INVESTIGATIONS OF PATTERNED GROUND AT SIGNY ISLAND, SOUTH ORKNEY ISLANDS: IV. LONG-TERM EXPERIMENTS

By M. J. G. Chambers*

Abstract. In 1962 a series of long-term experiments, designed to investigate the processes involved in patterned ground formation, was set up on Signy Island, South Orkney Islands. These sites were re-visited early in 1968 and the changes which had taken place during 6 years were analysed. Of particular significance are the rates of solifluction in areas of large sorted stripes, and the processes by which this sorting takes place. The availability of water throughout the summer months appears to be the major controlling factor here. Other experiments reveal the process and rate of formation of large sorted circles and polygons of the types encountered on Signy Island. There appears to have been some deterioration of miniature patterning during the experimental period, although the reason for this is unknown. Some assessment is made of the overall influence of periglacial activity on the landscape of Signy Island, although any quantitative solution to this problem must await a more detailed chronology of the glacial and post-glacial history.

During the Antarctic summer of 1961–62 a series of long-term experiments, designed to investigate the processes involved in patterned ground formation, was set up on Signy Island, South Orkney Islands. The environment of this small island group lying in the north-western sector of the Weddell Sea has been defined by Holdgate (1964) as maritime Antarctic. A full description of this environment relating to climate, soils, vegetation and periglacial activity, together with many of the results of the patterned ground experiments, has been presented in earlier papers (Chambers, 1966*a*, *b*, *c*, 1967; Holdgate and others, 1967). An opportunity of re-visiting Signy Island occurred at the beginning of 1968, and the present paper is concerned with reporting on several of the long-term experiments which by that time had been operating over a period of 6 years. In order to avoid repetition, frequent reference will be made to background information presented in the earlier papers.

Movement and Sorting in Large Patterns

Early in 1962 a series of white lines, each about 50 m. long, was painted across a number of large sorted stripes patterning a broad 10° slope. The local aspect was westerly, which meant that it received relatively high insolation and was therefore rendered snow-free early in the summer season. A semi-permanent melt stream, fed by sheltered snow patches higher up the slope, maintained part of the slope at saturation level. It soon became clear that this water supply was the critical factor in the rate of solifluction within the stone stripes. In the areas which thawed and drained rapidly during the early summer, little or no differential movement was observed between the coarse and fine parts of the stripes even after 6 years of observation. In the wetter sectors, however, where local melt water within the active layer was supplemented by a constant stream of water draining from higher up the slope, an average differential movement of 15 cm./yr. was observed between the fine and coarse parts (Fig. 1). It will not be many years before the stones comprising the line which once lay across the stripes are added to the coarse material parallel to them. In this way, rock fragments are sorted from the fines and added to the coarse stone stripes. The rate of this sorting is directly related to the rate of solifluction. There were other well-sorted stripes on this slope which, during 6 years, showed no active solifluction, indicating that some change of environment has taken place in the recent history of the island, thus bringing about a decrease in water supply to these areas of the slope. The steady ablation of permanent snow patches could account for this decrease. It is evident from the water-supply pipes installed by whalers in the early decades of this century that areas which were once reliable sources of large supplies of water are now no longer fed by substantial snow accumulations, except in the early weeks of summer when water is abundant everywhere.

If the segregation of coarse fragments from fine stripes described above was the only process operating on the slopes, the surface of the fines would soon be clear of large stones.

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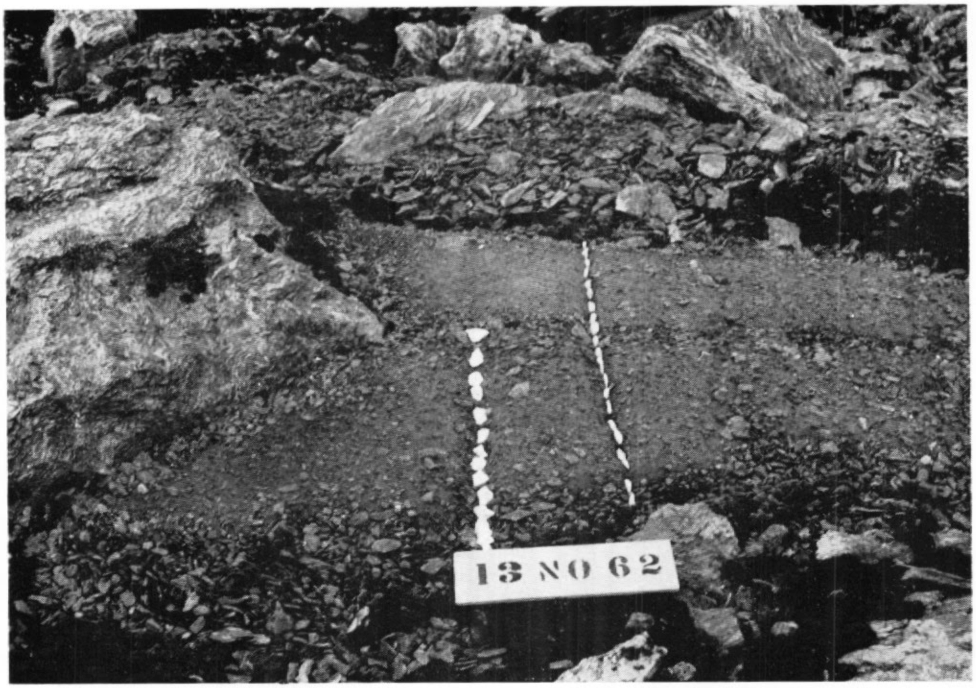
However, Fig. 1 shows that this is not the case, since even the most active stripes are covered by a mantle of rock particles ranging from a few millimetres to several centimetres across. It has already been demonstrated that stones of these dimensions are heaved up to the surface by frost-action within a large sorted circle (Chambers, 1967), but positive results at that time were confined to the upper 5 cm. of the fines through which the stones took 2 years to reach the surface. Owing to the rapid decrease of freeze-thaw cycles with depth, it was predicted on the basis of observed freeze-thaw frequency and moisture content that stones buried at 10 cm. would take 6 or 7 years to reach the surface. Examination of the experimental sites in 1968 confirmed this when the first two of the stones planted at 10 cm. were found at the surface. Comparing these results with earlier findings, it may be concluded that the rate of up-freezing accelerates as stones approach the surface in accordance with the increased frequency of freeze-thaw cycles. This up-freezing process also acts upon stones within the fine sector of large sorted stripes, constantly renewing the coarse material which is being swept to the edges of the stripe by solifluction. The speed and direction of a stone's upward movement in these circumstances will be the resultant of up-freezing normal to the surface and solifluction parallel to the surface.

Fig. 1. Differential movement between the fine and coarse sectors of large stripes; 15 January 1968. The date marker is 20 cm. long.

Another long-term experiment also designed to examine the movement of stones across the surface of a sorted pattern is illustrated in Fig. 2a and b. The site consists of an irregular mesh of large sorted polygons about 1·5 m. across, separated by areas of coarse bouldery debris completely devoid of fines. The centres are only partially active, the remainder being covered with small rock fragments and moss. In November 1962, white stones were planted in two lines across the centre of one of the polygons in an area of moist fines (Fig. 2a). After 6 years when the site was re-visited, it was found that the white stones had migrated outwards from



a

b

Fig. 2. a. Site 24. White stones planted across the fines of an irregular sorted polygon; 13 November 1962.
b. Site 24. Migration of the white stones towards the periphery of the fines; 9 January 1968.
The date marker is 20 cm. long.

the central fines to lie in a semi-circular formation against the surrounding coarse material (Fig. 2b). Some of the stones had moved as much as 30 cm. across the surface of the fines which exhibited no discernible gradient when unfrozen. It appears that this movement takes place just as the surface begins to thaw, when the top 1 cm. or so is turned to liquid mud, but beneath this the fines are still domed up by segregated ice lenses raising the centre of the pattern several centimetres above its usual level. This gradient created by differential frost heave and its influence on the outward radial movement of stones and fines has been described in detail in an earlier paper (Chambers, 1967). It is evident from Fig. 2 that even the strip of small stones dividing the two distinct cells of fines is subject to movement, and the white stones planted in this zone of coarser fragments have travelled at least 20 cm. towards the periphery of the major pattern. In an adjacent polygon, a group of much larger white stones was placed upon the central fines and these displayed a radial movement similar to that described above except that the rate of movement was lower. Unfortunately, this experiment (Chambers, 1967, p. 16) was destroyed some time after 1965 so the long-term results cannot be compared, but in 3 years none of the larger stones had moved further than 10 cm. If the mechanism for such radial dispersion outlined above is correct, the major factors which will influence the rate of movement are the amount of differential frost heave between the fines and the surrounding border, the quantity of water available at thaw, and the shape and size of the stones involved. It is unlikely that the frequency of short-term freeze-thaw cycles will have any effect on this rate as the necessary gradient is only produced after the freezing plane has descended for a considerable depth into the active layer and this does not occur except during the annual freeze-up.

The high rate of periglacial activity on Signy Island, involving both coarse and fine material, is illustrated in the study of a small solifluction lobe situated on a rocky hillside about 80 m. a.s.l. The surroundings consisted of a coarse bouldery mantle covering the local schist bedrock. Most areas were stable and covered with a mat of mosses and lichens in spite of the local 15° gradient. The lobe was also covered with rock fragments encasing a core of mobile fines but its comparative lack of vegetation cover made it stand out as a grey scar on the green hillside (Fig. 3). The rocky leading edge of the lobe was clearly encroaching upon the vegetation down-slope and, as loose rocks were removed at the front, dead moss could be found extending beneath the lobe indicating previous down-hill migration. Early in 1962 a line of white stones was placed across the lobe about 2 m. above the leading edge and the position of the foremost stones of the lobe noted. After 6 years the line of white stones had been considerably deformed (Fig. 3), so that the stones in the centre had moved down-slope as much as 120 cm. whilst those at each side were almost in their original positions. At the leading edge of the lobe, however, disturbance was far less and the overall advance was not more than 10 cm. This contrast in rate of movement between the leading edge and the material represented by the white stones can only mean that there is a steady accumulation at the front of the lobe, gradually building up the wall of stones. Already the surface gradient of the lobe is 5° less than the 15° slope around and it may be envisaged that ultimately the mobility of the lobe will be reduced by the diminished gradient. Alternatively, the moist fines may break through the wall of stones and continue down the hillside to form an isolated stone stream (Chambers, 1966*a*, p. 32). When a trench was dug across this lobe, the moist fines inside were found to extend 50 cm. deep in a stream 1·5 m. across. Although this core appeared to be one coherent mass, earlier experiments have shown that the mobility is concentrated at or near the surface, tailing off rapidly with depth so that below about 50 cm. the material is virtually stationary (Chambers, 1966*c*, p. 110).

Miniature Patterns

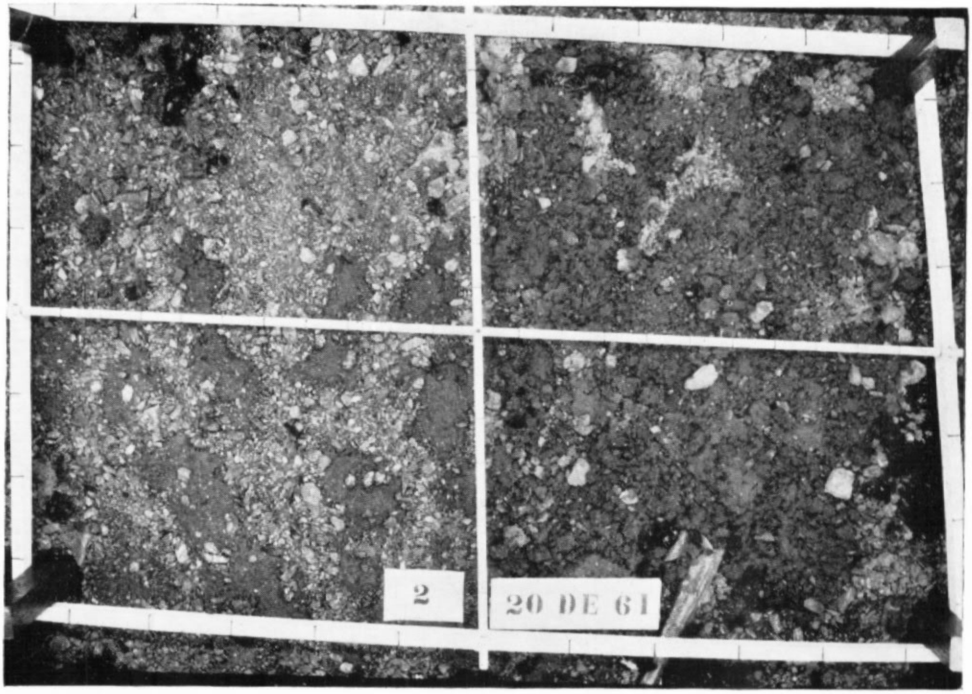
During the preliminary work on Signy Island a number of experiments was conducted on miniature patterns; the results of these have already been reported (Chambers, 1967). Some of these sites were still intact in 1968 but the overall impression given by a comparison of the photographs taken 6 years apart is rather disappointing. Patterns which were re-forming in 1965 appear to be less well sorted after the passage of a further 3 years. Site 2 illustrates this deterioration. The experiment involved the destruction of the patterning over one half of the site whilst the other half was left untouched (Fig. 4a). In 1964 the disturbed part of the site had

Fig. 3. Site 21. Mobile solifluction lobe on a 15° slope. The tape marks the original position of the white stones which now extend past the date marker; 26 January 1968. The date marker is 20 cm. long.

undergone fresh sorting, restoring it almost to its original condition, but a year later the appearance of numerous small stones at the surface of the fines had rendered the sorting less distinct (Chambers, 1967, p. 4). The 1968 photograph (Fig. 4b) shows that not only has the deterioration occurred on the disturbed half of the site but the untouched patterning on the other half of the site has also become less distinct. At first it was believed that this change was merely an apparent difference due to contrasting conditions of lighting and soil moisture, but careful comparison of the two photographs shows that the size of the patches of fines has actually decreased and the number of stones at the surface has increased. This tendency was also observed in other miniature pattern sites which suggests that some general influence has been at work. Possibly this change has resulted from unusual climatic events such as a series of heavy rainfalls. The other possibility is that the sorting of these small patterns undergoes some cyclic changes due to the difference in the rates of movement between stones and fines. Experiments of longer duration than these are necessary before such ideas can be tested.

Conclusion

The significance of all these periglacial forms of mass wastage on the overall landscape of Signy Island is difficult to assess for several reasons. Most of the major landforms of the island owe their form to glaciation and have only been modified by periglacial activity. The extent of modification is impossible to determine when so much of the debris has either been removed by subsequent glacial activity or covered by changing sea-levels. The area of the emerging Tioga Hill nunatak reveals strong evidence for an intense periglacial period prior to the presently receding glacial phase. From beneath the ice cap on the highest point of the island is appearing a mantle of shattered rock debris which in some parts shows distinct sorting and patterning. This material is still permanently frozen so it was not possible to determine its depth, but in several places it extended down for more than 1 m. and no bedrock was encoun-



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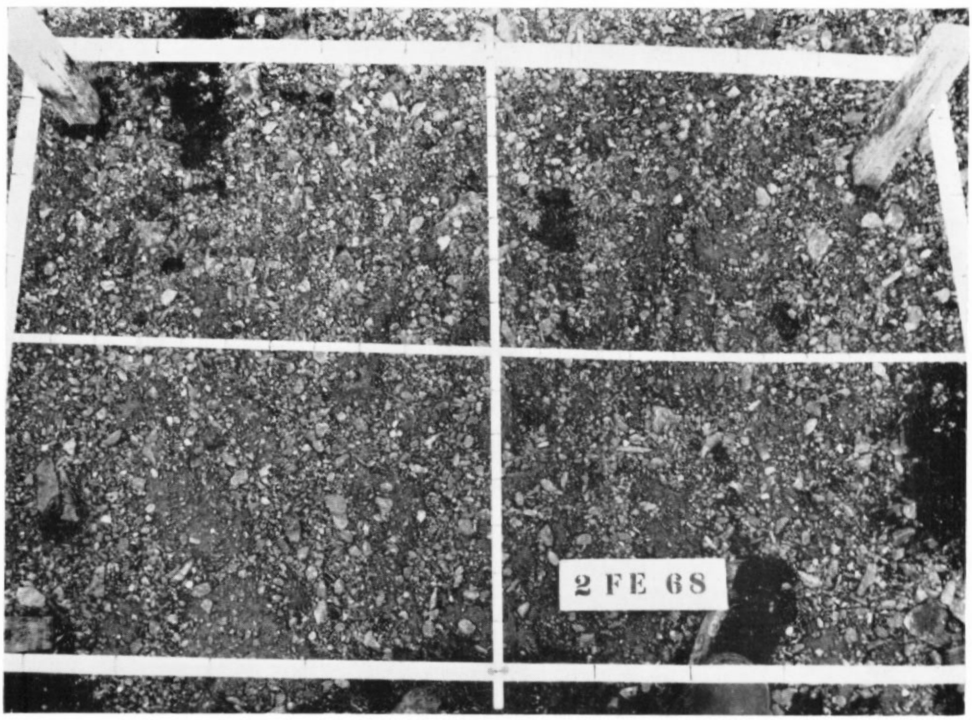

b

Fig. 4. a. Site 2. Irregular miniature patterning on the left. The right half of the site has been disturbed; 20 December 1961.
b. Site 2. Sorting is evident on the right half of the site but patterning has deteriorated on the left; 2 February 1968.
The date marker is 20 cm. long.

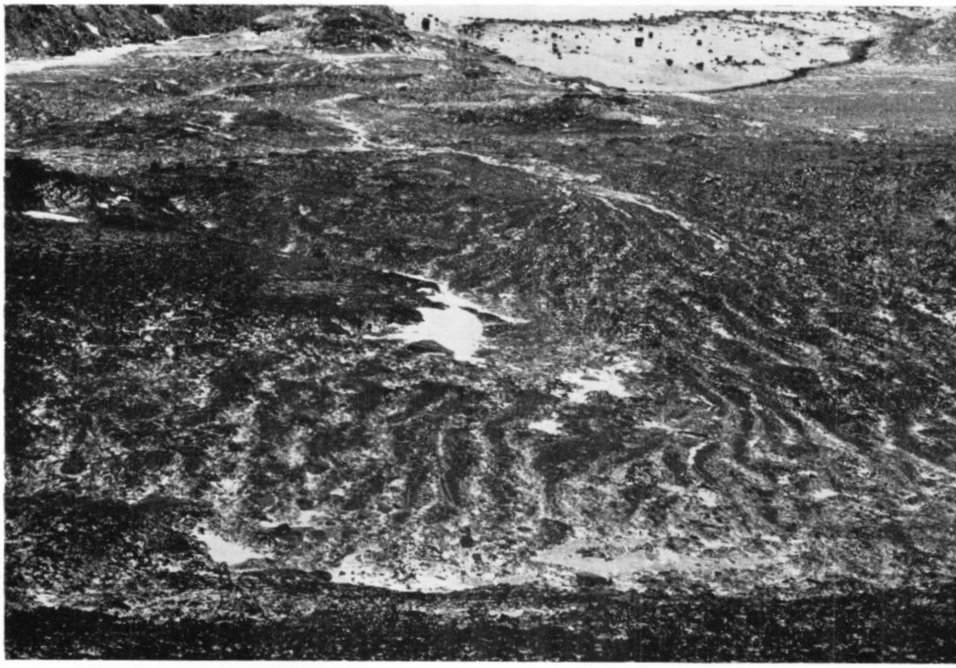

Fig. 5. Light snow shows up the sorting on a broad solifluction slope (8–15°); eastern flank of Moraine Valley, Signy Island.

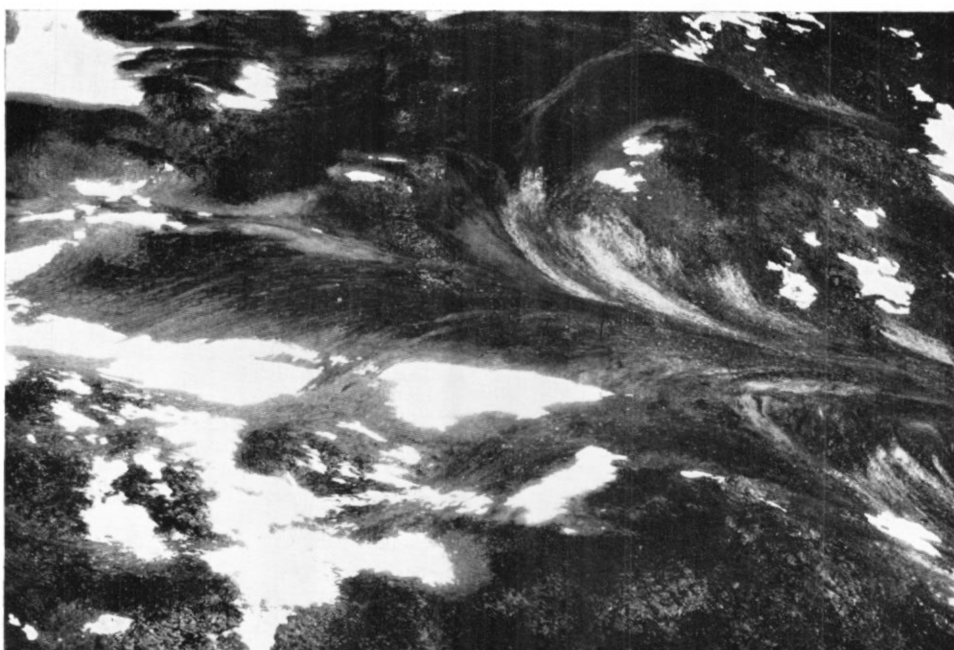

Fig. 6. A low-level aerial view of north-western Signy Island reveals stream lines of solifluction amongst flatter areas of vegetation and steep rock outcrops.

tered. It is clearly not morainic debris and therefore must be the result of weathering prior to being covered by ice. It is also evident that there has been no glacial erosion on this peak as the emerging patterning indicates the pre-ice surface. This mantle appears to be similar to deposits found on many of the highest parts of Signy Island and it suggests that much of the material moving down the slopes today is the product of an earlier phase of weathering.

That a great deal of debris is actually moving has already been demonstrated by numerous experiments, and scenes such as those shown in Figs. 5 and 6 are characteristic of the deglaciated areas. On the slope shown in Fig. 5 the entire surface is composed of irregular stripes winding down towards the sea. The volume of fines and coarser rocks involved in this process is enormous, although rates of movement vary with local conditions of slope angle, grain-size and availability of water. At the base of this slope a melt stream has sectioned the solifluction debris, revealing a semi-stratified accumulation of material partly filling the glaciated valley. Permafrost prevented the excavation of this fill but its depth is estimated at several metres. All of this has accumulated since deglaciation of the valley; it has been derived from a slope less than 500 m. in length in the relatively brief post-glacial history of the island.

The apparent stagnation of well-defined patterning indicates that there have also been changes in the local environment in the last few years, so that rates of movement recorded now do not necessarily represent the state of maximum solifluction. Knowledge of the glacial and post-glacial chronology of this area is so slight at present that the events may only be described in vague and relative terms, and there is a need for some absolute age determination before a more detailed pattern of geomorphic development can be presented.

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