Anders Rapp, Sten Rudberg

Uppsala-Göteborg

RECENT PERIGLACIAL PHENOMENA IN SWEDEN *

Abstract

The paper contains a discussion and a bibliography of recent periglacial phenomena in Sweden. They mainly occur above the timber line in the mountains in the „block-field zone" and the „tundra zone", where they show great variation and frequency. But there are also certain active phenomena (stone polygons etc.) found as extrazonal, scattered features in the „forest zone" down to southern Sweden. The distribution of permafrost is little known, but there exists *permafrost en ilots* in northern Lappland.

INTRODUCTION

In this report the recent periglacial phenomena have been grouped in approximate climate-morphological zones mainly in accordance with the classification proposed by Büdel (1948).

1. The block-field zone or the *frost-shatter zone* (German *Frostschutt-zone*, French *désert froide*, perhaps better than the proposed *désert polaire*, as this zone also occurs on the high mountains in middle and low latitudes, Swedish *blockhavszonen*).
2. The tundra zone.
3. The forest zone.

This classification seems to be quite satisfactory for Scandinavia both from a practical and theoretical point of view. The zones are in most cases easy enough to distinguish in the field and they also present different conditions (climate, vegetation) for the morphological activity. As regards the vegetation factor, zone no. 3 has the best protection against mass-movements. This protection is mainly offered by the tree roots. Zone no. 2 has weaker protection from its vegetation cover and zone no. 3 is practically without protection. A similar gradation exists as regards snow protection against *tjäle* in winter (forest zone: loose, thick, even snow cover; block-field zone and tundra zone: compacted, uneven snow-cover, leaving patches of ground bare as a consequence of snow-drifting).

* Some parts of this report have been worked out in cooperation with Prof. G. Hoppe, other parts after discussion with Dr G. Sandberg. Mr. N. Tomkinson, B. A. has revised the English text.

Periglacial phenomena active nowadays occur primarily within zones nos. 1 and 2 but some phenomena are also found in the forest zone (see below).

One can say that periglacial phenomena can be studied from two aspects: (a) qualitatively and (b) quantitatively.

The study of active periglacial phenomena in Sweden has as a whole started to advance from the qualitative into the quantitative stage.

As regards the regional distribution of the phenomena, Prof. G. Lundqvist has for many years gathered information, partly published in a general survey in Swedish (1948). Another step in the direction of quantitative studies is the series of investigations referred to in our bibliography under the heading of „Unpublished literature". Most of these were made by students on the initiative of Prof. S. Rudberg (formerly Uppsala, now Göteborg). They give us detailed informations on the frequency of periglacial phenomena within small, mapped areas.

CLIMATE

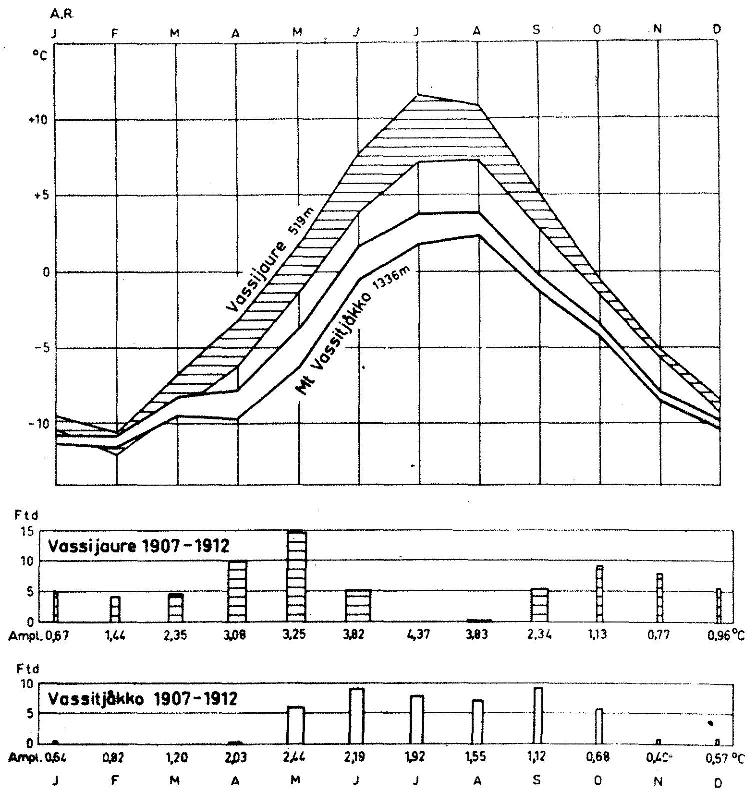
The number of frost cycles and their amplitude and duration is essentially of interest in this connection. We can here only give a short example of this and we choose our example from the northernmost part of Lappland. The diagram (fig. 1) gives the air temperature from synchronous records at Vassijaure close to Riksgränsen (valley bottom, 68° N.) in the tundra zone and the adjacent Mt. Vassitjåkko in the block-field zone. (Position of Riksgränsen see fig. 3).

This type of diagram has the advantages (a) of showing both mean annual and mean daily amplitude and (b) of making comparisons between different localities easy (Rapp 1960). The bars below the curves show the average number and amplitude of daily frost cycles (freeze — thaw days).

CONCLUSIONS

Both localities show an „Arctic" type of daily and annual frost cycles with few freeze—thaw days in comparison with high mountains in low latitudes (cf. Troll 1944) and a rather small daily amplitude but with a fairly large annual amplitude. The daily frost cycles are fewer and weaker on the mountain than in the Vassijaure valley.

The locality discussed is situated in the extreme NW. Generally it can be said that:



from Rapp 1960

Fig. 1. Diagram of air temperature and freeze—thaw days from synchronous records in the valley bottom at Vassijaure and on the adjacent summit of Mt. Vassitjåkko, northern Lappland (68 °N. Position: see fig. 3 — Riksgränsen)

The curves show the average daily max. and min. temperatures during four years (February three years, April two years), the bars show the average number of freeze-thaw days (height) and their mean periodical amplitude (width); the annual number of freeze—thaw days during the period was 71,2 at Vassijaure and 53,7 on Mt. Vassitjakko. Compare with fig. 2

1. the mountains in the west show maritime influence, smaller temperature amplitudes, larger precipitation, much snow but uneven snow cover (Hamberg), and that

2. the mountains and wood-land in the east have a local continental climate, larger temperature amplitudes, smaller precipitation, less snow but in the forest even snow cover. These climatic differences result in periglacial features of two types, maritime and continental. (See further section on „Permafrost" below).

Southwards the climate shows, of course, a more „temperated" character.

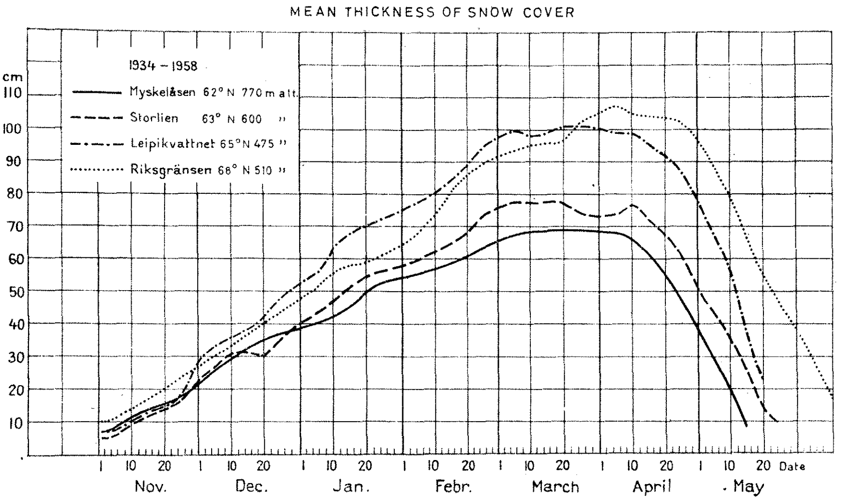


Fig. 2. Diagram of the mean thickness of snow cover at some weather stations in the Swedish Scandes. Latitude and altitude is given in rounded figures

Figure 2 gives [1] for some selected localities the mean thickness of snow cover. All the localities quoted are from the maritime mountains, except Myskelåsen, which is continental.

THE BLOCK-FIELD ZONE

This zone is characterized by a cover of mostly angular blocks or locally by naked bedrock. Its limit lower down, against the tundra zone, is generally rather distinct, for instance, in the amphibolite mountains but in certain areas with lower metamorphic rocks the limit is very diffuse and difficult to follow. The botanists distinguish a transition zone called the middle alpine belt in the lower part of the block-fields and the higher part of the tundra zone. As a whole, however, there is good reason for saying that the block-field zone in the Scandes forms a natural and characteristic region, long since distinguished by geologists, morphologists and botanists. They have not defined it exactly in the same way but have given it different names, for example, *blockhav* (Svenonius 1909), *regio alpina sterilis* (Tengwall 1920), *regio alpina secunda* (Smith 1920),

[1] after E. Schmacke — Samband mellan väderlek och lavinförekomst i svenska fjäll. S.M.H.I., Stockholm 1959.

the high-alpine belt (Du Rietz 1925, 1950), *obere Tundrazone* (Ekman 1957).

The lower limit of the block-field zone is not strictly horizontal. It reaches 1000—1200 m in the amphibolite mountains at Abisko (Söderlund 1959), 1100—1200 m in the mountains of Västerbotten (Rudberg 1954), while this limit is put as high as 1500—1600 m in southern Jämtland by Smith (1920). On the southernmost Swedish Scandes in northern Dalarna there are large block-fields down to about 1100 m and even down to 900 m, for instance, on Mt. Fulufjället, but probably they are not recent (Jansson 1957; Gedda 1959). At least the last-mentioned case is an example of the edaphic influences that can cause a pressing-down of the block-fields, in so far as the bedrock on Mt. Fulufjället is sandstone, forming a very meagre and dry substratum for the vegetation.

The block-field zone is generally considered to be the one with the most intense frost-bursting and denudation. As a whole we have still only little information concerning quantitative values on the rate and quantity of weathering, solifluction (congelifluction) etc. within the zone, so we can only refer to some general observations in this respect. The greater glacial sculpture (cirques etc. from the initial stage of the glaciation) is well preserved. The bedrock has as a rule been burst by the frost into angular boulders, but exceptionally there are also at high altitudes well-preserved *roches moutonnées* with glacial striae, indicating that destruction by frost weathering must not be overestimated. Svenonius considered that the boulders in the block-fields were produced in post-glacial times by weathering of the local bedrock. This is generally the case, but on the contrary it is not unusual to find many erratic boulders of foreign rocks, as a rule not frost weathered, scattered over the block-fields (Rapp). If such foreign erratic boulders occur to a great extent it is possible that the block-field consists of glacial drift, from which the finer material has been removed or the boulders accumulated on the surface by frost-heaving (see further below).

Assorting processes result in stone polygons on horizontal ground which became elongated on gently sloping surfaces. These features were observed on all the mountains investigated.

Transport by solifluction on moderate to gentle slopes probably goes on partly as rather uniform sheet movements, partly concentrated in stone stripes. The last-mentioned forms are very common. They often end in a bulging front.

Among the transport processes working on and forming the steep slopes within the block-field zone, rock-falls, mudflows and snow avalanches are worth special mention. At the foot of most steep rock-walls are talus formations, supplied by recent rock-falls. The recession of the rock-walls during post-glacial times seems to be rather restricted and does not exceed one or a few metres (Rapp 1957, 1960).

Snow avalanches have great morphological importance within higher parts of the Scandes. They transport rock debris towards the valley bottoms, depositing it in avalanche boulder tongues (German *Lawinenschuttzungen*) of various forms, for instance, as *road-bank tongues* and *fan tongues* (Rapp 1959). The fan tongues generally reach far out over flat valley bottoms and often mean an important local pressing down of the block-fields. In such cases they can easily be misinterpreted as boulder creep tongues or even rock streams. In this connection the following questions may be raised: „Where do avalanche boulder tongues occur elsewhere? How important is avalanche denudation as compared with other denudation processes?"

Within the block-field zone the streams have generally not formed gullies but run in broad outspread, sometimes anastomosing branches (Rudberg 1954). They flood wide areas in the flat bottoms of the trough-valleys during the intense snow-melting in June or after heavy snow or rainfall in summer or autumn. The spring floods occur when the ground is generally still frozen, which is perhaps one of the reasons for the insignificant vertical and lateral erosion, together with the coarse material and the supposed creep movements in the wet soil, which will fill the embryo channels.

THE TUNDRA ZONE

The tundra zone is situated below the block-field zone and reaches down to the timber line, which runs at an altitude of about 500—700 m in northern Lappland and of about 950 m in northern Dalarna. The ground within this zone is mainly covered by heaths and meadows with dwarf shrubs or grass.

The timber line is only locally a well-defined limit. Local climatic conditions (inversion etc.) may result in tundra patches in the birch-wood in the valley bottoms far below the highest situated trees.

The vegetation shows a detailed zoning of plant communities caused by the very uneven distribution of the snow in winter. Above the timber line snow drifting is wery strong and every winter certain parts of the ground lie bare, but the depressions close by may be covered by snow of some metres' thickness. This uneven distribution is rather constant and is of great importance for both vegetation (Sandberg 1958) and morphological processes.

As a whole, one can say that frost-weathering and denudation by periglacial processes is probably not so strong in the tundra zone as in the block-field zone. Well-preserved *roches moutonnées* are more common here than in the higher zone. The soil is more differentiated in the tundra zone as regards grain-size and this together with the variations in vegetation, causes a great variety of solifluction and frost-heaving features. We can only choose some of all the forms described for mention here.

On horizontal ground such phenomena as stone polygons and stone pits (Swedish *stengropar*) occur frequently on suitable localities, mudflat polygons (Swedish *jordrutor*) more occasionally from northern Dalarna to northern Lappland (Högbom 1914; Frödin 1914; Lundqvist 1948; Jansson 1957; German 1958; and others).

Of special interest are micro-polygons which, according to Troll (1944), are formed by frost-cycles of short duration and are therefore best developed on high mountains near the Equator. Micro-polygons (see picture in Lundqvist 1949) of a diameter between 0,1—0,2 m have been observed in several localities in northern Dalarna, Västerbotten and northern Lappland, always on wind-eroded patches (Rudberg 1955; Annersten 1957; and others).

Earth hummocks are common at many places within the zone, but are by no means restricted to this environment. They are frequent also on abandoned meadows and grassy fields in most parts of Sweden (Rudberg 1958).

Solifluction tongues and terraces of different types are common, especially in the western mountaines of Lappland (higher precipitation, rocks with fine-grained debris). They are often formed on the downslope side of snow patches. The movement of solifluction tongues in a few localities is recorded (Sandberg 1938; Rapp 1957; Rudberg 1958). In extremely rapid-moving tongues an annual advance of 30 cm has been measured, but in general the movement seems to be nil or at most a few centimeters per year.

It seems possible according to Rudberg that the well-developed solifluction tongues are bound up with special conditions, abrupt changes in inclination, flattening or steepening where surface layers are overrunning deeper layers (cf. also similar observations by Williams 1959, p. 7).

It is well known that the long axes of stones in the central parts of the tongues are orientated in the direction of the flow (Lundqvist 1949). The same orientation is commonly observed in superficial layers on slopes without visible signs of flow (Rudberg 1958) both in the tundra zone and the forest zone. Is this orientation caused by frost processes?

It may be remarked that earth slips forming tongues like solifluction tongues were released in great numbers after exceptionally heavy rains in October, 1959, in the W. Torneträsk area (Rapp).

An indication that post-glacial movements must be small on certain slopes is given by the existence of well-preserved series of lateral drainage channels formed at the deglaciation some thousands of years ago. These channels seem to be best preserved in sandstone and quartzite areas with coarse-grained till and with a continental climate.

On steep slopes mass-movements such as rock-falls, mudflows and snow avalanches are active. The last process doess not form such regular and distinct boulder tongues as in the block-field zone.

The streams within the tundra zone partly run in shallow, anastomosing branches as in the block-field zone, but they also in many cases cut out flat-bottomed valleys (Rudberg 1954) or deep canyons in the bedrock, especially at the mouth of hanging valleys. The last type of canyons can be called connection valleys.

It may be of some interest to mention that on some flat, swampy valley--bottoms and mountain plains within the Abisko area we have observed a special type of small, circular or elliptical lakes, only 10—20 m wide, surrounded by ridges of pressed soil with tangentially orientated boulders and with cracks. The whole feature looks like the remains of small pingos, described from Greenland, but as these „ring-ridge lakes" in Lappland have not yet been investigated, their genesis is an open question.

THE FOREST ZONE

The timber line is formed by mountain birch (*Betula pubescens* subsp. *tortuosa*) in the northern and western mountains and by mixed birches pines (*Pinus silvestris*) and spruces (*Picea Abies*) in the southern and eastern parts of the Swedish Scandes.

The forest zone or the forest region in Sweden can in this connection roughly be divided into (a) the birch-forest belt, with a vertical extension of about 300—400 m in northern Lappland, (b) the conifer-forest region, covering most of Sweden and dominated by pine and spruce, (c) the oak- and beech-forest region. The last-mentioned is a strip of land along the southern and western coasts of the country.

Glacial sculpture and striae are as a rule well preserved on the bedrock within the forest zone. Frost-bursting is active causing rock-

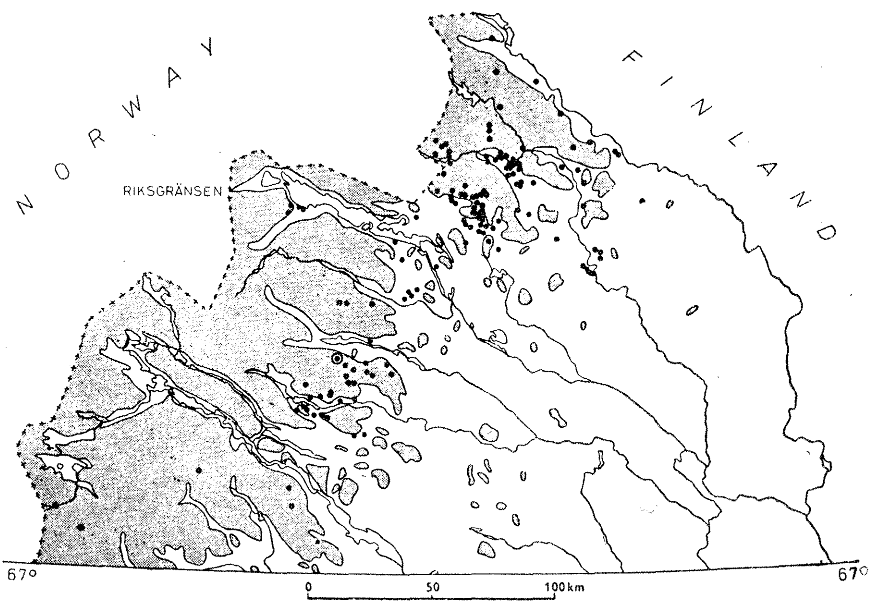
-falls and talus formations below rock-walls from Norrland to Skåne. Most of these walls were formed by glacial plucking.

Some of the periglacial features mentioned above from the tundra zone also occur on open places in the highest situated woods. As an example may be chosen the surroundings of Abisko where definitely active stone polygons occur frequently in the brich-wood far below the timber line (Sandberg 1938).

Extrazonal stone polygons occur on the shores of lakes in many localities down to southern Norrland (recent or not?). They have also been known for a long time on the islands of Gotland and Öland (cf. Hesselman 1915; Troll 1944). A paper about these recent phenomena, by F. Rydqvist, will appear in *Ymer* in early 1960.

Stone-filled hollows (Swedish *blocksänkor*) — depressions at least some metres wide, covered with frost-heaved boulders — are common all over Sweden, perhaps with the exception of the southernmost province, Skåne (Lundqvist 1940). In most cases the boulders are of morainic origin (cf. discussion on block-fields above).

The frost-heaving of boulders is a phenomenon which is well-known all over Sweden („the stone grow in the fields" is an old expression among farmers in the province of Småland).



from Lundqvist 1957

Fig. 3. The distribution of mires with *palsar* in north-eastern Lappland
Each dot — one mire with palsar; grey area — land above the timber line

The formation of *pipkrakar* (needle-ice) is also a common phenomenon in spring and autumn all over the country.

PERMAFROST IN SWEDEN

Very few data on this subject are available; most of them were summarized by Ekman in 1957. As far asi sknown, permafrost only appears in northernmost Lappland. It may characterized as *permafrost en îlots*. The greatest depth of the permafrost observed so far — about 70 m — is found east of Riksgränsen on Mt. Låktatjåkko at an altitude of 1220 m. In other places the permanently frozen ground is restricted to layers of a couple of metres. There are some indications that the permafrost is diminishing during this century. The area of *permafrost en îlots* fits very well with the distribution of the so-called *palsar* (Lundqvist 1957). See fig. 3.

References

A. Published papers

Beskow, G. 1930 — Erdfliessen und Strukturböden der Hochgebirge. *Geol. Fören. Stockholm Förhandl.*, Bd. 52.

Büdel, J. 1948 — Die klima-morphologischen Zonen der Polarländer. *Erdkunde*, Bd. 2.

Corbel, J. 1956 — Phénomènes périglaciaires au Svalbard et en Laponie. *Biuletyn Peryglacjalny*, nr 4.

Du Rietz, G. E. 1925 — Die regionale Gliederung der skandinavischen Vegetation. *Sv. Växtsoc. Sällsk. Handl.*, 8, Uppsala.

Du Rietz, G. E. 1950 — Phytogeographical excursion to the surroundings of Lake Torneträsk in Torne Lappmark (N. Sweden). 7th *Int. Botan. Congress Stockholm 1950*, Exc. guide C III c. Uppsala.

Ekman, S. 1957 — Die Gewässer des Abisko-Gebietes und ihre Bedingungen. *Kungl. Svenka Vetensk. Akad. Handl.*, ser. 4, Bd. 6, nr 6. Stockholm.

Enquist, F. 1918 — Die glaziale Entwicklungsgeschichte Nordwestskandinawiens. *Sveriges Geol. Unders.*, ser. C, no 285. Stockholm.

Frödin, J. 1914 — Geografiska studier i St. Lule älvs källområde. *Sveriges Geol. Unders.*, ser. C, no 257. Stockholm.

German, R. 1958 — Beobachtungen zur Solifluktion in Schwedisch Lappland. *Geogr. Helvetica*, 13.

Hamberg, A. 1907 — Die Eigenschaften der Schneedecke in den lappländischen Gebirgen. *Naturwiss. Untersuch. d. Sarekgeb. in Schwed. Lappland*, Bd. I, Lief. 1, Stockholm.

Hesselman, H. 1915 — Om förekomsten av rutmark på Gotland. *Geol. Fören. Stockholm Förhandl.*, Bd. 37.

Högbom, B. 1914 — Über die geologische Bedeutung des Frostes. *Bull. Geol. Inst. Univ. Upsala*, vol. 12.

Högbom, B. 1927 — Beobachtungen aus Nordschweden über den Frost als geologischer Faktor. *Bull. Geol. Inst. Univ. Upsala*, vol. 20.

Jansson, U—B. 1957 — Frostjordsbildningar av fossil och recent natur på Långfjället i Idre socken, norra Dalarna (summary: Frost earth forms of fossil and recent nature in the Långfjäll region, north-western Dalecarlia). *Geographica*, nr 31. Uppsala.

Lundqvist, G. 1940 — Bergslagens minerogena jordarter. *Sveriges Geol. Unders.*, ser. C, no 433. Stockholm.

Lundqvist, G. 1948 — De svenska fjällens natur. S.T.F. Stockholm.

Lundqvist, G. 1949 — The orientation of the block material in certain species of flow earth. *Geogr. Annaler*, årg. 31.

Lundqvist, G. 1957 — Sveriges geologi. Handbook by N. Magnusson, G. Lundqvist and E. Granlund. Stockholm.

Rapp, A. 1957 — Studien über Schutthalden in Lappland und auf Spitzbergen. *Zeitschr. f. Geomorphologie*, Bd. 1. N.F.

Rapp, A. 1959 — Avalanche boulder tongues in Lappland. *Geogr. Annaler*, årg. 41.

Rudberg, S. 1954 — Västerbottens berggrundsmorfologi. (summary: The morphology of Västerbotten). *Geographica*, nr 25. Uppsala.

Rudberg, S. 1958 — Some observations concerning mass movement on slopes in Sweden. *Geol. Fören. Stockholm Förhandl.*, Bd. 80.

Rydqvist, F. 1960 — On stone polygons on Öland. *Ymer*, in press.

Sandberg, G. 1938 — Redogörelser för undersökningar utförda med understöd av sällskapets stipendier. *Ymer*, årg. 58.

Sandberg, G. 1958 — Fjällens vegetationsregioner. *Lappväsendet-Renforskn. Meddel.*, nr 4. Uppsala. (by F. Skuncke and G. Sandberg).

Smith, H. 1920 — Vegetationen och dess utvecklingshistoria i det centralsvenska högfjällsområdet. *Norrländskt handbibl.*, 9. Uppsala.

Svenonius, F. 1909 — Om skärf- eller blockhafven på våra högfjäll. *Geol. Fören. Stockholm Förhandl.*, Bd. 31.

Tengwall, T. 1920 — Die Vegetation des Sarekgebietes. *Naturwiss. Untersuch. d. Sarekgeb. in Schwed. Lappland*, Bd. 3, Lief. 4. Stockholm.

Troll, C. 1914 — Strukturböden, Solifluktion und Frostklimate der Erde. *Geol. Rundschau*, Bd. 34.

Williams, P. J. 1959 — Solifluction and patterned ground in Rondane. Oslo.

B. Unpublished papers[1]

*Annersten, L. 1957 — Frostjordsbildningar i Strapibäckens dalgång ... (Västerbotten). Manuscr. Geogr. Inst. Uppsala.

* Blomquist, B., Danninge, I. 1956 — Frostjordsbildningar på Artfjället, Västerbottens län. Manuscr. Geogr. Inst. Uppsala.

* Gedda, S. 1960 — Frostmarksfenomen på Fulufjället ... (Dalarna). Manuscr. Geogr. Inst. Göteborg.

* Hagenfors, D. 1959 — Frostmarksbildningar på Snasahögarna, Jämtland. Manuscr. Geogr. Inst. Uppsala.

[1] * — report of periglacial phenomena from an area in the mountains.

* Halle, K., Krantz, U. 1959 — Frostmarksfenomen väster om Grövelsjön (Dalarna). Manuscr. Geogr. Inst. Uppsala.

* Heijer, A. 1945 — Frostsprängnings- och flytjordsföreteelser i mell. Lappland. Manuscr. Geogr. Inst. Uppsala.

* Malm, I., Nilsson, B—O. 1959 — Frostmarksfenomen i Låktavagge (Abisko). Manuscr. Geogr. Inst. Göteborg.

Mård, L-G. 1959 — Stenars längdaxelriktning i morän i barrskogssluttningar (Dalarna). Manuscr. Geogr. Inst. Uppsala.

Rapp, A. 1960—Recent development of mountain slopes in Kärkevagge and surroundings, N. Scandinavia. Manuscr. Geogr. Inst. Uppsala.

Rapp, A. 1960 a — Literature on slope denudation in Finland, Iceland, Norway, Sweden and on Spitsbergen. (To be printed as a report to XIXth Intern. Geogr. Congress in Stockholm, in *Zeitschr. f. Geomorphologie*).

Rudberg, S. 1955 — Den nivala erosionen och dess morfologiska resultat. Manuscr. Geogr. Inst. Göteborg.

*Söderlund, M. 1959 — Frostschuttzon-Tundrazon. Ett försök till gränsdragning (Abisko). Manuscr. Geogr. Inst. Uppsala.

* Tengsjö, A-K., Thorn, K. 1959 — Frostmarksfenomen i Rakkasjokks dalgång (Abisko). Manuscr. Geogr. Inst. Göteborg.

* Wassén, G. 1956 — Frostjordsformer i närheten av Dalovardo (Västerbotten). Manuscr. Geogr. Inst. Uppsala.