actual contact is hidden beneath the scree.

Field Relations

Mount Wegener Formation

The Mount Wegener Formation rests unconformably on gneisses of the Shackleton Range Metamorphic Complex at Nicol Crags and at the north-western corner of Mount Wegener. At Nicol Crags, 12 m of horizontally bedded quartzite with some thin purple shales rest unconformably on gneisses (Fig. 2), whereas at Mount Wegener a similar sequence dips at 45° to the south. At the latter locality, the top of the quartzite can be traced eastward to the shoulder of the mountain where there is continuous exposure upward through about 60 m of metasedimentary rocks to folded and cleaved siltstones. The 60 m of metasedimentary rocks comprise thinly bedded and fissile sandstones and quartzites and some pale grey limestones which may be up to 4 m thick. The folded and cleaved siltstones, with horizons of quartzite and conglomerate, form most of this formation. The quartzites and conglomerates are more competent than the siltstones and form large folds, whereas the siltstones are closely folded and have frequently developed a slaty cleavage. The rocks exposed on the ridges farther east are essentially similar to those on Mount Wegener, although conglomeratic horizons are commoner. Correlation between the ridges to the east and Mount Wegener is not possible due to the lack of marker horizons, except that the obvious basal metasedimentary sequence is not seen east of Mount Wegener.

The top of the formation is not known but, from a consideration of the structure and the exposed thicknesses, the total thickness of the Mount Wegener Formation is tentatively estimated at more than 2 500 m.

Flett Crags Formation

The Flett Crags Formation is exposed in the short north–south ridges on the north side of the

Fig. 3. Steeply dipping pebble-conglomerate and argillaceous strata with a strong bedding cleavage in the Flett Crags Formation.

Read Mountains escarpment. The rocks are largely slates with some pebble-conglomerates and quartzites. The lowest exposed strata of the formation are in Flett Crags, where they are separated from red granitic gneisses to the south by a snow col, beneath which there is presumably a fault relatively down-thrown to the north. The bedding in the more competent pebble-conglomerates dips steeply north and, although slaty cleavage is frequently developed, many horizons are dominated by a strong bedding cleavage (Fig. 3). An outlier of slate at Spath Crest cannot be reliably assigned to a particular formation but, by its geographical position, it is considered to belong to the Flett Crags Formation.

As neither the top nor the bottom of this formation is exposed, and as no way-up criteria were observed, the estimated thickness of > 1 500 m is dependent on the extent of the outcrops and the regional dip. The distribution of slate, quartzite and conglomerate in this formation is apparently similar to that in the upper parts of the Mount Wegener Formation so that it may be a lateral equivalent which has been folded and faulted across the escarpment of the Read Mountains.

Stephenson Bastion Formation

This formation forms Stephenson Bastion between Clayton Ramparts and the northern edge of Recovery Glacier. The lowest exposed bed, forming Clayton Ramparts, is a pebble-conglomerate, which is overturned and dips steeply northward, gradually passing downward and southward through the vertical to dip steeply southward. Stratigraphically above this conglomerate (to the south) is a white quartzite, an unknown thickness of cleaved siltstones and slates, and the thick (about 600 m) sequence of sub-horizontal quartzites with some slaty horizons between Ram Bow Bluff and Mount Greenfield (Fig. 4). The conglomerate at the base of this succession may be compared with the conglomerates of the Flett Crags and Mount

Fig. 4. Massive quartzites of the Stephenson Bastion Formation (Z.679 and 680) north-west of Ram Bow Bluff.

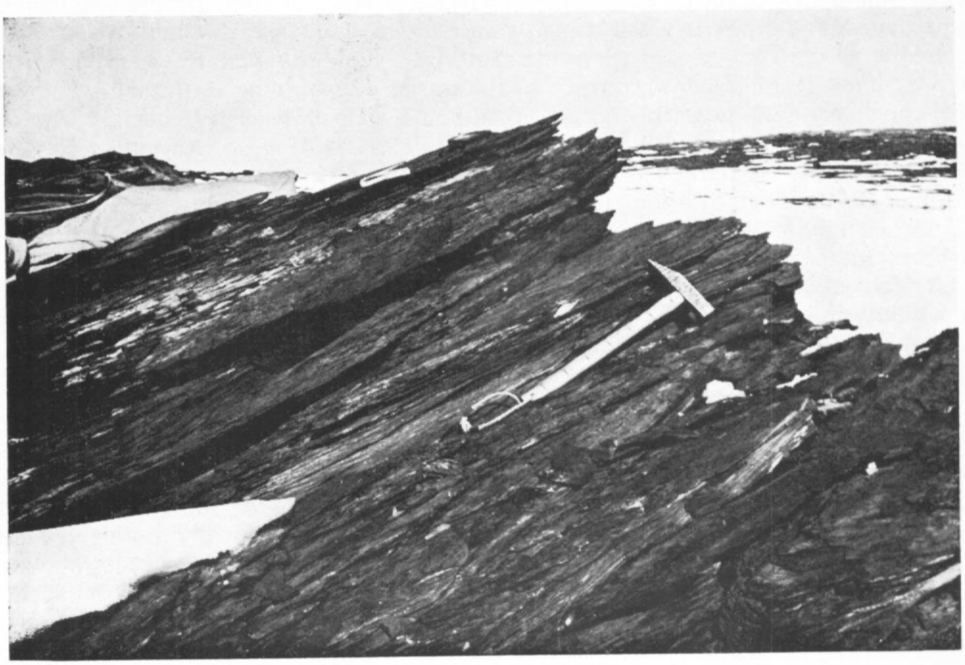


Fig. 5. Closely cleaved slates of the Wyeth Heights Formation.

Wegener Formations but the thick sequence of quartzite has not been found elsewhere so that the succession is recognized as a distinct younger formation. However, it is possible that this conglomerate could be equivalent to the highest part of the Flett Crags Formation by an overturned asymmetric syncline, or that the Flett Crags Formation is totally inverted and is part of the upturned limb in Clayton Ramparts, although this seems unlikely.

The base of this formation is presumed to be a fault against the Shackleton Range Metamorphic Complex to the north of Clayton Ramparts and the top of the formation is truncated by the pre-glacial peneplain. Thus, the thickness of the formation (>2 000 m) is estimated from the dip and the extent of the outcrop, although the thickness of the slaty strata may be exaggerated if there is east–west faulting, with a downthrow to the north, between Clayton Ramparts and Mount Greenfield.

Wyeth Heights Formation

The Wyeth Heights Formation is exposed between Turnpike Bluff and Wyeth Heights. It comprises slate (Fig. 5) and quartzite in approximately equal amounts with some gradational interbedding as quartzose sandstones. The absence of conglomeratic horizons and of a great thickness of quartzite distinguish this formation from all others in the group so that it is presumed to be the youngest.

Neither the top nor the bottom of the formation is exposed but the upper (northern) boundary is presumably an east–west fault against the Shackleton Range Metamorphic Complex and the lower (southern) boundary presumably lies beneath Recovery Glacier. The thickness of this formation is unknown.

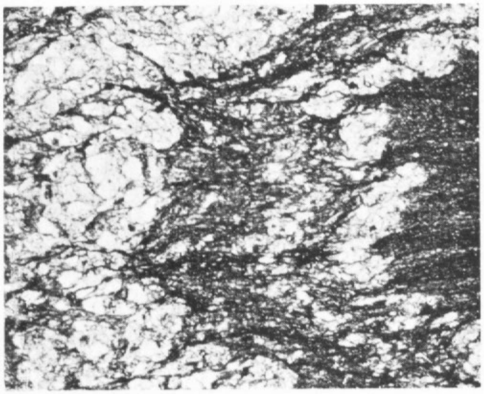
PETROGRAPHY

The rocks of the Turnpike Bluff Group are described under four main headings: slates, quartzites, conglomeratic rocks and metalimestones. Although certain rocks are distinctive and confined to certain formations, there is generally little petrographical difference between the rocks of the four formations.

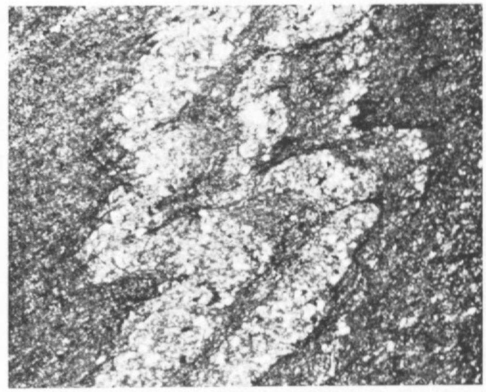
Slates

In the hand specimen the slates are fine-grained, cleaved sedimentary rocks; although typically grey in colour, purple and green varieties do occur, particularly in the Stephenson Bastion Formation where they are interbedded with massive quartzites. The best examples of slates are in the Wyeth Heights Formation where they are thinly fissile and often deeply weathered.

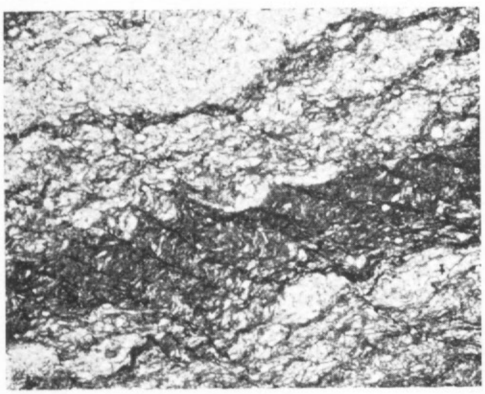
In thin section most slates are seen to be banded, layers of dark, fine-grained argillaceous siltstones (grain-size about 0.01 mm) alternating with pale medium-grained quartz-siltstones (grain-size about 0.05 mm). Small folds and undulating bedding are well displayed by these alternations and the cleavage is shown by sericite and chlorite flakes lying parallel to the axial planes of the folds and undulations (Fig. 6a). Although the boundaries between these alternations are clearly defined, they are frequently stepped by slip along the cleavage planes and the finer-grained bands often flame into the coarser bands (Fig. 6b). In some specimens the bedding has been extensively fractured during folding and the fine-grained siltstone bands are traceable as a series of isolated fragments separated by veinlets of the coarser bands. Kink bands in the argillaceous siltstone layers are usually related to undulating bedding where the cleavage is parallel to the axial planes of the undulating bedding but in certain cases the cleavage is more pronounced and lies at a shallow angle to the bedding, probably induced by internal gliding of thin layers along the sides of a fold during its formation (Fig. 6c). In extreme cases this secondary cleavage has developed almost perpendicular to the main axial-plane cleavage but only to a limited extent (Fig. 6d). This transverse cleavage has been observed



a



b



c

d

Fig. 6. a. Sericite and chlorite flakes parallel to the axial plane of folding in a slate (Z.790.1; ordinary light; ×25).
b. Stepped competent beds and flamed incompetent beds in a slate (Z.782.1; ordinary light; ×25).
c. Secondary cleavage oblique to the bedding around a fold in slate (Z.765.1; ordinary light; ×25).
d. Minor secondary cleavage developed perpendicular to the main axial-plane cleavage in slate (Z.614.2; ordinary light; ×25).

in only two specimens (Z.614.2 and 676.1), both of which are from the outermost (stratigraphically lowest) slate strata around the overfolded syncline at the foot of Clayton Ramparts.

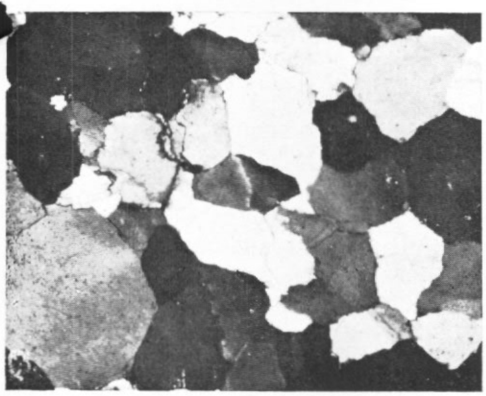
The argillaceous siltstone layers are composed of minute (up to 0.01 mm in diameter) quartz grains cemented by sericite and chlorite. The coarser siltstone layers comprise subangular quartz grains and minor plagioclase grains in a quartz, muscovite, sericite and biotite matrix which is coarser than the argillaceous layers. The coarser layers also contain rare accessory minerals which include epidote, sphene, zircon, ilmenite and haematite. In the thin section of specimen Z.790.1 from near Wyeth Heights, haematite staining is common, particularly along the cleavage planes.

The quartzose sandstones described earlier as being gradational between the quartzites and slates are included here as they are generally much less coarse than the quartzites and are considerably more argillaceous. Grains of quartz and fragments of quartzite (up to 1.5 mm in diameter or length) are all highly strained with sutured margins. Feldspar grains, mostly plagioclase but some perthite, are all heavily sericitized and of a similar size to the quartz grains. Biotite, chlorite, muscovite, sericite and calcite cement this rock and, with fine-grained quartz, constitute the matrix. The accessory minerals include zircon, epidote, sphene, ilmenite and haematite. The bedding of these rocks is well marked by the parallelism of the micas but there is no obvious cleavage development except parallel to the bedding.

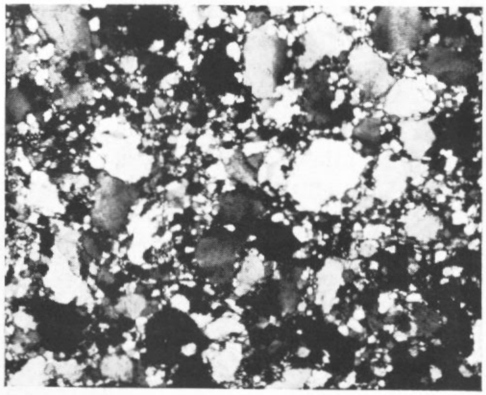
Quartzites

Apart from their colour, the quartzites are often similar in the hand specimen but three types have been recognized in thin section: two pure pale-coloured quartzites, one with a granoblastic texture and one with a mortar texture, and a third impure quartzite.

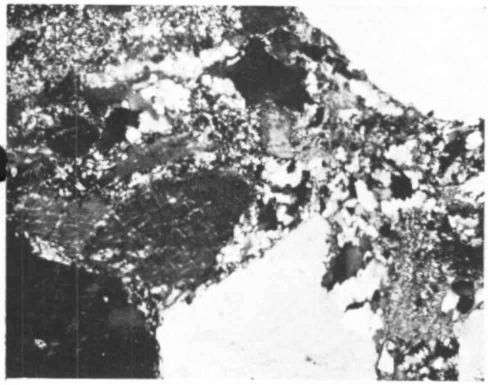
Specimen Z.887.8 from the north-western corner of Mount Wegener comprises over 99% quartz in a granoblastic texture (Fig. 7a). Individual crystals (about 0.3 mm in diameter) are strained, have sutured or smooth margins and none shows secondary crystal enlargement indicating that the rock has been completely recrystallized. Accessory minerals are rare but they include interstitial calcite and some small plates of muscovite. Specimen Z.883.1, from approximately the same horizon but on Nicol Crags, is almost identical but slightly less pure



a



b



c

d

Fig. 7. a. Granoblastic texture in quartzite (Z.887.8; X-nicols; ×25).
b. Mortar texture in quartzite (Z.766.2; X-nicols; ×25).
c. Detrital microcline, perthite, quartz and quartzite grains in a pebble-conglomerate (Z.670.1; X-nicols; ×25).
d. Fragments of limestone and quartzite in a pebble-conglomerate with a calcareous matrix (Z.901.1; X-nicols; ×25).

and contains interstitial sericite. The bedding, which is obvious in outcrop where false-bedding structures are also visible, is not marked in either thin section.

Specimen Z.766.2, from an outcrop on the eastern side of Turnpike Bluff, has a mortar texture of clastic quartz grains set in a granoblastic quartz matrix (Fig. 7b). The clastic grains (about 0.3 mm in diameter) are all strained and have sutured margins but show no secondary enlargement. The granoblastic matrix (grain-size about 0.03 mm) is less strained and contains interstitial haematite and haematite-stained sericite. Again, the bedding is not visible in thin section.

The impure quartzites contain a proportion of clastic feldspar and have an increased sericite content. In the thin section of specimen Z.680.3, from the buttress about 6 km west-north-west of Ram Bow Bluff, the clastic grains are about 0.3 mm in diameter; the quartz is strained and has sutured margins, whereas the feldspar has smooth margins. Feldspar grains include twinned plagioclase, perthites and some microcline. The matrix is very fine-grained quartz and probably feldspar with much sericite; some of the matrix could be grains of completely sericitized feldspar. The accessory minerals include muscovite, epidote and small aggregates of minute haematite crystals, and the thin section of specimen Z.760.2 from the Wyeth Heights Formation also contains some hornblende.

Conglomeratic rocks

Coarse sandstones, pebble-conglomerates and rare cobble-conglomerates are found to some extent in all the formations except the Wyeth Heights Formation. The coarsest conglomerate observed, at station Z.900 on the ridge on the eastern side of Lapworth Cirque, contains cobbles of quartzite, sandstone, limestone, gneiss and slaty material up to 20 cm in length.

In thin section these rocks generally comprise angular quartz grains and quartzite fragments in a sericite matrix. All quartz crystals are strained and many are shattered but some are relatively little strained possibly due to lower strain in a more ductile sericite matrix. Quartzite fragments are all badly strained, particularly those with a mosaic form. The thin section of specimen Z.670.1 from the eastern end of Clayton Ramparts (Fig. 7c) contains many feldspar clasts in addition to those of quartz and quartzite. The feldspar is largely perthitic, some microcline-perthite, and it is all remarkably fresh. The matrix is finely crystalline sericite with small quartz grains and fragments of fine-grained quartz mosaic. The accessory minerals include zircon, muscovite, ilmenite, leucoxene and haematite. Ilmenite occurs as trains of small crystals marking the bedding and is often associated with leucoxene. Haematite occurs as an interstitial stain and also as discrete crystals, one of which has a square cross-section with an ilmenite core.

In specimen Z.901.1 (Fig. 7d), from the southern end of the ridge on the eastern side of Lapworth Cirque, pebbles of quartzite, limestone or marble and fine-grained quartz-schist are set in a matrix of calcite, sericite and pale green chlorite. Individual quartz grains are strained and frequently shattered; feldspar is uncommon and largely confined to rock fragments where it is heavily sericitized, although individual grains are fresher and comprise twinned plagioclase, perthite and rare microcline. Calcareous fragments are almost entirely calcite with a little quartz and some muscovite. The accessory minerals include sub-rounded grains of brown sphene, some muscovite, olive-green biotite, zircon, ilmenite and haematite, and chlorite which forms as an alteration product of other unknown silicates.

Metalimestones

These rocks have been found only near the base of the Mount Wegener Formation at the north-western corner of Mount Wegener. They are a pale blue-grey colour in the hand specimen and are very similar to the metalimestones in the Shackleton Range Metamorphic Complex. However, in thin section they are composed almost totally of finely recrystallized calcite

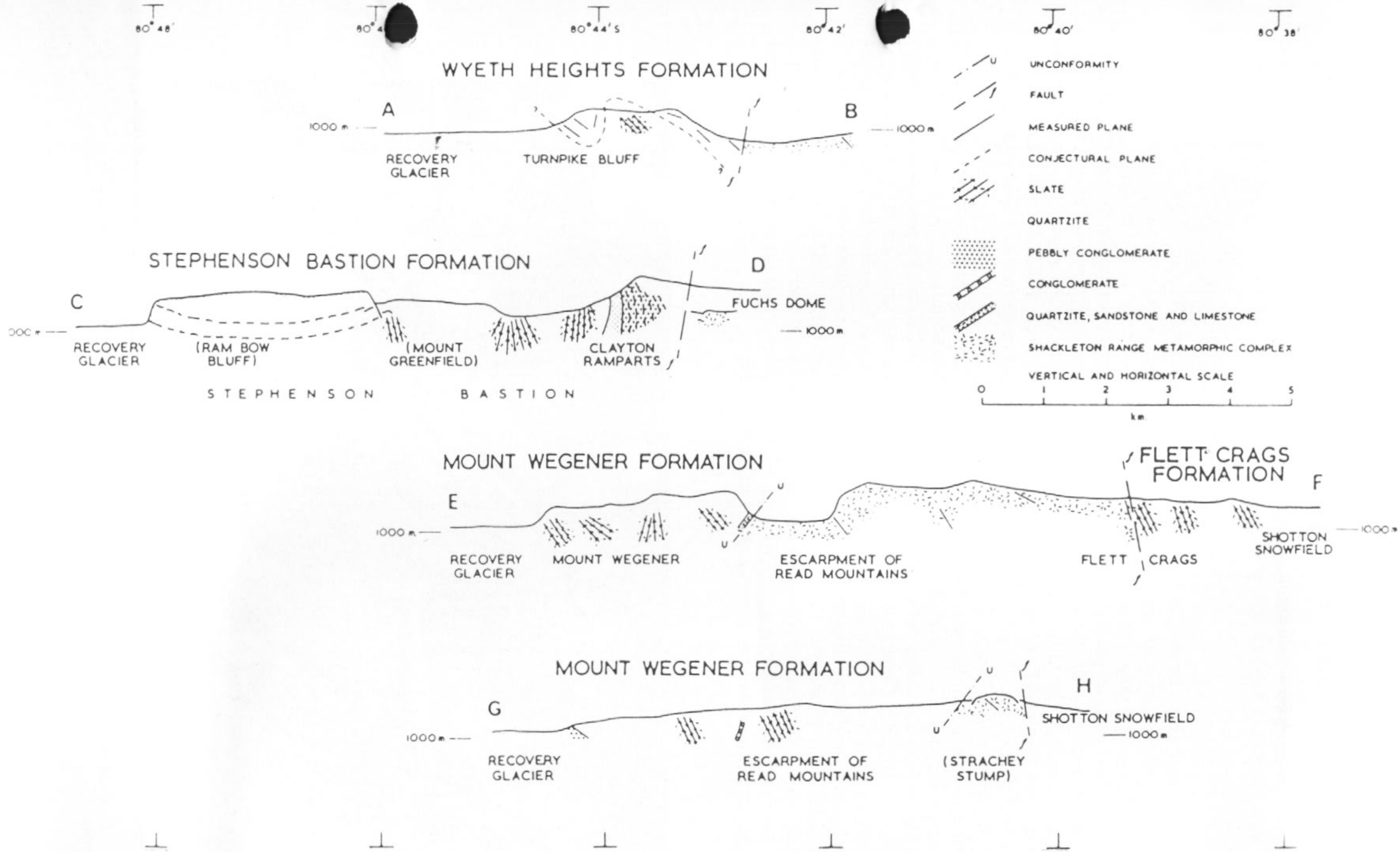


Fig. 8. Composite north–south cross-sections through the Turnpike Bluff Group. The positions of the sections are shown in Fig. 1.

with just a trace of brownish staining around some grains (Z.888.4) and thus differ from the older metalimestones by their lack of other minerals, notably tremolite.

Structure

The east–west trend of the fold axes is the major structural feature of the Turnpike Bluff Group. Individual fold axes are sub-horizontal with a westward regional plunge indicating a westward younging direction which agrees with the litho-stratigraphical evidence.

There are two megascopic styles of folding related to the competence of the beds; quartzites and conglomerates form open folds, whereas incompetent argillaceous strata are closely folded and cleaved. The broad open folds were rarely wholly observed and the best example, in the western face of Mount Wegener, is recumbent (Clarkson, 1972, fig. 3b). The synclinal form of both the Mount Wegener and Stephenson Bastion Formations has been deduced from widely separated observations (Fig. 8).

Most argillaceous strata are tightly folded into isoclinal, or more rarely chevron, folds with axial-plane cleavage. The original bedding may be preserved as alternating light and dark bands (Clarkson, 1972, fig. 3c) or as faint traces occasionally accentuated by a gypsiferous efflorescence (Fig. 9). Chevron folds were seen only on a small scale, generally near the crest of a fold whose limbs show bedding and crenulation cleavages. Extensive flattening of pebbles parallel to the bedding in adjacent pebbly strata may have necessitated additional shortening in the fold crest, leading to the development of chevron folds in the argillaceous layers. Paterson and Weiss (1966) proposed a mechanism whereby kink bands (crenulation cleavage) could develop into chevron folds and Ramsay (1967) considered that these probably developed as a late adjustment towards the end of the orogenic cycle.

Fig. 9. Original bedding in slate accentuated by a gypsiferous efflorescence on Mount Wegener, Read Mountains.

Three main types of cleavage have been recognized in the Turnpike Bluff Group: slaty cleavage (penetrative), crenulation cleavage (non-penetrative) and bedding cleavage (semi-penetrative).

The slaty cleavage is an axial-plane cleavage (the "schistosity" of Knill (1960) or the "flow cleavage" of Leith (1905)), in which there is phyllo-silicate re-alignment parallel to the cleavage plane. Most of the folded argillites show a slaty cleavage, frequently very well developed, but it is often modified by a crenulation cleavage.

The crenulation cleavage takes several forms. In thin section there are minor ruptures in the slaty cleavage where the competent layers are stepped and the incompetent layers flame into the competent layers. These ruptures are considered to be adjustment effects (p. 118) following the formation of the slaty cleavage and not an early shearing movement forming the slaty cleavage (González-Bonorino, 1960). Some rocks have a cleavage oblique to the slaty cleavage which is sub-parallel to adjacent bedding planes and is probably caused by bedding-plane slip, equivalent to the "strain-slip cleavage" of Knill (1960). Another example of strain-slip

Fig. 10. Intersecting cleavages in quartzite producing a puckered exposed surface at station Z.679 on Stephenson Bastion.

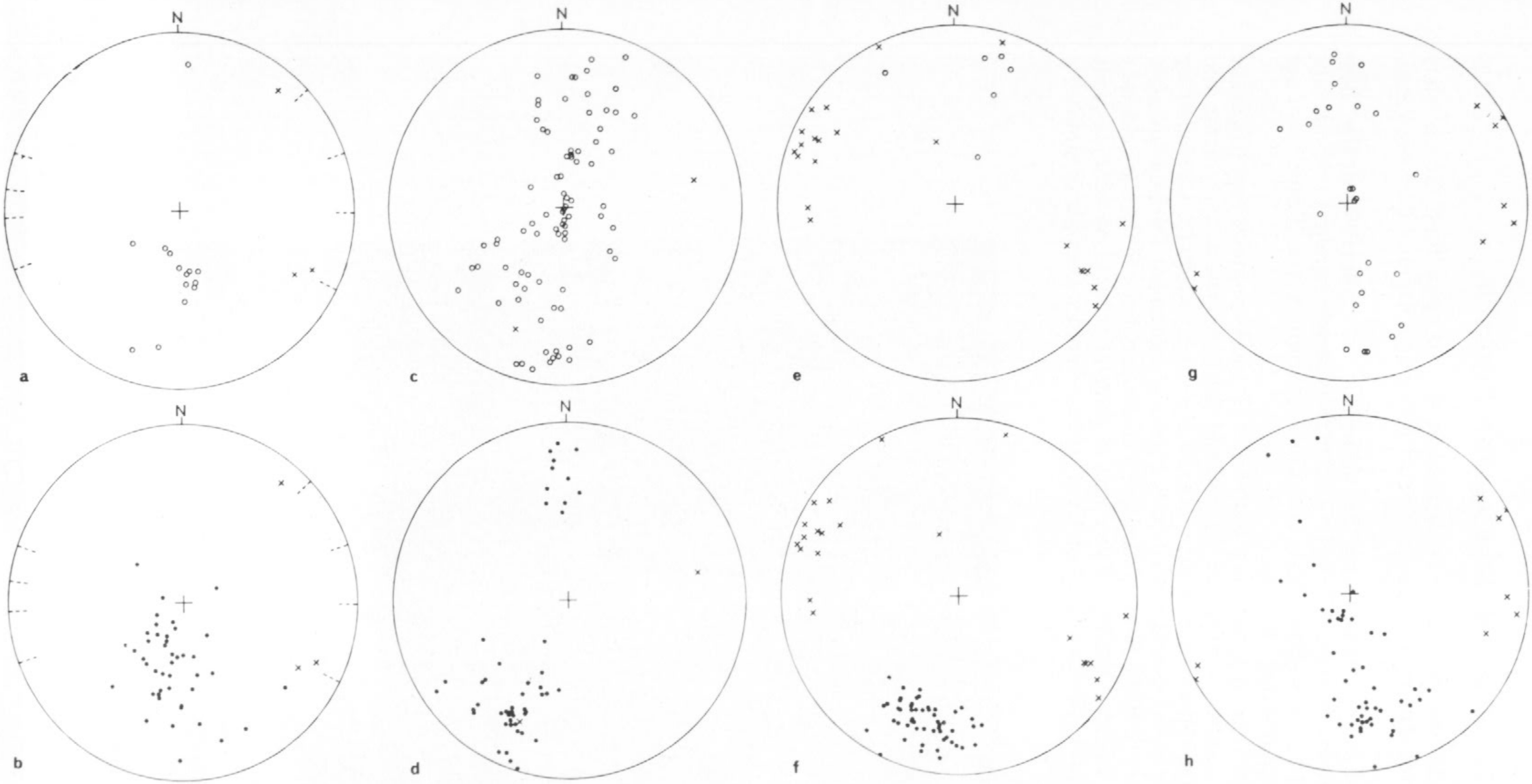


Fig. 11. Stereograms of poles to bedding and cleavage planes in the Turnpike Bluff Group. Fold-axial plunges (×) and trends of unknown plunge (– – –) are also shown.

a.	Poles to bedding planes	Wyeth Heights Formation
b.	Poles to cleavage planes	
c.	Poles to bedding planes	Stephenson Bastion Formation
d.	Poles to cleavage planes	
e.	Poles to bedding planes	Flett Crags Formation
f.	Poles to bedding-cleavage planes	
g.	Poles to bedding planes	Mount Wegener Formation
h.	Poles to cleavage planes	

cleavage occurs within the drag folds on the limbs of larger folds with bedding-plane cleavage in the Flett Crags Formation. Here, the cleavage is an axial-plane cleavage to the drag fold. The foregoing cleavages are also flow cleavages (Leith, 1905) with phyllo-silicate re-alignment but they are non-penetrative.

Crenulation cleavages without phyllo-silicate re-alignment (fracture cleavage) occur as the axial-plane cleavage in small chevron folds in the Flett Crags Formation, and associated with tension gashes, often quartz-filled, in the quartzites of the Stephenson Bastion Formation. At station Z. 679 on Stephenson Bastion, two sets of fracture cleavage intersect at acute angles at one horizon, producing a puckered exposed surface (Fig. 10).

In the Flett Crags Formation the commonest cleavage is a bedding-plane cleavage in argillaceous layers parallel to the bedding and the plane of flattening of pebbles in the pebble-conglomerates. This cleavage is also a flow cleavage but penetrative only through the argillaceous layers. It can be detected in the pebble-conglomerates by the flattening of the pebbles, and in the arenaceous layers by a fluting effect but it rarely develops to the status of a cleavage. It is not clear why bedding cleavage should be so well developed in the Flett Crags Formation, unless other occurrences elsewhere in the group have been misidentified. However, as the stratigraphical position of the Flett Crags Formation is uncertain, if it does represent a lateral equivalent of part of the Mount Wegener Formation, its present geographical position to the north of the main trend of the other three formations of the group could indicate a slightly different tectonic regime which might account for the different cleavage style.

The π-diagrams of poles to bedding and cleavage planes (Fig. 11) summarize the available structural data on the four formations of this group. The overall trend of the fold axes is well displayed, trending slightly north of east to south of west in each formation except the Flett Crags Formation. The anomaly of this trend, slightly north of west to south of east, may also be due to the slightly different tectonic regime already proposed to account for the different cleavage style in this formation. The fold axes of approximately north–south trend in the

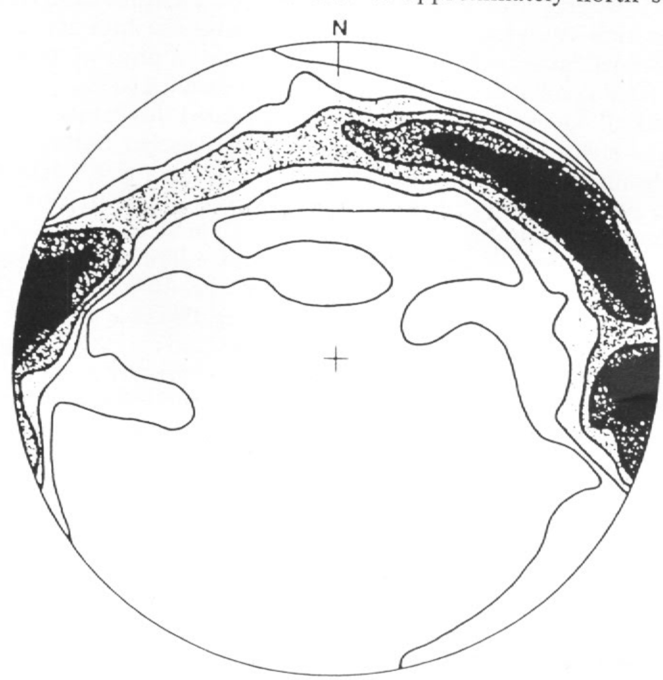


Fig. 12. β-diagram of bedding–cleavage intersections in the Wyeth Heights Formation. Contours at 0, 1, 2, 3, 5 and 8% per 1% unit area.

Stephenson Bastion and Flett Crags Formations may be due to minor local faulting or could possibly be related to the north–south folding in the Blaiklock Glacier Group during the Ross orogeny (p. 123). This trend would most likely be preserved in the youngest and westernmost formation, the Wyeth Heights Formation. A β-diagram of bedding–cleavage intersections in the Wyeth Heights Formation (Fig. 12) shows the few observed intersections and the numerous constructed intersections obtained from all available data. This diagram grossly magnifies the true data and is not regarded as reliable (Turner and Weiss, 1963) but it does illustrate an expected trend. This trend is not shown in the other formations of the Turnpike Bluff Group.

Age and Correlation

The Turnpike Bluff Group is younger than the Shackleton Range Metamorphic Complex on which it rests unconformably and it is presumed to be older than the Blaiklock Glacier Group by contrast with the relatively simple structure of the latter. This provides an age bracket between 1 446 Ma (Rex, 1971) and Cambro-Ordovician (Thomson, 1972). No other evidence for its age is available as neither intrusions nor fossils have been found. Thus, on purely negative evidence, the group is considered to be late Precambrian in age.

Lithologies similar to those of the Turnpike Bluff Group have been described from the Transantarctic Mountains and the Pensacola Mountains. Late Precambrian groups and formations of greywackes and argillites have been correlated from the Horlick Mountains through to northern Victoria Land (Elliot, 1975). The metamorphic grade of these rocks is commonly greenschist facies but later intrusion by the Granite Harbour Intrusives during the Ordovician has produced hornfelses. Interstratified metavolcanic horizons and the granitic intrusions distinguish these sequences from the Turnpike Bluff Group, although other lithologies are similar. Radiometric dating has suggested an orogenic event (the Beardmore orogeny) about 620–680 Ma ago (Grindley and McDougall, 1969) but any folding has been obliterated or overprinted by the Ross orogeny which probably followed a parallel axial trend.

The late Precambrian Patuxent Formation in the Pensacola Mountains consists of greywackes with interbedded lavas which were folded and cleaved prior to the Cambrian (Nelson and others, 1968). Again, volcanic horizons and the fold-axial trend distinguish this formation from the Turnpike Bluff Group. Neethling (1971) considered the Patuxent Formation to be a probable correlative of the Ahlmannrygg Group of the Ritscher Supergroup, for which he suggested a possible minimum age of Lower Proterozoic (before 1 600–1 760 Ma), considerably older than any age previously suggested for the Patuxent Formation. This age also pre-dates the current minimum age (1 446$\pm$60 Ma (Rex, 1971)) of the Shackleton Range Metamorphic Complex, which is unconformably overlain by the Turnpike Bluff Group. However, Neethling (1971) also suggested that regional metamorphism of the Ahlmannrygg Group may have occurred during an episode from 1 000 to 1 050 Ma. The available evidence is insufficient to make a reliable comparison between the Ahlmannrygg Group and the Turnpike Bluff Group.

In the Ellsworth Mountains, the Minaret Group is considerably more calcareous than the Turnpike Bluff Group but it is also of probable late Precambrian age, whereas the apparently conformable succeeding Heritage Group is increasingly argillaceous but contains a Cambrian fauna near its top (Craddock and others, 1964). Thus, there is little evidence to suggest correlation with the Turnpike Bluff Group unless the latter does extend into the Cambrian which is now thought unlikely.

Unfortunately, there are no other outcrops in eastern Antarctica westward along the axial trend of the group or eastward for 1 500 km and only the Permian rocks of the Beacon Supergroup are exposed to the south in the Whichaway Nunataks, across the probable major axis of the depositional basin. Stephenson (1966) suggested that the sediments of this group must have been derived from an extensive granitic region to the south and not from the Shackleton Range Metamorphic Complex. However, more recent field work has proved conglomeratic rocks farther east and stratigraphically lower in the succession than the rocks examined by

Stephenson. These indicate a polygenetic source area but the direction of sediment transport is not known and the Shackleton Range Metamorphic Complex is still considered an unlikely prime source for the sediments due to the lack of a metamorphic mineral assemblage.

The origin of the sedimentary basin is uncertain but the persistent east–west Precambrian structural trend throughout the range may indicate an underlying crustal weakness which resulted in a faulted intracratonic basin. Aughenbaugh and others (1965) suggested that the Littlewood Nunataks (dated by K-Ar methods at 840±30 Ma) could possibly represent an island arc, presumably related to the Beardmore orogeny but, if the trend of the Beardmore orogeny is parallel to the trend of the Ross orogeny, the Turnpike Bluff Group still has an anomalous perpendicular trend. However, Faure and others (1968) obtained a Rb-Sr age of 1 044 Ma for the same specimen of rhyolite, which could indicate a pre-Beardmore orogeny island arc to which the structural trend of the Turnpike Bluff Group may not be anomalous. This means that this group would be much older than was originally suspected and that it could have been deposited in a miogeosyncline marginal to an ancient craton to the south while the Shackleton Range formed a miogeanticline. In this case, flysch-type sedimentary rocks could be expected beneath the Theron Mountains but, unfortunately, apart from the Littlewood Volcanics, no Precambrian rocks are exposed between the Shackleton Range and Heimefrontfjella (Worsfold, 1967; Juckes, 1972).

Conclusions

The Turnpike Bluff Group crops out along the southern margin of the Shackleton Range where four formations have been distinguished by their differing lithologies. The base of the group rests unconformably on the basement complex and the succeeding stratigraphy has been determined by the lithological variations and the structural trend. The group has been folded about sub-horizontal east–west trending axes with a slight overall westward plunge; more argillaceous rocks are tightly folded and cleaved, whereas the more arenaceous strata form broad open folds. The sediments were probably deposited in a faulted intracratonic basin with its major axis trending east–west but the source of the sediment is unknown. The age of the group is considered to be late Precambrian but there is no direct evidence for this.

The closest lithological correlative of this group is the Patuxent Formation in the Pensacola Mountains but its fold style and trend are different. There is no other known outcrop of the Turnpike Bluff Group along the axial trend and the group has a unique structural trend in the Transantarctic Mountains.

Acknowledgements

I wish to thank Professors F. W. Shotton and A. Williams for providing facilities in the Department of Geological Sciences, University of Birmingham, and Dr R. J. Adie for advice during the preparation of this paper. I am indebted to M. J. Skidmore and R. B. Wyeth for permission to use their rock collections and field data which have contributed greatly to the work. I am grateful to all my field companions and, above all, to the US Navy squadron VXE-6, without whose transport facilities this work would not have been done.

MS received 14 February 1977

REFERENCES

AUGHENBAUGH, N. E., LOUNSBURY, R. W. *and* J. C. BEHRENDT. 1965. The Littlewood Nunataks, Antarctica. *J. Geol.*, **73**, No. 6, 889–94.

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

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

———. *and* R. B. WYETH. 1983. Geology of the Shackleton Range: III. The Blaiklock Glacier Group. *British Antarctic Survey Bulletin*, No. 52, 233–44.

CRADDOCK, C., ANDERSON, J. J. *and* G. F. WEBERS. 1964. Geologic outline of the Ellsworth Mountains. (*In* ADIE, R. J., *ed. Antarctic Geology*. Amsterdam, North-Holland Publishing Company, 155–70.)

ELLIOT, D. H. 1975. Tectonics of Antarctica: a review. *Am. J. Sci.*, **275–A**, 45–106.

FAURE, G., HILL, R. L., EASTIN, R. *and* R. J. E. MONTIGNY. 1968. Age determinations of rocks and minerals from the Transantarctic Mountains. *Antarct. Jnl U.S.*, **3**, No. 5, 173–75.

GONZÁLEZ-BONORINO, F. 1960. The mechanical factor in the formation of schistosity. *21st Int. geol. Congr., Norden, 1960*, Pt. 18, 303–16.

GRINDLEY, G. W. *and* I. McDOUGALL. 1969. Age and correlation of the Nimrod Group and other Precambrian rock units in the central Transantarctic Mountains, Antarctica. *N.Z. Jl Geol. Geophys.*, **12**, Nos. 2 and 3, 391–411.

JUCKES, L. M. 1972. The geology of north-eastern Heimefrontfjella, Dronning Maud Land. *British Antarctic Survey Scientific Reports*, No. 65, 44 pp.

KNILL, J. L. 1960. A classification of cleavages, with special reference to the Craignish district of the Scottish Highlands. *21st Int. geol. Congr., Norden, 1960*, Pt. 18, 317–25.

LEITH, C. K. 1905. Rock cleavage. *Bull. U.S. geol. Surv.*, No. 239, 23–118.

NEETHLING, D. C. 1971. Age and correlation of the Ritscher Supergroup and other Precambrian rock units, Dronning Maud Land. (*In* ADIE, R. J., *ed. Antarctic geology and geophysics*. Oslo, Universitetsforlaget, 547–56.)

NELSON, W. H., SCHMIDT, D. L. *and* J. M. SCHOPF. 1968. Structure and stratigraphy of the Pensacola Mountains, Antarctica. *Spec. Pap. geol. Soc. Am.*, No. 115, 344.

PATERSON, M. S. *and* L. E. WEISS. 1966. Experimental deformation and folding in phyllite. *Geol. Soc. Am. Bull.*, **77**, No. 4, 343–74.

RAMSAY, J. G. 1967. *Folding and fracturing of rocks*. New York, McGraw-Hill Book Co.

REX, D. C. 1971. K-Ar age determinations on volcanic and associated rocks from the Antarctic Peninsula and Dronning Maud Land. (*In* ADIE, R. J., *ed. Antarctic geology and geophysics*. Oslo, Universitetsforlaget, 133–36.)

STEPHENSON, P. J. 1966. Geology. 1. Theron Mountains, Shackleton Range and Whichaway Nunataks (with a section on palaeomagnetism of the dolerite intrusions, by D. J. Blundell). *Scient. Rep. transantarct. Exped.*, No. 8, 79 pp.

THOMSON, M. R. A. 1972. Inarticulate Brachiopoda from the Shackleton Range and their stratigraphical significance. *British Antarctic Survey Bulletin*, No. 31, 17–20.

TURNER, F. J. *and* L. E. WEISS. 1963. *Structural analysis of metamorphic tectonites*. New York, San Francisco, Toronto and London, McGraw-Hill Book Company Inc.

WORSFOLD, R. J. 1967. *The geology of southern Heimefrontfjella, Dronning Maud Land*. Ph.D. thesis, University of Birmingham, 176 pp. [Unpublished.]