RESULTS OF THE SWEDISH EXPEDITION TO SPITZBERGEN IN 1924.

I. QUARTERNARY GEOLOGY OF THE REGION AROUND THE KJELLSTRÖM VALLEY.

By *FREDRIK CÖSTER.*

In the summer of 1924 the present Author was afforded the opportunity of accompanying Fil. kand. T. Hagerman, on an expedition lead by him, and with the main purpose of a strateographic exploration of the neighbourhood of Van Mijen bay and the inland around the Kjellström valley. In connection with the strateographic research, some investigations of a quarternary and glaciographic nature were carried out as well. Some of the glaciers which end in Van Mijen bay, and in the Kjellström valley, are in fact, owing to their close vicinity of the Svea mine, easily accessible for renewed measurements, besides being of a great interest as to their present development, considering previous great fluctuations in their extension, a fact especially applicable to the Paula glacier. As other quarternary deposits, noteworthy from a geological point of view, may be mentioned some late glacial, marine delta rests, found in the Kjellström valley. A closer account of some of the results obtained is given below.

For all geographical names and as basis for the accompanying map of the Paula glacier the author has used the map. Spitzbergens Inland published by G. De Geer in Ymer 1919.

The Paula Glacier.

The Paula glacier is one of the larger Spitsbergenglaciers. It ends at the Rinder bay (Lat. N 77° 48′, Long East Greenwich 60° 52′) SE end of the Van Mijen bay.

The glacier sea-border was for the first time measured by Kjellström in 1898.[1] The second time by the Norwegian expedition of 1913, lead by Hoel.

It ranges principally to an extension of about 25 km length, NW-SE, with a width varying between 3 and 4 km. The main glacier receives 3 rather important side glaciers from the west, and an equal number from the east. In order to decide the position of the border as well as otherwise to map out the glacier and its moraines, some photographical panoramas were taken from two points, one on

[1] Kjellström, C. J. Otto Excursion pour le lever de Van Mijen Bay fait pendant l'expédition polaire suédoise de 1898. Ymer 1901.

Fig. 1. A general view of the Paula Glacier from Mt. Torell.

Mt. Torell, and one on Mt. Fagersta. At each point a stone beacon was erected, the level of which was then taken from a base on the shore below Mt. Fagersta, which was afterwards connected to the Norwegian triangulation net. The accompanying map is based on the above mentioned panorama, the position of the glacier seaborder of 1898 and 1913 being also marked off there.

The ice border, designated on the map as A B C D, forms a good section of the lower part of the glacier. In the autumn of 1924, the following different parts were discernible.

The largest W lateral moraine of the Paula glacier ends between A and B. The thick moraine layer has here protected the ice from melting. Consequently, this part must be a rest from an earliet state of development. The height of the ice cliff is at this point 36 m above sea level. At point B one of the large glacier-rivers merges out of glacier vault of considerable dimensions. Another one appears at C, where the largest medial moraine also ends. Between C and D the Paula glaciers's biggest north side tributary, the Vallåkra glacier, reaches the sea. It ends east of D on land, forming a mighty terminal moraine.

According to the Swedish nautical chart,[1] the bay in which the Paula glacier ends, is scarcely 15 m deep. At the present extension of the ice cliff it is probably much shallower. The height of the ice cliff is on an average about 20 m. so that the lifting power of the water does not give rise to any breaking of the ice. Instead of that, the cliff becomes undermined at the surface of the water, the height of the zone being dependent upon the tide, as well as on the splashing of the waves. The tide at the inner part of Van Mijen bay is 1.70 m.

[1] Svenska sjökortet N:o 301 Spetsbergen Belsund—Van Mijens Fjord, utgivet av Kungl. Sjökarteverket 1921.

When the undermining has proceeded far enough, the overlying sections of the ice give way, and fall into the sea. Several fractures of this kind have been observed, most of them, however, being of minor dimensions. As may be seen from the map, the fractures are however most prominent around the two big ice caves.

At present the main glacier is nearly dead, so that the projecting portion about the middle of the ice cliff has not arisen on account of the movement being greater here than at the sides of the glacier. The ice caves are, however, situated in a deep incision of the cliff. The explanation of this rapid fracturing around the caves may be found in the following circumstances.

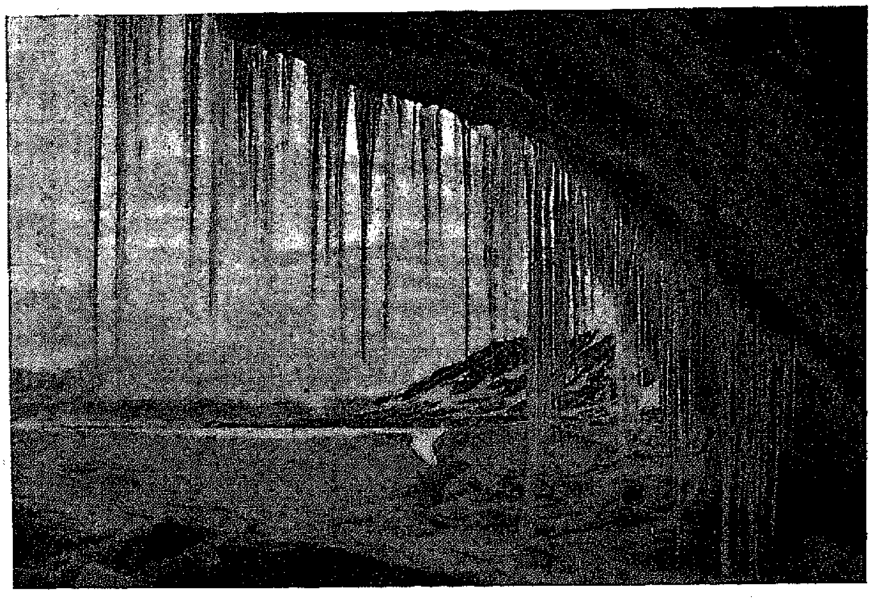


Fig. 2. Glacier vault in the western part of the Paula Glacier.

The sub-glacial stream erodes vaults of considerable dimensions. The setting in of the tide is hereby a supervening factor, and has probably the effect of making a dam, which augments the height of the erosion. The upper part of the stream cave is, however, — even at the highest tide — several meters above the sea level. The circulation of the air is the cause of the additional melting of the ceiling of the tunnel. When this has become thin enough, it breaks off from its own weight.

From the map is to be seen that since 1898 resession has been predominating, and proceeding at an even rate. The yearly mean values for 1898 to 1913 are 95 m., and for 1913 to 1924, 70 m.

The great advance, which the glacier has made at an earlier stage, and which extends 15 km. towards Van Mijen's bay, is as to its extension, according to G. De Geer probably without equal among Spitzbergen glaciers.[1]

Movement of the ice.

Since De Geer in 1919 gave a description of the Paula glacier, and the movement of its side nevés, some changes have set in. As already mentioned,

[1] G. De Geer: Om Spetsbergens natur i Sveagruvans omnejd. Ymer 1919, H. 4, s. 161.

the main glacier does scarcely move at all. The greatest advance appears in the Vallåkra glacier, though the motion of this glacier is but slight. Its large, arc-shaped, moraine, marked out on the map of De Geer, has moved as far as to the present ice cliff. The middle section has disappeared by fracturing. The north of the side sections forms a terminal moraine, with ridges of dead ice in front. The south section is squeezed in between the main glacier and the Vallåkra glacier itself. Instead, two other moraines appear on the Vallåkra glacier, both originally formed by side nevés on the N and S side of the Vallåkra glacier. These have temporally increased more than the main glacier itself, but the last named having however, later on, spread out again and pushed them aside to the position they hold now. As to the other lateral nevés of the Paula glacier, a slight movement seems to occur in the west part of the Scheele nevé. The large side-glacier on the east side of the Vallåkra glacier has formed a wide, arc-shaped terminal moraine at a much higher level than the sunken main glacier, thus appearing as an independent glacier.

Fig. 3. Ponds in the moraine on Kap Littrow.

The Former Extension of the Paula Glacier.

As mentioned above, the Paula glacier has had an exceptionally great transgression during late quarternary times.

This maximum transgression is defined by mighty morainic ridges. As is well known, these ridges extend in a westerly direction from Braganza bay to the Nordensköld valley, on the S and the E side from Kap Littrow to Kap Conwentz. At about 2 km. W from the Nordenskiöld valley, on a tongue of land of the present shore, a ridge is found (30 m. long, 3 m. high) of a clayish morainic consistency, containing shells of Saxicava arctica and Mya truncata. This ridge may, however, more likely have arisen from some ice block having pushed it up, than from the glacier itself.

All the terminal moraines contain dead ice. This has been established in several places, especially as pointed out by De Geer, at the quay of the Svea-mine, where the moraine has been washed off, so as to make the ice visible.

Numerous ponds and small lakes, being sunken parts of the dead ice, give everywhere evidence of its existence.

Besides, owing to the fact of this irregular melting off, and to the eroding influence of the melting water rivulets, the moraine landscape presents a strange, broken aspect. The Geikie moraine, extending from Kap Barry to the north of the Brusebäcken, is considerably lower than other remaining parts of the moraine zone. The explanation of this fact may be found in the circumstance that its position must have been — at least for some time — below the level of an ice dammed lake. The material is very clayish, and contains a considerable amount of mollusc shells, which have been pushed up from the bottom of Van Mijen bay.

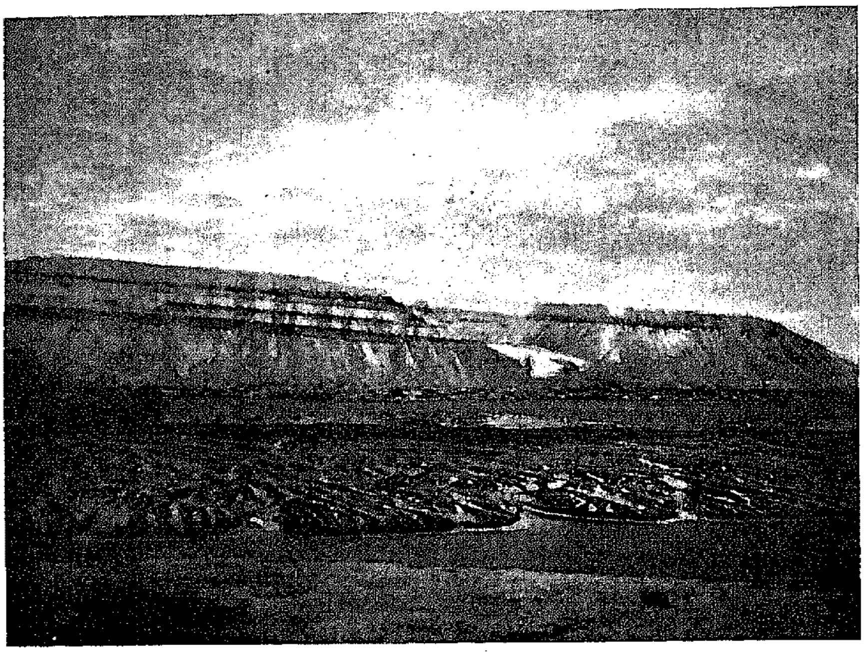


Fig. 4. The Geikie Moraine.

The Dames' moraine, situated between the rivulet Brusebäcken and the Nordenskiöld valley, gives the aspect of a landscape of small hills, interlaced with lakes and ponds. The melting water and old drainages take the direction northwards, towards the ancient glacier river channel, which leads from the mouth of the Brusebäcken to the Nordenskiöld valley. Shells of mollusca appear here and there on the top of the moraine as well as within it. The material is exceedingly varying, at some places very clayish.

The moraine of Credner occupies the distance from Kap Littrow to the Paula glacier. Lake Vallunden, the largest of all the moraine lakes, is situated on this moraine. This lake formed a part of the Braganza glacial lake during the glacial lake stage. This is evidenced by a row of shore lines up to the lake, and above its level. The moraine material is here much less clay-bound than on the N side of Van Mijen bay.

The moraine, extending from Kap Conwentz to the Paula glacier, is the one which is most influenced by later erosion. Thus, the rivulet from the Fagersta valley has washed off part of the material, forming a rather wide outwash plain. Here also, the morainal material is in part very clay-bound. No mollusca have been found on the surface or inside the moraine, nor along the beach.

A large marginal drainage channel proceeds between the moraine and the Fagersta mountains towards the Danziger valley.

The moraines from the maximum extension as well as other contemporary formations appear to be fairly young ones. The mollusc shells, which have been pushed up from the bottom of Van Mijen bay, and which have been found on the moraine or to the inside of it, have been determined by Dr. Hägg, who gives the following specimen:

Astarte crebricostata, a. borealis, a. montagui.
Cardium grönlandicum, c. ciliatum.
Pecten islandicus,
Mya truncata, Saxicava arctica, Lepeta caeca,
Pyrolofusus deformis.

According to Hägg the degree of warmth needed by the above mentioned specimens corresponds to the minimum temperature of the present Storfjord, maximally to the W coast of the Spitzbergen of the present time. As no mytilis or other specimens needing warmth have been found, one might be apt to draw the conclusion, that the great transgression of the Paula glacier should have preceeded this time. The young aspect of the moraines as well as the fact that no finds what-ever of mytilis are known from Van Mijen bay, however, seems to oppose this presumption. Thus, it appears as if this species did not live in the bay during the post-glacial warm period. The maximum extension may therefore very well have taken place after this time. The opposite to the firstmentioned supposition therefore seems more plausible. This is, besides, confirmed by the fact that no shore lines from the mytilis period of transgression were found on the moraines from the maximum extension, which consisted of a material easily worked upon.

During its maximum extension the Paula glacier dammed up a glacial lake, extending from the rivulet Brusebäcken to the slope at Mt. Storlängan. The highest shore line of this ice lake was levelled to 22 m. above the highest tide mark at a point 400 m. N of the mouth of the Brusebäcken.

At this time the drainage from the lake was afforded by a river, flowing on the north side of the Dames' moraine, from a point 2 km. W from the north of the Brusebäcken towards the Nordenskiöld valley. The ice river channel was at first shallow but became deeper further to the west. Furthest to the west, the outwash of the present Nordenskiöld river has afterwards dammed it up. S of Mt. Långstacken the level was taken of 5 other shore lines, corresponding to 9, 18, 8,10, 10, 6,59 5,09 4,70 m. above the highest tide. They correspond to different glacial lake periods from the time when the outlet took place through the moraine between Kap Barry and Kap Littrow, now-a-days eroded off.

The shore lines partly consist of beaches, partly of wave cut terraces, formed in fluvial deposits. The finest, and best develloped, of the first mentioned kind, is the broad beach, which is situated on the »rut-jord» or polygonic creep plane, close at the W of the Skut-river.

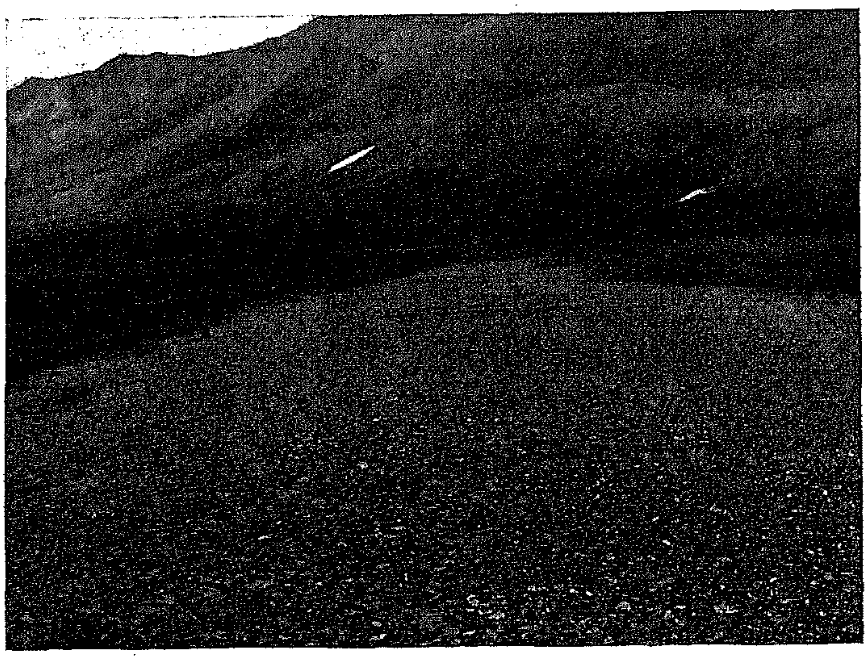


Fig. 5. Beach formed by the Braganza ice-lake. In the background M. Dalskutan.

This one is continuous for a distance of 400 m., and was found to be quite horizontal when the level was taken. The size of the pebbles was 5 cm in diameter. Beaches with a pronounced depression behind are formed SE of the Mt. Storlängan, consequently on the shorter side of the glacial lake, which is most exposed to the NW and N winds. Terraces, eroded in talus or moraine, were found W of the Lundström river, as well as on older moraines from the Kropp glacier.

A delta from this time occurs at the mouth of the Lundström river, lying isolated on the very bottom of the valley. It rose 4,7 m. above the present alluvial fan. The pebbles were 4 to 5 cm. in diameter, well worn by the water, and interstratified with layers of fine sand. The nature of the Kropp hillock as well as of the two minor ones under Mt. Dalskutan, are rather uncertain. The Kropp hillock consists almost entirely of clay and very fine sand, and may possibly be a witness of erosion from a stage, preceeding the Braganza glacial lake, or else it may have been formed below the lake, and thus forming part of its bottom filling.

Recent and previous Extension of the Glaciers of the Kjellström Valley and its side-Valleys.

More than 20 larger or smaller glaciers end in this valley complex. Although they possess certain common features yet they show as a rule different individual characters. Several different types of nevé region occur. Thus, the Höganäs-

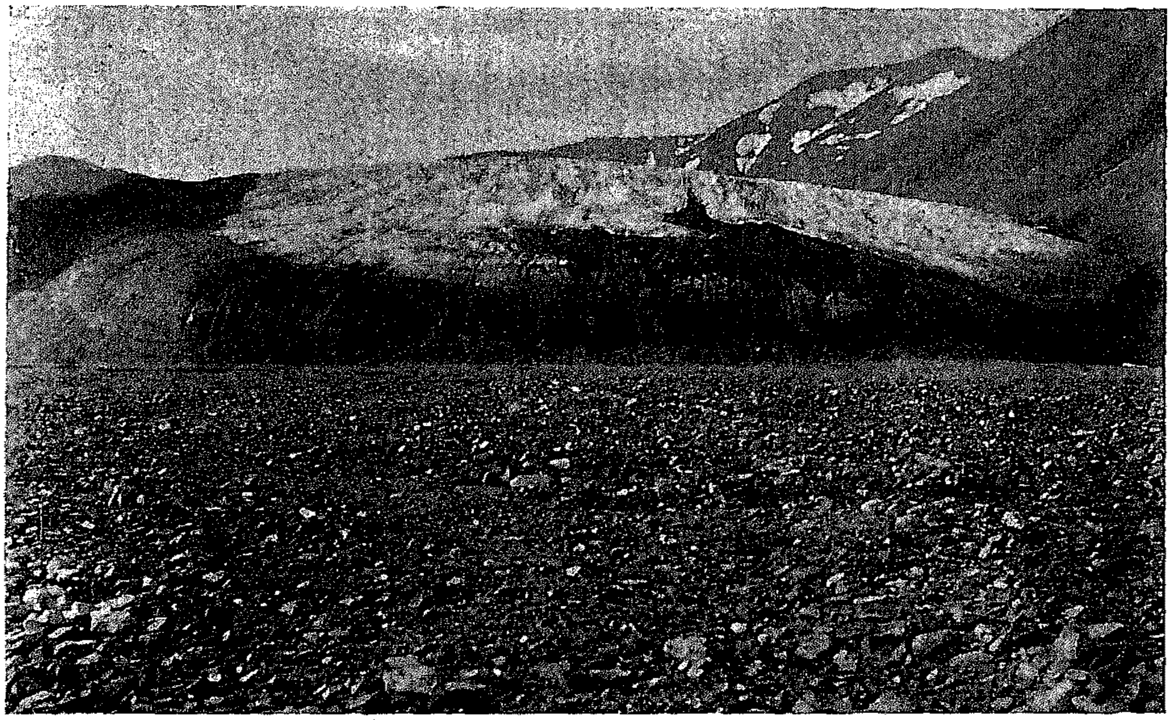


Fig. 6. The Höganäs Glacier seen from the S.

and Helsingborg glaciers form the drainage of the extensive plateau ice between the Conway- and Kjellström valleys, others on the contrary, as for instance the Kropp- and Edward glaciers, forming valley glaciers, the nevé region of which consists of the extensive plane valley complexes at the S and SE of the Kjellström valley. By far the greater part of the nevé region consists of smaller or larger cavities at the valley sides, having perhaps developed out of the glacial cirque formations, the positions of which may have been decided by the presence of certain weak zones in the rocks.

Although observations concerning the movement of the lateral margin are lacking, the slope of the lateral face, the amount of crevasses of the glacier as well as the position of the moraine in comparison to the glacier ends, give a certain amount of evidence concerning the melting off and moving conditions of the glaciers.

Observations in this direction have been made concerning several glaciers.

The Höganäs glacier, situated just N of the Braganza bay, showed a fairly well rounded edge; it had no distinctly marked terminal moraine, nor were any pronounced crevasses perceptible. It was evidently in a state of rest.

The Helsingborg glacier on the other hand, 3 km. E of the last mentioned one, presents several tokens of a proceeding movement. The lateral margin is nearly perpendicular, with pinnacles of ice on the surface of the glacier. A mighty terminal morainic arc occurs quite close to the end of the glacier.

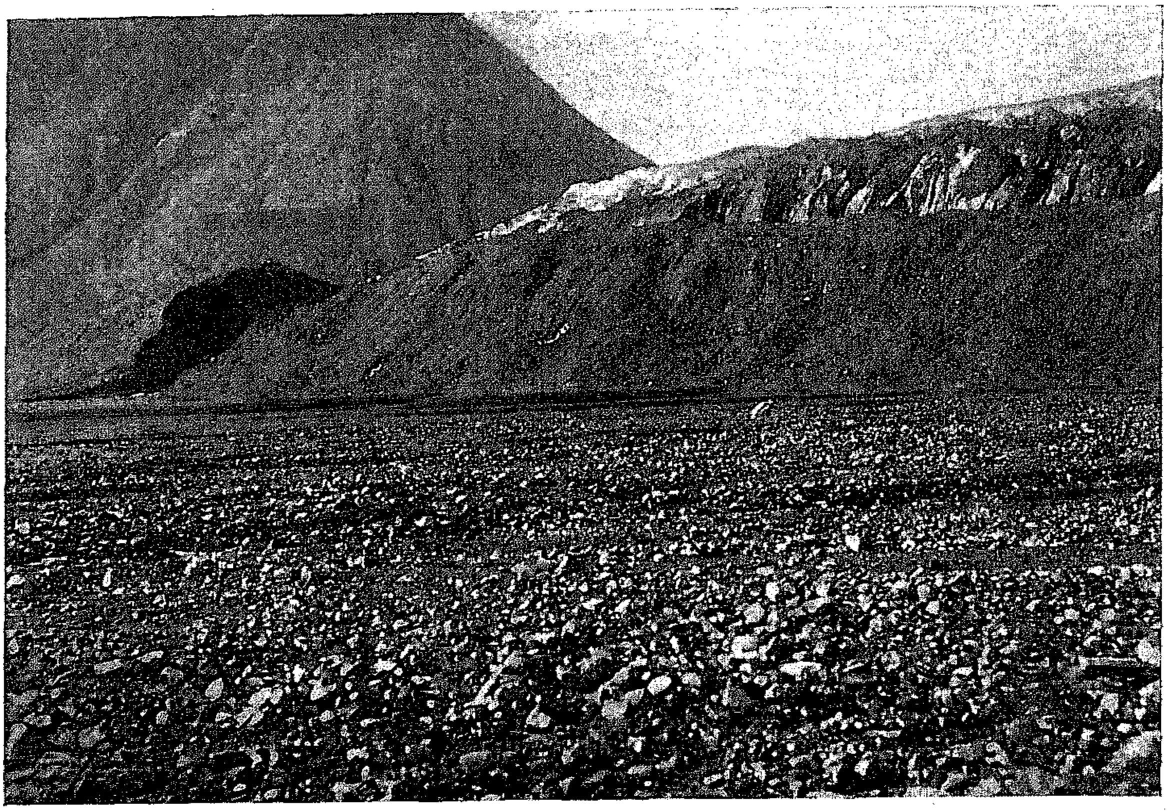


Fig. 7. The Helsingborg Glacier. Middle part of the border with terminal moraine.

Amongst the smaller glaciers two in the inner part of the Lundström valley are of a fairly great interest.

They are situated one at each side of the bottom af the valley, and have apparently at an earlier time had a considerably greater extension. After having melted off they have left quite a series of terminal moraines, forming a landscape of small hills, with minor ponds in depressions on the moraines. Very likely a great deal of dead ice is to be found beneath this moraine cover. The terminal lobe of the glacier, situated on the E side of the river, had withdrawn to the nevé valley. The bottom of the glacier was exposed, forming an open basin, the lowest part of which was found lying quite close to the terminal moraine. The lateral moraines rose in the shape of ridges, forming the sides of the basin.

Another glacier, also offering the aspect of recession, is a big glacier, situated at the NE corner of the upper widening part of the Lundström valley, the lateral margin of which is at present situated 100 to 120 m. inside its terminal moraine.

The character of a moraine is entirely dependent on the formation which surrounds its nevé and valley of erosion. As a rule, the size of the boulders is but slight, it is only the »fästningssandsten» which gives rise to any larger blocks. The largest ones carried by the glaciers were 2 to 3 km^3., and they were found on the alluvial plain of the Edward glacier. The soft cretaceous and jurassic schist horizonts on the other hand give rise to a very fine and sometimes clayey morainal material. The manner, in which the ice transports moraines, is very varying, generally, the glaciers carry a considerable amount of englacial moraine.

As a good instance of this may be mentioned the end of the Helsingborg glacier, which is interstratified with morainal debris.

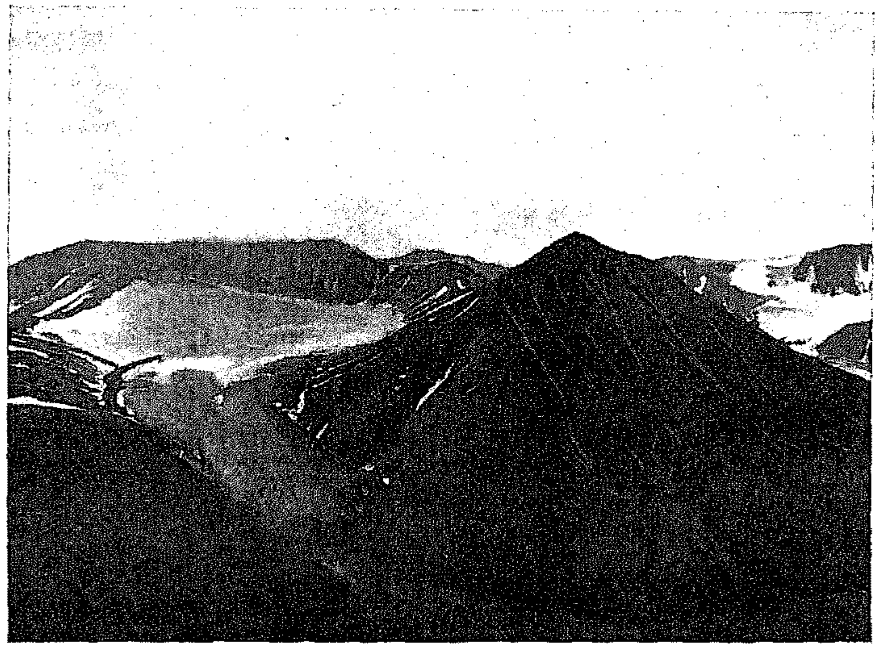


Fig. 8. The Tinkarp Glacier. Terminal lobe and nevé region.

A kind of morainal debris, which differs widely from all the rest, is that of the Edward glacier, which besides its former extension, offers a great deal other things of interest. Thus, the outer portion of the terminal moraine here consists of ridges of well assorted material, evidently water-worn the stones of which did not exceed 2 to 3 cm. in diameter. The ridges followed several abreast, with level depressions between the boundary limits of the end of the glacier. In some places, where the glacial rivulets had opened cuttings, the material was decidedly stratified. The height of the walls above the surroundings was 20 to 25 m. Inside these a moraine of an ordinary consistency sets in, unassorted, with sharp debris, in certain places clay-bound. Furthermore, the glacial face itself is entirely burried by the moraine, which has protected the underlying ice from melting off, so that the glacial surface nearest to it forms a depression, filled by water ponds.

Examples on water assorted moraines have been given by several authors, amongst others by Garwood and Gregory.[1] According to them, the outer moraine of the Ivory glacier, like that of the Edward glacier, consisted of well assorted material, but they also held marine molluscs, rests of whale bones, and other beach rests.

As an example of this fact Garwood holds forth that the glacier should have pushed an old beach in front of itself. This beach might have been remaining from the late glacial submergence, and afterwards to a certain extent have been

[1] E. J. Garwood and J. W. Gregory. On the Glacial Geology of Spitzbergen. Quart. Journal o the Geological Society of London Vol. 54, pp. 196—227.

restratified by the melting water of the glacier. The lateral moraine of the Edward glacier contained, as far as I could see, no shell rests or other marine remnants.

The previous extension of the Edward glacier will be treated in connection with the late glacial circumstances.

The Kropp glacier is situated close to the west end of the Edward glacier. Its nevé stretches southwards, to that of the Vallåkra glacier. On the present alluvial fans of the Kropp glacier, several rows of terminal moraines occur, marking off different ice margins. The material of these moraines is coarse. Those situated furthest to the W have pronounced wave cut terraces, formed by the Braganza lake.

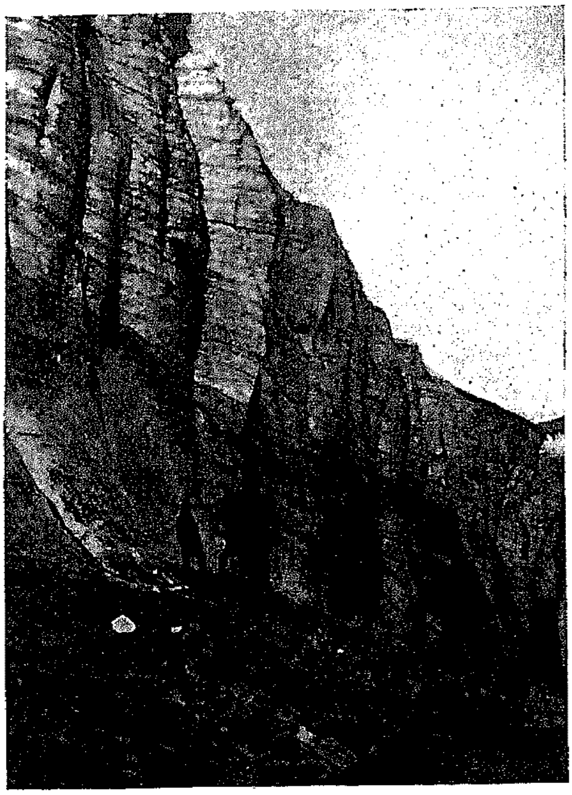


Fig. 9. The border of the Helsingborg Glacier with englacial moraine and spouting stream.

The Margit glacier, and two minor ones, end in the north part of the Kjellström valley, close at the W of Sir Martin's pass. The greater of the latter extends towards the pass in the north direction, but the principal nevé region consists of an ice plateau in the E, even part of the Mt Storlängan.

It appears as if the Margit glacier were retreating; it ends in a vast terminal moraine, fairly high up on the slope of the valley. The others show no sign of any previous greater extension. At present they seem to be stationary. Another glacier, the water of which is also, though not totally drained off towards the Kjellström valley, is to be found in a glacier, occupying the greatest part of the Bellsund valley, and which ends to the E in Agardhs valley, below Mt. Schmidt. It has also dammed up a pond, about 100 m. long, the level of which, however, judged by the well defined former shore lines, seems to have been 2 m. higher than it is now. The surface of the glacier was exceedingly even and free from crevasses.

The present Author had only the opportunity of seeing the Ivory glacier, the largest of all ending in the Agardh valley, from a distance of some kilometers. It however seemed to show a considerably sunken aspect, and its lateral margin was fairly plane. In 1919, the same circumstances were established by the Englishman Stevens[1] during a traverse from the Sassen valley; most likely the recession has continued since then.

[1] WORDIE 1921. Present-day Conditions in Spitzbergen. Geogr. Journ. 1921 58, pp. 25—49.

Most of the glaciers of the Kjellström valley showed recession or were at least stationary. Most of them have older morainal deposits, situated outside the present ones, accordingly showing that the glacier at an earlier time must have had a greater extension. This interval has scarcely coincided even for quite adjacent glaciers.

Consequently, it is not advisable to draw any conclusions concerning the climatic conditions from the fact of the sudden and violent push, appearing in some glaciers. A steadyly proceeding recession observed in the Kjellström valley as well as in other places on the Spitzbergen, seems, however, at present to indicate improved climatic conditions.

Alluvial Fans.

In front of most of the glaciers, alluvial fans are to be found, the characteristic formation and appearence of which is dependent on certain factors, which stand in relation to the climatic conditions. The transporting power of the water is greatest during the melting period in june and the beginning of july, but it decreases during summer. On account of this fact, the assorting of material, deposited on an alluvial fan of a glacier, is not very good. Smaller and larger debris appear together, declining in size towards the end of the alluvial plain.

The glacial river subdivides as soon as it has emerged from the ice caves and ravines, forming a net work of innumerable grooves and rivulets. The depth of these grooves seldom exceeds 0,50 m., but their width is varying considerably. As the rivers are overloaded with material, the dropping of the same is very rapid. This appears to be a contributing factor to the great subdivision of the river systems. Another factor which must be taken into consideration, is the constant frost in the ground, which to a certain extent prevents any erosion downwards.

The eroding influence of the running water on the frozen delta material is most clearly evidenced in the Kjellström valley by the glaci-fluvial deposits, belonging to the late glacial submergence, and which consequently are situated on another level than that of the present rivers. The course of the erosion is a characteristic one in the above mentioned deposits. This course is dependent on the tensile strength as well as on their capacity of resisting water erosion, the latter quality being assigned to them by the constant frost in the ground.

As for the eroding capacity of the water, it seems in this case as if it were dependent on the temperature, as a rising temperature adds to the melting power of the water. Thus it stands in a certain relation to how long the water has been exposed to the influence of the air and sun. Concerning the quality of tensile strength, these delta deposites seem to behave like ice. At the upper end of the north Kjellström valley for instance, strangely enough, the river was flowing in

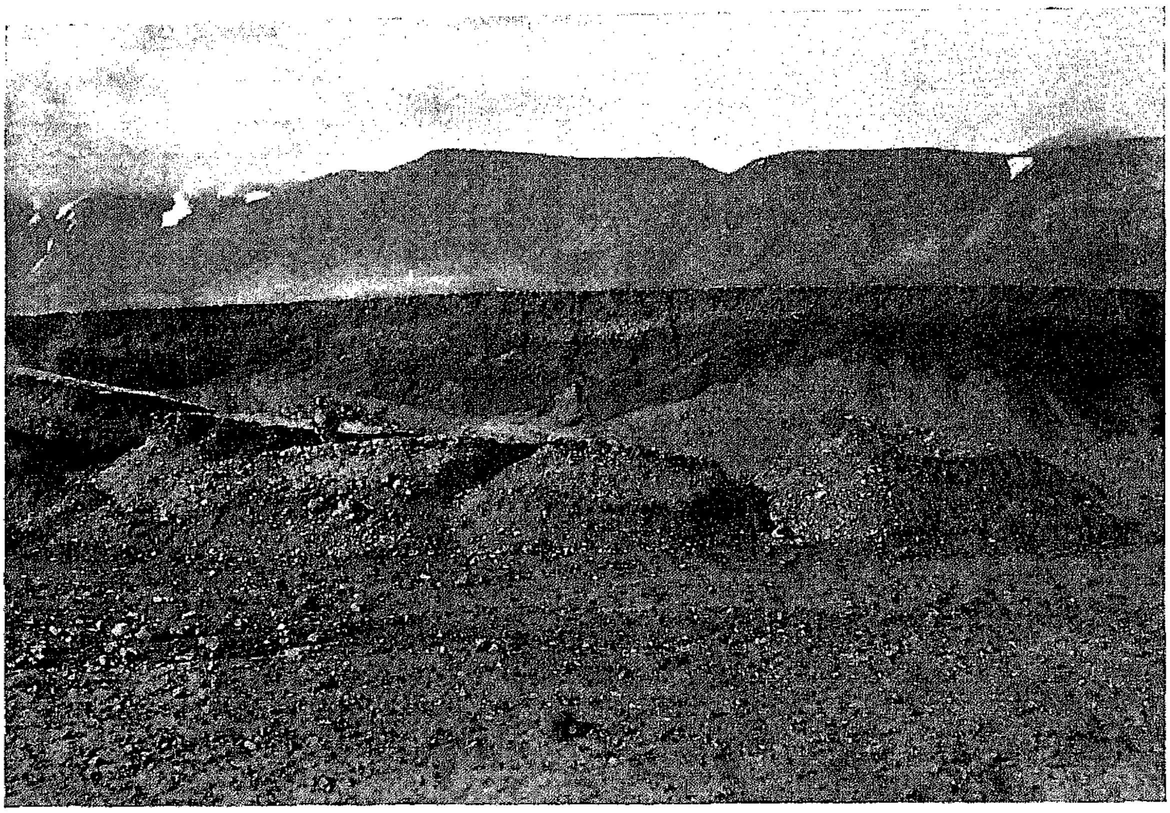


Fig. 10. The cutting of the Lundström River through a marine delta deposit. Large downfallen parts of the river bank, typical for the erosion in frozen ground.

a well developed tunnel through a delta formation of 5 to 6 cm. drift. The tunnel was more than 100 m. long, and 2 to 2,5 m. wide. Half a mile further down, near its entering on the alluvial fan, it disappeared again beneath the 10 m. mighty glacifluvial delta. In the latter case, the one most often appearing, the river has cut into the bank so that the river channel is principally running beneath a projecting part of the bank. The Lundström river which is chiefly eroding its W shore, presents the same aspect; the same is true of the glacier river ravine of the Helsingborg glacier.

It has been possible to observe different stages of the proceeding erosion on the left shore of the Lundström river. The eroding material here consists partly of fine sand, and partly of coarse delta drift. The circumstances in both kinds of material appear to be the same.

The process starts with an undermining of the river bank, which proceeds until a greater or lesser part of the shore is precipitated into the river channel. The river hereby becomes dammed up for a short while, and its eroding power is augmented. Small pieces are immediately washed off. The river was unable to carry along the bigger ones at once. In the Lundström river they could be as big as up to 40 m. long with a width of 10 to 15 m. The channel was therefore forced into a new direction. In this way large portions of the shore have disappeared during the lapse of a few weeks.

The erosion of the river into the solid rock presents other characteristics than the erosion into the loose fluvial deposits. Well developed canon formations have been observed at some places. The largest one is situated at the upper part of the Lundström valley, at a point where this valley joins the somewhat higher up situated Conway valley. The branch of the Lundström river, which comes from the last mentioned valley cuts into a series of black, loose schists, following beneath the »fästningssandsten». This canon is in some places more than 80 m. deep, with an almost perpendicular position of its walls. A smaller canon has been eroded in the tertiary layer by the rivulet coming from the Fagersta mountains. It is about 20 m. deep, and only 3 to 4 m. wide at its narrowest part. The speed of the water is here considerable. The diameter of the largest stones brought is of an average of 60 cm. (the smallest 30 cm.).

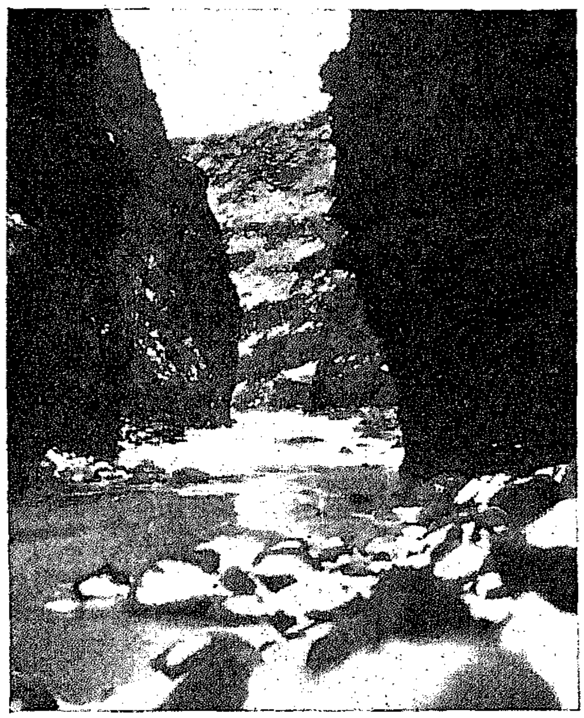


Fig. 11. The canon of the Fagersta Rivulet in tertiary sandstones.

Marine Deposits.

According to De Geer[1] the submergence of the surface which succeeded the ice period of the Spitzbergen for the greater part of the Isfjord region amounted to 70—80 m. It was found to be higher at the mouth of the fjord, probably about 130 m., as indicated by the shore lines on this level. The same submergence ought to have left similar traces in Van Mijen bay. They also occur along the shore between the Blåhuk and the Nordenskiöld valley, though they are partly effaced. At the Blåhuk a glaci-fluvial bank is to be seen, rising steeply 10 m. above the evenly slopping bottom of the valley, at about 100 m. from the present shore. The material is well water worn and assorted and contains shells of the Mya truncata and Saxicava arctica. On the E side of the Axel island, shore lines were observed at an estimated height of 20 to 30 m.

W of the Svea-mine, at the mouth of the Brusebäcken, above the level of the Braganza bay, are situated several banks of a fine glaci-fluvial material, rising 10 m. above the present slope of the valley, at about 30 m. above the sea level. They contain shells of Mya truncata and Saxicava rugusa.

[1] Ymer 1920, H. 3.

In the outer Kjellström valley, from the Svea mine to the Lundström river, creep as well as erosion from the glaciers has effaced all traces of the late glacial submergence. At the outlets of the Skut- and Lundström rivers, however, some formations occur, which stand in a certain relation to the above mentioned submergence.

The attention of the present writer was first drawn to these formations by the discovery of a whale vertebra on the over wash plain of the Lundström river. The bed rock to this find was searched, and appeared to be the section that the Lundström river had eroded in its W shore. The rib af a whale, 1,75 m long, was found here, projecting from a dark clay. The bottom layer contains shells insitu of Mya truncata and higher in the section Balanus porcatus as well as rests of sea-weeds show clearly enough, that marinal formations are present here. These are over laid by a delta deposit. This layer is dipping with an inclination of 24°—30° toward northeast.

Bands of finer and coarser sand alternate with fine black schist gravel. The material of each band becomes finer towards the bottom; further, most of the flat debris are lying horizontally. The steeping position of the layer must be connected with the fact of the outflow of a river into a lake or a bay of the sea with somewhat deeper water, where consequently a current bedding takes place at the edge of the accumulated formations.

Similar conditions seem to have been prevailing at the outflow of the Skut river in the Kjellström valley. The river has here cut through a mighty glacifluvial deposit with a dip of 24°—30° towards the S. The material has a coursness of 6 to 7 cm consequently a coarse delta drift, with bands of sharp sand in between. The height of the summit of the bank is 11 m above the shore lines of the Braganza icedammed lake, i. e. 32 m above sea level, which has cut out a terrace. The upper surface is plane, and reaches about 500 m against the mountain slope of the Mt. Storlänga.

Some finds of marinal mollusca and drift boulders of foreign rocks, found in the Kjellström valley, must also be considered as belonging to this time. Thus, the ridges close to the W of the Lundström river are partly covered with clay, containing moraine gravel as well as erratic blocks, and the following marine shells: Pecten islandicus, Saxicava rugosa and Mya truncata. The depth of the morainic material of these ridges cannot be ascertained as it has not been possible to obtain any section. The solid schist rock is however out-cropping in the vicinity of and at the bottom of the ridges. Erratic blocks have also been met with S and SE of the Dalskuta, together with glaci-fluvial formations. Further, marine shells occur in some of the ravines E of Mt. Storlängan enclosed in old delta deposits at a height of about 30 m above the sea level. It is difficult to decide with any certainty how these erratic blocks, and especially the mollusca, on the ridges W of the Lundström river, have reached their present position, but the topography of the neighbourhood as well as the position of the different deposits seem to show that the said morainal formations have been pushed up during an advancing movement of the Edward glacier. This advance may have taken place during the late glacial submergence. The glacier advanced over the sea bottom of that time, but was stopped by the solid rock, close to which the moraine was dropped. The maximum height above sea level for marine mollusc is here 50 m. The glaci-fluvial stratifications E of these ridges, described above, were formed after the withdrawal af the glacier. The marine clay was formed first, and after this — when the depth of the water had decreased, and the speed of the stream increased — the other layers were deposited.

Concerning the original position of the erratic blocks may be noted, that it may to the S be limited to the ice parting between the Ingefield- and Edward glaciers. In the N it is only the inland ice which may have carried them. They have not yet been investigated, but strangely enough, they consist of several different types of granite, as well as of diabases and quartzites.

Probably the inland ice within the range of the Edward glacier has left a collection of blocks, which have been forwarded by it to the position they have now.

The present development of the Kjellström valley and side-valleys proceeds according to fairly decided lines. The largest tributary on the N side of the Lundström river extends its range of drainage towards NW and W at the cost of the Conway river. This range occupies the part of the Conway valley which is situated furthest to the east, with the 3 glaciers ending there. Two of them get their entire drainage from the Lundström river, the third — and most westbound one — partly from the Conway valley. The plane bottom of the Conway valley is however situated about 100 m higher than the Lundström valley proper. This fact is clearly evidenced by a well defined precipice or step, at a point where the two valley systems meet eachother. The deep canon formation earlier described which has been eroded by the Lundström river, has arisen in consequence of this difference of level. It is difficult to explain how this great difference of level between the two valleys has arisen but it seems however probable that some fairly recent glacial erosion may have played an important rôle hereby. The original development of both valley systems on the other hand must have been stipulated by certain weakness zones, arising from tectonic disturbances in the fairly plane sedimentaiton surface.

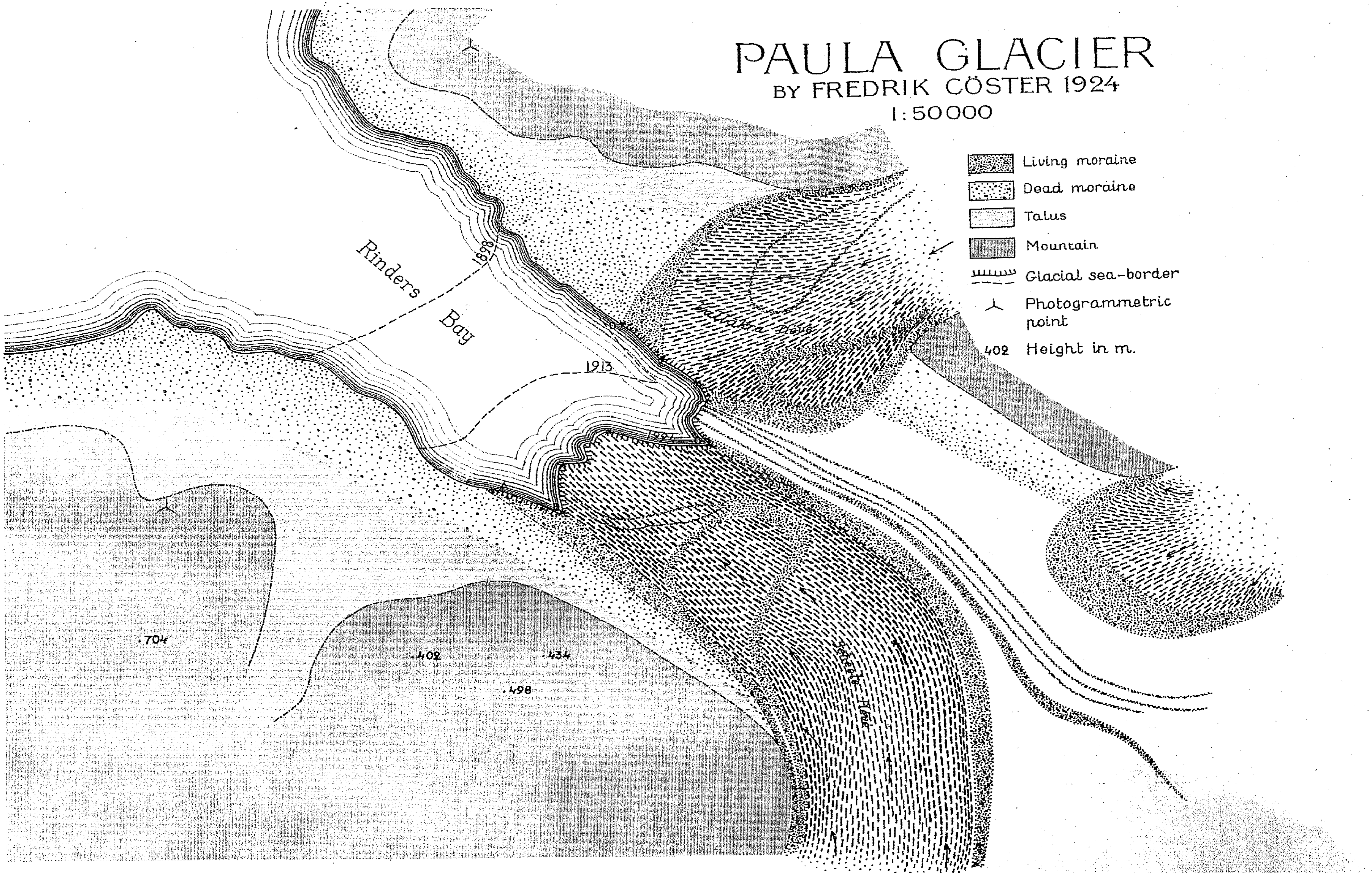
The Lundström river having left the canon enters the upper, eastwards, widening part of the Lundström valley itself. There it receives tributaries from three glaciers in NE, and forms together with them a pronounced region of accumulation. It flows in one channel between the before mentioned terminal moraine, and later on through the Lundström valley southwards. The erosion here acts almost entirely in a horizontal direction, enlarging the wide river bed at the cost of the bottom of the valley, which is filled by detritus. At its outflow in the

Kjellström valley all material is successively discharged, with the exception of the finest silt, upon an alluvial fan, several km wide. This is formed by a well rounded and water-worn material, in small triangular banks and ridges, with numerous grooves and rivulets in between. The depth of the deepest river grooves, however, did not exceed 1,25 to 1,20 m; the width varied considerably. The material is currend bedded. The levelling, comprising about 900 m. of the delta, gave the following section: 500 m. — 4,17 m. fall; 276 m. — 2,17 m. fall; 265 m. — 2,06 m. fall; 352 m. — 2,35 m. fall. The coarseness of the material decreases towards the lateral margin of the delta; in dead river grooves, however, and in hollows, a material of fine clay is directly stratified on the top of the coarse drift. This cover of clay may be several dm thick. It appears, however, only during the later part of the summer and is most likely as a rule washed off by next year's spring flow. Erosion is only proceeding in the W boarder, which consists of glaci-fluvial deltas, possibly remaining from the late glacial period. They are quickly carried away by the river. The lateral margin of the alluvial plain rises to between 6 and 7 m. above sea level.

Fig. 12. The Kjellström Valley seen from Mt. Dalskutan towards SW. In front: The junction of the Lundström River with the Kjellström River.

The Skut river, which has its outflow 3 km E of the Lundström river, only drains off one larger, and one smaller glacier in the N and NW corner of the Skut valley. At first it only erodes ordinary detritus, but like the Lundström river at its mouth, it erodes marine deposits.

The main river of the valley system, the Kjellström river, begins beneath the pass point towards the Agard valley. In the north part of the Kjellström valley, the bottom of the valley rises to 50—55 m. above sea level. Its fall is slighter than that of the Skut- and Lundström rivers; the greatest fall, however, occurs in the northern part of the Kjellström valley. The fall of the river from beneath Mt. Storbullen and to the Braganza bay on a distance of about 25 km. is only 12 to 15 m.



Generalst. Litogr. Anstalt Stockholm 1925

Furthest to the NE the bottom of the valley consists of an even plain of fine detritus, further down of the alluvial fan of the Margit glacier, and quite close to the outlet in the S of the Kjellström valley it consits of marine deposits. Here also the river erosion acts almost entirely in a horizontal direction, enlarging the river bed.

As soon as the river has entered into the middle region of the Kjellström valley it becomes sub-divided, especially after having received tributaries from the Edward glacier, and from the Skut- and Lundström rivers. During the high water period of july it rather presented the aspect of a shallow lake than that of a river system.

It is only when the river has passed the Pålsjö glacier that any proper main channel may be said to exist. The one in question during the middle of september when the water supply had decreased considerably. The main channel makes a big Shaped bending from the south side by the Mt. Rånghummel in the direction of the alluvial fan of the Pålsjö glacier, afterwards bending in the direction of the Braganza bay. In some places it was more than 1,5 m deep, and about 50 m wide.

The material carried by the Kjellström river in its middle and lower course is very fine. Accumulation takes place along the whole length of the river system, and continues after the outflow into the Braganza bay. The river does not form any pronounced delta, but the silt is deposited in extensive banks wherever the stream and tide do not hinder its dropping. The tide seems to a certain extent to prevent the filling out of the Braganza bay, the inner parts of wich are exceedingly shallow.

The late quarternary development of the Kjellström valley has suffered two periods of a pronounced accumulation, accompanied by a following erosion. The first of these periods was caused by the late quarternary submergence of the land, during which the glaci-fluvial formations around the mouth of the Lundström- and Skut valleys, and in the northern parts of the Kjellström valley, were formed. These deposits described earlier consist of deltas, which have extended all over the middle part of the Kjellström valley. When the land rose, a renewed erosion set in, destroying the greatest part of the former. With the damming up of the Braganza lake, a new accumulation epoque occured. The isolated delta rest at the mouth of the Lundström valley forms a witness of the erosion from this time. With the draining of the Braganza lake the conditions now prevailing came into existence.