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Glacial forms and deposits of Ebba Glacier and its foreland (Petuniabukta region, Spitsbergen)

ABSTRACT: This paper presents the results of geomorphological investigations in the area of Ebba Glacier. A granulometric characteristic is presented of some types of deposits localised both within the glacier and in its forefiels. Some complexes of glacial forms were distinguished, on the basis of which an attempt was made to establish the chronology of events responsible for the development of Ebba Valley. Their preliminary analysis permitted the hypothesis of the Würm glaciation of the valley and of the four — fold advancement of Holocene glaciers to be set.

Key words: Arctic, Spitsbergen, geomorphology

1. Introduction

The area considered below lies in the central part of Spitsbergen, on the east border of Petuniabukta, one of the bays of Billefiord (Fig. 1). It consists of Ebba Glacier (Ebbabreen), the adjacent zone of marginal forms and Ebba Valley (Ebbadalen).

Both within the glacier and in its direct forefield, and also in the valley, during the scientific reconnaissance in the summer season of 1977 (Kłysz 1983), a rich inventory of glacial forms and deposits was registered, of which so far there has been no mention in the literature. Their preliminary geomorphological characteristic is the content of the present elaboration.

2. Ebba Glacier

This is a small, about 3-4 km long, ice tongue originating from the vast ice plateau Lomonosovfonny. Its entry into the depression of Ebba Valley is signalled by a system of transverse cracks revealing the existence of a morphological barrier in the floor of the glacier.

A characteristic feature of Ebba Valley is its morphological bipartition The division line is constituted by the strip of a central moraine. Namely, the northwest part is higher, very irregular, cut by a dense network of transverse cracks, whereas its front part is steep (Fig. 2). The southwest part is much lower. Its front descends smoothly, meshing with the glacial forms in the forefield. It should be believed that the morphological differentiation of the surface of the glacier reflects above all the diverse morphology of its base, where the ice masses of the northwest wing lie in an area with the diversified relief of a rock socle higher up, whereas the southeast part consists of a depression without any large height differences of terrain.

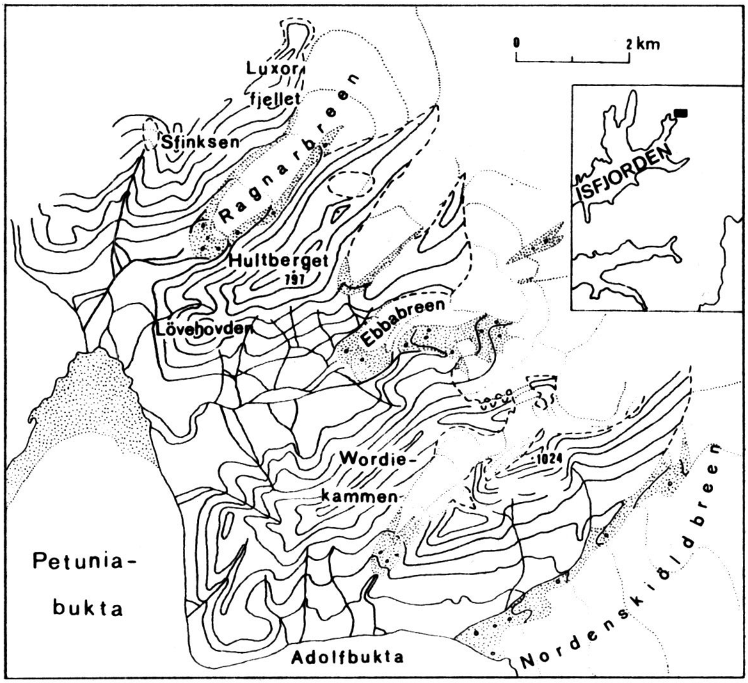

Fig. 1. Hypsometric map of the region of the Ebba Valley based on "Dicksonfjorden", 1:100000, Norsk Polarinstitutt, Oslo, 1972

On the surface of the front part of the glacier, there is some amount of moraine material reaching here from numerous slide surfaces. There are two characteristic ways in which this material emerges and occurs on the surface of the glacier: a point one, as a result of which the characteristic forms of ablation cones appear, and an areal one, when material emerges from the slide surface along a wide front (Fig. 3). In the summer season of 1977 ablation cones were not many here. The basic mineral mass

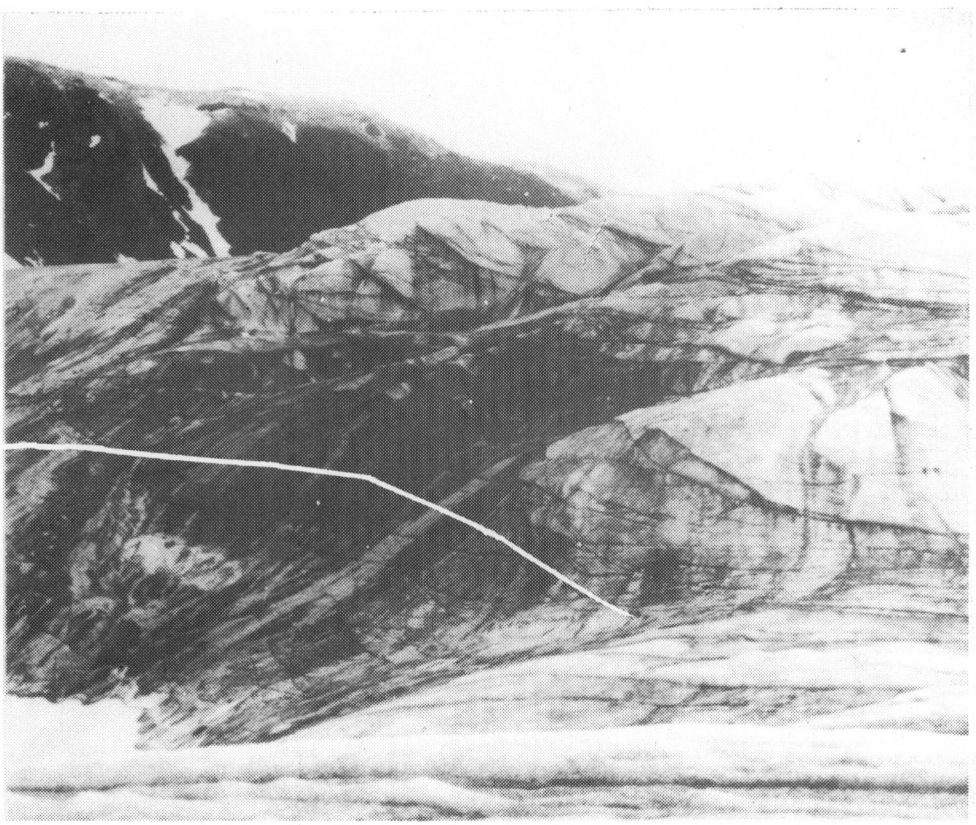

Fig. 2. The steep front of the Ebba Glacier

Fig. 3. The moraine cover over flat part of glacier tongue

forming the supraglacial cover emerged to the surface areally. It should be stressed here that it is the latter way of material accumulation that leads to a relatively fast dying of the border parts of the glacier and the formation of passive and dead ice zone, and, as a consequence, of ice-moraine banks.

In terms of mechanical composition, the material of the supraglacial cover occurs as a complex of particles with very large fractional differentiation — from the smallest fractions to coarse rock pieces of several score cm. Their more accurate characteristic (without the boulder fraction) is revealed from granulometric investigations of deposit samples taken from an ablation cone and the material emerging from the slide surface. The cumulative curves (Fig. 4) of these deposits confirm the general regularity mentioned above. At the same time, one can see that there is a distinct difference between deposits building a cone and those emerging currently from the slide surface. Namely, the cone deposits (Fig. 4, curve 1) are poorer in the smallest fractions, which can be found in the deposits of the slide surface (Fig. 4, curve 2). The above phenomenon can be explained by the fact that both kinds of material are at different stages of secondary transformations. The material from the slide surface should be recognized as inglacial, in turn the deposits of the ablation cone have already been in a supraglacial position for a long time. They cover the ice core of the form which disappears systematically as a result of ablation. It is just owing to the ablation processes that the finest particles, the lack, of wchich is revealed by the cumulative curve, an led aut of the deposit.

A fuller image of the grain-size distribution in the deposits investigated was presented by means of the generally used statistic indices: diameter (M_z), standard deviation (δ), kurtosis (K_G), calculated according to Folk and Ward (1957), and asymmetry (α_s), according to Friedman's formula (1962). They are shown in Table I.

An attempt was also made to determine the abrasion of quartz grains by means of a abrasion index (W_o) and material heterogeneity (Nm), according to Krygowski's formulae (1964). It proved impossible to obtain the desired grain population from the deposits of the slide surface. The grain of the ablation cone occurs as unabraded prismatic material The index Nm indicates that the material studied exhibits high homogeneity in terms of abrasion (Table I).

3. Ice-moraine ridges

In the direct foreland and in the lateral zone of the now retreating Ebba Glacier, there extend imposing sequences of ice-moraine radges terminal and lateral moraines, indicating one of the steady-state positions

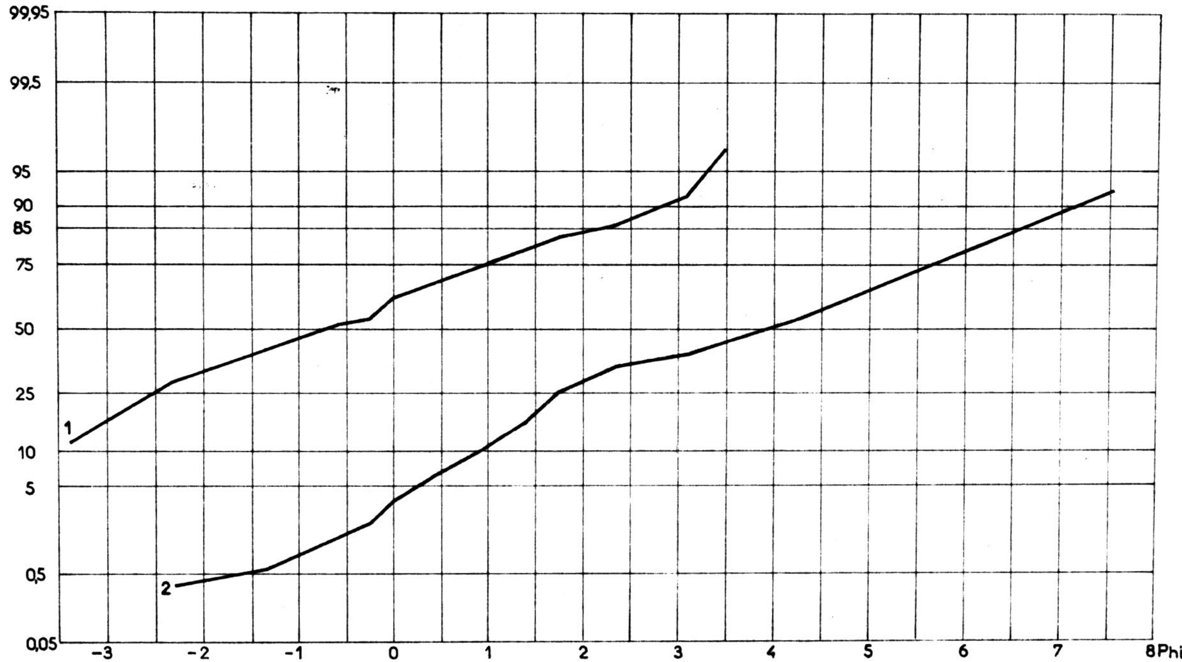

Fig. 4. The cumulation curves of the grain size distribution of the ablation cone (1) and the supraglacial cover (2)

of the glacier. In the course of investigations, the present author paid most attention to the zone of terminal moraine ridges.

Observations show that this zone is differentiated spatially. Namely, as Szupryczyński (1963) observed, the maximum heights of ice-moraine ridges can be found in an area where they combine with the sequence of central moraine. In addition, in the part adjacent to the steep part of the glacier front, only one moraine ridge is distinct, whereas in the foreland of a flat front there emerge another three successive sequences, divided by distinct depressions parallel to the ice edge. This spatial differentiation of the terminal moraine zone has been effected genetically. The wide moraine zone accompanying the flat part of the glacier front arises as a result of successive division of the dead parts of a glacier tongue from active ice, forming the forms of ice-moraine ridges Lucid schemes of their formation can be found e.g. the papers by Szupryczyński (1963) and by Kozarski and Szupryczyński (1973). The narrow ridge enclosing the steep part of the glacier has had a different origin. This ridge forms to the largest extent as a result of gravitational displacement of moraine material along the steep ice slope and its deposition at the foot. This leads to a form, bereft of an ice core, although still resting on an ice base, which, after Klimaszewski (1978), can be called the accumulation-scree terminal moraine (Fig. 5). Such a way of formation of the marginal zone is thus at the same time an expression of a differentiated manner of glacier recession, where the steep part decays mainly frontally, and the flat part — areally. It seems that this fact is also essential for the reconstruction of the Pleistocene glacial environment, for it indicates that over a relatively small surface area considerable differences can be expected to occur in the interactions of ice masses.

It is commonly known that ice-moraine ridges in view of the fact that in their insides they contain a thick ice core, are transitory formations undergoing systematic degradation. The ice-moraine ridges of the Ebba Glacier are a perfect confirmation of this phenomenon. Within them, extensive spaces can be found, where the ice core has melted out. This results in a low, water-logged surface composed of numerous hill-like bulges of coarse gravel and stone material, sunk in sand and sludgy series of ablation deposits (Fig. 6). The mechanism itself of the decay of the form presented resembles that which has repeatedly been described for the other glacial zones of Spitsbergen (Jewtuchowicz 1962, 1966, Kozarski 1974, Szponar 1974, 1975, Kłysz 1978 and others).

The author carried out a penetration into one of such hills down to 0.9 m, obtaining the following profile (Fig. 7). At the top there is a layer of silts, about 20 cm thick, which are at first brown and then dark grey. They cover a series of heterogeneous deposits, occurring up to the floor of the penetration, from silt deposits to the boulder fraction. It should be noted that single boulders are also stuck in the upper silt layer. Macroscopic observations are confirmed by the granulometric analyses of deposit samples taken at depths of 5, 20, 40 and 90 cm. The results are given in the form of grain cumulative curves (Fig. 8) and the basic statistical indices (Table I).

Table I

Statistical indices of the grain size distribution and material working

Site no.	Localization no.	Sample no.	Grain size distribution				Working			
							Ø 1.02–0.75		Ø 1.02–1.2	
			Mz	δ	K_G	αs	Wo	Nm	Wo	Nm
1.	Ablation cone		−0.65	2.38	0.87	0.42	793	2.8	686	3.0
2.	Slide surface		3.87	2.40	0.81	0.35	–	–	–	–
3.	Ablation hill	1	5.54	1.65	1.49	1.40	–	–	–	–
		2	4.36	2.93	2.97	−2.30	–	–	–	–
		3	1.30	4.40	3.78	2.45	604	2.9	574	2.6
		4	2.90	3.78	0.94	−0.05	593	3.1	662	2.5
4.	Terminal moraine III — proximal side	1	−2.14	1.84	1.86	4.13	–	–	–	–
		2	6.73	4.25	0.98	−1.05	–	–	–	–
		3	2.63	4.79	0.95	−1.90	572	3.4	–	–
		4	3.40	3.78	0.91	1.88	–	–	–	–
		5	1.58	8.36	0.90	3.25	–	–	715	2.1
5.	— culmination	1	−0.77	2.12	1.01	1.59	830	2.8	585	3.1
		2	−0.99	0.90	1.23	0.90	634	4.0	467	3.7
6.	— distal side	1	3.25	3.66	1.67	0.80	–	–	–	–
		2	−0.37	1.86	0.98	−1.82	605	3.6	–	–
		3	−0.74	1.64	1.10	−0.35	–	–	744	3.5
		4	−2.23	1.32	1.14	1.83	–	–	466	5.8

In terms of grain abrasion which for technical reasons was only determined for two samples of the floor series, the deposit studied represents a homogeneous type of unabraded prismatic grains. The index Wo for the two grain fractions mentioned above is contained within the interval 574–662, whereas the index Nm reaches values of 2.5–3.1 (Table I).

The compact sequences of ice-moraine ridges and of a scree moraine do not define, however, the boundary of the occurrence of glacial forms. In their direct foreland already within the outwash (in the northwest region of the valley slope), inside the super ice cover, a few elongated ridges and hills, with courses both perpendicular and parallel to the

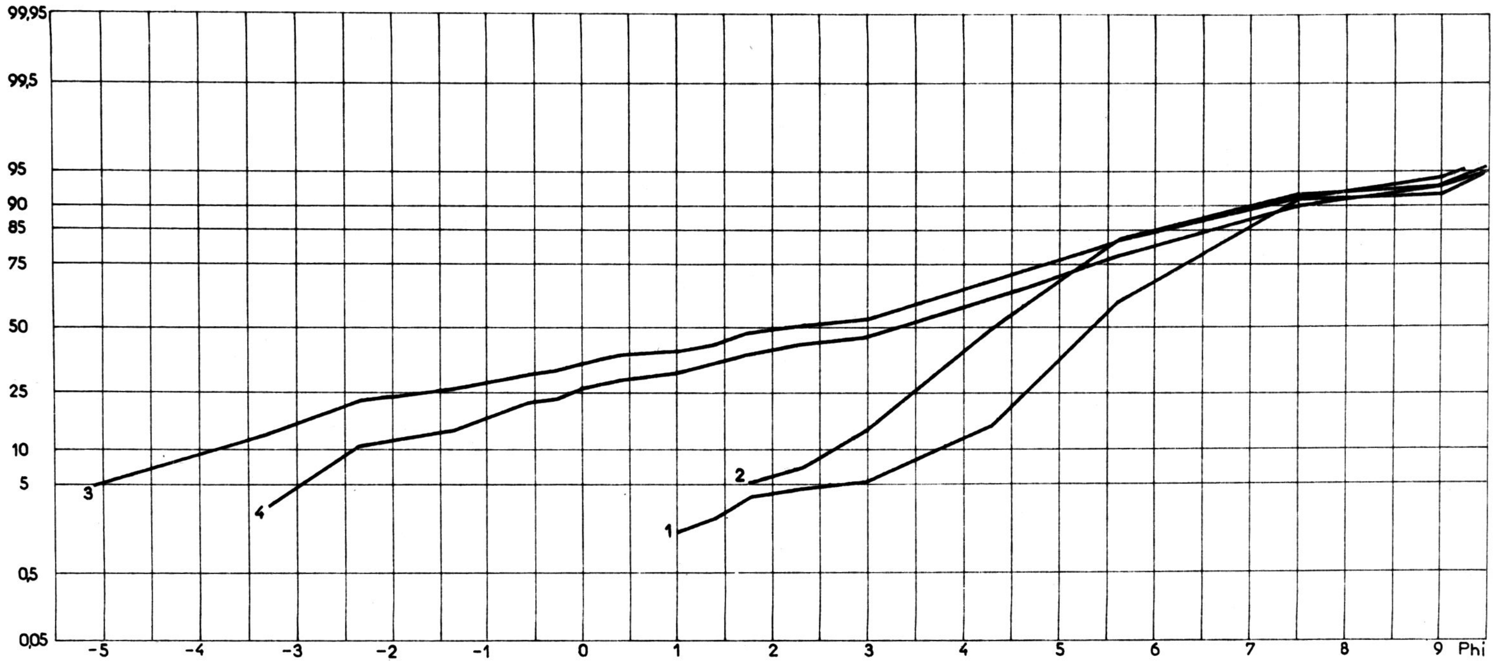

Fig. 8. The cumulation curves of the grain size distribution in the ablation hill. The numbering of the curves correspond to the numbers in Fig. 7

morphological axis of the moraines, were localised. Their length varies from a few to several score m (Fig. 5). The presented general morphological situation of these forms offers a few possibilities of their genetic classification. It can thus be stated that these are ozo- and kemolike slit forms, forms of moraine erosion remnants of a moraine cut apart by outwash waters or accumulation forms emerged in the super ice cover at their base. It was possible to eliminate, in the course of more precise observations, the latter case. For, as a result of the degradation of these forms at the end of the polar summer, their interval structure revealed itself (Fig. 9). It appeared then that under a thin cover of moraine material, these forms contain inside a thick layer of glacier ice: of ice which is at the same time the base for the proximal part of the extramarginal outwash occurring there. Thus the super ice cover was not a morphocreative factor, but was only imposed on the surface of the glacier ice, and in this situation it played rather the preserving function, braking the rate of degradation processes in the glacier ice lying below. The question, however, whether these forms are of crack or erosion origin should be recognized as open, although when considering, e.g. their position on the outwash dehydration line, a suggestion occurs that they result from erosion cutting apart of a sequence of ice-moraine ridges Irrespective, however, of genetic classification, it appears to be of more importance and also of significance in reconstructing the Pleistocene events that the outline of the steady-state position of the glacier is determined here not by the compact sequences of ice moraine, or moraine, ridges but the above mentioned small glacial forms in their foreland.

4. Ebba Valley

The Ebba Valley, about 4 km long and 1.5 km wide, is one of the valleys going into Petuniabukta. Its axis is oriented from southwest to northeast. It cuts into the mountain ranges of Lövehovden and Hultberget (797 m over the sea level) from the northwest, and into Wordiekammen from the south and east. The valley is closed by the Ebba Glacier, presented above. The valley is dehydrated by the Ebbaelva, flowing from the glacier, which, collecting the water from mountain creeks, flows into the Petunia Bay, heaping together with the other outwash rivers, an extensive delta.

The Ebba Valley deserves attention because of the rich inventory of glacial forms occurring there. In the previous considerations, the zone of ice moraine bank occurring in the direct foreland of the Ebba Glacier, was distinguished. This zone marks one of the last of its steady-state positions In the Ebba Valley, it was possible to localise a complex of forms suggesting that its development should be related to the functioning of the glacier over a much larger surface area compared to the present one. This statement is evidenced by a zone of mutated rock outcrops of the base, extending in the foreland of the ice-moraine ridges.

Further evidence of the glacial history of the valley can be found in its central part (Fig. 10). Namely, a high ridge is adjacent to the slope of Wordiekammen. Although no precise geological research has been carried out inside it, but a number of its morphological features offer the possibility of recognizing it as the old sequence of a lateral moraine.

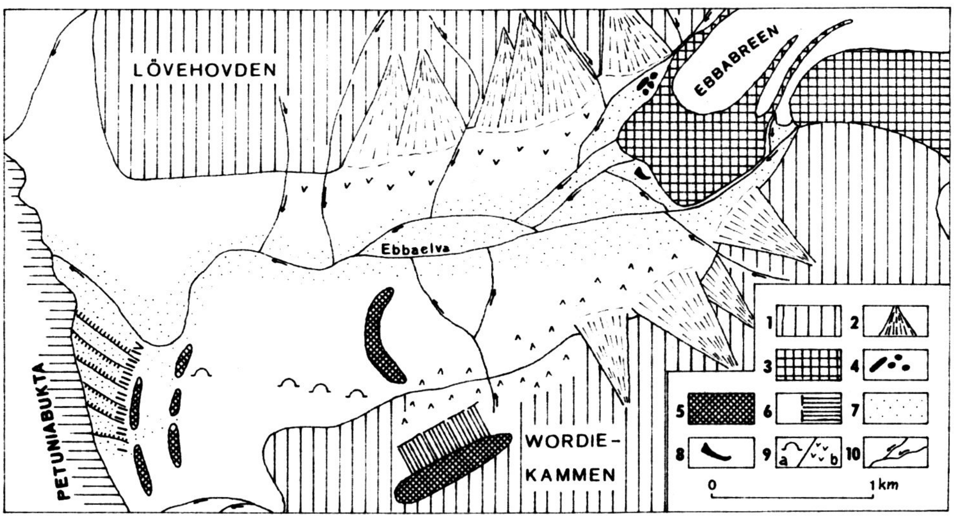

Fig. 10. A geomorphological schematic diagram of the Ebba Valley

1 — mountain ridges, 2 — scree and outwash cones, 3 — ice-moraine ridges 4 — ice — core hills and banks, 5 — old moraine banks, 6 — keme terraces, 7 — outwashes, 8 — muttons, 9 — periglacial phenomena: a) tufur type hills, b) other phenomena (soliflux surfaces, frost cracks etc.), 10 — rivers

This form is accompanied, in a few spots, by small surfaces inclined mildly towards the direction of the axis of the valley, which the author is willing to identify as the level of kame terrace. If the future investigations confirm these observations, this would prove that in the past the Ebba Valley was filled with ice masses of large thickness.

However, this is not the whole complex of glacial and glaciofluvial forms identified in the valley. Another set of them can be found in the axial part (Figs. 10 and 11). Thus, not far from the shore of the fiord, parallel to it, there extends a low bank, which, according to the author's opinion, can also, on the basis of the morphological criterion, be recognized as a terminal moraine. Between this ridge and the shoreline of the fjord,

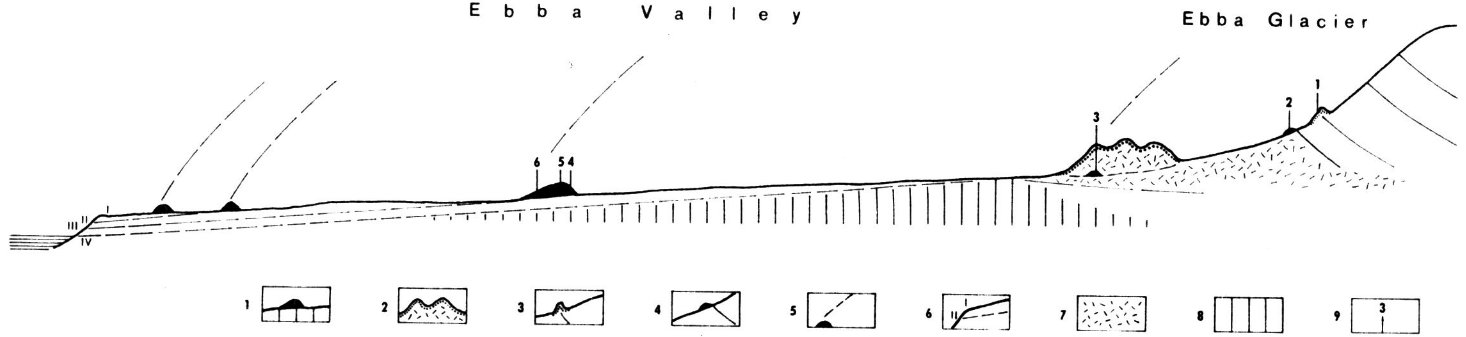

Fig. 11. A schematic longitudinal section along the axis of the Ebba Valley

1 — old terminal moraine banks, 2 — ice — moraine banks, 3 — ablation cone, 4 — outcrops of slide surfaces, 5 — hypothetical ranges of Ebba Glacier, 6 — outwash levels, 7 — glacier ice, 8 — rock base, 9 — points of sampling for granulometric analyses

Fig. 5. The terminal scree moraine at the foot of the steep part of the glacier front. In the forefield, there are isolated forms of transitory hills.

Fig. 6. The morphological effect of the decay of an ice-moraine bank

Fig. 7. The internal structure of an ablation hill. The black points mark the sampling spots

Fig. 9. The structure of a transitory hill in the forefield od a scree moraine bank

Fig. 12. The third moraine sequence extending in the valley (marked by an arrow)

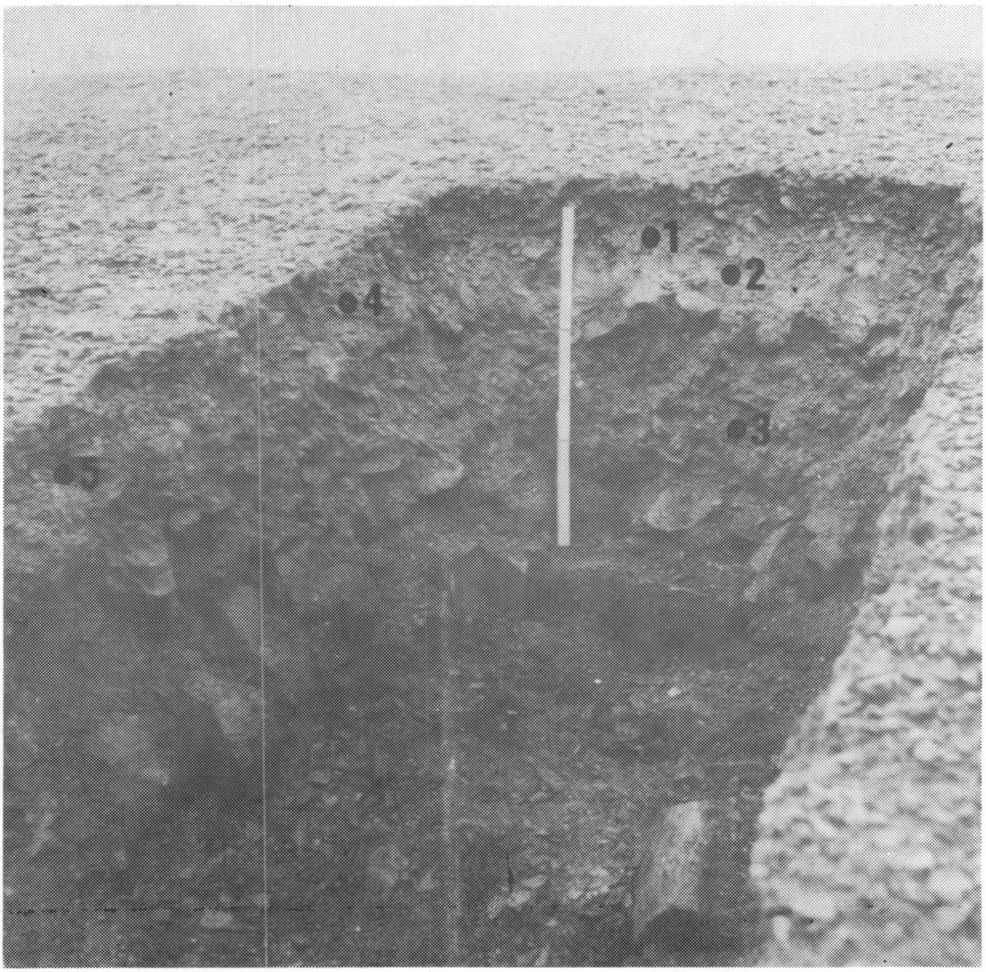

Fig. 13. The internal structure of the proximal part of the third moraine sequence. The dark points mark the sampling points

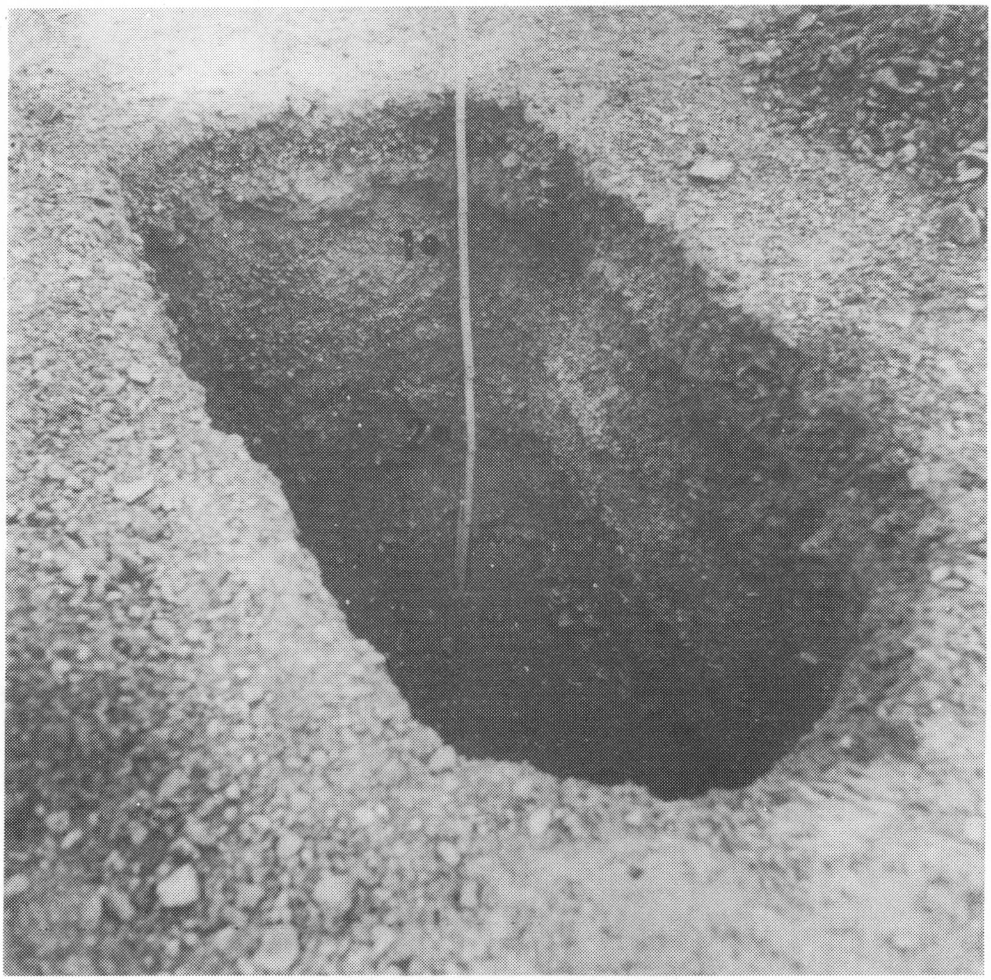

Fig. 15. The internal structure of the culmination of the third moraine sequence. The black points mark the sampling point

there is a small outwash plaine. At a distance of about 100 150 m from the moraine mentioned above, there extends another terminal moraine sequence, cut by two breakthrough sections, and at a distance of a further few hundred meters there is wide zone of the third ridge (Fig. 12). These moraine sequences have also their outwash counterparts. Their fullest documentation is also in the zone between the shore of the fjord and the first terminal moraine ridge (Figs. 10 and 11). Namely the outwash surface already indicated is cut by a lower level which should be related to the functioning of the glacier at the line determined by the second terminal moraine sequence. In the terrain morphology this level is represented by a system of arc-like curved outwash remnants among which there extends a third level of the outwash, which should be correlated with the third, last, moraine sequence occurring in the valley. It is only below, in the vicinity of the northwest slope of the valley that contemporary flow is organized, taking out the thaw water of the present-day glacier.

The inventory of glacial forms presented above allows some suggestions to be drawn about the chronology of events which took place within the valley. Thus, from their spatial arrangement, it can be concluded that they register the events which occurred there both in the Würm period and the Holocene. The moraine ridge high up the mountain slope and the adjacent fragments of kame terrace can all be recognized as evidence of the Würm glaciation. It was then that the Ebba Glacier filled up the whole valley, combining with the main glacier of Isfiord. It is difficult to say at the moment whether the forms indicated register the maximum of the Würm glaciation, which, according to Baranowski (1977), Salvigsen (1977) and Boulton (1979) occurred at about 46-40 years B.C., or whether they are a record of events which took place in the early Würm.

The successive, already Holocene, transgressions of the Ebba Glacier must have been preceded by a considerable recession of the Würm glaciers, when the area of the present-day vallev depression was a sea bay. The presence of the sea is evidenced here by characteristic deposits and numerous build-ups of the shells of sea clams, localised e.g. in penetrations carried out in the third moraine sequence.

The traces, in turn, of the presence of Holocene glaciers in the valley are, as mentioned above, the sequences of moraine ridges and the corresponding outwashes. As has been already said above, in the valley, apart from the ice-moraine ridges at the front of the contemporary glacier, there are another three ridge sequences, which the present author classifies as old terminal moraine banks (Fig. 10). The structure of the third sequence was investigated in greater detail. Three excavations were made — in the proximal part, in the culmination and on the distal part of the form (Fig. 11). At each of the excavations samples were taken for granulometric analyses.

Excavations 1. It was made in the steep proximal slope of the form (Fig. 13). Its depth was about 50 cm, with solid rock below. In the rock layer there is sharp — edged erosion rubble, covered by a heterogeneous sand-gravel-stone series with extremely low differentiation ($\delta = 3.78$—8.36). At a depth of about 15 cm this series is divided by about 5 cm layer of smaller, silt deposits. The profile of the site presented is closed at the top by a several cm thick cover of washed sand and small boulders. In the profile studied, it is interesting to note in addition a concentration of a large number of clamshells, localised at the contact between the erosion rubble and the sand-gravel-stone cover. In greater detail, the granulometry of the deposits indicated is illustrated by the cumulative curves (Fig. 14) and the statistical indices of grain distribution and grain abrasion shown in Table I.

An interesting structure is shown by pit 2, excavated down to a depth of 1.1 m with permafrost below in the culmination of the form studied (Fig. 15). The whole of the profile is constituted by series of larger and smaller boulders, without the smallest particles. Their position, particularly in the central and lower parts of the profile, gives them the features of fractional layers. Here, it is possible to note a much better differentiation of deposits compared to the layer building up the ceiling of the profile studied. This is shown by the cumulative curves of grain distribution (Fig. 16), and the list of statistical indices (Table I). In terms of grain abrasion the deposits investigated resemble the other deposit series presented already. Namely, they represent a homogeneous type of prismatic grains, unabraded. A characteristic feature is here the occurrence of clam shells throughout the whole profile of the site.

A similar structure of the ridge presented is shown by exavation 3, carried out in the distal part of the form, which descends mildly to the foreland. Its depth was 1.3 m, where the top of permafrost was reached. In order to obtain a fuller characteristic of the deposits, 4 samples were taken there at depths of 8, 25, 50 and 100 cm. The results obtained, shown in the form of cumulative curves (Fig. 17) and statistical indices (Table I), confirm the structural similarity of the proximal part of the bank to the cumulative one. It is only in the top of this part of form that a layer of smaller deposits, of low thickness, can be found, which is absent in the culmination part. Also at this site, clam shells were found to occur, and their greater concentration occurred at depths below 50 cm.

The geological structure of the ridge studied, as shown above, shows distinctly the lithological bipartition cross-section. The proximal part of the form is composed of deposits showing a close relationship with the glacial environment. In turn, the further parts are built up of deposits which resemble in their character sea material of which often storm ridges

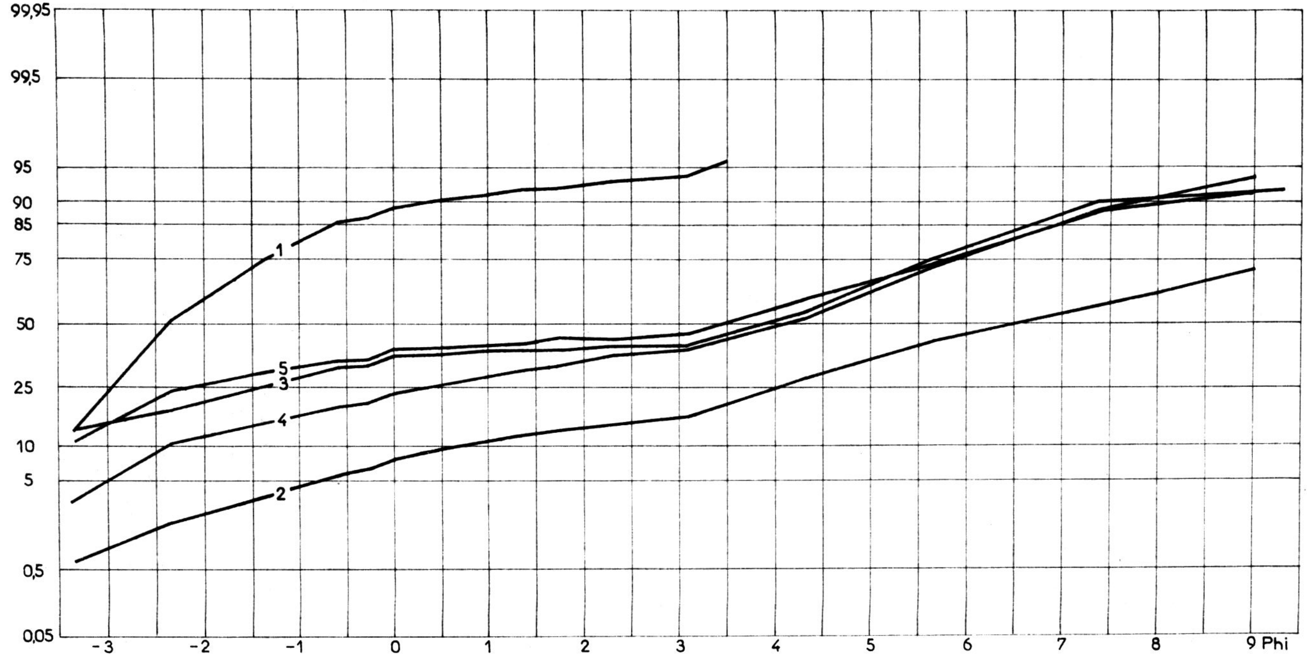

Fig. 14. The cumulation curves of the grain size distribution in the deposits in the proximal part of the third moraine sequence. The numbering of the curves corresponds to the numbers in Fig. 13

are formed, indicating the participation of the marine environment in the development of the valley. However, a complex morphological-geological analysis permits the form studied to be recognized as a terminal moraine.

When it is recognized that the geometric differentiations of the forms presented above within the Ebba Valley are valid, they would then be evidence of four stages of the decay of the Ebba Glacier. This would contribute greatly to knowledge of the glacial history of Spitsbergen. In the previous divisions of Holocene glaciation in Spitsbergen, the practice has been to distinguish two stages: the so called Magdalenefjorden stage, corresponding

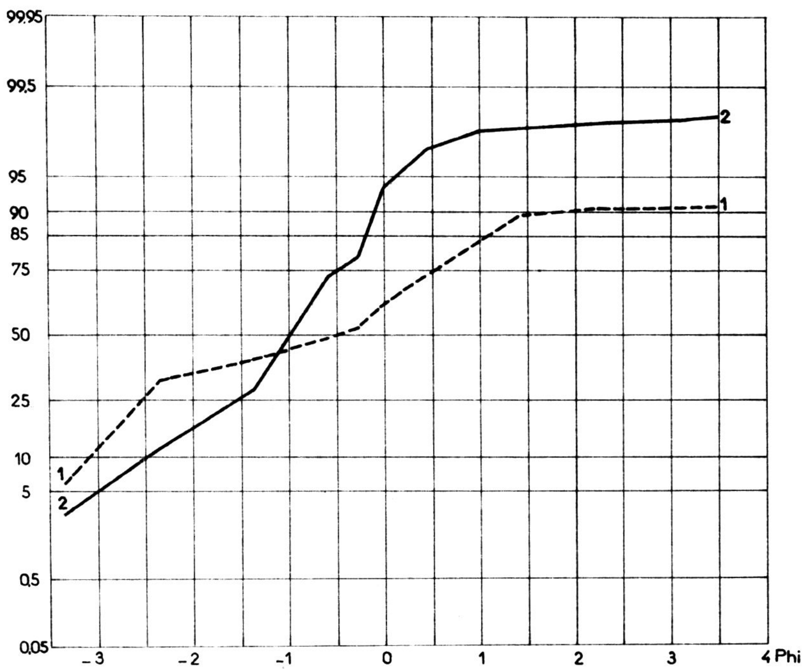

Fig. 16. The cumulation curves of the grain size distribution in the deposits of the culmination part of the third moraine sequence. The numbering of the curves. corresponds to the numbers in Fig. 15

to the period of 2400 years ago (Szupryczyński 1968) or about 3500–2000 years ago (Baranowski 1977), and the contemporary stage, called the Little Ice Epoch, which began about 750 years ago (Baranowski 1977) or 600 years ago (Pękala 1980) and had lasted up to 100 years ago. Recently, Kłysz and Lindner (1981) proposed a hypothesis of triple advance of the glaciers in the Holocene. Namely, on the basis of investigations in the Slakla Valley on Sörkappoland, they distinguish glaciation in the early Holocene, which would have occurred 10–11 thousand years ago. The complex of glacial forms shown to occur in the Ebba Valley supports in

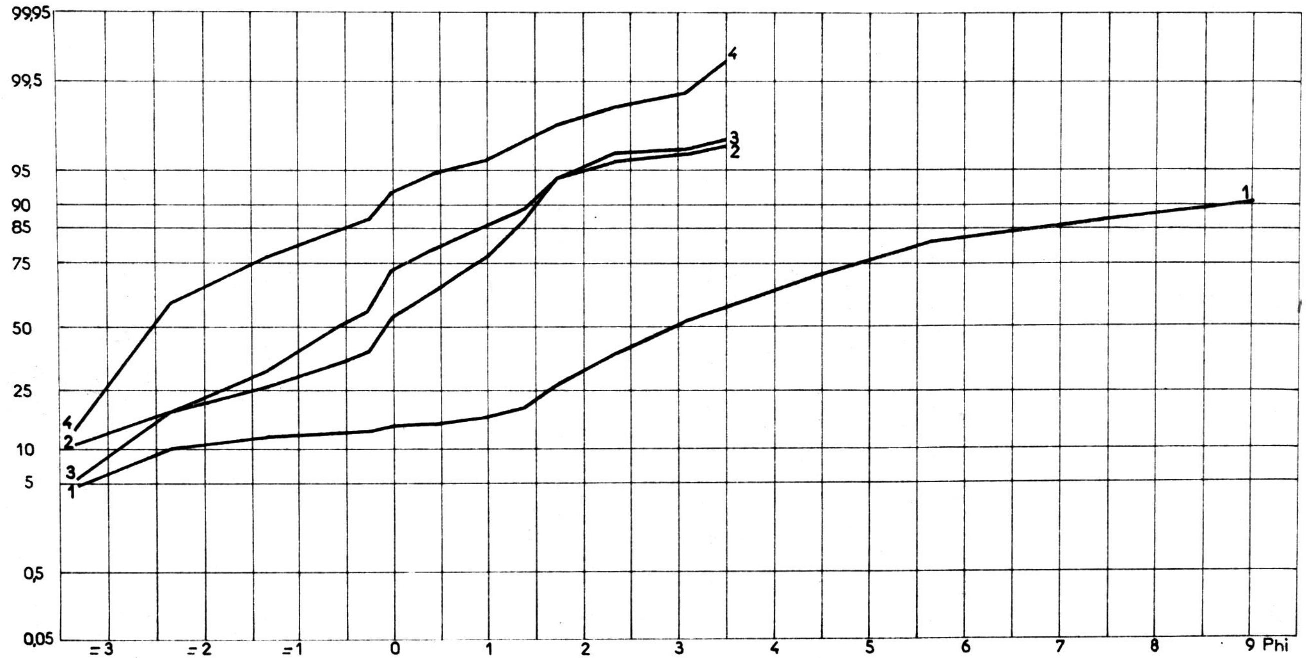

Fig. 17. The cumulation curves of the grain size distribution in the deposits of the distal part of the third moraine sequence. The numbering of the curves corresponds in succession to depths of 8, 25, 50 and 100 cm

turn the statement that its development has been related to four advances of the Holocene glaciers. At present, however, it would be difficult to show to which age interval the fourth period of steady-state position of the glacier should be related. The solution this problem and others mentioned above, is however, the object of future, much more detailed, investigations.

5. Резюме

Настоящая работа является результатом научного обследования, проведенного автором в летнем сезоне 1977 года, в центральном районе Шпицбергена. Наблюдения проводились на леднике Эбба и в долине Эбба, расположенной на восточном окаймлении Петуниябукта (фиг. 1). Главным объектом исследований были некоторые формы и отложения, обнаруженные на леднике и на его предпольи.

Исследовался гранулометрический состав выбранных отложений, залегающих на поверхности ледника (фиг. 4, табл. 1), в зоне ледниково-моренных валов (фиг. 7, 8, таб. 1) и в долине в границах древнего моренного вала (фиг. 13—17, табл. 1).

Выделены несколько ледниковых и водноледниковых комплексов, обнаруженных в долине: 1. расположенный высоко на горном склоне Вордиекаммен вал боковой морены и прилегающая к нему камовая терраса; 2. три вала древних краевых морен и связанных с ними зандров; 3. ледниково-моренные валы у края современного ледника (фиг. 10—12).

Обследованный инвентарь форм позволил сделать попытку хронологического упорядочения явлений, благодаря которым сформировалась долина Эбба. По тезису автора оледенение долины произошло в вюрме, а в голоцене подвижки ледника Эбба повторялись четыре раза.

6. Streszczenie

Opracowanie niniejsze jest wynikiem rekonesansu naukowego jaki odbył autor w sezonie letnim 1977 roku w rejonie środkowego Spitsbergenu. Obserwacjami terenowymi objęty został lodowiec Ebba oraz dolina Ebba zlokalizowana we wschodnim obramowaniu Petuniabukta (Fig. 1). Przedmiotem zainteresowania stały się tu niektóre formy i osady występujące na lodowcu a także na jego przedpolu.

Dokonano charakterystyki granulometrycznej wybranych serii osadów znajdujących się — na powierzchni lodowca (Fig. 4, Tab. I), w strefie wałów lodowo-morenowych (Figs 7,8, Tab. I), oraz w dolinie w obrębie starego ciągu morenowego (Figs 13–17, Tab. I).

Wyróżniono kilka zespołów form glacjalnych i glacjofluwialnych występujących w dolinie, a mianowicie: 1. wysoko położony, na stoku górskim Wordiekammen, wał moreny bocznej i przylegające do niego półki terasy kemowej; 2. trzy ciągi starych moren czołowych i odpowiadających im poziomów sandrowych; 3. wały lodowo-morenowe u czoła współczesnego lodowca (Figs. 10–12).

Rozpoznany inwentarz form pozwolił na próbę ustalenia chronologii wydarzeń odpowiedzialnych za rozwój doliny Ebba. Postawiono tezę o würmskim zlodowaceniu doliny oraz czterokrotnym awansie lodowca Ebba w

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