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Types of rock glaciers in northwestern Wedel Jarlsberg Land, Spitsbergen

ABSTRACT: Three types of rock glaciers (moraine, cirque and subslope ones) were distinguished in northwestern Wedel Jarlsberg Land. Subslope rock glaciers were found different from nival moraines. A development of subslope and fossil cirque rock glaciers was connected with the older Holocene whereas of active cirque and moraine rock glaciers with the Little Ice Age.

Key words: Arctic, Spitsbergen, rock glaciers.

Introduction

During the expedition to Spitsbergen in summer 1986, organized by the M. Curie-Skłodowska University of Lublin, the authors studied rock glaciers in the northwestern Wedel Jarlsberg Land (Fig. 1). A rock glacier is a body of rock debris deposited on glacial ice, with flow structures developed due to deformation of buried ice or independent movement of debris itself (Johnson 1978). Such features are formed in cool climatic conditions that favor a rich supply with rock material (frost weathering) and enable its transport influenced by an ice core. Rock glaciers form either ramparts at slope feet or systems of ridges that run outside glacial cirques. They can be lobate due to plastic remodelling of terminal moraines (Humlum 1982).

Such landforms have been previously defined as old moraine ridges (Jahn 1959, Szupryczyński 1963, 1968), talus moraines (Birkenmajer 1982), protalus ramparts (Lindner and Marks 1985), slope moraines (Baranowski 1977), nival moraines (Czeppe 1966; Karczewski, Kostrzewski and Marks 1981; Lindner and Marks 1985) and only some of them were considered for rock glaciers (Johnson 1974, 1978; Lindner and Marks 1985). They were found to be the effect of slope processes and also associated with glacial deposition or nival processes.

Rock glaciers occur in the mountains of almost the whole world. They were described from the Alps (Barsch 1977, Barsch and King 1975), the Pyrenees (Serrat 1979), Alaska (Wahrhaftig and Cox 1959), Canada (Johnson 1978, 1980), Greenland (Humlum 1982), Spitsbergen (Karczewski, Kostrzewski and Marks 1981; Lindner and Marks 1985), the Slovakian Tatra Mts (Nemčok and Mahr 1974) as well as the Polish Tatra Mts (Dzierżek and Nitychoruk 1986). Proposals of their genetic classification were also prepared (Johnson 1978, Humlum 1982, Lindner and Marks 1985, Dzierżek and Nitychoruk 1986), based on morphologic characteristics, structure, shapes and locations of these landforms. Basing on observations and field works the authors ditinguished three types of rock glaciers in the northwestern Wedel Jarlsberg Land *i.e.* moraine, cirque and subslope ones, apart from the nival moraines (Fig. 1).

Moraine rock glaciers

This term was used for the first time by Johnson (1974) and then followed by Lindner and Marks (1985). Such landforms are so strictly connected with glacial moraines as this term seems to be the most suitable one.

Moraine rock glaciers in the northwestern Wedel Jarlsberg Land are noted (Fig. 1) in the northern part of the Dunderdalen (4 features), in the Chamberlindalen (4 features; Pl. 1, Fig. 1), on eastern slope of the valley with the Recherchebreen (1 feature), in a morainal part of the Blümckebreane (1 feature; Pl. 1, Fig. 2), in the Blomlidalen (1 feature), Tjörndalen (1 feature; Pl. 2), Dyrstaddalen (2 features) and Lognedalen (2 features). From a point of view of remodelling pattern of terminal ice-cored moraines (partial or complete), two types of moraine rock glaciers are to be distinguished in this area. The first group encloses partly remodelled terminal ice-cored moraines in the Dyrstaddalen, Tjörndalen (Pl. 2, Fig. 1) and Blomlidalen, in which are bent or penetrated by a rock glacier lobe. All the other forms belong to, the other group, in which a row of terminal ice-cored moraines has been entirely transformed by a rock glacier.

Moraine rock glaciers of the first group enter always with an immense rampart (30—40 m high and lobate in shape) the outwash of present glaciers. Such lobe is up to 400 m long and to 200 m wide (Dyrstaddalen). Surface of these features is composed of numerous elevations and depressions, occasionally filled with snow or water. They can seldom form a system

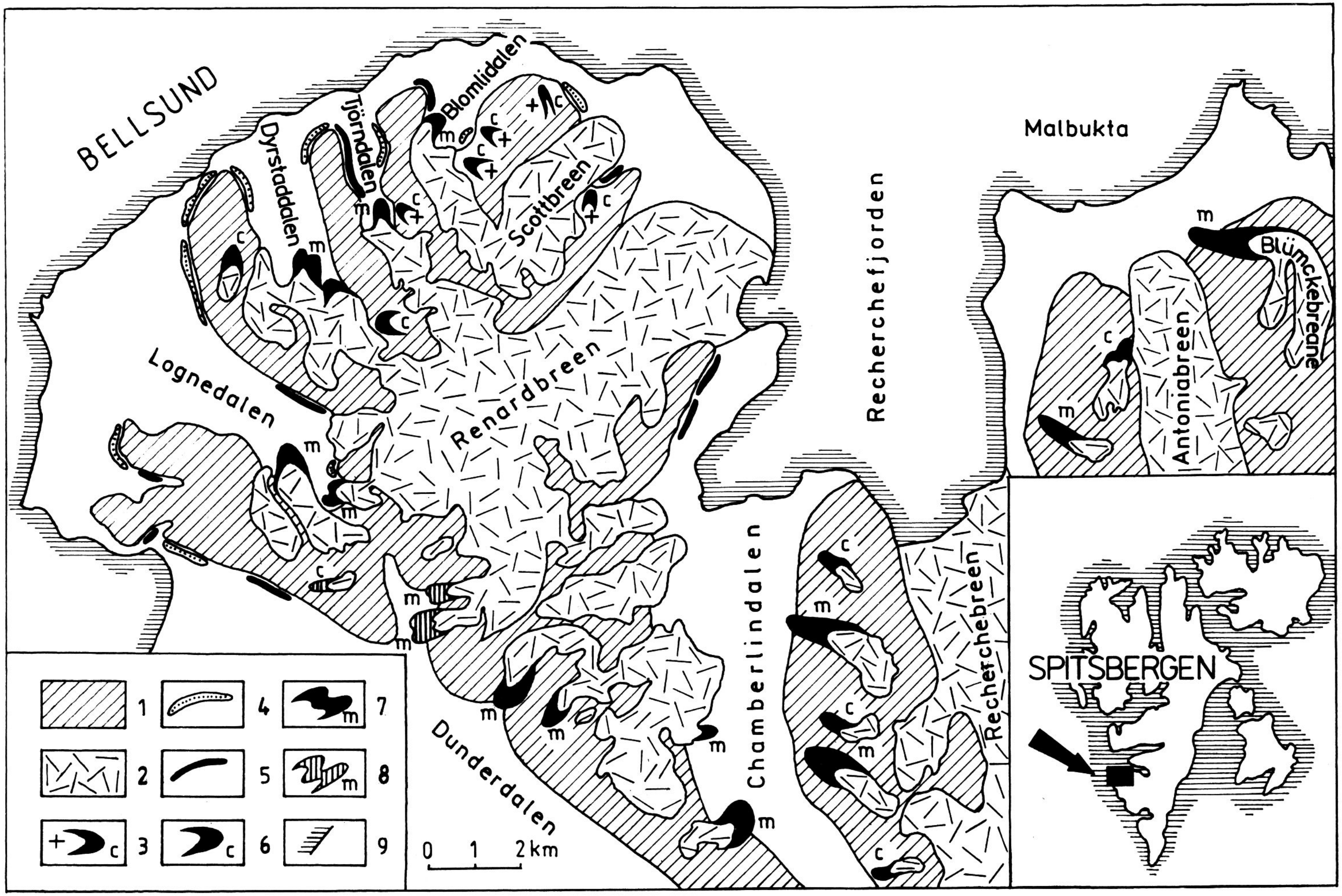

Fig. 1. Location of rock glaciers in the northwestern Wedel Jarlsberg Land: 1 — mountain massifs, 2 — glaciers, 3 — fossil cirque rock glaciers, 4 — subslope rock glaciers, 5 — nival moraines, 6 — active cirque rock glaciers, 7 — moraine rock glaciers, 8 — probable moraine rock glaciers, 9 — coastline

of lobes that reflect the first, largest ridge. Such surface morphology of moraine rock glaciers proves their movement. Ridges are composed of rock blocks, usually 20—50 cm but occasionally up to 5 m large. Depressions are filled with finer debris (2—20 cm). Sandy and clayey material is washed into inner parts of the feature.

Glaciers of Dyrstaddalen, Tjörndalen and Blomlidalen do not occur below 150 m a.s.l. and therefore, their retreat is not so quick as *e.g.* of the Renardbreen, a snout of which has moved 1.5—2 km up-glacier since 1936. Such locations of glaciers allow for a long-time contact of glacial ice with debris of terminal moraines (Pl. 2, Fig. 2); in connection with a slow ablation it results in a continuous movement of debris and development of morainic lobes of these rock glaciers. The area on which such movement occurs, slopes gently (5—10°) and so a movement depends mainly on supply with rock debris and rate of glacier ablation. Debris from taluses is transported on or inside a glacial ice. For this reason such rock glaciers are formed at terminuses of median moraines (Pl. 2, Fig. 1).

Moraine rock glaciers of the second group are also strictly connected with terminal ice-cored moraines. They are formed in forefields of small glaciers that fill narrow and short valleys, surrounded by high rock walls (Pl. 1, Fig. 1). Such location favors a rich supply with material and a conservation of glacial ice. Moraine rock glaciers of this type flow on a bedrock that is locally inclined as much as 25°. Due to this their surface is composed of longitudinal ridges parallel to a valley axis (Blümckebreane, eastern Chamberlindalen) or of several transversal lobes (western Chamberlindalen, northern Dunderdalen). The material has similar sizes as the one of the first group (Pl. 1, Fig. 2). Frequently such rock glacier is cut by a stream that contains meltwaters from the upvalley glacier. In this case a buried glacial ice, filled with rock debris, outcrops from under a several meters thick rock mantle. Such relation of debris and ice noted on highly inclined surfaces favors a flow of debris on ice what forms a pattern composed of longitudinal ridges. Moraine rock glaciers of the first group are usually exposed northwards while the ones of the second group westwards. All they possess an ice core, similarly as the features to the south of this area in the Hornsund Region (Lindner and Marks 1985). Activity of these features depends mainly on supply with material whereas the latter on size of accompanying glacier and rate of slope processes on adjacent rock walls. Most rock material of these rock glaciers comes from walls of northeastern and northern expositions (Nitychoruk and Dzierżek 1988).

Formation and development of these rock glaciers is to be connected with the Little Ice Age what is indicated by their relation to terminal moraines of this time (*cf.* Lindner and Marks 1985).

Cirque rock glaciers

Single glacial cirques separated from the presently glaciated valleys occur on higher fragments of mountain slopes in the northwestern Wedel Jarlsberg Land. In the eastern surroundings of the Ringarbreen (that fills the southern Dyrstaddalen) there is a cirque-like form, hanging at 360—450 m a.s.l. It has a semicircular shape of about 200 m in radius. To the east of a glacier snout in the Tjörndalen there is at 270—320 m a.s.l. a flattening on a mountain slope, 400 m long and 200 m wide (Pl. 3, Fig. 1). On southeastern slopes of the Blomlidalen there are two cirques, about 400 m in diameter and open northwestwards. An outlet of the cirque which is closer to the glacier, occurs at 250 m a.s.l. and is partly dammed by a lateral moraine of this glacier. On a northern fragment of the same slope there is a long and deep depression that steps down to 200 m a.s.l. and is much similar to classic glacial cirques. In eastern surroundings of the Scottbreen at 230—300 m a.s.l. a shallow but deep cirque occurs (Pl. 4, Fig. 1). Another such feature, of about 2 km in diameter, hangs at 400—600 m a.s.l. on eastern slope of the Chamberlindalen.

Some of these forms are partly filled with ice and all are mantled with snow for the whole summer. Intensive slope processes develop on adjacent steep slopes and taluses with gradients over 35° are common (Nitychoruk and Dzierżek 1988). All cirques have ramparts of rock debris at their floors or thersholds (Pl. 3, Fig. 2). Some ramparts run parallel to a cirque axis whereas the others reflect a shape of a slope or are lobate. Heights are varying from several to 30 m. They are composed of debris with predominant fraction of 50—100 cm although there are also considerable amounts of finer rock pieces especially within depressions amidst the ridges. Individual ridges or their systems occur at various altitudes and fragments of cirque floors and locally run out their thresholds (Pl. 3, Fig. 1; Pl. 4, Fig. 1). An outer slope of such ridge has usually gradients of 37°.

Such features were previously termed the cirque rock glaciers (Dzierżek and Nitychoruk 1986). They develop due to deposition of debris on surfaces of relic cirque glaciers and its transport on or within ice at small distances. Deposition of snow on cirque floors covered with debris may supply such deposits with ice what facilitates their further plastic modelling. Cirque rock glaciers can develop only in the case when supply with slope material predominates a deposition of firn and ice in cirques.

Two principal types of cirque rock glaciers were distinguished *i.e.* active and fossil ones. The former include vast stone fields at thresholds of disappearing firn fields and resemble moraine rock glaciers. They are located on eastern slope of the Chamberlindalen, in vicinities of the Antoniabreen and the Ringarbreane that fills a fragment of the Dyrstaddalen (Fig. 1). Fossil cirque rock glaciers are located on cirque floors devoid of clean ice. Degree of debris weathering, partial cover with moss and lichens and lack of movement symptons suggest them to be ancient and inactive features. But a presence of ice core under or inside a debris mantle seems probable. Such rock glaciers occur within the Tjörndalen and the Blomlidalen as well as in vicinity of the Scottbreen (Fig. 1).

A debris fill arranged in small (several meters) ridges parallel to a slope (on a flattening 150—200 m a.s.l. at the foot of a wide chute to the west of the snout of the Scottbreen) is of another origin. Its features are typical for a cirque and subslope rock glaciers.

Subslope rock glaciers

At foot or on flattenings of mountain slopes in the northwestern Wedel Jarlsberg Land there are common concentrates of slope debris, forming vast ridges parallel to slopes. The largest one is located around a rock spur that separates the Dyrstaddalen and the Lognedalen. These ridges run at distances of several kilometers and are even several hundred meters wide. Slightly smaller features occur in the Tjörndalen and Blomlidalen area and to the west of the Scottbreen (Pl. 5, Fig. 1), and probably also on northern slopes of the Dunderdalen (Fig. 1).

Such ridges are up to 50 m high and their width is varying within individual features. The surface is hummocky and encloses numerous secondary crests, depressions and flattenings. Height differences reach 10 m. Ridges are separated from mountain slopes by depressions what creates a characteristic slope profile. Mountain slopes are usually inclined at angle of 32° whereas outer ridge edges at 40°. Contacts with a slope foot, commonly formed of a flat plain of the marine beach at 70—100 m a.s.l., are very sharp (Pl. 5). Subslope ridges are composed of coarse and angular slope debris. On the surface there are only weathered blocks of 0.5—3 m in diameter. Finer fractions occur on floors of drainegeless depressions, most of which are filled with snow for the whole summer. Frequently wet places are overgrown with mosses. Steep outer slopes of subslope ramparts show outcrops of debris up to 20—30 cm in diameter. At their feet there are numerous rock blocks that have moved down from a ridge crest area.

Similar features were described by Lindner and Marks (1985) from southern Spitsbergen and termed the protalus rock glaciers. Dzierżek and Nitychoruk (1986) named such accumulations in the Polish Tatra Mts the subslope rock glaciers. The term "subslope" defines more precisely a location of these forms and their connection with an inclined surface.

Development of subslope rock glaciers should be referred to intensive deposition of debris in lower fragments of slopes and its further displacement caused by interestitial ice. Rock material coming from slopes or taluses is unable to move on flattenings and grows vertically. Snow and water (gradually transformed into ice) are deposited within a debris. The latter, being cemented with ice, is not subjected to gravitation for a certain time and so, can form shelves at lower parts of slopes. Not unless a certain critical thickness is passed, such ice-cemented debris can be plasticly modelled. And so, ice-debris rampart flows down a slope and is still able to move on a flat surface underneath. Shapes of ramparts prove that this process is not uniform and many a time renewed: in plan there arched or wavy ridges while heights of individual lobes are varying.

Highest outer ridges of some rock glaciers of this type possess cracks, 1.5 m deep and 3 m wide, what suggests them to be saturated with ice. Presence of ice can result in decay of slope processes on steep outer slope of a ridge, composed of non-weathered rock debris of various fractions. Contact of the ridge with a flat surface of a marine beach is very sharp (Pl. 5, Fig. 2). Outer slopes of these forms have 2—3 m beneath a top a slightly daker strip, several centimeters wide. This zone is probably saturated with water what results from ablation of ground ice. A consideration of this ice for a buried glacial ice seems doubtful as occurrence of subslope rock glaciers does not indicate any relation with glacial valleys (Fig. 1). No similarities are noted with lateral moraines *e.g.* of the Renardbreen where a clean ice outcrops from under a thin (30—50 cm) debris mantle.

Fresh outer slopes of subslope glaciers and presence of cracks in their crest zones can be symptoms of continued movements of such features. Several markers were installed on slopes and at feet of rock glaciers and in adjacent areas for needs of evaluation of such movement. But no changes were noted during several weeks of summer 1986.

Nival moraines

They are similar in shape but slightly smaller than subslope rock glaciers (Fig. 1). Nival moraines are located either at slope feet on marine beaches or on higher fragments of mountain slopes. Their bases occur at 130—150 m a.s.l. in the Tjörndalen (Pl. 6, Fig. 1) and in the Blomlidalen, and at 180 m a.s.l. in vicinity of the Scottbreen. In the northwestern Chamberlindalen there is a system of three and locally of four rock ramparts that are located at various altitudes (Pl. 6, Fig. 2). Nival moraines are common in the Lognedalen and Dunderdalen areas.

Nival moraines are up to 40 m high, several kilometers long and occasionally over 50 m wide. They are separated from a slope by depressions or flattenings, frequently filled with snow. Surfaces of these features are composed of weathered rock blocks, mantled with fresh material from taluses. A microrelief of these features is similar to the one of subslope rock glaciers.

Origin of nival moraines corresponds to the first stage of development of subslope rock glaciers (*cf.* Lindner and Marks 1985). Intensive supply with rock material concentrates on slope flattenings, on glacial rock shelves (Szczęsny 1987) or at slope feet (marine beaches, valley floors). Snow accumulates in flattened zones and facilitates a transport of debris (avalanches, taluses) and development of ramparts at short distances aside a slope. Nival moraines do not indicate any symptoms of movement.

Conclusions

Analysis of slope and glacial landforms and sediments in the northwestern Wedel Jarlsberg Land allowed to distinguish rock glaciers and nival moraines. They are debris accumulations, connected with glacial transport in specific morphologic and climatic conditions. A presence of such features indicates a slow deglaciation and intensive slope processes.

Most features indicate symptoms of moving. All the moraine and some of the cirque rock glaciers are still subjected to modelling by processes that occur on mountain glaciers. Fossil cirque and subslope rok glaciers seem to have already passed through their main development phase. Their age is to be defined on the basis of location of two such features in the vicinity of the Scottbreen (Fig. 2). A fossil cirque rock glacier on southeastern slope (Pl. 4, Fig. 1) as well as a subslope one on northwestern slope (Pl. 5, Fig. 1) are partly covered by deposits of lateral or terminal moraines of the Scottbreen (Pl. 4, Fig. 2) dated for the Little Ice Age (*cf.* Kosiba 1958). Thus both rock glaciers are older than moraines of the Scottbreen. The subslope rock glacier occurs on the terrace 70—100 m a.s.l., correlated with the terrace 61—96 m a.s.l. from the Isfjorden dated for 7000 years B.C. and with the terrace 7.5—10 m a.s.l. from the Hornsund dated for 9200 years B.P. (Birkenmajer 1960, Birkenmajer and Olsson 1970). Therefore, the rock glacier to the west of the Scottbreen snout was formed between 9200 and 600 years B.P. (Fig. 2). Maximum diameters of the lichen *Rhizocarpon geographicum* measured by the authors on surface rock blocks of this subslope rock glacier were equal 75 mm. Such sizes of lichens allow, according to André (1986), to date deposits for 3500—2000 years B.P. This date corresponds with the second Holocene glacial episode (Baranowski 1977). A similar weathering of debris that forms other subslope and fossil cirque rock glaciers permits to refer their origin to the same time.

A connection of moraine and other cirque rock glaciers with glacial moraines from the Little Ice Age allows to date them for the maximum advance of glaciers in that time. It occurred in the 18th century (*cf.* Kosiba 1958) and these features are already marked on the maps from 1936.

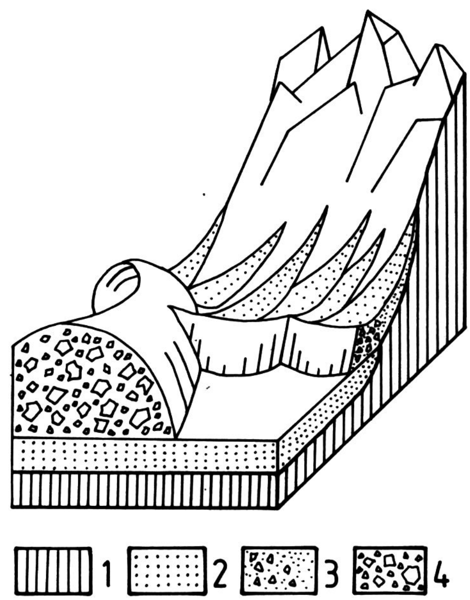

Fig. 2. Location of a subslope rock glacier in northwestern vicinity of the Scottbreen: 1 — bedrock, 2 — deposits of the marine terrace 70—100 m a.s.l., 3 — deposits of taluses and a subslope rock glacier, 4 — deposits of a terminal moraine of the Scottbreen

Further data on age of rock glaciers from the northwestern Wedel Jarlsberg Land are expected from TL datings of samples collected from these features.

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Streszczenie

Na podstawie analizy form i osadów zboczowych i lodowcowych w północno-zachodniej części Ziemi Wedel Jarlsberga wyróżniono trzy typy lodowców gruzowych (fig. 1): morenowe (pl. 1, pl. 2. fig. 1), cyrkowe (pl. 3. fig. 1, pl. 4. fig. 1) i podstokowe (pl. 5). Wydzielono także moreny niwalne (pl. 6). Wszystkie te formy zbudowane są z grubookruchowego materiału skalnego (pl. 1, fig. 2; pl. 2, fig. 2; pl. 3, fig. 2; pl. 4, fig. 2), ułożonego w postaci szeregu wałów o wysokości do 50 m. Tworzą one szerokie pola gruzu w czołowych partiach lodowców, cyrków lodowcowych oraz rozległe spłaszczenia pod lub na stokach. Genezę lodowców gruzowych należy wiązać z intensywną dostawą osadów zboczowych i ich przemodelowaniem plastycznym przy udziale lodu. Główny etap rozwoju podstokowych i niektórych cyrkowych lodowców gruzowych określono na starszą część holocenu, zaś morenowych lodowców gruzowych na Małą Epokę Lodową (fig. 2).

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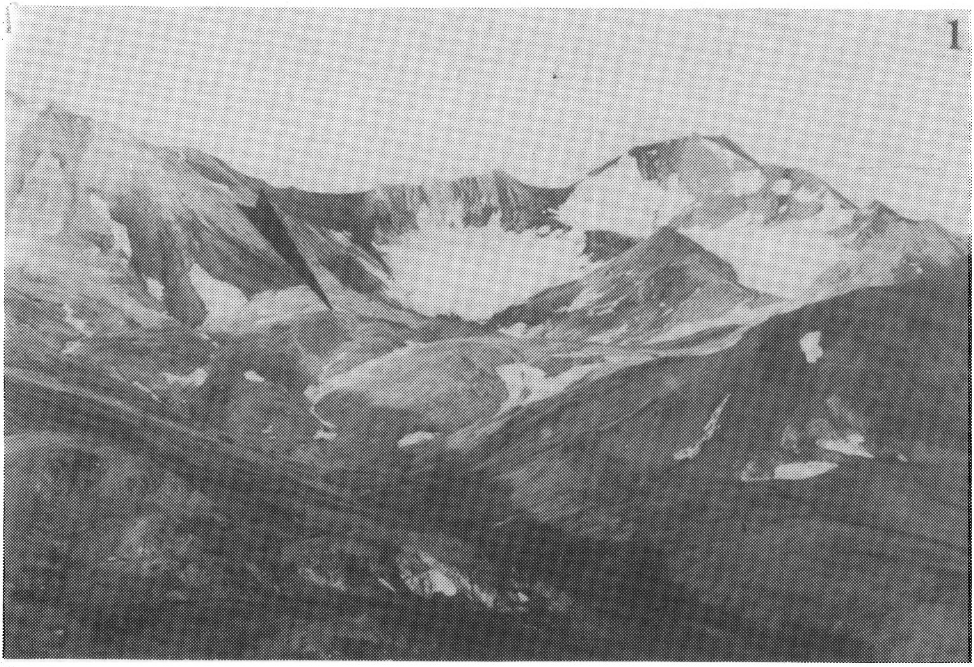
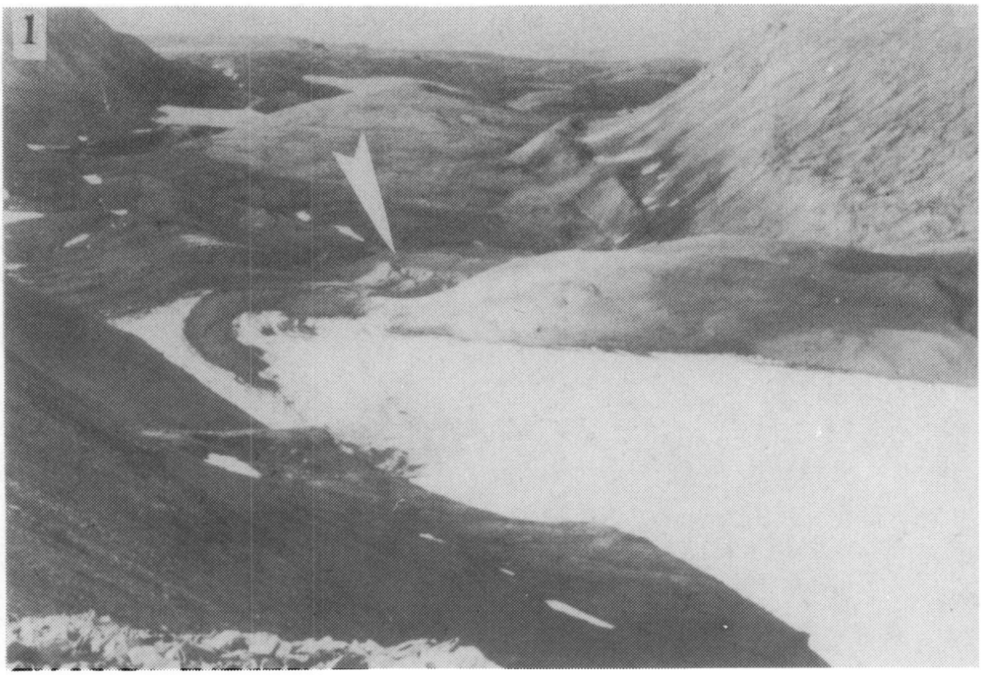


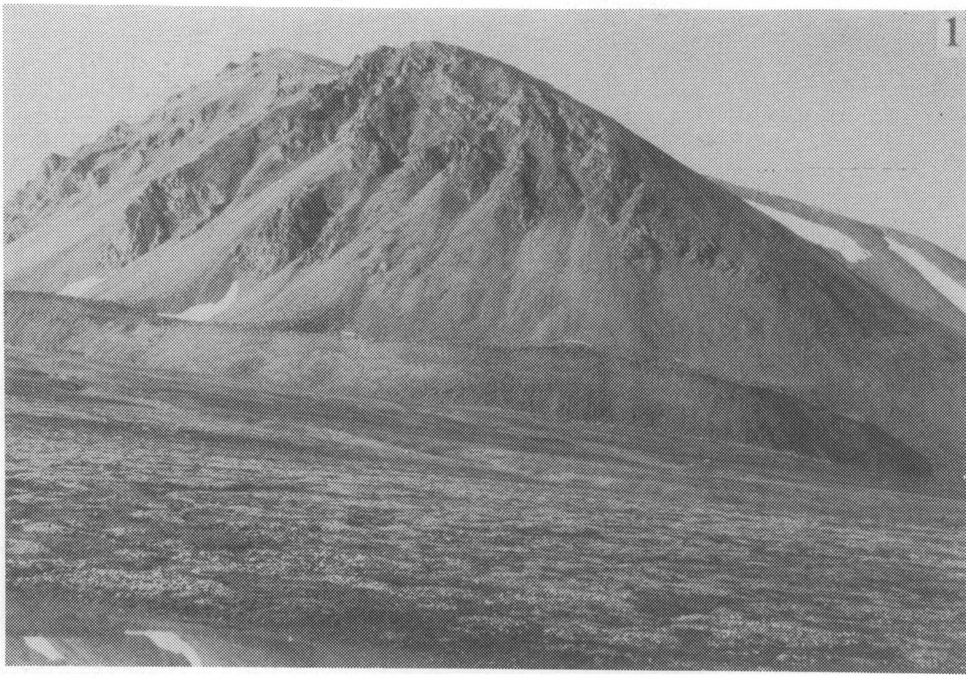
1. Moraine rock glacier on eastern slope of the Chamberlindalen (arrowed)
2. Deposits of a moraine rock glacier in forefield of the Biümekebreane

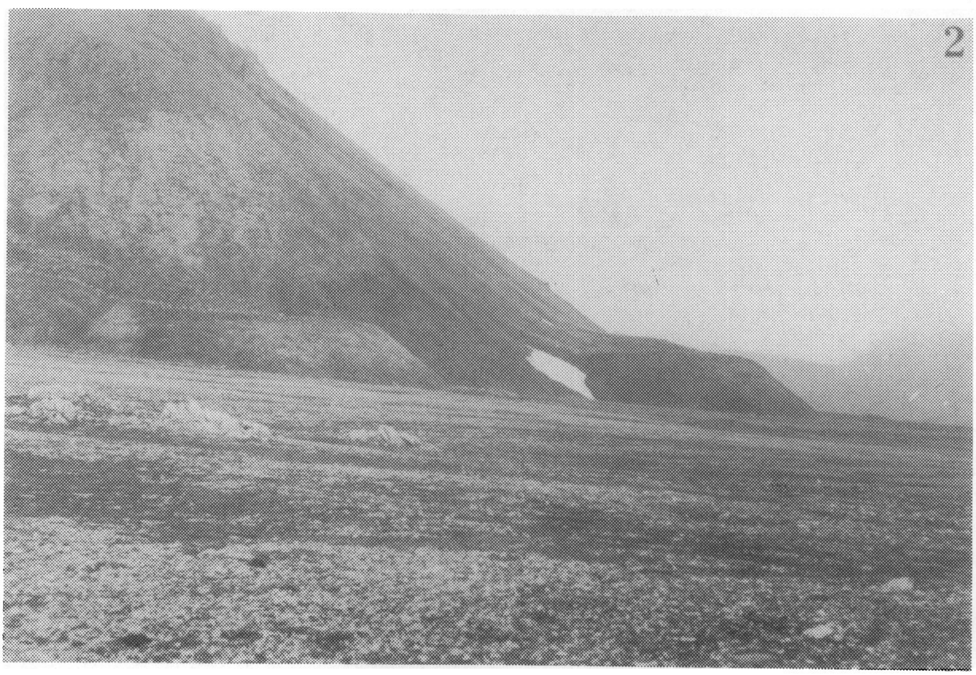


1. Moraine rock glacier in the Tjörndalen (arrowed); to the right nival moraines at foot of a mountain massif
2. Deposits of a moraine rock glacier on glacial ice in the Tjörndalen

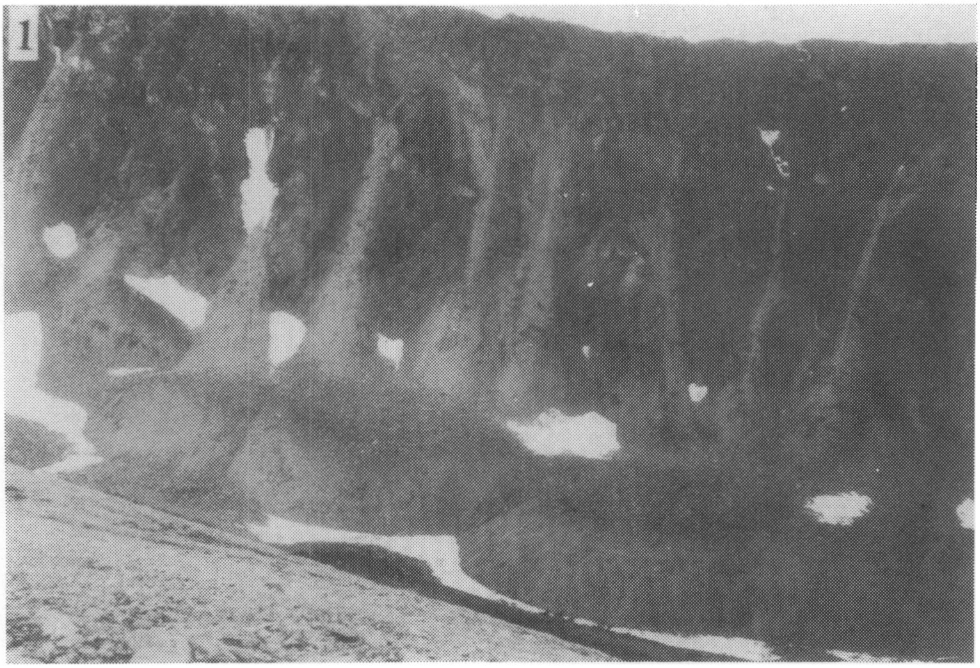
1. Fossil cirque rock glacier in the Tjörndalen (arrowed)
2. Deposits of a cirque rock glacier in the Tjörndalen

1. Fossil cirque rock glacier in southeastern vicinity of the Scottbreen
2. Contact of deposits of a lateral moraine of the Scottbreen (to the right) with deposits of a fossil cirque rock glacier





1. Subslope rock glacier to the west of a terminal ice-cored moraine of the Scottbreen
2. Subslope rock glaciers in vicinity of the Dyrstaddalen



1. Nival moraines on western slope of the Tjörndalen
2. Three levels of nival moraines on western slope of the Chamberlindalen