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Preliminary geomorphological characteristic of Linnédalen (Spitsbergen, Svalbard Archipelago) *)

ABSTRACT: On the basis of observations and topographic surveys carried out mainly in the northern part of Linnédalen on Spitsbergen, geological structure of the valley was described and determination of the forms of relief by the means of lithology was demonstrated. The relief of the valley was characterized with particular regard to periglacial processes. A geomorphological map of the northern part of Linnédalen was made and a part of a cataloque of polygonal and structural soils was prepared.

Key words: Arctic, Spitsbergen, Linnédalen, geomorphology.

The aim of this study is a preliminary presentation of the course and intensity of periglacial and glacial processes at Linnédalen with the purpose in view to make in the future a complex physiographic characteristic of the valley. Observations of geological structure and relief were performed from 17 July to 10 September 1978.

The area of the studies was Linnédalen lying in the north-western part of Nordenskiöldland, at about 78°N lat., and 14°E long. (Fig. 1).

It is a valley of a tectonic character, filled in the head part with a small glacier — Linnébreen, at present moulded by periglacial processes. The valley's lenght is about 15 km and its width varies from about 1.5 to 2 km. It is blocked in the west by the massif of Mount Griegfjellet (778 m, a.s.l.), in the south by Linnébreen, in the east by massifs: Vardeborg (588 m a.s.l.), Sokolovtoppen (544 m a.s.l.), Vöringen (675 m a.s.l.) and Kalkegga.

*) This study was carried out during the Students' Expedition, Faculty of Geography and Regional Studies, Warsaw University, to Spitsbergen (Linnédalen-Nordenskiöldland-West Spitsbergen) in the summer season of 1978.

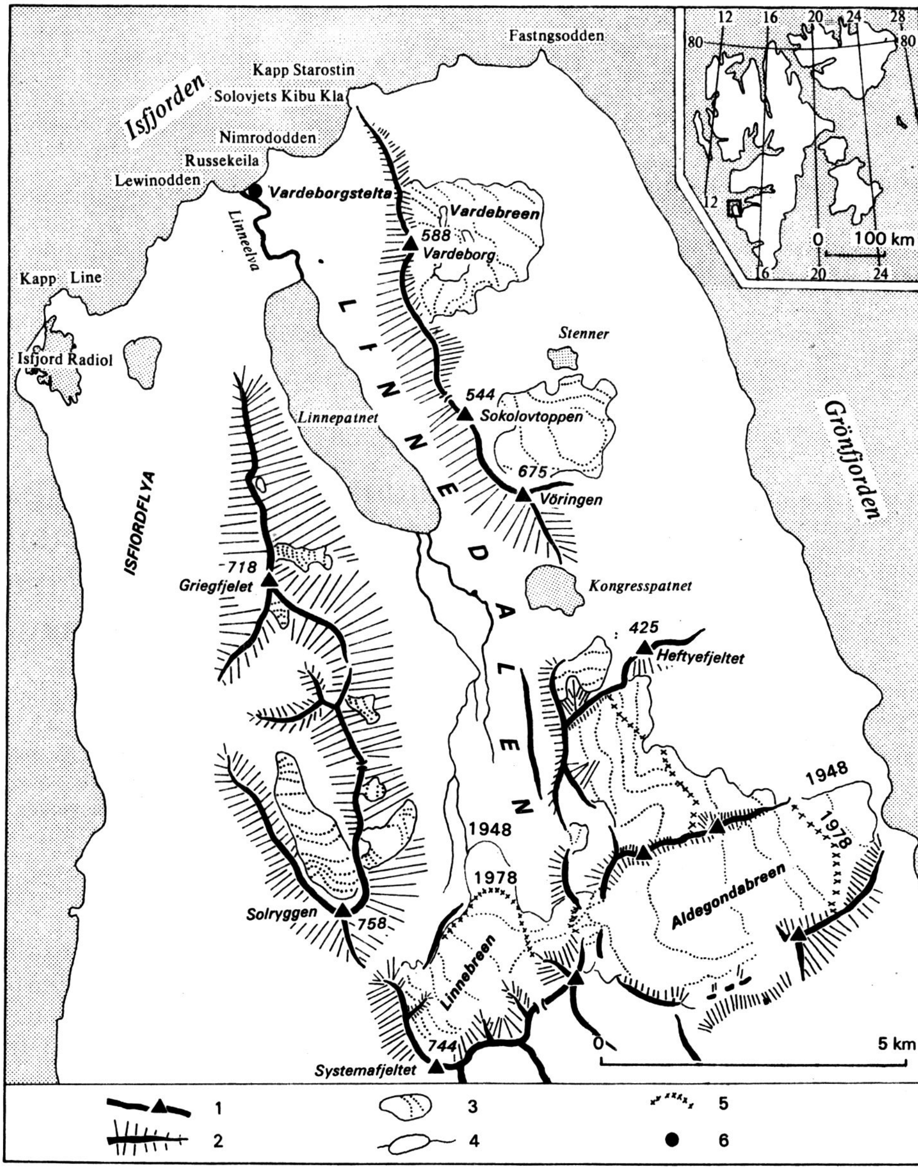

Fig. 1. Situation of Linnédalen (Spitsbergen). Scale 1:100,000
1 — Ridges and summits (tops), 2 — Rock-faces (cliffs), 3 — Glaciers and snowfields, 4 — Lakes and rivers, 5 — Estimated extent of glaciers, 6 — Base of the Expedition.

The inclination of the slopes of the massifs surrounding the valley ranges from 25° to 45°. In the north the valley is connected with a terraced plain of marine accumulation lying on the Isfjord — Vardeborsletta. In the central part of the valley lies second largest lake of Spitsbergen — Linnépatnet (about 4.65 km^2).

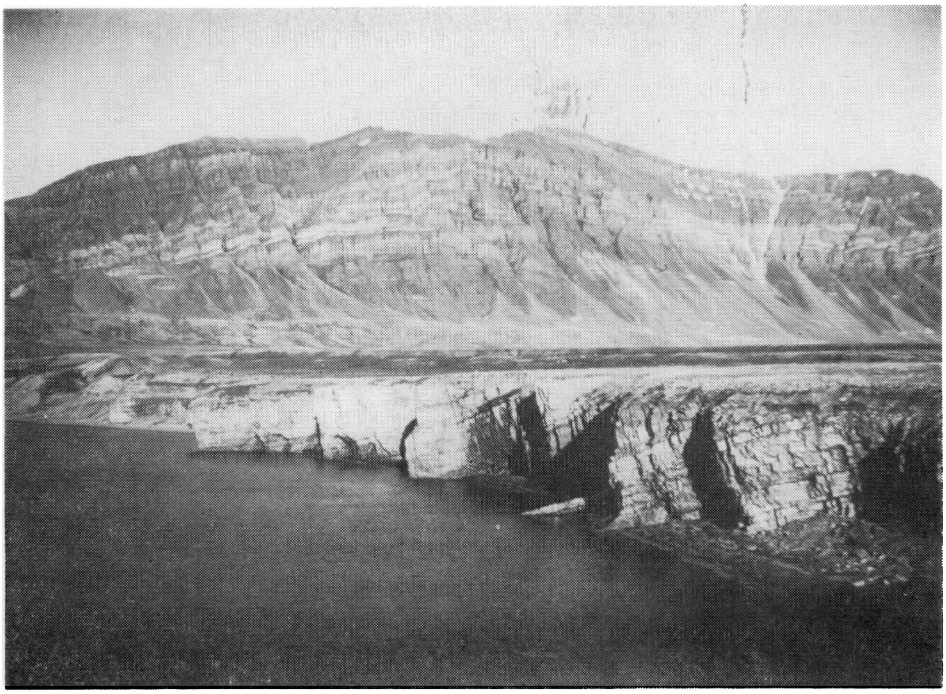

Fig. 2. Outcrops of Carboniferous conglomerates (foreground) at Solovjetskibukta and rock-face of Vardeborga (background) revealing Carboniferous and Permian rocks

Photo H. Prószyńska

67 measurements of the depth were carried out in four profiles localized in the northern part of the lake. The maximum measured depth was 26.7 m. The depth of the lake increases towards its western shores. The water level of the Linnépatnet Lake is 8 m a.s.l., thus the lake bottom is a cryptodepression.

The Linnéelva river flows out of the lake emptying into Isfjord (approximate rate of the river flow is 5.304 $m^3 \cdot s^{-1}$ — the measurements were made on 6 August 1978). The Linnéelva river drains nearly 90 per cent of the total area of the valley.

Geological structure of Linnédalen is characterized by age sequence of rocks and their meridional distribution, from the oldest in the west to the youngest in the east. In the west wing of the valley two massifs: Griegfjellet and Linnéfjella arise, formed by old metamorphosed Proterozoic rocks and Pre-Cambrian formations (Hoecla Hoek)[1]).

The geological age sequence is particularly easy observed along the shores of Isfjord, which form a series of peninsulas and semicircular coves near Linnédalen. Each peninsula is built of different kind of rock. Moving eastwards of Kapp Linné younger and younger formations are observed. On the Hoecla Hoek rock formations carbon occurs animously (Różycki 1936) the outcrop of which in the form of pale grey quazitic schist with pit coal interbeddings is found at Levinodden. More resistant schists form abrasive spurs separated by niches in the places of the occurrance of coal interbeddings. At the next cape — Nimrododden a fragment of Carboniferous conglomerates outcrops is observed. These are culm rocks similar to above — described schist.

At Solovjetskibukta (Fig. 2) the Middle and Upper Carboniferous and partly Permian rock series occur represented by the Kapp Starostin formations consisting of slates and marine shales, mudstones, carbonaceous rocks and locally sandstones[1]). In the eastern part of the valley calcareous rock series occur with numerous fauna organisms, Brachiopods of genus *Productus*, sponges, corals and *Bryozoa*.

Rocks of Hoecla Hoek formation were strongly cracked by numerous small faults. The Carboniferous and Permian formations fall down monoclinally at an angle of 10—25° mainly eastwards.

The greatest part of the valley is modeled by periglacial and fluvial processes, also by aeolian ones and in some fragments of the surface by glacial, glaciofluvial and nival processes. The distribution of all these formations and processes is ilustrated in a geomorphologic map of the northern part of Linnédalen (Fig. 3).

In the valley, macroforms with well discernible geological structure predominate, partly concealed by vast alluvial cones and scree slopes. The more steep slopes are cut through by numerous gullies often filled up with snowfields and small glaciers.

Terraced forms lying at the foot of Vardeborga are very interesting with tops levelled at the heigh of 90—100 m a.s.l. (Fig. 4). They are formed by sharp-edged rubble and large boulders (up to 2—3 m diameter) of native

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[1]) Geological map of Svalbard, 1971.

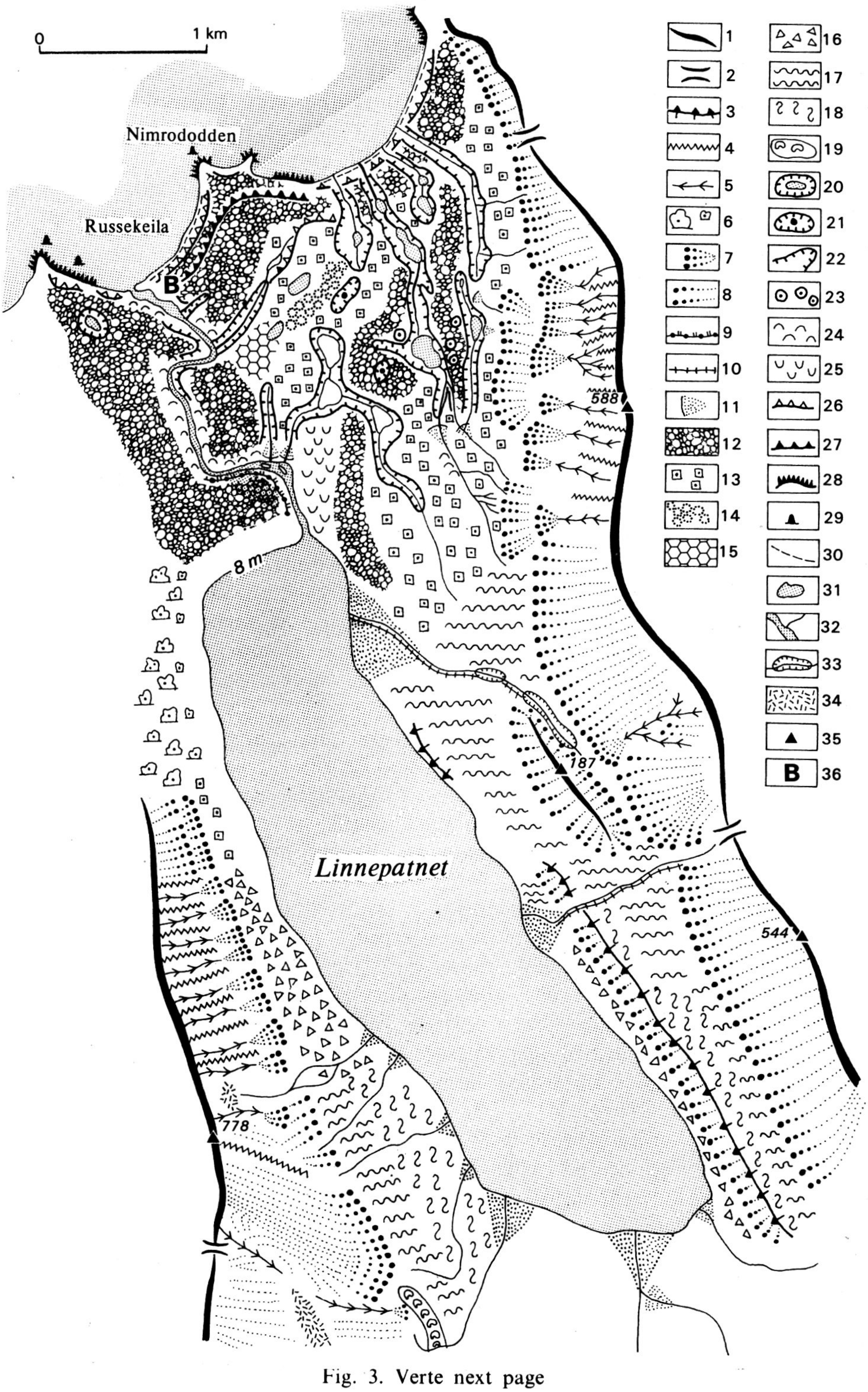


Fig. 3. Verte next page

origin. Their tops are in general levelled with small depressions on the surface, some of them are filled with water. These depressions separate two ranges of low banks of rubble lying on the flattened surfaces. Slopes are steep, slinghtly protuberant, inclined at an angle of about 35—40 . They make up a series of continiuous forms lying at the same level. These forms were observed also in other parts of Spitsbergen. Their genesis is discussed. Czeppe (1966) considers then as névé moraines formed at a time of an intensified breaking off of the fragments of rocks sliding down over large fields of névé. Jahn (1959) considers them as glacial moraines associated with the Holocene maximum glaciation. Birkenmajer (after Czeppe 1966) suggests that these are the remnants of the Late Würm moraines. Szupryczyński (1963) assumes that they are partially typical head and lateral moraines of larger glaciers and partially moraines deposited by slope glaciers. Our observations confirm the debris character of these forms. On the slopes of Vardeborga remnants of the patches of preserved snow still remain in the deeper guilles (Fig. 4). However, it is difficult to exclude thoroughly glacial origin of these forms, but is also possible they originated under the effect of tectonic and marine agency.

According to Różycki (1936) in the regions of Isfjord and Grönfjord the marine terraces are found at the height of 300 m a.s.l. Jahn (1959) estimated the post-glacial elevation of the Spitsbergen coastline as rising to the height of 300 m a.s.l. and Szupryczyński — as 350 m a.s.l. in the region of Hornsund. Feyling-Hansen (after Marcinkiewicz 1961) did not observe in Isfjord higher terraces than 96 m a.s.l., which is consistent with our observations in Linnédalen.

At present the coasts of Spitsbergen are stabilized (Feyling-Hansen, after Szupryczyński 1968). This is confirmed in a way by the position of the relicts of the cabin of Ivan Starostin. They are situated close to the edge of an older than the present one terrace a score of meters from the

Fig. 3. Geomorphological sketch of the northern part of Linnédalen. Scale 1:26,000

I. Formations originating from endogenous agencies — denudation processes. 1 — Ridges, 2 — Mountain passes, 3 — Monoclinal structural ledges, 4 — Rock ribs, 5 — Gullies, 6 — Small denuded monadknocks, 7 — Taluses of scree (alluvial cones), 8 — Taluses and waste heaps of scree (25—30).

II. Formations of fluvial origin. 9 — Permanent river-beds cut in alluvium, 10 — Permanent river-beds cut in rock, 11 — Gravel-sand alluvial cones.

III. Criogenic forms. 12 — Tundra polygons (large, disintegrating ice-polygons), 13 — Other types of structural soils (smaller and less distinct forms), 14 — Stone circles, 15 — Stone net on wet ground (flooded), 16 — Rubble cover, 17 — Slopes modeled chiefly by solifluxion, 18 — Solifluxional accumulations, 19 — Névé banks of scree.

IV. Thermokarstic formations. 20 — Igneous bowls and troughs filled with water, 21 — Igneous dry bowls and troughs, 22 — Thermo-Karstic craters, 23 — Thermo-Karstic valleys, 24 — Thermo-Karstic denudation slopes, 25 — Areas of Thermo-Karstic subsidence of sediments.

V. Thalassic formations. 26 — Ledges of elder marine terraces and "dead" cliff, 27 — Active cliff, 28 — Abrasive spurs, 29 — Small abrasive monadknocks, 30 — Storm banks, 31 — Lakes, 32 — Rivers, 33 — Permanent ice-fields, 34 — Permanent snow-fields, 35 — Summits, 36 — Base.

coastline over Russekeila at the mounth of the Linnéelva river[2]). Distinct traces of the regressive agency of the sea are visible only north of the shores of the Linnépatnet Lake in the form of a series of ledges of marine terraces, tiers of gravel-pebble, sand-gravel and sandy deposits cut across by the Linnéelva river. The Linnéelva cuts its way through the sediments to about 30 m. The river banks disclose numerous outcrops with fragments of mollusc shells and remains of whale bones. Also glaciotectonic disturbances are distinctly visible, which may evidence the extent of the glacier in the valley.

The twofold layers of these sediments are very characteristic and well visible at the outlet of a small side-valley on the right side bank of the river, in the vicinity of the Stations of the Expedition. The upper layer 15 m thick consists of yellow, brown and rust coloured sand and gravel, horizontally stratifield, with numerous shels of molluscs. The lower layer consists of displaced glaciotectonic sands and dark grey silts likewise with a great number of molluscs. Such a sequence of sediments suggests the presence of the sea in that place twice. Both floods occurred in the Pleistocene and were separated by the transgression of glaciers. Other traces of glacier agency at the outlet of the valley are visible in the small area of the uncovered ice pavement close to the mounth of the Linnéelva river. Correlating the height of this ice pavement position with the double-layer of the sediments in the Linnéelva valley it may be assumed that it is connected with glacier transgression separating two periods of the presence of the sea in Linnédale.

Another evidence of a wider than present range of the glacier expansion in Linnédalen is the presence of erratic blocks in the central part of the valley at the southern shore of the Linnépatnet Lake. These are old, metamorphized rocks of Hoecla Hoek formation. They are found on the top of a washed-out morainic hummocks.

The most imposing form in Linnédalen is the kneding through of the Linnépatnet. Presumably, its genesis is very complex.

Numerous stream and river-beds are cut out in the form of gullies and canyons (in Linnédalen about 10 m deep) through the not much resistant Carboniferous system of rocks. Such an intensive erosion is caused by the postglacial decline of the erosive base due to acclivous isostatic movements. Large alluvial cones are deposited (Fig. 3). In Linnédalen two generations of alluvial cones can be differentiated. The elder one, higher, cut through by a stream flowing downwards from a mountain pass between Vardeborg and Sokolvtoppen and the younger one, lower, not less extensive, deposited by the same stream in present times.

Periglacial and glacial forms are very characteristic for Spitsbergen. Periglacial forms in the valley are extremely well-shaped. The permafrost reach in the Swalbard Archipelago the depth of 150—200 m below the ground and it is at the surface strongly transformed by cryogenic processes. It has been found that in July 1978 the active zone at the level of the second, elder marine terrace in Russekeila extended tothe depth of 1.20 m down the ground.

[2]) This Cabin was built at the end of 18th century by Starostin, who lived there for 39 years. He died there in 1826 and was buried close by.

Fig. 4. Foot of Vardeborga Massif

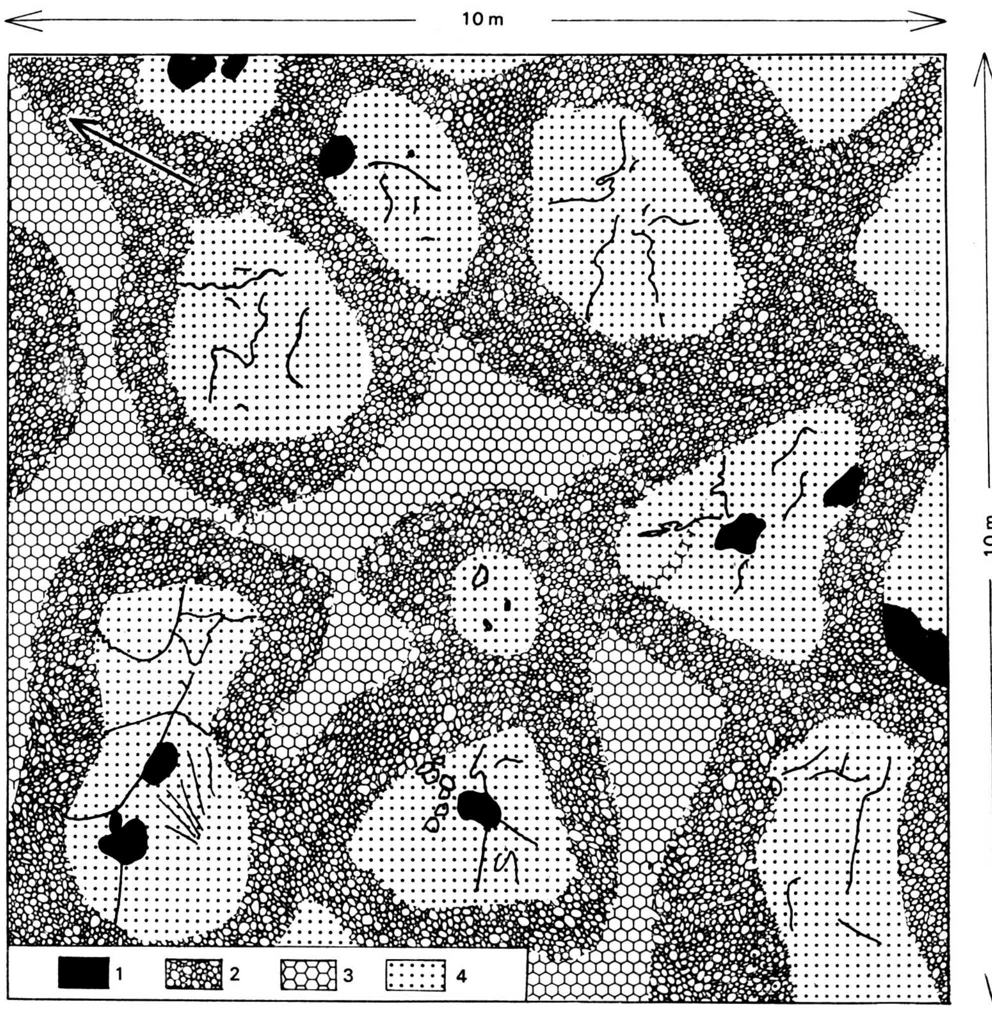
Vast thermo-Krast trough (foreground) formed of three thermo-Krast bowls. Slopes modeled by thermo-Krast denudation and solifluxion. A series of névé moraines (background).

Photo T. Sadowski

Figs. 5, 6 and 7. Stony rings. Plain of Vardeborgletta

1 — Clumps of mosses, 2 — Sharp-edged detrital material (5—10 cm in dia.), 3 — Sharp-edged detrital material (2—3 cm in dia.), 4 — Plastic loamy mass with rock fragments. Inner differentiation of the fields with weakly developed miniature polygonal net is very characteristic.


10cm



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The cryogenic forms at Linnédalen occur every-where, from the sea level up to the peaks of the mountains surrounding the valley. For instance, stone circles formed in sharp-edged rubble with small amount of fine-grained, detrital material was observed on the planation surface at the top of Vardeborga.

In the Vardeborgsletta and Isfjordflya plains almost all types of polygonal and structural soils are observed (stony rings and polygonal nets, stone circles and stony stripes, tundral polygonal forms and earth hummocks), (Jahn 1975). The variety of cryogenic forms occurring in Linnédalen is presented in the geomorphological sketch (Fig. 3).

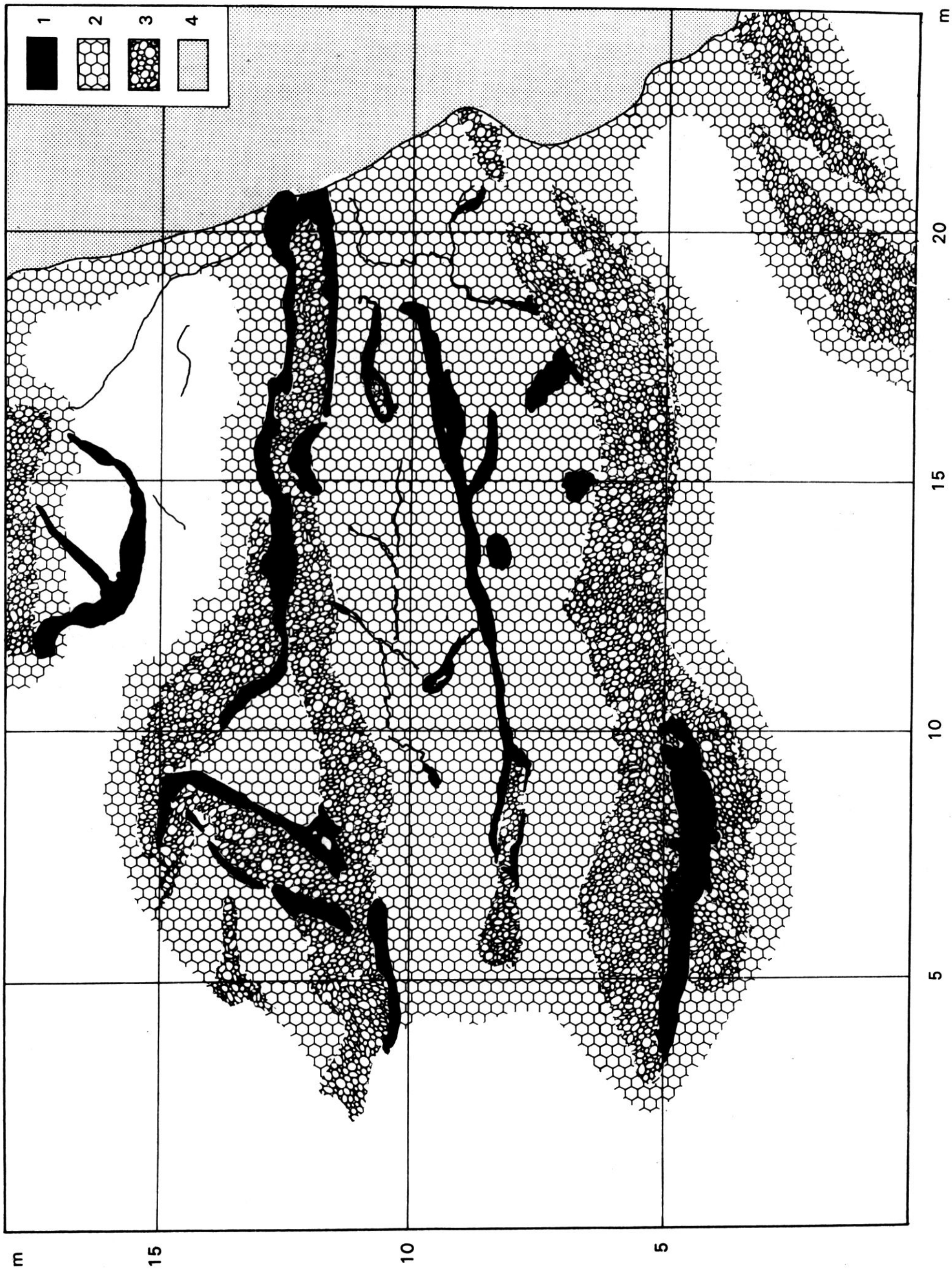

Fig. 8. Stone-rubble strips
Presumably, shifted from stone circles lying higher (about 15 m) uphill. Slope (about 5 incline) — length of banks 8—12 m, width 0.2—1.7 m, height 0.35—0.40 m. Between the banks weakly developed miniature polygonal net
1 — Moss, 2 — Sharp-edged detrital material (2—3 cm in dia.), 3 — Medium-sized detrital material (2—50 cm in dia.). 4 — Lake.

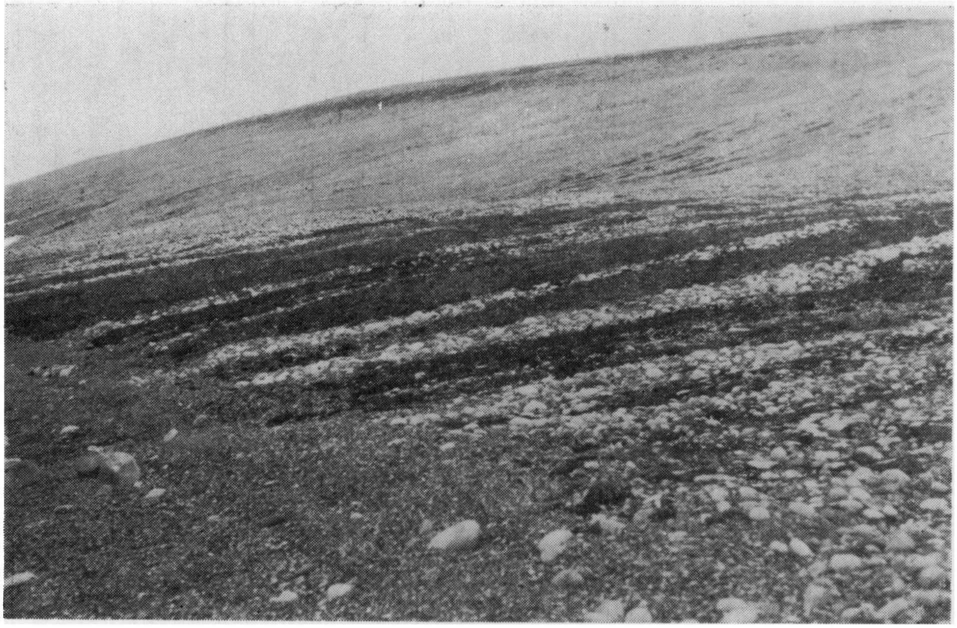

Fig. 9. Stone strips on the shores of the Linnépatnet Lake
Rubble (up to 20 cm in diameter).

Photo W. Gogołek

Fig. 10. Ice-polygons (Marine terrace near Vardeborg)

Photo T. Malanowski

Among many different forms of structural soils the perfect shape of the well developed forms of stony rings in the plain of Vardeborgsletta are worthy of a particular notice (Figs. 5, 6 and 7). Within the stony rings a miniature net of polygonal forms is observed very often, which is younger in relation to the "main" net (Karagodina 1964). It has been found in the in the cross section that these are rings of the "suspension type" (according to the nomenclature proposed by Klimaszewski 1978). The debris is suspended in a loamy, easily moulded material saturated with water.

In the places with slopes of more than 3° inclination (Klimaszewski 1978) stone circles stretch out and transform into stony strips. According to Washburn (1956) stony strips are formed on the slopes with inclination from 3—7° to 15—30°. Stony strips occur quite often in a self-contained independent form (Figs. 8 and 9). These are forms of cryogenic origin. Czeppe (1966) has observed in the region of Hornsund the formation of a stony net and stony strips of fluvial origin. Such forms were not observed in Linnédalen but it is not unlikely that during the time of thaw melt glacial waters use stony strips as a specific drainage system.

In the central part of Vardeborgsletta on the ground covered with water in the summer 1978 stony nets poorly sorted out were observed (Fig. 3). The sorting-out of this type of stony nets occurs only in the transitional autumn-winter time, when water dries up (Karpov 1964).

Huge forms up to 10 m in diameter consist of ice-wedged tundral polygons occurring at the level of gravel-cobble layers of Vardeborgsletta (Figs. 3, 10 and 11). These forms have the shape of tetra-, penta-, and hexagonal polygons, convex inside, filled with unsorted debris. The polygons are bordered with 30—80 cm wide hollows overgrown with moss and lichen. They are not filled with detrital material. Klimaszewski (1960, 1978) considers these forms as the youngest in the cycle of development of polygonal soils formation. Washburn (1956, 1973) calls them ice-wedge polygons and describes them as unsorted forms. The position of the forms at Linnédalen on flat, relatively dry surfaces, often rising above their surroundings, confirms their young age. Under such conditions cryogenic processes are slower. The distribution of the forms prevailing in the northern part of Linnédalen is presented in the geomorphological sketch (Fig. 3).

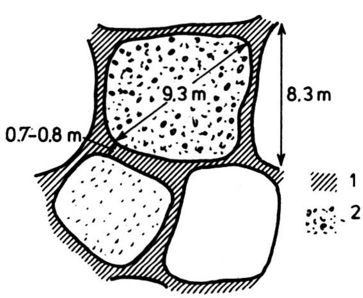

Fig. 11. Ice-polygons (Marine terrace near Vardeborgsletta)
1 — Moss, 2 — Sands, gravels and small boulders up to 40 cm in diameter. Permanent frost at the depth of 1.20 m.

In the eastern part of Linnédalen near the Linnépatnet Lake solifluxional tongues (1.5 m long and up to 1 m wide) are observed separated from one another by a few or several centimetres high ridges. For the greater part these ridges are overgrown with mountain avens (*Dryas octopetalla*) forming a clear-cut boundary of the tongue supported by a strongly developed root system. The inner part of the tongues is filled with detrital material mixed with coarse rubble and overgrown sporadically with tufs of *Saxifraga*. This is an example of an interrelated solifluxion (Klimaszewski 1978). These forms were found only at the foot of Vardeborga in the places of where wheathered limestone rock occur. Limestone rocks belong to the solifluid forms (Tricart and Wiliams, after Klimaszewski 1978).

Numerous small lakes and streams in Vardeborgsletta form widespread systems of thermokarstic bowls, gullies and valleys. Their slopes are modeled by thermokarstic denudation (Figs. 3 and 4). The most intensive denudation is observed along the Linnéelva river. The river forms a gorge between Linnépatnet and Isfjord cutting through marine sand-pebble sediments. The slopes of the valley are steep and form in some parts systems of sandy bastions and ribs cut by incisions and gullies through which limy, muddy tongues of landslide are flowing down. In these parts the slopes of the gorge are disrupted around the landslip recesses.

A particular attention was given to the intense solifluxional processes in the Linnéelva valley. In the summer of 1978 intense but not very large muddy surface run-offs were observed. The observations were made every hour at the edge of a patch of snow. The rate of flow of the run-offs was about 90—115 $cm \cdot h^{-1}$. Similar processes were observed by Jahn (1975). The methods of measurements are given in Figs. 12A and 12B and the effects of muddy solifluxion are presented in Fig. 13.

Frost-weathering is a common phenomenon causing disintegration of boulders, cobbles, pebbles and rock fragments and destruction of rock-faces. The effects of frost weathering depend on the type of rock and its shape and occur in a different way. Sandstone pebbles and cobbles flake off concentrically, schist split into slabs or sheets, quarcite and limestone boulders disintegrate into blocks.

Glacial forms, except small glaciers filling up some parts of river beds, gullies and shaded rock-faces, are observed only in the upper part of Linnédalen. The foreland of Linnébreen is closed by a lofty, frontal ice-core moraine, cut through by the gorge of glacier's river passing on the wings of the glacier into a vast zone of a lateral moraine. Frontal ice-core moraines are very characteristic for Spitsbergen landscape. They were described by Szupryczyński (1968). They remain only as a transitory phenomenon in the nearest vicinity of the glacier.

The formation of numerous landslip recesses with flowing down solifluxional tongues was observed at the end of the summer season 1978 on the lateral ice-cored moraine of Linnébreen at its eastern proximal slope. The muddy detrital material carried along rock debris and even large boulders (up to 1.5 m in diameter). The landslip recesses were up to 10 m in diameter and the length of solifluxional tongues was up to 20 m. These phenomena

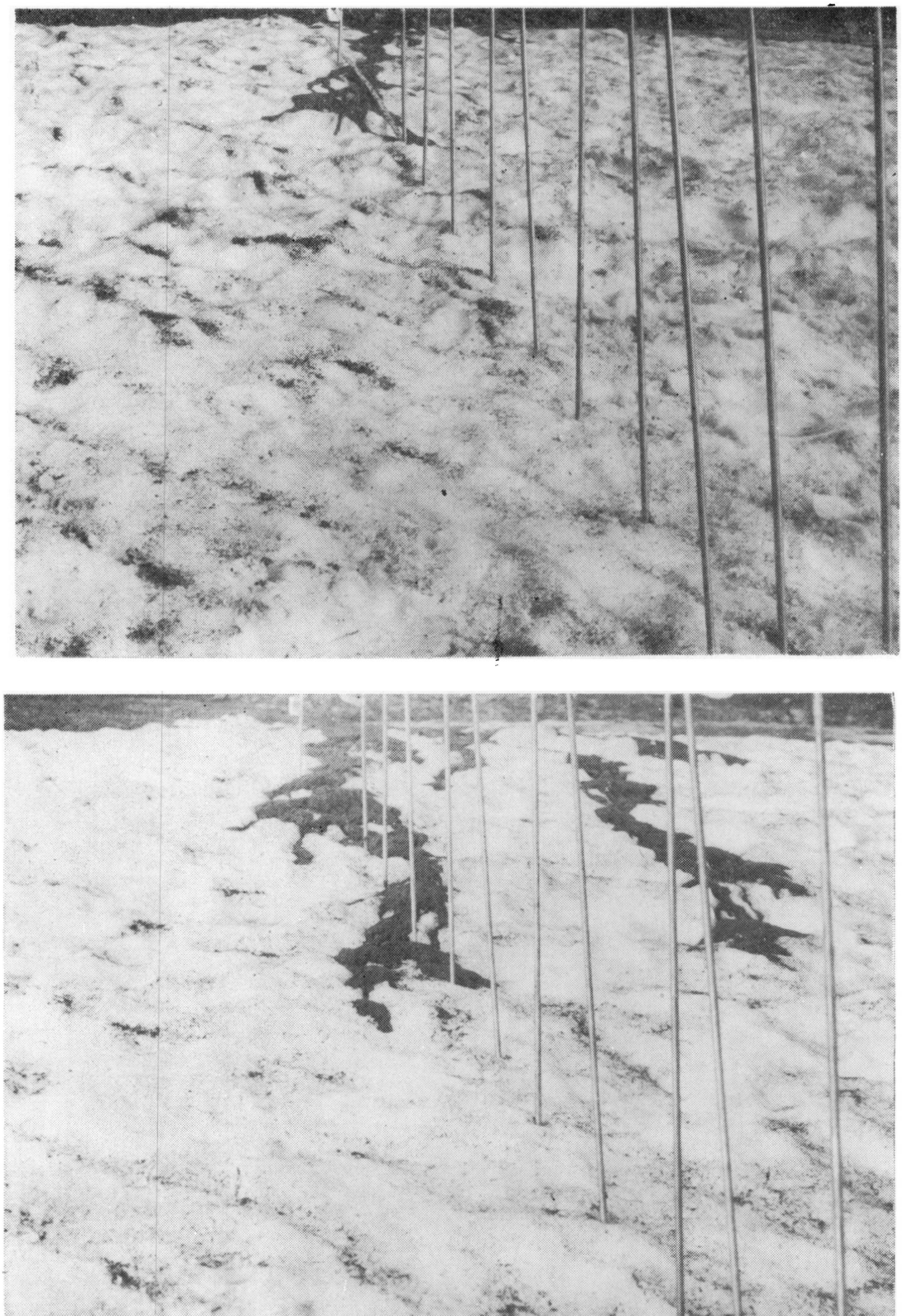

Fig. 12. Tongue of muddy runoff observed at the edge of a snow-field in the Linnéelva Valley in the first stage (A) and after one hour (B)
Distance between poles — 30 cm.

Photo T. Malanowski

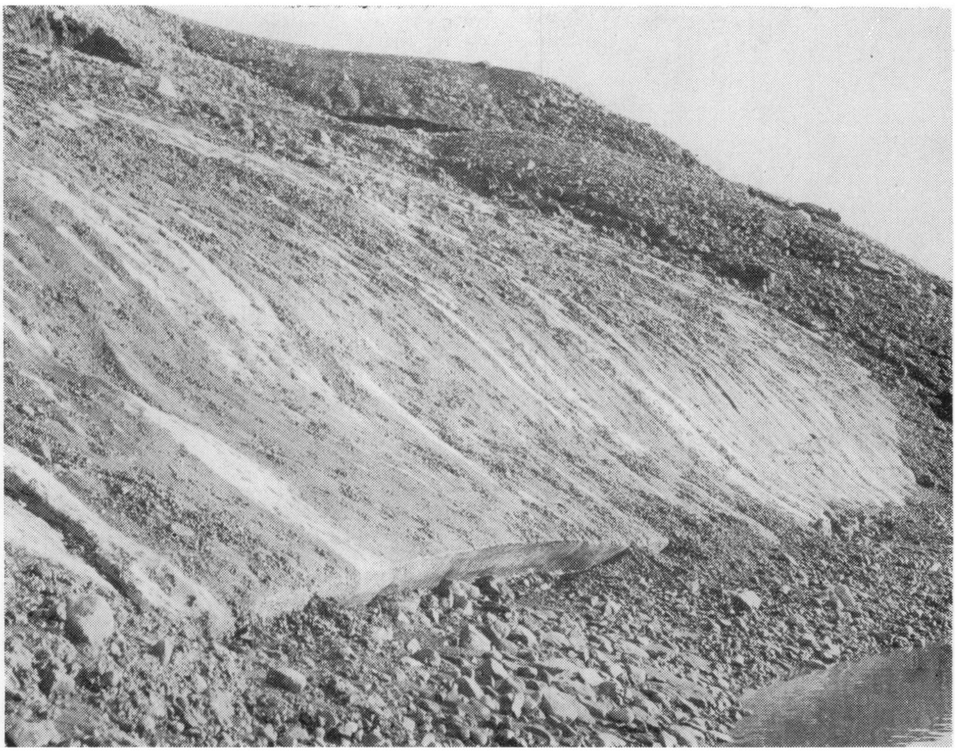

Fig. 13. Snow-field in the Linnéelva valley covered with detrital material from the muddy runoffs (muddy solifluxion)

Photo T. Malanowski

were observed by Szupryczyński (1963) on the distal slopes of ice-cored morraines of the Werenskiold glacier.

A small marginal lake, eskers and a series of ice-cored moraine hills partially continguous to the glacier head were found within the area surrounded by ice-cored moraine of Linnébreen in front of the glacier head. Linnébreen is a good example of the recession of glaciers in Spitsbergen (Fig. 1).

The southern part of Linnédalen between the lake and the glacier is a flat zone of a series of washout morainic hummocks consisting of coarse rock rubble. They are partially covered with fluvioglacial detrital material deposited by Linnébreen. Among the morainic hills are small lakes, some of them without outflow. Brooks and streams flow out from Linnébreen and Tjornskardet (a ramification of Linnédalen) and spread over extensively. The detrital material deposited by these streams consists chiefly of gravel.

Due to the great variety of forms occurring in Linnédalen and the limited time of the studies characterization of the valley is confined to the subject of geomorphological description concentrated particularly on the northern part at the valley. Many phenomena and problems were merely signalized.

Summary

The Linneaean Valley (Linnédalen) lying in the Nordeskiolda Land (Spitsbergen) was characterized from the geological viewpoint. A detailed geomorphological analysis of Linnédalen was made. The greater part of the studies and observations was concentrated on the northern part of the valley, where the processes and phenomena were most characteristic for periglacial climate prevail. Geomorphological sketch of the northern part of Linnédalen and a part of a catalogue of structural soils were prepared (Figs. 3 5 and 8).

The most characteristic feature of Linnédalen is a meridional trend of the arrangement and distribution of the series of rocks from the oldest, Proterozoic and Pre-Cambrian in the west to more recent Carboniferous and partially Permian in the east (Fig. 2). There is a stratigraphic gap between the oldest rocks of Hoecla Hoek formation and Carboniferous rocks. The bottom of the valley is covered with slope, fluvial, glacial and fluvioglacial deposits and at the outlet of the valley with marine sediments.

Rubble and morainic forms at the foot of the slope of Vardeborga are described. The origin of these forms is still under discussion. Their scree-néval character has been confirmed, but it is difficult to exclude a possibility of a glacial origin. It is also possible that they originate under the effect of tectonic or sea agency.

It was found that the range of the expansion of the Linnébreen glacier reached much farther than at present. At the mouth of the Linnéelva river, close to the sea, fragments of morainic ice pavement were found and on the riverside disturbed glaciotectonic marine sediments were observed. In the central part of the valley near the Linnépatnet Lake erratic boulders occur.

The sediments exposed at shore of the Linnéelva river were bipartited. The lower part were disturbed glaciotectonically. The upper part were stratified horizontally. This gives evidence of the twice repeated presence of the sea in the Vardeborgsletta plain lying at the outlet of the valley.

Cryogenic and frost-weathering forms are described (Figs. 6 7, 9 and 11).

Резюме

Долину Линнеуша (Linnedalen) находящуюся в Земле Нордескиольда (Шпицберген) охарактеризовано с точки зрения геологии, а также проведено более подробный анализ геоморфологии Леннедален. Большую часть наблюдений и исследований сосредоточено в северной части долины, в которой преобладают процессы и явления характерные для перигляциального климата. Сделано также геоморфологический эскиз северной части Линнедален и части каталога структуральных почв (рис. 3, 5 и 8).

Линнедален характеризуется меридиановой полосатостью залеживания старейших протерозоических пород и эокембричеких на западе до каменноугольных и частично пермских на востоке (рис. 2). Среди старейших пород формации Хекля и Хоэк а карбоном выступает стратиграфический перерыв. Дно долины заполнено склонлвыми, речными, ледниковыми и флювиогляциальными отложениями, а у выхода морскими.

Описано оболомочно-моренные формы у подножья склона Вардеборга, которых генезие до сих пор подвергается дискуссии. Проведенные наблюдения подтвержают их россыпно-нивальный характер, но не можно исключить ледникового происхождения. Возможно, что на их генезис повлияла тектоника и деятельность моря. Констатировано что радиус действия ледника Линнеуша (Linnebreen) большое чем сегодня. На взморье у устья реки Линнеуша (Linneelva) найдено фрагменты моренного каменного материяла, а на её берегах нарушенные ледниково-тектонические морские отложения. В серединной части долины над Озером Линнеуша выступают эрратические велуны. Отложения открытые на берегах Линнеельва это такие, которые состоят из двух частей или внизу нарушенные ледниково-тектонические. Над ними выступает горизонтальное слоение. Это свидетельствует о двукратном пребывании моря на равнине Вардеборгслетта находящейся у выхода долины.

Описано многочисленные выступающие здесь роды криогенных форм (рис. 6, 7, 9 и 18).

Представлено также формы морозного выветривания валунов и чалек.

Streszczenie

Scharakteryzowano Dolinę Linneusza (Linnédalen), znajdującą się na Ziemi Nordeskiolda (Spitsbergen), z punktu widzenia geologii, oraz przeprowadzono bardziej szczegółową analizę geomorfologii Linnédalen. Większą część badań i obserwacji skupiono na północnej części doliny, w której dominują procesy i zjawiska charakterystyczne dla klimatu peryglacjalnego. Wykonano szkic geomorfologiczny północnej części Linnédalen i część katalogu gleb strukturalnych (rys. 3, 5 i 8).

Dla Linnédalen charakterystyczna jest południkowa pasowość zalegania skał, od najstarszych proterozoicznych i eokambryjskich na zachodzie, po karbońskie i częściowo permskie na wschodzie (rys. 2). Pomiędzy najstarszymi skałami formacji Hoecla Hoek a karbonem, występuje luka stratygraficzna. Dno doliny wypełnione jest osadami stokowymi, fluwialnymi, glacjalnymi i fluwioglacjalnymi, a u wylotu morskimi.

Opisano formy gruzowo-morenowe u podstawy stoku Vardeborga, których geneza jest dotąd dyskutowana. Przeprowadzone obserwacje potwierdzają ich usypiskowo-niwalny charakter, ale trudno jest wykluczyć ich glacjalne pochodzenie. Możliwe jest, że na ich genezę miała wpływ tektonika i działalność morza. Stwierdzono znacznie większy zasięg lodowca Linneausza (Linnébreen) niż obecnie. Nad morzem, u ujścia rzeki Linneusza (Linnéelva) znaleziono fragmenty bruku morenowego, a w jej brzegach zaburzone glacitektoniczne osady morskie. W środkowej części doliny nad Jeziorem Linneusza występują głazy narzutowe.

Osady odsłonięte na brzegach Linnéelva są dwudzielne, a na dole zaburzone glacitekto-

nicznie. Nad nimi występuje warstwowanie poziome. Świadczy to o dwukrotnym pobycie morza na równinie Vardeborgsletta, znajdującej się u wylotu doliny.

Opisano licznie tu występujące rodzaje form kriogenicznych (rys. 6, 7, 9 i 11). Przedstawiono też formy wietrzenia mrozowego głazów i otoczaków.

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