PHYSIOGRAPHY AND GLACIAL GEOMORPHOLOGY OF THE SHACKLETON RANGE

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ABSTRACT. As the whole of the Shackleton Range has now been seen by the authors, this paper revises, enlarges and extends the work of Stephenson (1966). The physiographical evolution of the major land forms is described with particular reference to the peneplaned surface which forms summit plateaux in certain parts of the range. The glaciation and morphology of the range are related, where possible, to the underlying geology. The implications of patterned ground and gypsum soils as evidence of a former interstadial period are discussed.

THIS paper describes the physiography and glacial geomorphology of the Shackleton Range (lat. 80°07′–80°50′S., long. 31°–19°W.) from observations made during the three austral summers between 1968 and 1971. The work was undertaken from the British Antarctic Survey scientific station at Halley Bay, Coats Land (lat. 75°30′S., long. 26°20′W.) by parties air-lifted into the Shackleton Range by the U.S. Navy.

The Shackleton Range (Fig. 1) is 50–65 km. wide and extends eastward from the eastern margin of the Filchner Ice Shelf for about 180 km. before being completely covered by the Antarctic ice sheet at a height of about 2,000 m. The range is a dissected ice-covered plateau with peripheral areas of rock outcrop elevated between two major glaciers. The ice plateau, a remnant of a previously greater ice cover, is 1,200–1,600 m. high with the highest peaks (1,575–1,873 m.) at its margins in the Herbert and Read Mountains.

150 km. to the north across Slessor Glacier the Theron Mountains escarpment trends south-west to Parry Point (about 80 km. north of Mount Provender). 130 km. to the south across Recovery Glacier the escarpment of the Whichaway Nunataks is parallel and complementary to the southern escarpment of the Shackleton Range. East of the Theron Mountains and the Shackleton Range, and south of the Whichaway Nunataks, the polar plateau rises imperceptibly into the interior of the Antarctic continent to a height of about 3,000 m.

The Shackleton Range was first sighted during a reconnaissance flight southward from "Shackleton" (lat. 77°59′S., long. 37°09′W.), the Weddell Sea base of the Trans-Antarctic Expedition, 1955–58. On 20 January 1957, the range was first crossed and on subsequent flights to the advance base of "South Ice" (approx. lat. 81°57′S., long. 28°52′W.) some observations on the geology and geomorphology were made.

In October 1957, during 10 days in the range, P. J. Stephenson investigated the geology of much of the area west of Stratton Glacier. The surveyors, K. V. Blaiklock and D. G. Stratton, made a 20 day traverse eastwards, circumnavigating Fuchs Dome, and the specimens they collected made it possible for Stephenson to extrapolate the known geology farther eastwards.

Stephenson (1966) considered that the Shackleton Range comprised three sections (western, central and eastern), separated by broad snowfield passes trending north–south. He described and discussed summit, flank and scarp erosion surfaces, and the occurrence of abrupt margins to the western and southern parts of the range were explained. Patterned ground and fossil gypsum soils were also described with a brief reference to the glaciology.

In November 1968, an overland tractor party from the Halley Bay scientific station, using International Harvester BTD–8 and Muskeg tractors, reached the extreme eastern end of the range. However, they were only able to spend a few days there after establishing a feasible overland route and leaving a substantial depot for the 1969–70 field season. Two astro fixes established their position and a compass survey was made. Geological specimens were collected and geomorphological observations were made.

At the same time, two surveyors, two geologists with two assistants and three dog teams were flown into the range to provide ground control for the U.S. trimetrogon air photography and to extend the geological mapping of Stephenson (1966). The following year a similar party completed the ground control and further extended the reconnaissance geological mapping. In the 1970–71 season, two geologists with two assistants and three dog teams were again flown

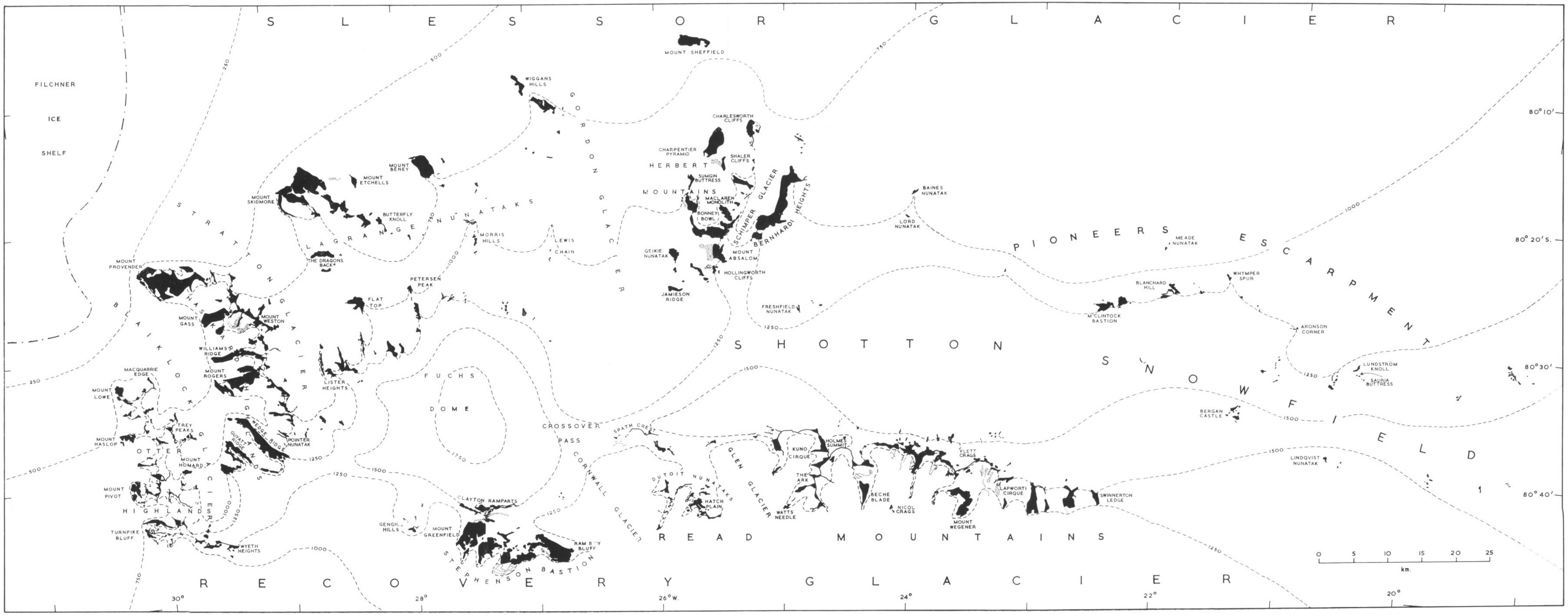

Fig. 1. Sketch map of the Shackleton Range.

into the range to complete the reconnaissance mapping and to examine critical localities in greater detail.

PHYSIOGRAPHY

The Shackleton Range is a rectangular horst with the major fault zones parallel to the long axis of the range and now defined by Slessor and Recovery Glaciers. The northern margin of the range is a crevassed subglacial scarp which continues westward to the Filchner Ice Shelf (Stephenson, 1966). By contrast, the southern margin of the range is marked by discontinuous outcrops, often rock escarpments, against the northern edge of Recovery Glacier. The western termination of the range is a discontinuous erosional escarpment, whereas the eastern end gradually disappears beneath the Antarctic ice sheet.

Within the margins of the range a dissected ice-covered plateau generally shows greater relief with increasing distance from the Antarctic ice sheet. This plateau is south of the axis of the range so that the longest drainage glaciers flow northwards. Its altitude (1,200–1,600 m.) is greatest in the east. The present drainage scheme, generally north–south, is probably due largely to the pre-glacial pattern consequent on the "plateau ridge" of the range and partly to underlying structural and lithological controls.

The plateau erosion surface, a discontinuous undulating peneplain, is best exposed on the south side of the range (Fig. 2). This surface has been faulted, which probably accounts for

Fig. 2. A view southward from Clayton Ramparts to the central part of Stephenson Bastion, showing the peneplain as an undulating summit erosion surface.

discordant plateau levels, and subsequently modified by erosion. The age of the peneplain is not known but it must be younger than mid-Ordovician, the probable age of the youngest rocks (Thomson, 1972). At The Dragons Back these youngest rocks are cut by a dolerite dyke dated at 297 ± 12 m. yr. (Rex, 1971), but the exposure is below the level of the peneplain. Because no strata are known above the peneplain, it may be an original surface as old as late Ordovician, a younger original surface or even an exhumed surface from which all later strata have been removed. The present evidence for its age is therefore inconclusive and correlation is not possible with other major surfaces, e.g. in the Transantarctic Mountains, the pre-Devonian Kukri peneplain (Gunn and Warren, 1962), the Devonian–Carboniferous Maya peneplain (Harrington, 1965), and in western Dronning Maud Land, the pre-Jurassic surface in north-eastern Heimefrontfjella (Juckes, 1969) and Kirwanveggan (Aucamp and others, 1971).

However, the map "Geomorphic features of Antarctica" (Nichols, 1970) shows that the "Kukri Peneplain is exposed" in the north-western Shackleton Range and it also shows, in the south-eastern parts of the range, an area "where evidence of a [?] tertiary peneplain has been reported". The reference quoted for the former observation is Schmidt and others (1964) and for the latter Stephenson (1966). Schmidt and others referred to Stephenson (1960), the sole data source for the Shackleton Range at that time, but Stephenson did not mention the Kukri peneplain by name in either his 1960 or 1966 papers; the Blaiklock Beds (? Permian (Stephenson, 1966, p. 18)), which unconformably overlie the metamorphic basement, are now considered to be Cambro-Ordovician (Thomson, 1972). As evidence for a Tertiary peneplain, Stephenson (1966, p. 68) suggested as a possible explanation "Post-Permian warping or faulting has affected the region, uplifting the Shackleton Range from which a former Gondwana sedimentary cover has been stripped subsequently". Similarly, Stephenson (1966) made no mention of the Kukri peneplain being exposed in the Whichaway Nunataks, and neither Stephenson nor Brook (1972) mentioned the Kukri peneplain in the Theron Mountains.

Thus, the Kukri peneplain is not exposed in either the Theron Mountains or Whichaway Nunataks, where the base of the Beacon Supergroup is not seen, and as it is not known whether the Shackleton Range was a ridge during the Permian no age can be given for the peneplain.

The present work has necessitated a revision of Stephenson's (1966) concept of a three-fold sub-division of the Shackleton Range. The range has been effectively divided into two parts by the strong valley development of Gordon and Cornwall Glaciers. Where these two glaciers meet at Crossover Pass, the plateau narrows and joins Fuchs Dome in the west to Shotton Snowfield in the east. An underlying fault zone may control this division.

Western Shackleton Range

The western Shackleton Range west of Gordon and Cornwall Glaciers has three major glacial units: Fuchs Dome, and Stratton and Blaiklock Glaciers which separate four major mountain blocks.

Otter Highlands, west of Blaiklock Glacier, form the western end of the range. East of Turnpike Bluff an eroded fault scarp forms part of the southern margin of the range against Recovery Glacier. North of Turnpike Bluff an erosion scarp, trending north to Mount Lowe, forms the western margin of the range and is approximately co-linear with the eastern edge of the Filchner Ice Shelf. Small glaciers or snowfields trending west from the middle of this area cut through the western escarpment and those trending east discharge into Blaiklock Glacier. Within this area the mountains are more elevated in the south where the peneplain is preserved as a summit plateau at about 1,300 m. on Turnpike Bluff. Except at Mount Pivot, where there is a small summit plateau, the mountains north of Turnpike Bluff have summit peaks at lower altitudes than Turnpike Bluff, indicating more intensive glacial erosion with former greater development of Blaiklock Glacier. The highest summit of Trey Peaks, which form a typical cirque, is 1,141 m. (Fig. 3).

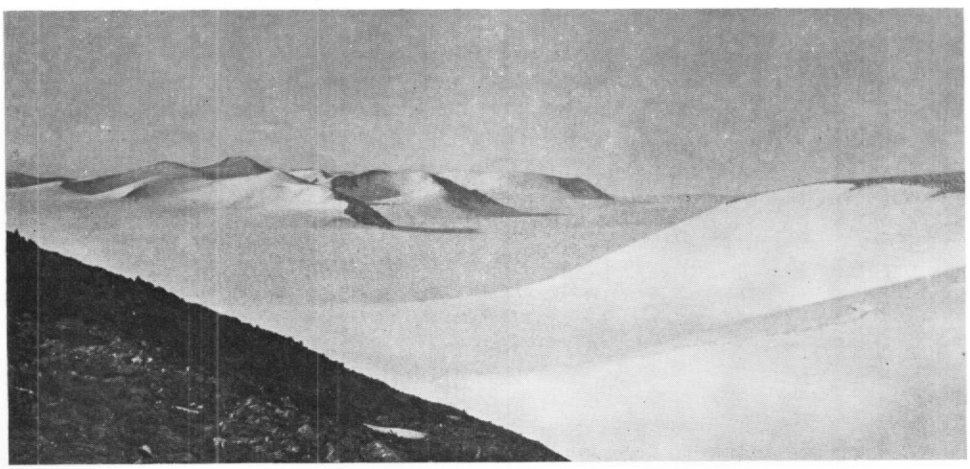

Fig. 3. A view north-westward across Blaiklock Glacier from south of Guyatt Ridge, showing the cirque at Trey Peaks (left of centre) and the summit erosion surface on Guyatt Ridge (right).

Haskard Highlands, between Blaiklock and Stratton Glaciers, form a mountainous ridge trending north-west for 30 km. from Wedge Ridge. Their western flank has been deeply incised by previous westward overflow of Stratton Glacier to form long ridges at right-angles to the two glaciers. The ice in the valleys between these ridges is now largely static as shown by blue icefields and necklace moraines, particularly below Mount Weston (Fig. 7). Immediately south of Pointer Nunatak, Wedge Ridge and Guyatt Ridge have summit plateaux at 1,300 m., whereas north of Wedge Ridge no summit plateaux are preserved and the highest peak, Mount Weston (1,211 m.), is below the level of the peneplain.

Lagrange Nunataks, between Stratton and Gordon Glaciers and north of Fuchs Dome, are a group of isolated nunataks which, with the exception of Flat Top (about 1,330 m.), are mostly north–south ridges with summits at their southern ends. These ridges rise through a broad snow plain which gradually descends from the northern edge of Fuchs Dome to an ice escarpment on the southern side of Slessor Glacier and, like Otter and Haskard Highlands, their summit altitudes decrease northward. Apart from Flat Top, the only summit plateaux preserved are on the ridges extending from Fuchs Dome (Fig. 4). These ridges show small

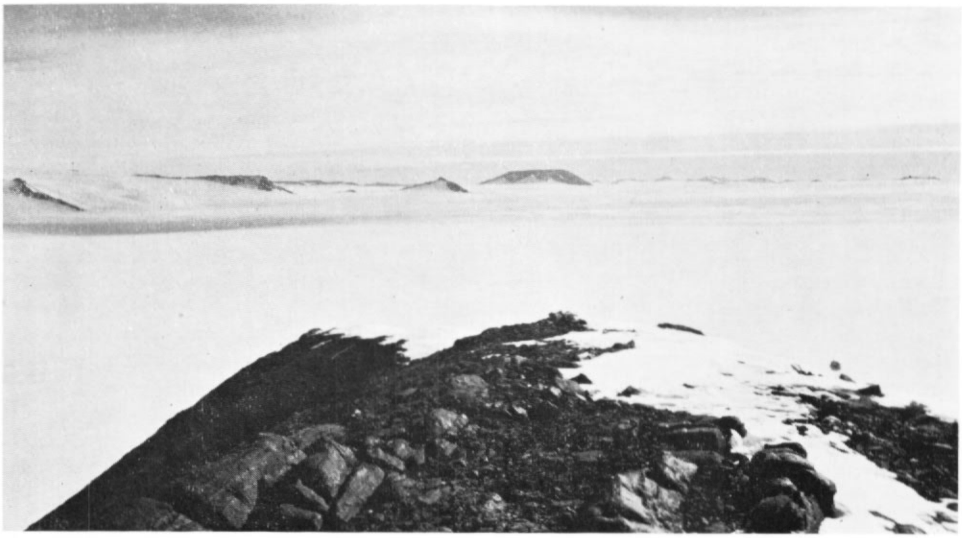

Fig. 4. A view westward from Morris Hills, showing the northern margin of Fuchs Dome. Petersen Peak and Flat Top are in the centre.

summit plateaux abutting against the dome at about 1,300 m. but these soon develop into sharp ridges; the best examples are between Petersen Peak and Lister Heights. It would seem probable that, while the ice cap of Fuchs Dome preserves the peneplain, frost action on the emergent plateaux quickly reduces them to sharp ridges.

The massif of Stephenson Bastion, south of Fuchs Dome, is composed of low-grade slates and quartzites. About 3 km. north of Mount Greenfield vertical strata form the west–east erosion scarp of Clayton Ramparts. A 2 km. wide valley is cut in slates between this scarp and the main massif. This massif of sub-horizontal quartzites has a summit plateau undulating between 1,450 and 1,600 m. (Fig. 2) and it is approximately rectangular with steep scarp faces on all sides, notably the 300 m. high southern scarp which extends westward for 16 km. from Ram Bow Bluff. This southern scarp has been indented by a deep cirque in an area of folding 3 km. west of Ram Bow Bluff, and both the north and south scarps have been considerably modified east of Mount Greenfield where quartzites give way to slates. About 5 km. north-east of Mount Greenfield a high rounded summit of debris is at a higher altitude than the summit plateau of Stephenson Bastion. Genghis Hills, 8 km. west of Mount Greenfield, are composed of basement schists and the general summit level is about 1,300 m.; these differences between rock type and altitude of the peneplain are due to faulting.

Eastern Shackleton Range

There are three main features in the eastern Shackleton Range: the ice plateau of Shotton Snowfield with fringing rock windows and scarps, the Read Mountains and the Herbert Mountains.

Pioneers Escarpment, the northern margin of Shotton Snowfield, is an ice escarpment trending approximately north-east from Crossover Pass (1,492 m.) and decreasing in altitude to Lord Nunatak (1,050 m.), where it trends slightly south of east and gradually increases in height to about 1,300 m. Meade Nunatak is north of the escarpment and is just southward of the subglacial escarpment which defines the southern margin of Slessor Glacier. Farther east, at long. 21° and 20°W., the escarpment is deeply indented by two large embayments which extend 8 km. south into the plateau. East of long. 19°W. there are no further outcrops, although the escarpment continues for some distance as an ice slope. No outcrops occur in the central area of the plateau west of long. 22°10′W., whereas east of this line three main nunatak groups are present along a south-easterly trend. The heights of these groups are, from west to east, 1,353, 1,589 (Bergan Castle) and 1,470 m. East of long. 19°30′W. outcrops give way to snow hills at increasing heights until they merge with the Antarctic ice sheet at about 2,000 m.

The southern margin of the ice plateau is marked by a rock and ice escarpment which trends almost due east from Crossover Pass (1,492 m.) to long. 22°W. (1,520 m.) where there are no rock outcrops. Its eastward continuation is ill-defined, although the nunataks east of Lindqvist Nunatak may lie along it.

Below the southern escarpment of Shotton Snowfield are the Read Mountains and Dutoit Nunataks. The Read Mountains are essentially a group of arêtes trending south from the 200–400 m. high escarpment (Fig. 5). Between these arêtes, cirques floored with blue ice descend gradually to Recovery Glacier where their mouths and the southern ends of the arêtes form a linear feature. The mountains are largely composed of schists and gneisses, but at Mount Wegener and in the ridges to the east slates overlie the gneisses, and these plateau-topped ridges represent remnants of a peneplain at about 1,500 m.

Fig. 5. An aerial view eastward through the Read Mountains, showing approximately 50 km. of the escarpment. (Drawn from U.S. Navy air photographs.)

Hatch Plain in the Dutoit Nunataks is largely plateau-topped at about 1,320 m., although west of a small south-westerly flowing glacier a nunatak peak rises to 1,473 m. which is closely comparable with the height of the escarpment at Crossover Pass. The height difference between these two summit levels and those in the Read Mountains is probably due to faulting.

Immediately north of the Read Mountains, slates and quartzites crop out as short north–south ridges which, although occurring in Shotton Snowfield, can be considered as part of the Read Mountains. Thus, it seems likely that the Read Mountains were originally a block which has been subsequently cut by ice overflowing from the plateau along lines of weakness until the ice retreated from the top of the escarpment. By contrast, the larger part of Stephenson Bastion still forms a block because of the west–east line of easily eroded slates below Clayton Ramparts, a feature not present in the Read Mountains.

The Herbert Mountains occupy an approximately rectangular area with its long axis along long. 25°20′W. Schimper Glacier flows north from near Mount Absalom along a fault line, thereby dividing the area in two, and an east–west fault north of Mount Absalom further divides the western half. East of Schimper Glacier, Bernhardi Heights form an 11 km. long ridge with a western flank descending steeply for about 400 m. to Schimper Glacier, whereas the eastern flank is a short gentle slope to another unnamed glacier. The western half of the area comprises several curved ridges around three, now inactive, cirque glaciers. The two southern cirques open north-westwards into Gordon Glacier and the northern one opens towards Slessor Glacier. The peak of Mount Absalom (1,575 m.) dominates the group and summit altitudes decrease northward. As small summit plateaux are preserved at only three localities, the whole area may have been considerably uplifted and then deeply eroded by glacial action.

Mount Sheffield, the northernmost mountain in the range, lies 11 km. north of the Herbert Mountains across a large expanse of crevassed ice. Geologically, it belongs to the Herbert Mountains as it is composed of similar gneisses, but it may have been separated by preferential erosion along the axis of a syncline. It is not an "island" in Slessor Glacier as the glacier margin lies close to the foot of the northern side of the mountain.

Thus the major physiographical feature of the Shackleton Range is a pre-glacial peneplain which is preserved as summit plateaux, mainly in the southern and western parts of the range. The variable summit altitudes are almost certainly due to the undulating nature of the peneplain and to post-peneplanation faulting.

Glacial Geomorphology

Glaciation

The major glacial features in the Shackleton Range are the boundary glaciers, the central ice plateau and the drainage glaciers.

Slessor Glacier to the north and Recovery Glacier to the south of the Shackleton Range are among the largest glaciers in Antarctica but the definition of these two features as glaciers is debatable as they could equally well be called "ice streams" (Swithinbank, 1959). However, as they both possess well-defined margins against mountain ranges, Stephenson (1966) suggested that they should be classified as true valley glaciers even though they are extremely large, i.e. 40–60 km. wide and over 320 km. long.

The source of Slessor Glacier lies in a vast trefoil basin about 160 km. wide in long. 16°W. where it comprises several active tributary lobes. As it flows westward it narrows appreciably and becomes a series of medial crevasse zones, but the crevasse pattern disappears where the glacier flows into the Filchner Ice Shelf. For most of its length, ice escarpments form its northern and southern margins; both are sub-parallel to the northern edge of the Shackleton Range and the former coincides with the Theron Mountains escarpment at Parry Point.

Recovery Glacier is less well known but its position relative to the south side of the range suggests that, whereas it has a similar shape to Slessor Glacier, it is considerably larger as it is 80–100 km. wide between Stephenson Bastion and the Whichaway Nunataks. North of the Whichaway Nunataks crevassing occurs in discontinuous sub-parallel bands unlike the continuous crevassing in Slessor Glacier. Crevassing is generally much less severe and the northern margin is virtually crevasse-free for 35 km. south of the western Shackleton Range, whereas the southern margin is severely affected (Stephenson, 1966).

Fuchs Dome forms the western end of the central ice plateau between Stratton Glacier and Crossover Pass. At Crossover Pass this plateau is less than 1 km. wide but towards the east it broadens northward to 32 km. at long. 24°W. and then narrows and continues eastward until it merges with the Antarctic ice sheet east of long. 19°W. Throughout its length it maintains an average height of about 1,500 m., sloping gradually northward to between 1,100 and 1,300 m. at its northern margin. The margins of the plateau are generally steep ice slopes, often crevassed, and with some ice falls, particularly adjacent to rock windows in the scarp.

All of the drainage glaciers of the range flow from the central ice plateau except Blaiklock Glacier which has cut back into the plateau. The longest glaciers flow northward and are more mature towards the west with increasing distance from the Antarctic ice sheet.

Blaiklock Glacier is the westernmost and most mature glacier in the range. Initially flowing northward as a dip-slope glacier on slates and gneisses, it then turns north-westward as it crosses on to sediments and flows along the strike of less resistant shales which are presumed to lie beneath it. The valley sides are truncated spurs, often bevelled where they join summit plateaux. It is unlikely that the small tributary glaciers or snowfields between these spurs nourish the main glacier. The eastern margin of Blaiklock Glacier parallels, in part at least, the unconformity between the sedimentary rocks and the metamorphic basement.

Stratton Glacier, which flows parallel to Blaiklock Glacier, is much younger. It rises at the edge of Fuchs Dome and initially flows northward as a dip-slope glacier on the metamorphic basement before turning north-westward at Mount Weston to parallel the strike of the foliation. Its surface level is about 400 m. above that of Blaiklock Glacier and at Wedge Ridge it overflows westward into Blaiklock Glacier. At this locality the overflow channels represent the initial stages in the formation of the east–west ridges and of the cirque glaciers along the eastern side of Blaiklock Glacier. Elsewhere, the west side of the valley is a discontinuous erosion scarp, whereas the east side is mainly an ice slope with rock walls only at Mount Skidmore and alongside Lister Heights. Ice from Fuchs Dome and the plain of Lagrange Nunataks may flow westward over this slope into Stratton Glacier.

Gordon Glacier is basically a long broad snowfield descending from Crossover Pass. Although there is no crevassing or positive evidence of movement, a group of ice falls occurs in its upper reaches and there are broad deep undulations in its middle reaches.

Schimper Glacier in the Herbert Mountains descends quite steeply northward from near Mount Absalom in a series of crevassed ice bulges, but it levels out at lat. 80°21′S. into a large uncrevassed blue icefield. Despite the apparent head of ice in its upper reaches, this glacier shows no obvious signs of movement. The east side of the glacier is flanked by the massive ridge of Bernhardi Heights, whereas the west side is a discontinuous erosion scarp, the gaps having been made by the cutting back of the cirque glaciers to the west. On the east side of the Herbert Mountains a small apparently static glacier trends northward over a subglacial east–west ridge at lat. 80°22′S.

Cornwall and Glen Glaciers, the only two southward-flowing glaciers, are comparatively short, immature and appear to be static. Both have side valleys on each flank but it is unlikely that these contribute ice to the main glaciers.

The cirque-like valleys beside the main drainage glaciers are mostly occupied by subordinate snowfields or blue icefields with small surface slope showing little or no signs of movement.

Blue icefields are commonest in the Read and Herbert Mountains, and to a lesser extent between Blaiklock and Stratton Glaciers. They form in areas sheltered from the prevailing easterly wind, most commonly at the heads of steep-walled cirques where the ice level is often lower than in the centre of the cirque, i.e. probably indicating a negative regime due to sublimation (Van Autenboer, 1964). Although most blue icefields are lobate, the only true glacier lobes seen were near Mount Skidmore (Fig. 6). Large areas of ice-free patterned ground are usually associated with blue icefields, indicating substantial insolation and possibly comparatively thin blue ice. Arcuate necklace moraines (Fig. 7) are associated with some cirques, indicating either previous static phases in the development of the glacier or upthrusting in the ice (Crary and Wilson, 1961; Stephenson, 1966).

Glare ice, or hard white ice, occurs on the southern side of Stephenson Bastion, and between Mount Sheffield and the Herbert Mountains. These ice surfaces are crossed by random net-

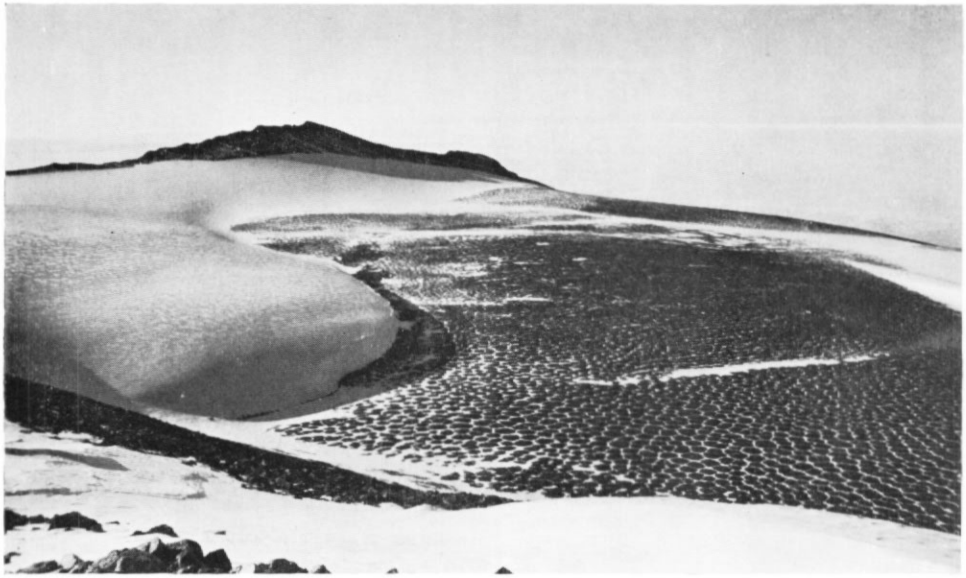

Fig. 6. A view westward across a glacial lobe with patterned ground near its foot. The ice cliff is about 12 m. high. The peak of Mount Skidmore is about 4 km. away.

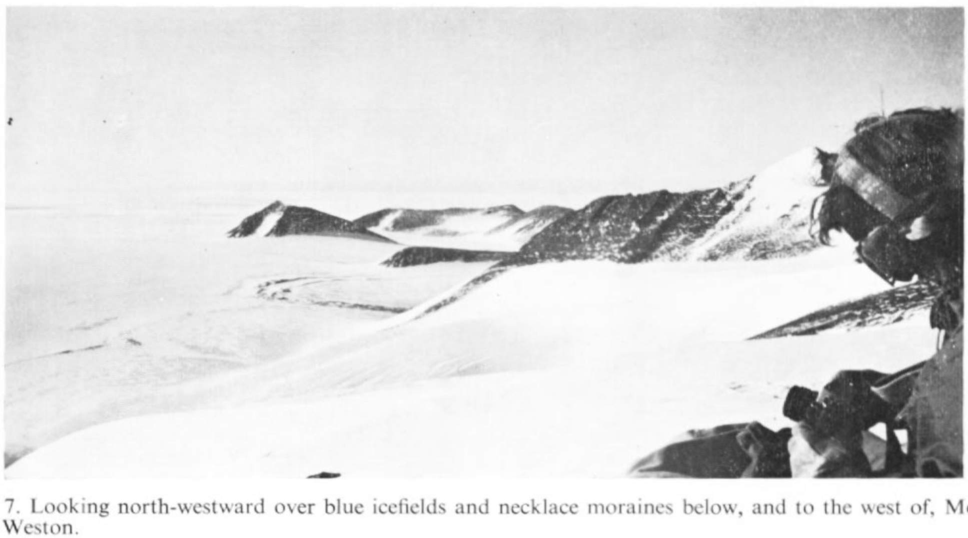

Fig. 7. Looking north-westward over blue icefields and necklace moraines below, and to the west of, Mount Weston.

works of thin expansion cracks and seem to be restricted to open windswept areas where there is little or no accumulation.

Cryoconite holes are common in moraines on ice, and on debris-strewn areas of blue ice.

Climate

No systematic meteorological observations have been made in the Shackleton Range but during the 1970–71 summer season the mean temperature from random readings was −10° C. It is difficult to assess mean wind speeds and each season has been more windy than the previous one. In general, it seems that west of Stratton Glacier the climate is sunnier, calmer and more settled than in the more easterly areas.

Weathering

Throughout the range there is ample evidence of frost action in the form of steep cliff faces and scree slopes. The debris is generally angular where the rock has been fractured along joint planes, although certain horizons, notably friable schists, have been broken down to a gravel. Frost action is also a factor in the formation of patterned ground.

Chemical weathering is represented throughout the range by white gypsiferous encrustations. These are commonest on slates, schists and gneisses but on certain amphibolites turquoise-coloured encrustations probably indicate the presence of the copper ion.

Honeycomb weathering was found at a few localities in friable schists and gneisses. Most cavities face south-east, are 1–2 m. high and up to 1 m. wide, except where there is considerable lateral development along a particular horizon.

Wind-formed ice features

Wind-formed ice features occur around exposed nunataks and ridges throughout the range. A short, steep snow slope leads up to the rock on the windward side and a long snow dune extends down-wind on the leeward side. The height of the exposed rock face on the windward side depends on the height to which the snow rises and on whether or not a scoop is developed below the face. These scoops are probably formed primarily by melting due to radiation from the cliff face and partly by wind scouring. They are 2–30 m. deep but generally less than 15 m. wide. The leeward snow dunes vary in size and may be 3 km. long depending on the shape and position of the nunatak. Most dunes extend westward, i.e. with the direction of the prevailing wind, but those in the Read Mountains usually trend southward and are probably due to local katabatic winds blowing down the escarpment. Some large nunataks have multiple dunes with deep central scoops which are often floored with blue melt ice or patterned ground moraine.

Surface wind-formed features such as sastrugi are rare, possibly indicating that wind-drifted snow is not now a very effective "accumulative" element in the Shackleton Range.

Patterned ground

Patterned ground occurs throughout the range on slopes and summit plateaux, usually as "non-sorted polygons" (Washburn, 1956). They are 0·5–8·0 m. in diameter and the larger rock fragments are 5–30 cm. Frequently the polygons are separated by channels up to 4 m. wide, often snow-filled, and composed only of the larger blocks. The absence of fine material in the channels is attributed to erosion by ground water in summer, but what determines the trend of the channels is unknown.

On the summit plateau east of Turnpike Bluff there are small sorted polygons 0·5–1·0 m. in diameter. Slate fragments about 5 cm. across form the margins and they may also be randomly distributed over the centres. A number of upstanding slates are associated with these polygons along the northern edge of the summit plateau (Fig. 8). These slates, which stand edge on to the prevailing wind and are parallel to the cleavage in the bedrock, tend to lean slightly northward or down slope. There is no satisfactory explanation for the formation of this phenomenon but frost action is probably a prime factor.

Non-sorted rock stripes, usually separated by stripes of snow, occur on some hillsides. On the north side of Mount Gass, polygons or steps (Washburn, 1956) seem to co-exist within the stripes.

Fig. 8. Vertical slates in a *felsenmeer* east of Turnpike Bluff.

In the Shackleton Range, patterned ground either disappears beneath semi-permanent snowfields or ends abruptly a short distance from icefields. Assuming that patterned ground is destroyed by glaciation and cannot form beneath ice thicker than 10 m. (due to lack of diurnal temperature variation), patterns disappearing beneath semi-permanent snowfields must be fossil, whereas those terminating abruptly some distance from a glacier must be recent in origin if the ice is currently retreating. A comparison of present summer snow levels with those shown on air photographs taken 3 years earlier indicates definite retreat in certain localities. Therefore, at least two generations of patterned ground are present in the range, indicating at least one former interstadial, but its age and duration cannot be determined at present.

The few erratics in the Shackleton Range are probably locally derived and the fossiliferous shale erratics near Mount Provender are presumed to have originated beneath Blaiklock Glacier (Stephenson, 1966). Less easily explained are the conglomerate erratics found on basement terrain at Genghis Hills and Dutoit Nunataks. These were probably derived from pebble conglomerates exposed farther east in the Read Mountains.

Gypsum in soils

Gypsum occurs directly below the debris surface in many places throughout the range. Stephenson (1961, 1966) suggested that, since gypsum is deposited by ground water in an arid climate, its occurrence in the Shackleton Range must be fossil because the present climate is too cold to permit movement of ground water. However, Gibson (1962) has suggested that in the dry valleys of Victoria Land adequate ground water moves towards the lakes to transport and deposit gypsum. There is ample evidence of melt water in the Shackleton Range in summer and thawed ground was observed at a depth of 20 cm. in early December and 30 cm. in mid-January. It therefore seems probable that gypsum could be deposited in the present frigid-arid conditions as in Victoria Land.

Large plates of free-growing gypsum crystals were found in the side of a small channel in moraine along the east side of Schimper Glacier in the Herbert Mountains (Fig. 9). These crystals must have developed *in situ* as they are far too delicate to have been carried by ice to their present position. If the growth rate of these crystals could be determined, it would provide a useful indication of the age of the moraine, and hence the duration of the present glacial stage.

It is therefore likely that gypsum in fossil patterned ground represents an interstadial period

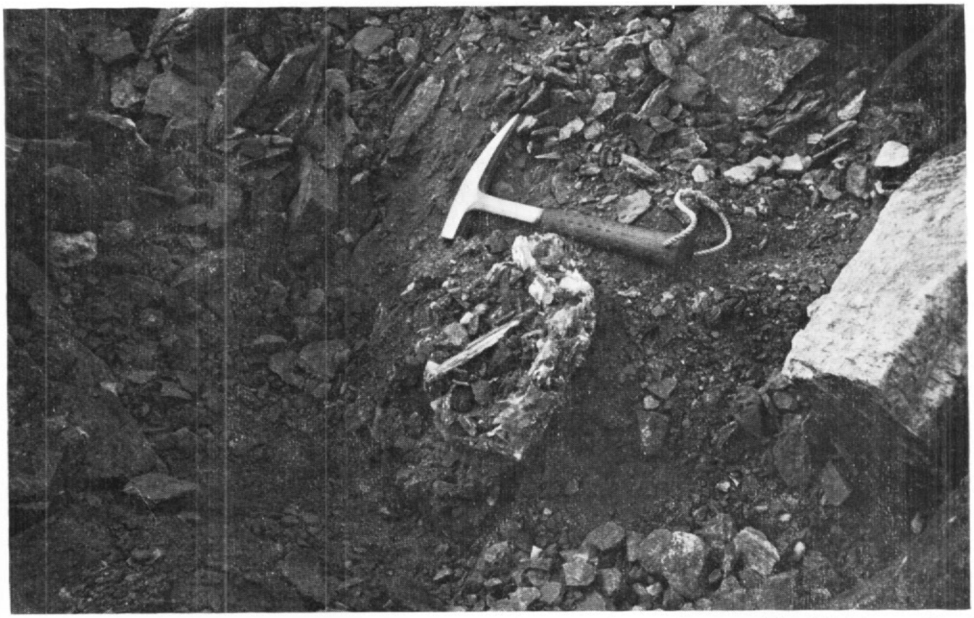

Fig. 9. Gypsum crystals growing in the side of a channel in moraine on the east side of Schimper Glacier.

succeeded by a glacial advance. Such an interstadial may have been warmer than the present but there is no direct evidence for this.

Conclusions

The Shackleton Range is an elongate block upthrust between two major fault zones, to the north and south, now occupied by major glaciers. The dominant erosion feature is a discontinuous, deeply eroded pre-glacial peneplain with flanking escarpments. Available evidence indicates that the peneplain cannot be older than late Ordovician, although it may be much younger. Post-peneplanation faulting has caused discordant summit plateau levels, and a long history of subaerial and subglacial erosion has considerably modified the topography. The glacial drainage pattern, predominantly north–south, is superimposed on the pre-glacial pattern which is largely consequent on the "plateau ridge" of the range and partly due to underlying structural and lithological controls.

The present glaciation in the range seems to be largely static or in retreat in certain areas. The evidence for recent and fossil patterned ground suggests at least one former interstadial, although its age and duration are unknown. The glaciation and topography are mature around Blaiklock Glacier but they become increasing juvenile farther eastward. Thus, the overall concept of the Shackleton Range is that of an upthrust dissected plateau emerging from the retreating Antarctic ice sheet.

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