Sten Rudberg
Göteborg

A REPORT ON SOME FIELD OBSERVATIONS CONCERNING PERIGLACIAL GEOMORPHOLOGY AND MASS MOVEMENT ON SLOPES IN SWEDEN *

Swedish papers on periglacial problems are not numerous in post-war time. To be mentioned are the finds and studies of fossil periglacial features in southern Sweden by G. Johnsson (1956, 1958, 1959), notably of ice--wedges and frost-folding of types well known from continental Europe. As regards recent periglacial activity there is no more thorough study, dealing with the problem as a whole. The classical paper by B. Högbom (1914) is still the most representative. A general survey in popular form is found in a textbook by G. Lundqvist (1949). Recently published papers have generally treated selected periglacial problems. The actual stage in Swedish periglacial research work is briefly reported by Rapp & Rudberg (1960). The present paper is an addition to that report, mainly in the form of selected observations from the author's field of interest.

The regional distribution of recent periglacial phenomena is, however, dealt with in a number of unpublished studies (started on the author's proposal), most of them written by students for their examination in geography (Dep. of Geography in Uppsala and Göteborg). The first attempt was made 1945, the latest contributions have been given 1960.

These studies give detailed information on the frequency of periglacial phenomena within small mapped areas. The main interest except of the pure description has been the environment of the observed periglacial features, e.g. altitude, slope, bedrock, grain-size, vegetation, snow-cover etc. In the latter studies a more exact mapping of the total area has been pursued — by means of measured sections or coordinate-lines. In that respect the investigations have started to pass from a qualitative stage to a more quantitative. The special difficulties, when working with a staff

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* This paper is slightly modified from one of the author's introductory lectures at the Abisko symposium. Some new investigations are referred to and new observations added.

of young people with different qualifications, are in this case the often indistinct terms and the many transitional forms as are also the absence of generally accepted methods of making periglacial maps.

The areas investigated by the students are scattered within the mountain area from the sandstone fjells in northern Dalecarlia to the Abisko mountains — with some concentration to the latter area, the Tärna region in Västerbotten and northern Dalecarlia. The highest mountains, the low mountain of the Köli area and the isolated small mountains in the Archaean part of the country have hitherto only been paid little attention.

A map, redrawn from the maps of two of the student groups is presented here as a special plate (fig. 1).

The classification system of Beskow (1930) is generally used.

So far the numerous different observations have not been collected in a general survey. For that purpose further experience is required.

The following account of observations — concerning weathering, assorting processes and down-slope movement are gathered from the studies mentioned above and from the author's personal experience.

The observed periglacial phenomena are grouped in the same three climate-morphological zones as in the report by Rapp & Rudberg (1960): (1) The "block-field" zone or frost shatter zone, (2) The tundra zone, (3) The forest zone.

THE FROST-SHATTER ZONE

Frost-weathering is everywhere visible, where outcrops are found. Well preserved *roches moutonnées* are not numerous. Outcrops are, however, often very few except for steep slopes. The area of naked rock sinks approximately below 5% of the total area in many waste, flat-lying block-fields. Moderately steep and gentle slopes and most flat areas are covered by boulders, blocks and stones, to a high degree originating from frost-weathering *in situ.* Such autochthonous block-fields (according to the terminology of B. Högbom, 1926) with angular debris of the same composition as the solid rock at the place should be distinguished from block-fields mainly built of material of morainic origin, with more weathered forms and more varying in rock composition. As a whole the autochthonous block-fields seem to be by far the more frequent (e. g. within areas mapped in the Tärna region by: Jonasson, J. & Jonasson, M. 1960; Lomander & Werner 1960; Karlsson & Larsson 1960; Nömm & Severinsson 1960). Many block-fields are of mixed type, notably within the lower parts of the frost-shatter zone. But also at higher altitudes scattered erratics prove that even these block-fields are not entirely autochthonous. The erratics may, however, be extremely few in high altitudes. Several summits were supposed to be nunataks until some single erratic was found during later visits.

Fine-graned material in the surface layers is in the block-field zone restricted to small scattered earthy islets or to some flat depressions or broad crest. In such localities stone-polygons are developed, elongated on gentle slopes. The area of this small patches of fine material amounts probably not to five percent of the total area, perhaps not to more than some single percent within well-developed block-fields e.g. within amphibolite or migmatite areas. The percent may, however, be much higher within regions, where the weathering of the parent rock results in more fine-grained material, such as the mica-shist areas S of Lake Torneträsk.

As little work has been spent in detailed studies of block-fields, sections are very few. Of interest are therefore some observtions from some student groups. Below the surface, totally covered by coarse debris follows a bed poor in stones but rich in silty material measuring from a couple of decimetres to more than one metre in thickness. Observations are reported both from flat areas and gentle slopes (Jonasson & Jonasson 1960; Lomander & Werner 1960).

Indications of down-slope movement are numerous: stones on edge and often strongly pressed, indistinctly delimited stone stripes often terminating with bulging block-fronts. The lowest angle of slope, where signs of movement have been observed are c. 2—3° (Rudberg 1954, p. 207; Lomander & Werner 1960).

Quantitative data concerning down-slope movement are still not numerous. A few values were published by the author (1958). These values (from the Tärna area) and some new ones gathered within the Torneträsk area for the Abisko symposium are presented in table I.

The annual movement is obviously rather slow in the investigated localities. As to the mechanics of movement in stone stripes almost lacking fine material no facts have been gathered (the problem already observed by B. Högbom 1914). Of course the movement may in several cases be caused by pressure from debris richer in fine material higher up on the slope.

The lower limit of the block-field zone is as a whole not difficult to follow in the field. Roughly spoken it is at an altitude of about 1000—1200 m in the Abisko area (Söderlund 1959), 1100—1200 m in the Västerbotten mountains (Rudberg 1954) in the more detail-mapped Tärna region in the same province, 1150—1250 m and locally higher

(Annersten 1958; Jonasson & Jonasson 1960; Lomander & Werner 1960; Karlsson & Larsson 1960; Nömm Severinsson 1960). In each area investigated in more detail it proves that the lower limit fluctuates in height some hundred or two hundred metres. The limit is affected by down-slope movement of blocks and stones and by different edaphic influences as snow cover and notably the parent rock. The block-fields are as a whole better developed in areas with hard fissured rocks such as amphibolites, granites and quartzites. On a quartzite mountain in northern Dalecarlia (Mt. Nipfjället) the distinct limit may be found at an altitude as low as 1100 m. Sandstone mountains in the same part of the country have great block-fields down to below 900 m (Gedda 1960). In an area of the last-named type where the bedrock is both hard and homogenous over wide areas, however, it is not easy to distinguish block-fields originating from weathering of the under-lying solid rock from such as are produced by frost-heaving of boulders in the drift. In Finnish Lapland one of the small mountains in the group Nattastunturit has excellent block-fields at about 500 m above sea-level. It should be mentioned that the last-named localities in Dalecarlia and Finnish Lapland belong to regions with a local continental climate.

Table I

Site	Height above sea level in m	Slope-inclination	No of markings	Movement in cm/year			Period
				Mean	Max.	Min.	
Mt. Dalåive, Tärna							
Stone stripe free of fine material in the							
surface layers, A	1310	15°	46	1,6	3,0	0,9	1955—1957
surface layers, B	1310	25°	61	0,7	2,8	0	1955—1957
Mt. Låktatjåkko, Torneträsk area							
Stone stripe with fine material in the surface layers	1240	10°	31	0,7	1,3	0	1957—1960
Stone stripe poor in fine material in the surface layers	1270	17°	43	0,9	2,3	0	1957—1960
Stone stripe free of fine material	1290	11°	22	0,2	0,8	0	1957—1960

A small-scale map showing the regional distribution of the different areas belonging to the frost-shatter zone has recently been published (Rudberg 1960).

THE TUNDRA ZONE

Frost-weathering has not been studied in detail. The result can be observed, where suitable outcrops occur in the drift-covered areas. *Roches moutonnées* with striae are better preserved than in the block-field zone, notably on crests. But they are often destroyed.

As environments show greater variations in this zone (e. g. grain-size of soils in the surface layers, protection by vegetation etc.) the variety of periglacial assorting and transporting processes seem to be greater. The impression might be caused at least partially by insufficient information about the frost-shatter zone.

As concerns assorting processes there are in most studies found observations of stone polygons, belonging to the "polar" type with a diameter of 1—3 m. Of special interest are the micro-polygons, according to Troll (1944) not reported from the Scandinavian mountains. A single picture (pl. 1) of well-developed micro-polygons was taken by the writer 1946 (publ. by G. Lundqvist 1948). Later such forms have proved to be rather common on localities lacking vegetation, notably on wind--eroded surfaces. These are bare of snow during a part of the winter and during the late winter they are very likely to be exposed to frost-cycles of short duration. Some observations show that there might be two types of micro-polygons, one originating from fine-earth concentrations within the superficial layers which lead to formation of fine-earth circles with stone rings, the other originating from dessication cracks and later concentration of stones in these cracks. The latter type can be observed in the top layers of earth hummocks with destroyed vegetational cover.

Stone polygons occur always on flat ground as do stone-pits (often waterfilled) and earth-hummocks (thufur). They can all of them be observed as single forms but mostly they occur in larger associations. Less frequent are observations on cellular soils. Stone pavements are common features within the tundra zone, but not yet studied in detail.

Observations on forms proving down-slope movement are numerous, such as elongated earth hummocks and stone-polygons, stone-stripes sometimes ending in stone-garlands, series with small terracettes with the upper surface lacking vegetation, greater solifluction tongues or terraces or lobes with out-bulging, either stone- or turf-banked fronts, corrugations parallel to the contours, "wandering" or "gliding" boulders with an open ditch behind and a small earth-bank before it.

As concerns the frequency of different periglacial features, their regional distribution, the influence exercised by the varying environments, and the possibility to state upper and lower limits for the different features — the gathered observations are so far not sufficient for definite statements, though distinct altitude zones have been distinguished in different maps on smaller areas. The following may, however, be said:

Well-defined forms, indicating assorting processes or down-slope movement seem always to cover a smaller part of the total region investigated in each case (when maps are adequate enough for an estimation). Locally rather large areas can be characterized by a single well-defined form, e. g. broad slopes with solifluction tongues, or wide crests with stone polygons (Gedda 1960). The richest variety of forms has been presented from investigated areas in the Lapland part of the country (Heijer 1945; Annersten 1957; Flink & Söderlund 1958; Malm & Nilsson 1959; Tengsjö & Thorn 1959; Jonasson & Jonasson 1960; Lomander & Werner 1960; Karlsson & Larsson 1960; Nömm & Severinsson 1960). In the S an investigated sandstone mountain gives only example of a few types, but these types, block-fields, stone-polygons, stone-stripes are well-developed and of great areal importance (Gedda 1960). It is an open question, whether this contrast is caused by differences in climate (more maritime in N, more continental is S) or is mainly due to differences in bedrock. The latter alternative seems at least to be of great importance. It can be noticed, that a study of a small area of soft easily disintergrated Köli rock (phyllites, limestones etc.) showed high frequency of solifluction tongues and thufurs but few or no examples of stone-polygons, stone-stripes and block-fields (Wassén 1956). The influence of bedrock is also felt in type differentiation within smaller investigated areas in Dalecarlia (Jansson 1957) and in the Tärna region.

It is often observed, that solifluction tongues or terraces are well-developed on slopes with late melting snow-patches. The reason may be the uneven distribution of water-saturated and frozen ground (the latter below the snow), causing intermittent acceleration and retardation in down--slope movement of the masses. In some places the most well-developed solifluction tongues seem to be connected to abrupt changings in inclination, flattening or steepening of the slope. Here the surface layers overrun the deeper layers.

Most periglacial phenomena are reported within a rather large vertical space. Thufurs, generally also stone pits and wandering boulders belong to the lower part of the tundra zone. Micro-polygons are located on wind-eroded surfaces and mud flats within the tundra zone. Terracettes and solifluction tongues show not quite as clear a tendency though the better developed types belong to the lower part of the tundra zone, the terracettes to clearly dryer areas. Stone-banked tongues seem to increase in importance in the upper parts. Ordinary stone-polygons

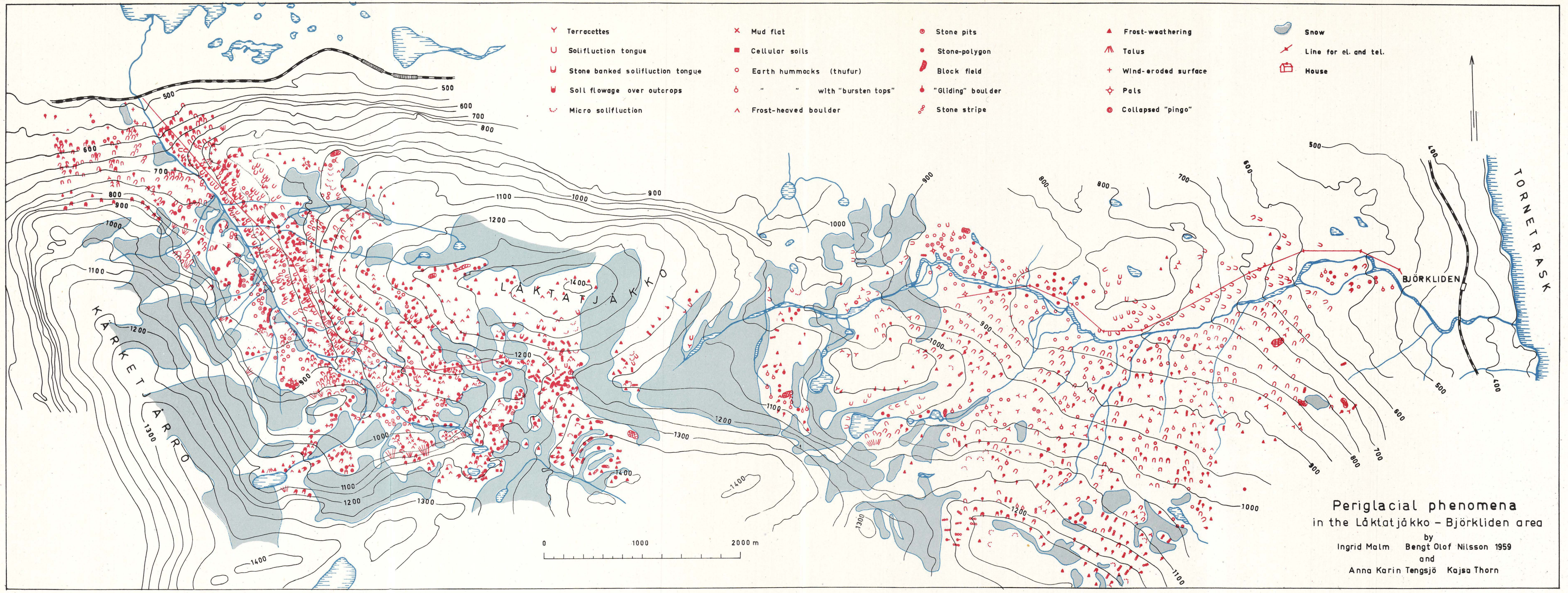

Fig. 1 Glacier map of Kebnekajse, Sweden
prepared from aerial photographs and from original contour line drawings etc. made by Rikets allmanna kartverk. Printed with permission from R.A.K. 21/11 — 1961

and stone-stripes increase in frequency towards the upper part of the zone and the transition to the frost-shatter zone.

Quantitative data of mass-movement are not numerous within the tundra zone. This concerns both the rate of movement and the thickness of the layers moving down-slope. Values obtained (by painted markings etc.) show values between nil and a few cm per year. In table II some values from the Tärna area (most of them also publ. in Rudberg 1958) and newly obtained values from the Torneträsk area are given.

Table II

Site	Height above sea level in m	Slope-inclination	No of markings	Movement in cm/year			Period
				Mean	Max.	Min.	
N and NW of Hemavan, Tärna Water-saturated solifluction soil	800	5°	22	1,8	3,3	1,0	1955—1956
Same site	800	5°	17	0,9	3,5	0	1956—1957
Same site	800	5°	17	1,8	2,8	0,8	1957—1960
Solifluction terrace with outwards bulging front	930	20°	24	6,0	7,5	4,5	1955—1957
W of Björkliden, Torneträsk area Water-saturated solifluction soil below snow-patch	900	Slow	90	2,0	4,2	0	1957—1960
S of Låktatjåkka station, Torneträsk area Water saturated solifluction soil in a snow-patch area	615	Slow	11	1,9	2,7	1,0	1957—1960

Given values here are greater than in the localities investigated in the frost-shatter zone, about twice as great in most cases where the water content is high [1]. A greater value is measured in the solifluction terrace, a value of the same order as found in single measurements of the surface layers in solifluction terraces in other localities (see below) [2].

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[1] It is of course of great importance for the zonal development of slopes, if this tendency from a few measurements should reveal a real difference in the rate of mass movement within the two zones. An eventually slower mass movement within the frost-shatter zone, however, does not necessarily say that the total amount of degradation within the zone should be lower.

[2] A mean movement (period 1953—56) of 10 cm/year in a very wet locality is reported from Kärkevagge in the Torneträsk area by Rapp (1957).

To get information on the vertical velocity profile and the thickness of the moving layer a special method has been tried by the author. Markers (plastic cylinders 2 × 2 cm, occasionally wooden cylinders) are lowered through an iron pipe pressed into the ground. When the pipe is removed these cylinders form test pillars which may easily be pushed apart by differential movements in the ground itself. Results from different prepared localities have so far only been obtained from solifluction tongues. They are given in table III.

Table III

Annual movement at different depths (period 1957—60) in solifluction tongues in the Torneträsk area

No	Site	Surface layer	Depth in cm						
			10	20	30	40	50	60	70
1	Kärkevagge, 750 m a.s.l.	5,0	3,8	2,8	1,7	0,8	0,3	0,2	0,3
2	S of Låktatjåkka station, 600 m a.s.l.	5,0	3,9	3,0	2,4	1,9	1,7	—	—
3	Mt. Nuolja, 845 m a.s.l.	2,5	1,9	1,6	1,4	1,2	0,9	0,2	—

The form of the three test pillars at the time when they were prepared for measuring is seen in fig. 2. This figure and the table show that the movement is faster in the upper layers and gradually diminishes towards the depth. In No. 1 (also illustrated with pl. 2) the test pillar shows a bend forwards at about 70 cm below the surface, thus demonstrating a slightly increased movement in these layers. In No. 3 an abrupt change in displacement occurs at the depth of 50 cm. About the same values as in No. 1 and 2 are reconstructed from a locality in the Tärna mountains (measured between 1955 and 1956). In other cases, where the test pillars are not yet measured, the surface layer at least has shown only a movement of a few centimetres in 1—3 years. In the test section No. 2, a soil profile of podsolic type was overridden — phenomena observed also in other cases. These observations prove that the solifluction is intermittent. The most simple explanation of this latter phenomenon is: variations in water supply, i. g. caused by variations in the snow cover.

Another method, which may give some information about movement and thickness of the moved layer is to gather observations on the orientation of the long axes of stones. It is well-known that the stones in the central part of the solifluction tongues are oriented in the direction of flow (Lundqvist 1949). The same orientation is commonly observed in superficial layers without visible signs of flow (Rudberg 1958). A

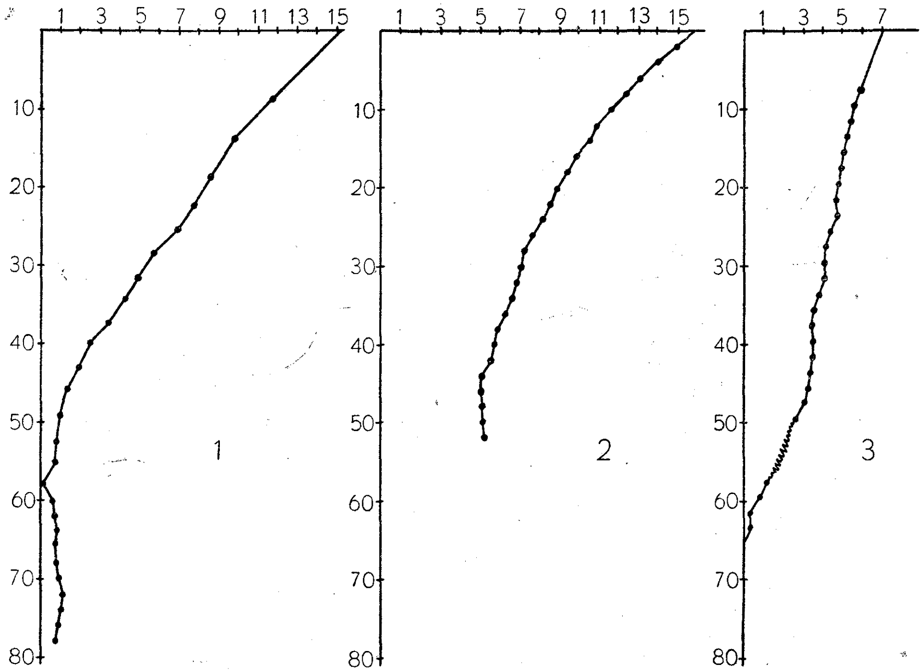

Fig. 2. Test pillars measured at the time when they were prepared for measuring. Nos as in table III. Each point in the curve represents one individual marker. Horizontal axis movement in cm, vertical axis depth below surface in cm

the depth of 50 cm the orientation is generally not so good. Instead a tendency to orientation in the direction of the last ice-movement can be observed in some cases (see fig. 3).

Of importance are also observations concerning slope inclination on places, where well-defined forms indicating down-slope movement are found. Stone-polygons get a more longish shape when the inclination reaches 3—4° (Jansson 1957; Flink & Söderlund 1958; Gedda 1960). Earth hummocks show the same transition at 3—6° (Wassén 1956; Jansson 1957, unpubl. 1954; Blomqvist & Danninge 1956; Flink & Söderlund 1958). Minimum inclination figures for solifluction tongues are few. They can be developed at least at the inclination of 4—7° (Rudberg 1954). A minimum inclination of 3° is reported in one study (Lomander & Werner 1960). Signs of movement on somewhat lower slopes have been observed in the block-field region.

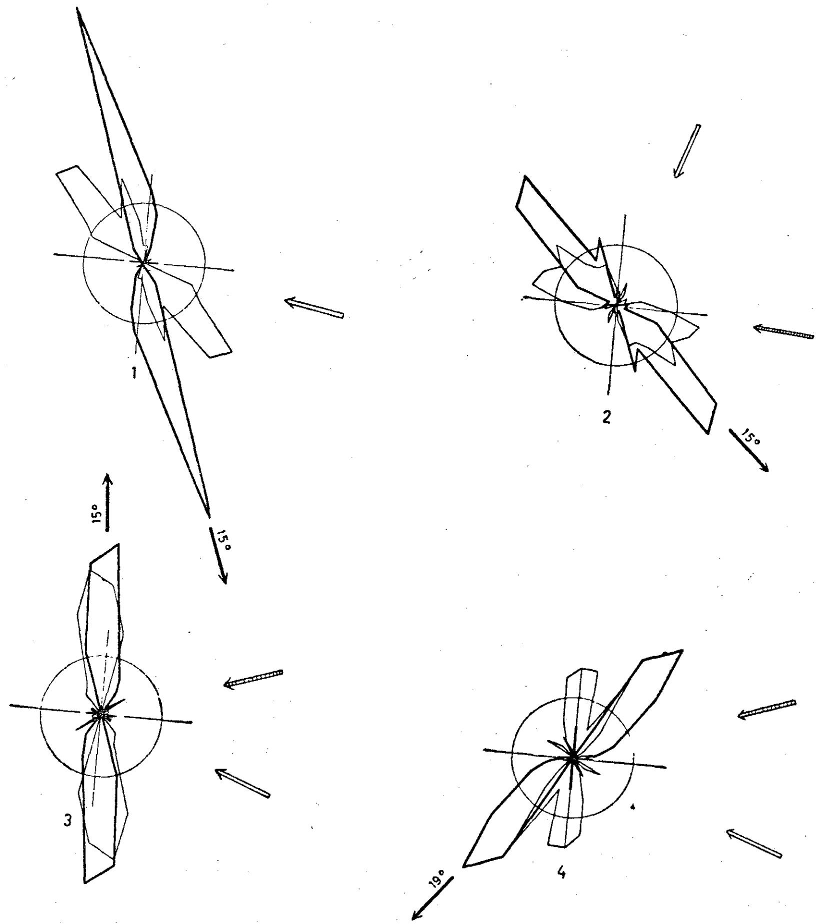

Fig. 3. Rose diagrams showing the orientation of the long axes of stones from sites in the Tärna mountains

No 1 is from the slope of the peak Kittelhobben at 780 m above sea level, no 2 from the same peak at 930 m, no 3 from southern side of the stream Dåriesjokk at 900 m, no 4 from the northern side of the same stream at 915 m. In each diagram the circle represents a frequency of 10%. The heavy line represents the surface layers from 0—20 (2,5) cm depth, and the thin line observations from 40—60 cm depth. A black arrow indicates direction of slope, and a white arrow the striae. When two directions of ice movement are observed the more recent one is indicated by the white arrow, the older one by a gray arrow

THE FOREST ZONE

Results of periglacial activity are not absent. Frost-weathering occur on steep slopes. Phenomena of wide distribution are earth-hummocks. They are frequent in most part of Sweden on abandoned meadows and grassy fields. Other phenomena are the block-fields of a type (described by B. Högbom 1926; Lundqvist 1951 and earlier), which in Sweden are sometimes called *block-sänkor* (i. e. "boulder depressions", stone-field hollows). They are from a few metres to some hundred metres wide and are caused essentially by frost-heaving of stones and boulders of morainic origin but partly also by frost-weathering *in situ*, accompanied by frost-sorting processes (B. Högbom 1926). The type is in northern Sweden often very well developed along lake shores and rivers (B. Högbom 1926). The boulder depressions are common over the greater part of the country (perhaps except for southern and southwestern Sweden — see map by Lundqvist). They are found also above the timber line and here not always easy to distinguish from other sorts of block-fields.

The same orientation of stones in the direction of slope, that was mentioned from the tundra zone is also observed in the forest zone, at least down to the province of Småland in southern Sweden (Rudberg 1958). As this phenomenon is also observed below the upper marine limit (cf. also Mård 1959), it might be developed under present climate conditions.

Extra-zonal stone-polygons occur along the shores of lakes and rivers and on the bottom of dried-up ponds in northern Sweden. The well known, still active stone-polygons on Öland and Gotland have recently been studied by Rydqvist (1960). Gliding boulders are loccally found far below the timber line in silty sediments (oral communication by Å. Hörnsten). Stone stripes can be observed in different parts of northern Dalecarlia. If they are of a fossil nature or still active is not known.

SOME REMARKS TO THE MORPHOLOGICAL ACTIVITY OF A SNOW-COVER IN THE MOUNTAINS

During the melting of the snow it happens that rivulets are formed in the snow-cover, guided by snow walls without any relation to the normal water ways. Erosion is sometimes caused, visible in small furrows or hollows and in material accumulated on the vegetation cover or in the snow, in the latter case occasionally resulting in formation of dirt-cones after continued melting (example by S. Rudberg 1954). The frequency of these phenomena is not studied.

The role of snow-patch erosion in the periglacial cycle is a problem of interest. If the periglacial denudation in general is active all over the surface in the mountain region, the snow-patch erosion will probably tend to accentuate depressions, notably such which are connected with structures or an uneven distribution of loose deposits.

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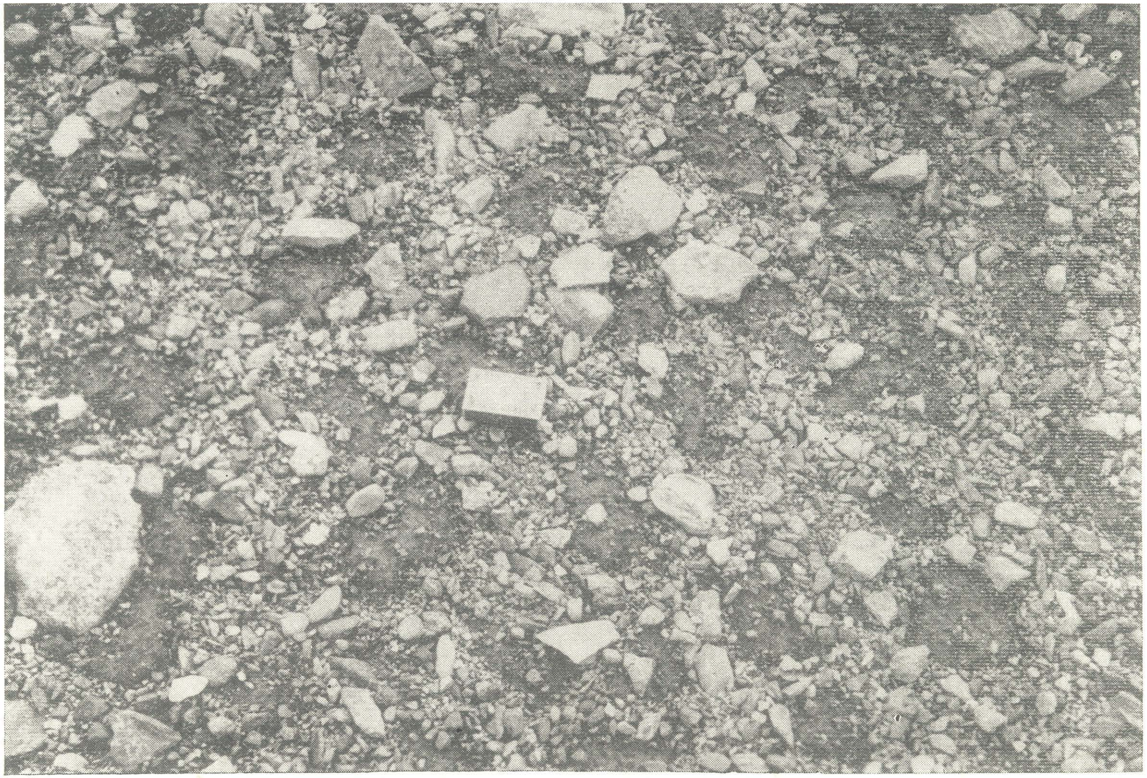

Pl. 1. Micro-polygons, consisting of fine-earth circles and broad stone rings. From Mt. Gardfjället, Västerbotten

Pl. 2. Test pillar in a solifluction tongue in Kärkevagge. Each single marker is 2 cm broad