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CRYOTURBATION DATA FROM SOUTH GEORGIA

Abstract

The movement of cryoturbate ground on a 21° slope at Grytviken, South Georgia was studied by observing the positions of stones resting on the surface and stakes buried vertically to depths of 10, 25 and 50 cm. The surface stones moved throughout the seven snow-free months an average distance of 47cm., but movement of the stakes, the amount of which varied with their depth of burial, took place only during the spring thaw and following heavy autum frosts. Movement was confined to the upper 25 cm. and was predominantly due to the formation and thawing of ice lenses within the soil.

INTRODUCTION

In a periglacial environment the principal agent of denudation is cryoturbation, a term introduced by Edelman, Florschütz and Jeswiet (1936, p. 332) for the kind of mass movement resulting from seasonal and diurnal freezing and thawing of the ground. In polar and alpine regions the effect of cryoturbation has been demonstrated by the bending of a lead cable placed vertically in the ground (Williams 1957) and by measurements of the orientations of rock fragments which show a streamlined relationship to the direction of slope (Lundqvist 1949; Hoppe 1952; Smith 1956). In the laboratory Tricart (1954) produced a transfer of soil on a 15° slope after 15 alternations of freezing and thawing temperatures.

The significance of cryoturbation as an agent of denudation cannot be judged fully without knowledge of the rate of movement under a given set of circumstances, and the depth of soil affected. Michaud (1950) and Kobayashi (1956) investigated the rate of organization of cryoturbate ground into polygonal or striped patterns, and Michaud (1950) also measured the motion of individual stones in a „rock glacier" (maximum 75 cm./year) and in talus (maximum 225 cm./year). In Norway Williams (1957) estimated a minimum advance of 0,3 cm./year of grass-covered terrace on a slope of 20° to 30° and quotes a rate of 50 cm./year measured by Dahl.

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An opportunity to undertake long-term observations of cryoturbation arose when the writer was glaciologist to the Falkland Islands Dependencies Survey in South Georgia during the International Geophysical Year. The observations reported cover the year April 1957 to March 1958.

South Georgia is a mountainous island in the South Atlantic Ocean in latitude 54° S.; longitude 36° W. Climatic records have been kept at Grytviken since 1905 from which the following data have been extracted:

Mean annual temperature	+ 1,7° C
Mean temperature for January	+ 4,7° C
Mean temperature for July	— 1,5° C
Mean annual precipitation	1395 mm

The island is heavily glacierized but in the neighbourhood of Grytviken, where the elevation of the firn line is about 450 m., there are considerable areas of ground outside the glacier margins where the fissile greywacke bedrock and morainic surface deposits are exposed to the action of frost.

SITE

A site was chosen for cryopedological observations at an altitude of 120 m. and two kilometres south-west of Grytviken meteorological station. The surface of the ground slopes 21° towards the south-east and is devoid of vegetation except where a few stones are encrusted with lichens. Half of the surface is bare soil broken by a polygonal pattern of desiccation cracks while the remainder is covered with an open textured rubble containing rounded and striated as well as weathered, angular rock fragments. These rubble areas are arranged in rough stripes parallel to the line of slope and are up to a metre in width. The water table is at a depth of at least two metres and probably much deeper. Beneath the surface the soil is a light brown, fine-sandy loam with a friable, cloddy structure and abundant boulders. The uppermost 20 cm. is more orange in colour recalling the B-horizon of a podzol, and it is probable that the site has been colonized by a moorland plant association which was more widespread before the climatic deterioration of the past few centuries.

The greywacke bedrock was encountered at a depth of 1,5 m. It was remarkably weathered and it was possible to dig through it for a further 50 cm.

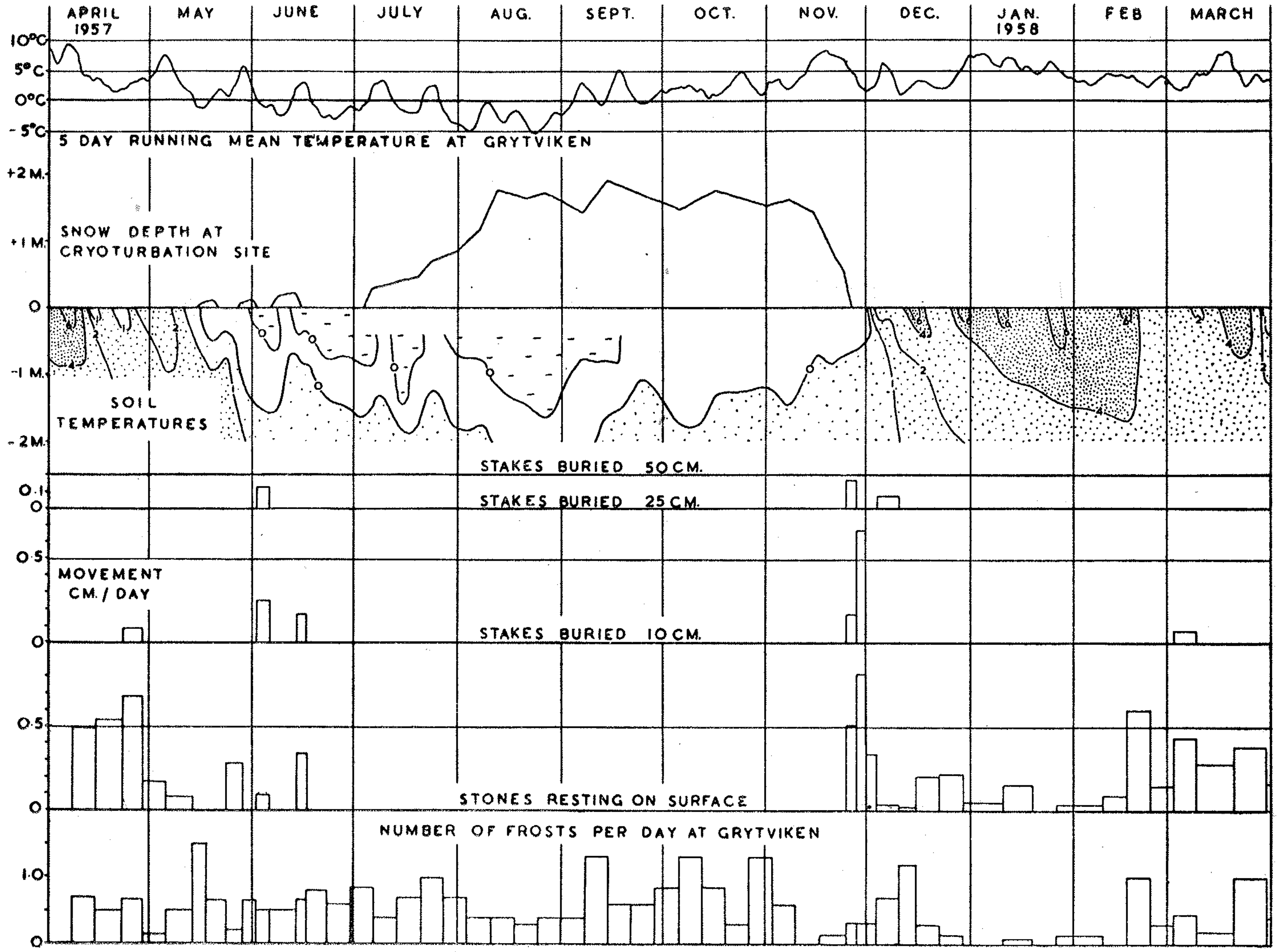

Fig. 1. Soil temperature and cryoturbation data from South Georgia

a. temperature at Grytviken, 5-day running means; b. depth of snow at cryoturbation site; c. soil temperature; d. rate of movement in cm./day of (I) stakes buried to 50 cm., (II) stakes buried to 25 cm., (III) stakes buried to 10 cm., (IV) stones on the surface of the ground; e. daily frequency of frost at Grytviken

METHODS

Fifteen wooden stakes were buried vertically in the ground, five to a depth of 50 cm., five to 25 cm. and five to 10 cm., each one projecting 3 cm. above the surface. In addition twenty numbered stones about 10 cm. in maximum diameter were grouped on the surface. Periodically the position of each stake or stone was found to an accuracy of ± 1 cm. by measuring with a steel tape its distance from two fixed points on a rock outcrop. Nearby, ,,Rototherm'' bi-metallic thermometers were buried to depths of 5, 10 and 25 cm., while soil temperatures were also read at 50 cm., 1 m. and 2 m. by lowering a lagged thermometer down iron tubes buried to these depths.

Samples of frozen soil were taken from various depths in November and for each the quantity of ice was found by the difference in weight between the frozen and air-dried sample.

Orientations of the long axes of rock fragments (not the twenty numbered stones) were measured with a ,,Brunton'' compass-clinometer. One hundred poles were plotted from each locality on the lower hemisphere of a Lambert equal-area projection and the concentrations of poles found by contouring (fig. 2).

OBSERVATIONS

In fig. 1 the results of the soil temperature and movement observations are shown together with the depth of snow covering the site, and the air temperature (5 day running mean) and frequency of frost at Grytviken. A frost is an occasion when the pen of the thermograph, sited 1,5 m. above ground level, crosses the 0° C isotherm on its downward movement; it should be noted that the meteorological station is situated in a hollow and experiences frosts which may not affect the mountainsides above (Mansfield and Glassey 1957, p. 24).

Some figures for total amounts of movements during the year are listed in Table I.

Table I

	Max. yearly movement (cm)	Min. yearly movement (cm)	Mean
Stakes buried to 50 cm.	0	0	0
,, ,, ,, 25 cm.	5	2,5	3
,, ,, ,, 10 cm.	5	2,5	5
Twenty numbered stones on surface	71	25	47

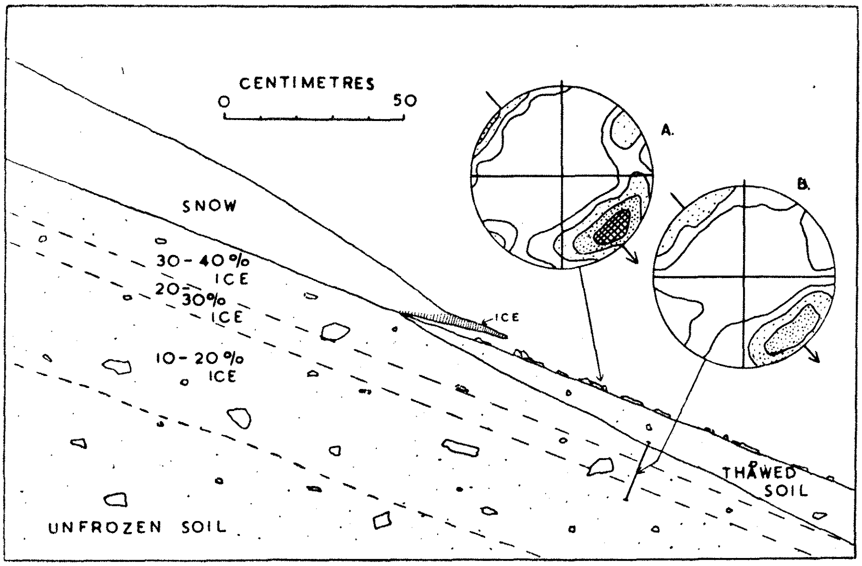

Fig. 2. The lower edge of a melting snow-patch in spring

The amounts oy ice at various depths in the frozen soil are marked and also the fabric diagrams of the block material on the surface and between 8 and 25 cm. (contours 2, 4, 8 and 12 poles per 1%; arrows mark the direction of slope)

The conditions at the lower edge of a melting snow-patch in the late spring are shown in fig. 2 along with fabric diagrams of the block material on the surface and between 8 and 25 cm., and the quantities of ice at various depths in the frozen soil. The results of these ground-ice analyses are listed in Table II.

Table II

Horizon	Ice as weight % of frozen soil
0— 7 cm.	34%
10—15 cm.	32%
18—28 cm.	15%

DISCUSSION

Movement both of the stakes buried in the soil and of the surface stones is shown to take place only during the seven snow free months December——June. During this period a week seldom passed without some of the stones moving one or two centimetres. This independent movement of stones is described as rock creep by Sharpe (1938) and it is accounted for by the growth of ice crystals beneath the stones lifting them perpendicularly to the surface and then collapsing with a slight down-slope component when the ground thaws (Taber 1930). The greatest movement of a single stone was 36 cm. in six days; it was found upside down and presumably it had rolled this distance after thawing had released it from a position of instability. The periods of movement corresponded to frost occurrences, and it was found that one heavy frost was more effective than a number of mild ones, although it has not been possible to express this relationship graphically. Movements of stones were also recorded during periods without frost but when there had been heavy falls of rain.

The stakes buried to a depth of 50 cm. remained stationary throughout the year, but those buried to 25 cm. and 10 cm. moved during the spring thaw and following heavy frosts during the autumn. Their displacement points to soil creep (Sharpe 1938) in the upper decimetres of the ground.

In mid-November the quantity of ice in the soil (table II) was greater than the 10% that might be absorbed by its internal surfaces, and in an excavation it was seen that the excess ice had segregated into layers a few millimetres thick and parallel to the surface of the ground. The vertical displacement caused by this ice (h) and the downslope displacement resulting from its thawing ($h.\ tang\ \alpha$) have been calculated for different depths in Table III. It is assumed that the specific gravity of moist soil is 2,2 and that 10% of the ice represents water normally held by capillarity.

Table III

Depth cm.	*h*. Frost heave beneath this depth (cm)	*h. tang a*. Downslope component resulting from thaw (cm)
0	9,5	3,6
5	6,6	2,5
10	4,4	1,7
15	2,7	1,0
20	1,0	0,4

The average movement recorded during the thaw of this ice, between 25 November and 4 December 1957, was 1,0 cm. for the stakes buried to 25 cm., and 2,5 cm. for those buried to 10 cm. corresponding to the calculated values at half the depths of burial. This suggests that the motion of each stake results from the mean of forces acting along its lentgh. The fact that many were tilted at the end of the observation period indicates a velocity increasing towards the surface. The immobility of the stakes buried to 50 cm. points to a maximum downward limit of movement of about 25 cm.

In the two orientation diagrams the concentrations of poles show that there is a tendency for the stones to lie parallel to and dip concordantly with the line of slope, a relationship already found to result from the creep process in cryoturbation (Smith 1956).

An interesting fact emerging from the soil isotherms is the blanketing effect of the snow cover which produces a slight warming in the upper layers of the soil as the following figures show:

Estimated annual mean air temperature at site	1,3° C
Annual mean temperature at 25 cm.	1,5° C
,, ,, ,, ,, 50 cm.	1,4° C
,, ,, ,, ,, 1 m.	1,3° C
,, ,, ,, ,, 2 m.	1,3° C

The steep inclination of the isotherms in spring and autumn is noteworthy. In autumn they plunge sharply as melt-water from early snowfalls percolates through the ground, while in late spring, when the ground is relieved of its snow cover and suddenly exposed to the sun at almost its highest elevation, they rise as steeply.

SUMMARY

A study of cryoturbation in South Georgia has shown that it takes place only during the snow-free months. Two forms of movement were examined, soil creep causing an *en masse* movement to a depth of 25 cm. which took place in the spring and following heavy frosts in autumn, and rock creep or the independent downslope movement of stones resting on the surface which occurred throughout the snow-free period. Both kinds of movement result when segregations of ice within the soil or beneath the surface stones collapse upon thawing.

References

Edelman, C. H., Florschütz, F., Jeswiet, J. 1936 — Ueber spätpleistozäne und frühholozäne kryoturbate Ablagerungen in den östlichen Niederlanden. *Verh. geol.-mijnb. Genoot. Ned. Kolon.*, Geol. Ser., Deel 11; p. 301—336.

Hoppe, G. 1952 — Hummocky moraine regions with special reference to the interior of Norrbotten. *Geogr. Annaler*, Bd. 34; p. 1—72.

Kobayashi, K. 1956 — Periglacial morphology in Japan. *Rapp. Comm. Morph. Périgl. UGI, Rio de Janeiro 1956*; *Biuletyn Peryglacjalny*, nr 4; p. 15—36.

Lundqvist, C. 1949 — The orientation of the block-material in certain species of flow-earth. *Geogr. Annaler*, Bd. 31; p. 335—347.

Mansfield, A. W., Glassey, S. D. 1957 — Notes on weather analysis in the Falkland Islands Dependencies, Antarctica. *Falkland Islands Dependencies Survey Scientific Reports*, no 16; 27 pp.

Michaud, J. 1950 — Emploi de marques dans l'étude des mouvements du sol. *Rev. Géomorph. Dyn.*, vol. 1; p. 180—189.

Sharpe, C. F. S. 1938 — Landslides and related phenomena. New York, Columbia University Press; 137 pp.

Smith, J. 1956 — Some moving soils in Spitsbergen. *Jour. Soil Sci.*, vol. 7; p. 10—21.

Taber, S. 1930 — The mechanics of frost heaving. *Jour. Geol.*, vol. 38; p. 303—317.

Tricart, J. 1954 — Premiers résultats d'expériences de solifluxion périglaciaire. *C. R. Acad. Sci.*, t. 238, Paris; p. 259—261.

Williams, P. J. 1957 — Some investigations into solifluction features in Norway. *Geogr. Jour.*, vol. 123; p. 42—58.