PHYSIOGRAPHY AND GLACIAL GEOMORPHOLOGY OF HEIMEFRONTFJELLA, DRONNING MAUD LAND

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THIS paper describes some of the results of geological and topographical surveying undertaken in Heimefrontfjella from the British Antarctic Survey station at Halley Bay during the two seasons 1963–64 and 1964–65.

A sun-fix observed in early December 1963 at the eastern end of the northern ridge of "Peaks E", near the southern end of Heimefrontfjella (Fig. 1), gave a position of lat. 75°00′15″S., long. 12°49′25″W. The range, which extends for approximately 100 miles (160 km.) in a north-easterly direction, consists of three distinct parts separated by wide crevassed snow slopes, and associated nunataks. At its narrowest part the snow-filled valley separating the south-western block (Tottanfjella) from the central block is 7·5 miles (12·0 km.) wide but the one between the central and north-eastern blocks is approximately 25 miles (40 km.) wide.

North-west of the range the ice level has an average height of 5,000 ft. (1,525 m.) above sea-level, but to the south-east of the range it reaches 6,000 ft. (1,830 m.) in the vicinity of Tottanfjella and 8,500 ft. (2,590 m.) in the central part. There is a gradual rise on the south-east side to the polar plateau. The peaks of Heimefrontfjella reach heights of between 6,000 ft. (1,830 m.) and 9,650 ft. (2,940 m.) above sea-level.

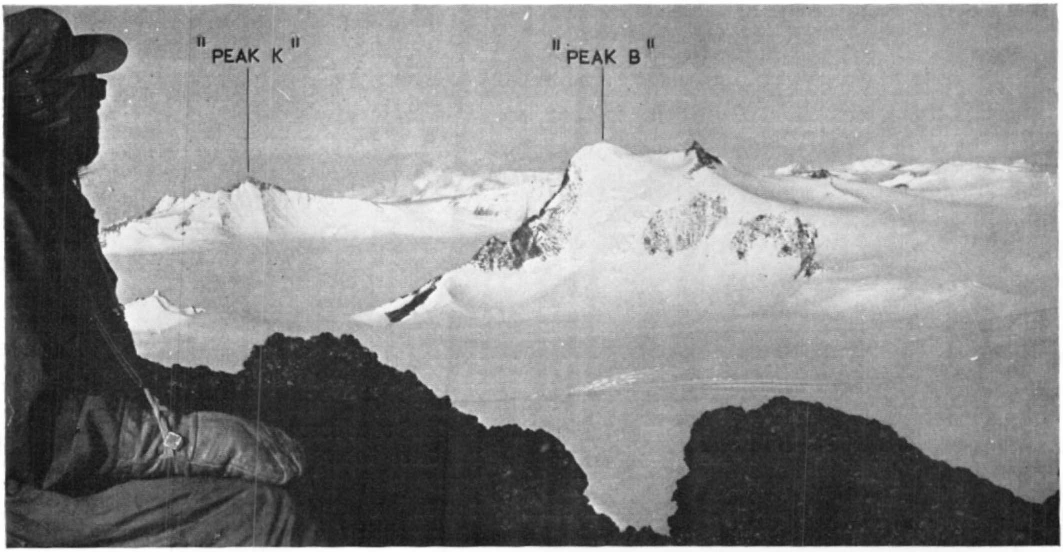

Fig. 2. A general view of the central part of Tottanfjella, looking north-east from the summit of "Peak A" towards "Peak B" (in the foreground), "Peak K" (left) and the ridges associated with them.

PREVIOUS WORK

Between 19 January and 15 February 1939, members of the German *Schwabenland* expedition under the command of A. Ritscher flew over 300,000 sq. miles (776,700 km.^{2}) of Dronning Maud Land between long. 14°W. and 20°E., reaching approximately lat. 75°S. The range described here was named "Kottas" by him, and another somewhat larger mountain range to the north was named "Kraul". The photographs taken on these flights were not ground-controlled and many of them were destroyed during World War II.

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The Norwegian-British-Swedish Antarctic Expedition, 1949–52, under the command of J. Giaever photographed a large area on flights from Maudheim. They flew as far west as long. 21°W. and as far east as long. 3°E., between lat. 70° and 75°S. Many of the photographic runs were ground-controlled, but for those flights over the area described here no ground control was available and only oblique photographs were taken. These included photographs of the whole range, the associated nunataks and a somewhat larger range to the north. The names, Heimefrontfjella and Vestfjella, were given to these two ranges and they correspond to the "Kottas" and "Kraul" mountains unofficially named by Ritscher. A small group of nunataks between these two ranges was called Milorgknausane.

During preparations for the Trans-Antarctic Expedition, 1955–58, Sir Vivian Fuchs in an "Otter" aircraft piloted by J. H. Lewis and accompanied by W. G. Lowe observed a range of mountains east of Halley Bay on 11 January 1957. They had flown from the Royal Society I.G.Y. Expedition station at Halley Bay on an approximate bearing of 110° mag. This mountain range was named Tottanfjella and oblique air photographs were taken; these confirm that while the range is an entity, both structurally and topographically Tottanfjella are a south-westerly extension of Heimefrontfjella and the name is used here in that sense.

On a dog-sledge journey for glaciological studies, D. A. Ardus and C. Johnson travelled eastwards from the Falkland Islands Dependencies Survey station at Halley Bay, spending 14–17 November 1961 in Tottanfjella. During this time photographs were taken, geological specimens were collected and glaciological observations were recorded (Ardus, 1964, 1965).

A reconnaissance journey similar to that of Ardus and Johnson was made from Halley Bay by G. Blundell and M. J. Winterton. During the period 30 November–10 December 1962 they visited Milorgknausane and the western end of Vestfjella where they took photographs and collected some geological specimens.

GEOMORPHOLOGY OF HEIMEFRONTFJELLA

Heimefrontfjella consists of three distinct blocks which are in different stages of dissection by erosional processes. Each of these is described separately below.

Tottanfjella

As described by Ardus (1964), Tottanfjella is composed of schists, well-foliated gneisses and amphibolites, and granites, forming a deeply dissected plateau escarpment. The trend of the general foliation in the rocks follows the same direction as Tottanfjella and the whole range. The rock outcrops form a series of peaks and ridges along a line approximately north-east to south-west. The original escarpment was probably formed by block-faulting but, because of erosion during a previous epoch coupled with present-day freeze-thaw denudation, this has been cut back so that Tottanfjella are represented by peaks and ridges normal to the original escarpment. The peaks and ridges are separated by wide ice-filled valleys which channel the ice from a higher level in the south-east (Amundsenisen) towards the lower north-west side. As Ardus has pointed out, the most important form of denudation at the present time is freeze-thaw action, which has broken the continuity of the ridges.

The control of topography by rock type and structure is well illustrated in Tottanfjella. The peaks terminating the north-western ends of the ridges are composed of hard, massive augen-gneisses, granite-gneisses or granites, while the narrow ridges are formed of schists and well-cleaved gneisses, which are more amenable to freeze-thaw action. The isolated nunataks north-west of the peaks are also composed of the harder rock types. Small-scale faulting and jointing have resulted in small cliff faces forming along the ridges and on the arêtes between the peaks. Throughout Tottanfjella the scree slopes are steep and the ice covers them to within a few hundred feet of the summits of the ridges.

Schytt (1961, p. 202) has established that the ice level in this part of Dronning Maud Land is generally stable at the present time, and his evidence suggests there is very slow ablation locally. Definite evidence on photographs from the 1939 German expedition showed the ice level was at one time 985 ft. (300 m.) higher than at present, and Schytt's (1961, p. 195) observations confirmed this. Bearing this in mind, it seems probable that the general form of Tottanfjella must have been caused at least in part by a previous erosion cycle. Recent freeze-thaw erosion is certainly responsible for the formation of the small but steep scree slopes, but the wide shallow valleys could not possibly have formed in this way. Traces of any previous erosion cycle are obscured by the snow cover and detritus, and it is not possible to say whether it was a normal subaerial or glacial cycle.

The tectonic control suggested by Ardus (in the sense that block-faulting was responsible for the general form of Tottanfjella) is confirmed by detailed geological mapping. Between Tottanfjella and the central part of Heimefrontfjella there is a major discontinuity of rock types. On each side of this wide valley there are thick successions of gneisses at the same height above sea-level, but these gneisses are completely different from one another. This fact, together with the marked difference in relief between the two blocks of the range, suggests large-scale block movement. It is thought that differential uplift occurred subsequent to the last phase of metamorphism. In Tottanfjella and the central part of Heimefrontfjella the general foliation direction and dip is the same, but the rock types and structures are quite different. Tottanfjella is characterized by small- and medium-scale isoclinal folding, whereas large-scale isoclinal and recumbent folds are a feature of the central part of the range.

The fact that Tottanfjella is far more deeply dissected than other blocks of the range can also be related to the concept of differential uplift. If the block forming Tottanfjella was uplifted either earlier or higher than the remainder of the range, then subaerial erosion would have been relatively more severe. This suggestion is supported by rocks of the highest grade of metamorphism (possibly the most deep-seated rocks) being exposed in Tottanfjella.

Localized erosional features. The peaks and ridges in Tottanfjella are characterized by scarp erosion processes which have given rise to steep scree slopes. This steepness of the topography has generally prevented the formation of features associated with permafrost, such as patterned ground. There is evidence of an erosional process other than freeze-thaw at several localities in Tottanfjella. Here, granular quartz-feldspar-gneisses have extremely pitted surfaces (Fig. 3) with depressions varying in size from 6 in. to 2 ft. (15 to 61 cm.) in diameter and with an approximate depth of 3–9 in. (7·6–22·9 cm.). These surfaces face the direction of the prevailing wind at various angles and the largest cavities occur on either vertical or sub-vertical

Fig. 3. Erosional cavities on a wind-exposed surface in Tottanfjella, 3·5 miles (5·6 km.) south-west of "Peak H". The hammer head is 8 in. (20 cm.) long.

faces; an example almost 5 ft. (1·5 m.) long and 2 ft. (0·6 m.) deep was found on one such face. The general pattern of such cavities becomes more complicated when they intersect; where the coarser-grained rocks possess a well-defined lineation, the cavities appear to develop an elongated outline and intersection between them is more common.

The origin of such cavities in the Antarctic has been discussed by Van Autenboer (1964*a*, p. 96–99; 1964*b*, p. 25–30), who concluded that the wind is not an erosional agent but that it acts as a transporting agent, because similar cavities occur on faces of all aspects in the Sør-Rondane, Dronning Maud Land.

In agreement with the conclusions of Wilhelmy (1958) and other authors, he has suggested that the processes which lead to the break-down of rocks in this way are "strong insolation, excessive dryness, and the resulting chemical weathering and concentration of the free salts, and strong wind action". He has further suggested that limited freeze-thaw possibly plays a part.

In Heimefrontfjella all the cavities are found on exposed faces, and this emphasizes the role of the wind in a transporting sense, both as the medium by which particles of sand and snow enter and possibly increase the size of the cavities by abrasion, and in the more important role of removing debris.

The rock type clearly dictates the extent of erosion; in the coarse augen-gneisses the highly shattered crystals of feldspar would be very amenable to erosion by the processes mentioned above. Cavities produced by the break-down of the augen could become enlarged by the scouring action of the wind's load and other physical processes, and the removal of the debris by the wind would expose other parts of the cavity to further erosion.

The central block

This block is the largest, most massive and highest part of Heimefrontfjella, and the two highest peaks are situated near its western end (Fig. 4). These are "Peak F" and "Peak S" which are, respectively, 9,500 ft. (2,895 m.) and 9,650 ft. (2,940 m.) above sea-level. The north-western edge of the block is formed by a pronounced scarp which follows the general

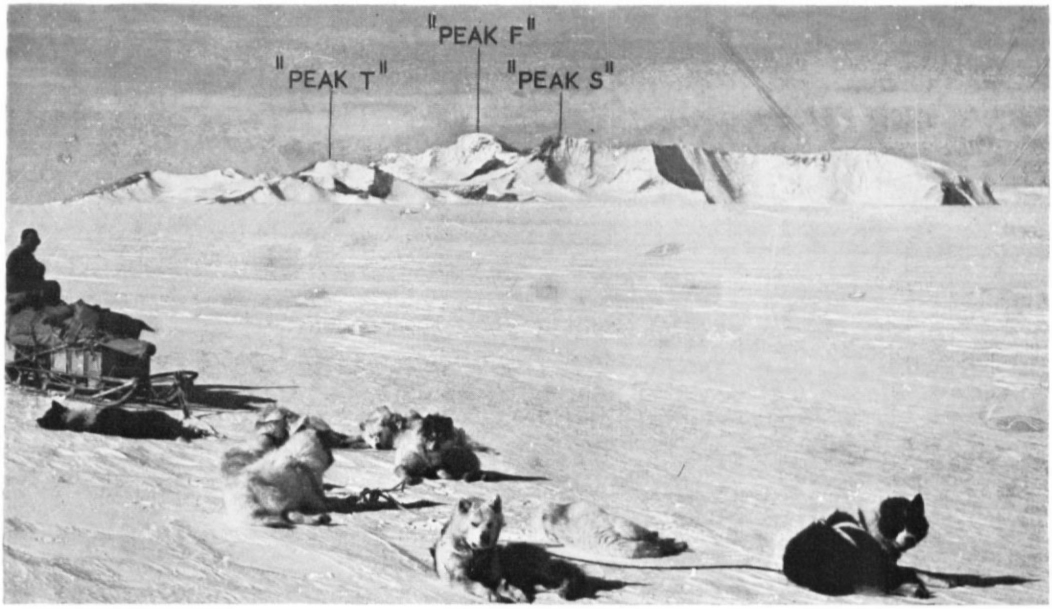

Fig. 4. A view towards the south-east to the highest point of the central block of Heimefrontfjella with north-trending ridges. The western face and cirque mentioned in the text (p. 53) is on the right of the photograph. (Photograph by G. T. Bowra.)

trend of the range and, although deeply embayed, it is not broken for its length of approximately 17 miles (27·4 km.).

The south-western end of this block is defined by an embayed, snow-covered rock face broken near its centre by a glacier occupying a zone of probable structural weakness. This rock face narrows and drops in height towards the south-east where its extremity is covered by the higher ice plateau.

The north-eastern end of the block is almost completely formed by a steep snow slope and ice falls, with the exception of two steep ridges and several small rock exposures. At its eastern end this steep snow slope bends sharply to the south-west and thus forms the southern limb of the block.

All but the highest peaks of this block are covered by a thin ice cap which rests on a gently undulating surface. This ice cap merges with Amundsenisen to the south by way of ice falls, and south of "Peak S" by a gentle snow slope.

Arêtes, reaching a length of 2 miles (3·2 km.), trend from each of the main faces of the block. In some cases these bifurcate at their extremities and small isolated nunataks occur beyond them. At the north-eastern end of the block there are two ridges which extend 3 miles (4·8 km.) in length from the face of "Peak V" to "Peaks X and Y", respectively. Extending north-westward from these peaks is a series of nunataks, the farthest of which is 11 miles (17·7 km.) from the main face of the block. Field observation has shown there is strong evidence that these long ridges and the line of nunataks are caused by sub-vertical thrust-faulting. East of these features there are no nunataks until the eastern part of the range is reached, strongly suggesting that this line of nunataks is a remnant of an interfluve belonging to an earlier glacial cycle.

Erosion by freeze-thaw action is also prominent on the ridges and arêtes but the ice cap seems to have offered some degree of protection to the underlying rock against this form of erosion, and the spectacular splintered crags are not as well developed as in Tottanfjella. Similarly, the control of topography by rock type is not as well marked in the central block as in Tottanfjella, because the gneisses comprising the central block are all of a similar hardness. There is, however, a greater degree of structural control, and the three ridges trending south-west from "Peak Q" are the axial zones of large overturned anticlines and the ice-filled valleys between them are probably the corresponding asymmetric synclines.

At the south-western end of the central block there is a well-developed cirque, with snow-covered faces and with arms approximately 0·75 miles (1·2 km.) apart at their lowest points. The *névé* in this cirque drains down a steep crevassed slope into the main drainage glacier between Tottanfjella and the central block.

No examples of local erosional processes other than freeze-thaw were recorded in this area.

The north-eastern block

The north-eastern block of Heimefrontfjella was not closely examined but its form is similar to that of the central block. Although it is smaller than the central block and has a lower surface altitude, the north-eastern block has a scarp of similar aspect to that of the central block but it has even deeper embayments. In several places this embayed scarp has been cut back by the ice cap, and towards the south-west this erosion has resulted in the exposure of isolated nunataks along a line of ice falls. Many of the ridges extending north-westwards from the scarp have considerable deposits of moraine near their terminations. These moraines in Heimefrontfjella are discussed on p. 55.

A prominent feature, which occurs only in the north-eastern block, is a capping of gently dipping sedimentary and volcanic rocks. These rocks unconformably overlie the metamorphic rocks which form all the other exposures and where they are exposed they have given a characteristic shape to some of the promontories and peaks.

Outlying nunataks

Apart from the nunataks which are morphologically part of the ridges and which are referred to above, there are two main groups of nunataks in the vicinity of Heimefrontfjella. Neither of these groups has been visited by the author but a careful examination by binoculars from "Peaks Q and X" has revealed their salient details. The largest nunatak is approximately

30 miles (48 km.) south-east of the eastern end of the central block of Heimefrontfjella. It has a steep north-west face rising 200–300 ft. (61–91 m.) above the ice level and it appears to be composed of a "basaltic rock". Its flat top has a thin snow cover and it has no visible arêtes or ridges; the nunatak appears as a small block projecting through Amundsenisen. There are two smaller nunataks several miles south-east of this one.

Approximately 45 miles (72 km.) east of the north-eastern block of Heimefrontfjella is another group of nunataks which has not been visited and whose form is not clear. It is possible that this nunatak group is more closely related to the mountain ranges north-east of Heimefrontfjella than to Heimefrontfjella itself.

Apart from the "basalt" block in Amundsenisen, no other mountains are visible to the south of Heimefrontfjella.

GLACIAL GEOMORPHOLOGICAL FEATURES

Glacierization

The main ice forms in Heimefrontfjella are those that would be expected in a small range of mountains interrupting the seaward flow of ice from the polar plateau. Drainage glaciers occupy the two major valleys and elsewhere smaller ice streams separate the ridges from one another. Around each end of the range there is evidence suggesting more rapid flow of the ice than elsewhere; snow slopes are steeper, and chasms, crevasses and ice falls are more pronounced. Indeed, the two main drainage glaciers of the range slope gently from Amundsenisen to the north-west and join the lower ice level with only a slight change in slope. It is only the heavily crevassed nature of these glacier tongues that suggests ice flow from the south-east to the north-west.

The thin ice cap of the central block is drained by small local glaciers to the general ice level to the north-west, and to the main drainage glaciers. These local glaciers are arranged in a radial pattern and they are much steeper than the main drainage glaciers.

Away from the range the snow surface is not crevassed and it is typified throughout the year by sastrugi 1–2 ft. (0·3–0·6 m.) high. At present no detailed information is available on either the thickness of the inland ice or the polar plateau in the vicinity of Heimefrontfjella.

Blue ice-fields occur in sheltered areas on the north side of the range. They correspond closely to the descriptions given by Schytt (1961) and Van Autenboer (1964*a*). The best example recorded is between the two long ridges at the eastern end of the central block (Fig. 1). The undulating surface is due to snow accumulation below gaps in the ridges. These accumulations have the blue rippled appearance of the rest of the ice-field on their northern sides, but on their south-facing slopes they are white, although strongly crystalline. The remainder of the blue ice-field has scalloped and rippled surfaces which, in the opinion of various authors, are indicative of a negative regime. Vertical cracks a few millimetres in width and arranged at right-angles to one another are present throughout these ice-fields. They have been attributed by Schytt (1961) to have been one of the results of tension. The loud reports heard during the evenings (when temperatures dropped markedly) are thought to be related to tensional forces.

Cryoconite holes are common; where morainic material is present near the surface, local melting occurs to give irregular areas of clear ice. Running melt water was seen in the warmest months of the year around blocks of detritus on the surface.

In his discussion on the mechanism responsible for the formation of blue ice-fields, Van Autenboer (1964*a*, p. 88) has concluded that erosion of the snow surface has revealed older glacier ice, forming modern blue ice-fields. The blue ice-fields in Heimefrontfjella appear to be identical to those described by him, with possibly some exceptions. It is thought that there are several small areas of blue ice in Heimefrontfjella where surface melting and subsequent re-freezing of the melt water and accumulated snow provides the best explanation for their existence. One of these blue ice patches occurs as a small accumulation in the bottom of a large windscoop below the northern face of "Peak V". One side of the windscoop is formed of solid rock and scree, while the other is composed of snow and rock debris. This patch of blue ice is, however, surrounded *entirely* by scree and there is no evidence of any glacier ice below it. Local surface melting has been observed in this area and it appears to be the only possible explanation for the formation of the blue ice patches.

Within some areas of morainic material there are "pools" of completely clear ice with flat non-rippled surfaces. This ice appears to have resulted from the accumulation of water from melt streams in sheltered areas.

The largest blue ice-field contains long lines of moraine (Fig. 5), and it is believed that they represent the tops of moraine ridges resulting from an earlier glacial epoch which have been exhumed by surface ablation of the blue ice-field.

Fig. 5. A blue ice-field between the two long ridges at the eastern end of the central block of Heimefrontfjella, showing the long line of moraine and isolated scree blocks described in the text.

Near these blue ice-fields, in relatively sheltered areas but usually some distance from rock exposures, the snow surface is indented by large (3–20 ft.; 0·9–6·1 m.) depressions a few inches deep and with overhanging edges. Since they occur in sheltered areas and their shape apparently has little connection with the prevailing wind direction, it is thought that they represent areas of temporary ablation; indeed, the heavy snowfalls towards the end of the summer obliterated them.

Wind-formed ice features

Some of the more spectacular ice features observed in Heimefrontfjella occur around exposed nunataks and peaks on ridges. On the windward sides of these features the snow level rises sharply and it is separated from the exposed rock by a deep windscoop. These windscoops often reach a depth of 100 ft. (30·5 m.) and the snow cliffs usually have impressive cornices which periodically break off and fall to the bottom of the windscoop. Radiation reflected from the rock face and from blocks of detritus cause local melting. The windscoop extends around the nunatak and immediately in its lee; a blue-ice valley forming down-wind is flanked on either side by "tailed" snow dunes which may extend for 0·75 miles (1·2 km.). With irregular-shaped nunataks, this pattern is not followed exactly and one of the snow dunes may be absent, or the windscoop may become filled. It has been observed that for small nunataks (such as "Peak J") elongated normal to the prevailing wind, the result was a single snow dune in the lee extending to the summit of the nunatak (Ardus, 1965, fig. 9).

Frost-action

The action of freeze-thaw on exposed rock faces, which has already been discussed, is responsible for their morphology.

A search for permafrost features was made throughout Heimefrontfjella. The general absence of features such as patterned ground in the range can be attributed to the steepness of the scree slopes and the coarseness of the detrital material. There were two areas, however, where permafrost features were recorded. On a gentle scree slope near the end of one of the ridges from the central block there are some very poorly preserved stone polygons very similar in appearance to those illustrated by Schytt (1961, pl. 9c). They are completely unsorted and have dimensions between 5 and 10 ft. (1·5 and 3·0 m.). Photographs of the surface in this area fail to show the feature satisfactorily because of the snow cover and the unsorted nature of the material.

Another pattern was seen in scree detritus on the southern slopes of a large nunatak at the eastern end of the central range (Fig. 6). The material forming the scree slope is coarse, angular and of one rock type. The boulders are up to 6 ft. (1·8 m.) in length and 4 ft. (1·2 m.) in width. On this slope, which is approximately 150 yd. (137·2 m.) from top to bottom, there is a network of gullies which follows a dendritic pattern. The scree mounds, which occur between these gullies, are up to 20 yd. (18·3 m.) across. Washburn (1956), in his classification of patterned ground, has described many sorted and unsorted forms, and the type of patterning described here does not correspond to anything he has discussed. The sizes of both the blocks and the mounds between the gullies, which are approximately 2 ft. (0·6 m.) in depth and with a V cross-section, suggest that an alternative explanation should be sought. This pattern of gullies represents drainage channels for melt water which forms during the warmest months of the year. At this time, running water is clearly audible on these scree slopes, suggesting that beneath the scree surface there are many small streams.

Fig. 6. Part of a scree slope on a nunatak north of the eastern end of the central block of Heimefrontfjella. The origin of the patterning on this slope is discussed in the text.

It is considered that under these conditions running water below the scree could have two possible effects:

i. To produce a localized area where there would be an increased amount of freeze-thaw action.
ii. To remove and transport some of the eroded material.

These two processes would eventually lead to slumping of the overlying material thus producing gullies. The variation in the configuration of the scree slope is responsible for the somewhat erratic pattern of the gullies.

CONCLUSIONS

Heimefrontfjella is a small dissected range of block mountains which interrupts the northward flow of the Antarctic Ice Sheet towards the coast of the Weddell Sea. The tectonics, geological structure, rock type, and the thickness and flow of the ice have been responsible for its form. Its present morphology has largely resulted from freeze-thaw action superimposed on a previous erosional cycle.

The ice features of this area are in keeping with the morphology of Heimefrontfjella, its climate and geographical location.

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