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Late Pleistocene and Holocene relief remodelling in the Ebbadalen-Nordenskiöldbreen region in Olav V Land, central Spitsbergen

ABSTRACT. This article presents characteristics of the Quaternary deposits and landforms of Ebbadalen, the Nordenskiöldbreen foreland and the Wordiekammen massif on the basis of geomorphological mapping of this area and a number of geologic profiles A—L studied in detail. Glaciers were much more expanded during the Pleistocene than they are nowadays. Over a period referred to by the present authors as the Petuniabukta-Adolfbukta Stage they occupied the whole Ebbadalen area and the eastern part of Adolfbukta. Marine terraces of 70—80, 60—65 and 50—55 m a.s.l. were formed earlier. At the turn of the Pleistocene three marine terraces were produced at 40—45, 30—35 and 20—25 m a.s.l. Throughout the Early Holocene transgression (the Ebbadalen Stage= the Thomsondalen Stage) glaciers occurred in nearly the entire Ebbadalen area and occupied a larger part of Adolfbukta than nowadays. During the Middle and Late Holocene marine terraces of 12—15, 5—8, 3—4 and 1—2 m a.s.l. were initiated. Two more glacier advances, the later relating to the Little Ice Age, took place during the Late Holocene.

Key words: Arctic, Spitsbergen, Quaternary, landforms and sediments

Introduction

The objective of this article is to present characteristics of deposits and landforms of Ebbadalen and the Nordenskiöldbreen foreland, as well as those preserved on slopes of the Wordiekammen and De Geerfjellet massives (Fig. 1). This region has an area of about 70 sq km and lies in the northern portion of Billefjorden where it is part of the western portion of Olav V Land. Its western boundary is formed by the Petuniabukta, while the Adolfbukta lies in the south. To the north there are massifs and slopes of Løvehovden, Hultberget and Sporehøgda. Areas feeding the Ebba and Nordenskiöldbreen in the Cabefjellet region extend in the east.

The present authors carried out fieldwork there in late June and in July of 1984. The fieldwork was largely combined with observations made earlier by Kłysz (1983 a and b, 1985a). Inferences could be drawn from field evidence about the occurrence of a set of glacial and glacio-aqueous deposits and landforms in Ebbadalen and on the north-facing slope of Wordiekammen. The evidence suggests that this area may have been occupied by the Late Pleistocene glaciers and that the Ebbabreen terminus advanced

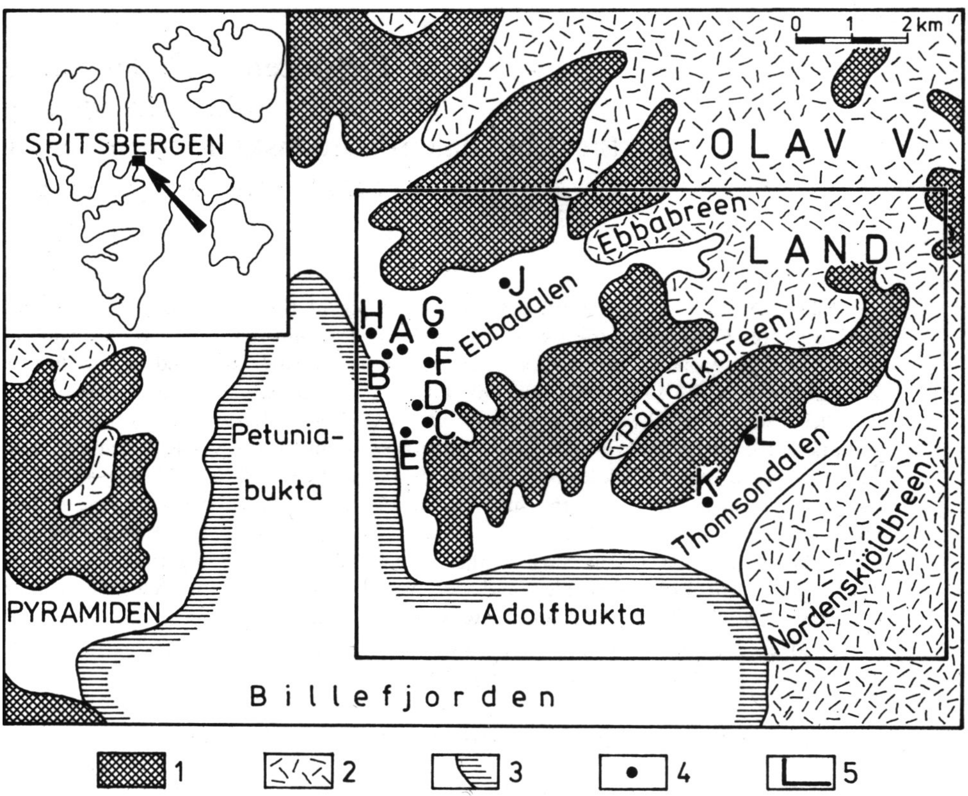

Fig. 1. Location map of the Ebbadalen-Nordenskiöldbreen region

1:mountain massif tops, 2: glaciers, 3: present-day sea coastline, 4: exposures studied in detail, 5: area covered by a 1:20000 scale map of the Quaternary deposits and landforms (under wrapper) considerably and was formed three- or fourfold during the Holocene. An age has been demonstrated for these glacial episodes with reference to later observations of marine deposits and landforms occurring around Petuniabukta as two earlier episodes can be correlated with the expansion of glaciers which took place about 70 and 41—39 ka BP, the third one can be identified with the date of about 11 ka BP (Billefjorden Stage?) and the fourth one can be associated with the Little Ice Age (*see* Kasprzak *et al.* 1985).

The research programme of 1984 included first of all geomorphological and geological mapping of the Quaternary deposits and landforms occurring in the study area on a 1:10000 scale base-sheet provided by the enlarged Norwegian air photos of 1961. For the purpose of obtaining full characteristics of the deposits and landforms under investigation, drawings of their many geologic profiles (A—L in Fig. 1) produced by excavations have been made and described. Sediments from most of these profiles were sampled for the lithogenetic analysis, as well as radiocarbon and thermoluminescence dating. The boulder-sized fraction was not used for laboratory investigations of the particle-size distribution.

Particle-size distributions were determined by sieving. For sedimentological interpretation needs, groupings of deposits into clases of the main fractions were established in accord with PN-54/B-02480. Within the sand-sized fraction, subdivision was made on the basis of the Pacowska classification (1955). Sieving was supplemented, where necessary, by Casagrande's velocity settling modified by Prószyński.

The results are presented as cumulative frequency curves on logarithmic probability paper. They serve as a basis for calculating a few typical statistical size parameters:

(1) the mean particle diameter after Folk and Ward (1957)

$$Mz = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

(2) the standard deviation of the distribution as above

$$\delta = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

(3) kurtosis as above

$$K_G = \frac{\phi 95 - \phi 5}{2.44(\o 75 - \o 25)}$$

(4) asymmetry index after Friedman (1962)

$$\alpha_s = (\phi 95 + \phi 5) - 2\,(\phi 50)$$

(5) sorting index after Rotnicki (1970)

$$P_S = \phi 90 - \phi 10$$

(6) clay ratio after Karczewski (1963)

$$I = \frac{< 0.002 \text{ mm}}{> 0.002 \text{ mm}}$$

The $CaCO_3$ constants of the deposit have been identified. Particle-size distributions, the estimated parameters and percentage $CaCO_3$ contents are presented in graphic form as diagrams for a given site. The study of the degree of abrasion has been abandoned because of indiscernible quartz grain contents of the deposit.

The resulting geomorphological and geological data are presented on a 1:20000 scale map based on a hypsometric sheet (Kłysz *et al.* 1987: under wrapper) due to autogrammetric compilation of the Norwegian air photos of 1961 at the scale of 1:50000.

Bedrock

In the eastern portion of the study area, the bedrock of the Quaternary deposits and bottom of the existing glaciers (Ebbabreen, Nordenskiöldbreen) is made up of largely metamorphosed Late Precambrian carbonate rocks and tillites of the lower part of the Hecla Hoek formation (Hjelle and Lauritzen 1982). In the Nordenskiöldbreen region of nunataks granite intrusions are often encountered in these rocks. They are dated using the K/Ar method to 420—405 Ma BP (Gayer *et al.* 1966).

In the centre of the study area rocks of the Hecla Hoek formation are erosionally truncated and covered with nearly flat-lying Lower Carboniferous clastic rocks at dips of several degrees in a westerly direction. The rocks contain hard coal intercolations which pass upwards the Upper Carboniferous and Permian carbonate rocks, sandstones and conglomerates (Hjelle and Lauritzen 1982). They make up the mountain massives of Wordiekammen, Hultberget and Løvehovden, the top part of De Geerfjellet and the base of the Pollockbreen where they reach a few hundred metres in thickness. In the Ebbadalen they are dissected by systems of meridionally oriented faults, thereby giving rise to numerous gullies on the slopes of the surrounding mountain massives. The faults are associated with a displacement system running from Austfjorden through the Piramiden region towards the western shores of Billefjorden (Harland *et al.* 1974).

In the western portion of the study area there is a marked increase in the thickness of the Carboniferous and Permian rocks to about 500 m. On the west side of Petuniabukta stone coal is now being mined from the exposures of the Lower Carboniferous rocks (Pyramiden).

Characteristics of Quaternary landforms and deposits

There is a diversity of the Quaternary landforms and deposits in the Ebbadalen-Nordenskiöldbreen region. The mouth section of Ebbadalen contains chiefly raised marine terraces which remain as a narrow strip at the foot of Wordiekammen, along the eastern shores of Petuniabukta and the northern shores of Adolfbukta. Glacial landforms and deposits occupy the floor of Ebbadalen and partially, its slopes. They also occur on the south-facing slope of De Geerfjellet adjacent to Nordenskiöldbreen and in the valley of Pollockbreen. Slope landforms and deposits prevail on the slopes of the mountain massifs Hultberget, Wordiekammen and De Geerfjellet.

The study area consists of three distinct units differing in types of the prevailing deposits and landforms. In Ebbadalen glacial deposits and landforms with a great contribution from marine landforms and deposits have assumed dominance. The immediate foreland of Nordenskiöldbreen contains almost only glacial deposits and landforms, whereas there are only slope deposits and landforms with the underlying marine deposits in the Wordiekammen region (*cf.* the enclosed map and Figs 11 and 12).

Ebbadalen region

Raised marine terraces of 1—2, 3—4, 5—8, 12—15, 20—25, 30—35 and 40—45 m a.s.l. are found in the lower section of Ebbadalen (Pl. 1). Considerable expansion of their belt for as long as 1.3 km in the middle reaches of the valley, down the Ebbaelva, is indicative of the presence of a deep sea bay in the past (*cf.* the enclosed map).

The marine terraces are composed of gravels and sands which often contain mollusc shell fragments. The structure of the terraces of 5—8, 12—15, 30—35 and 40—45 m has been recognized in more detail due to the existing exposures.

The terrace of 12—15 m a.s.l. found in the gap section of Ebbaelva has been best studied (exposure A on the map and in Figs 1, 2). The thickness of marine deposits underlain by a bed of glacial till is 10 m there (Pl. 2, Fig. 1). The marine series is characterized by a considerably uniform

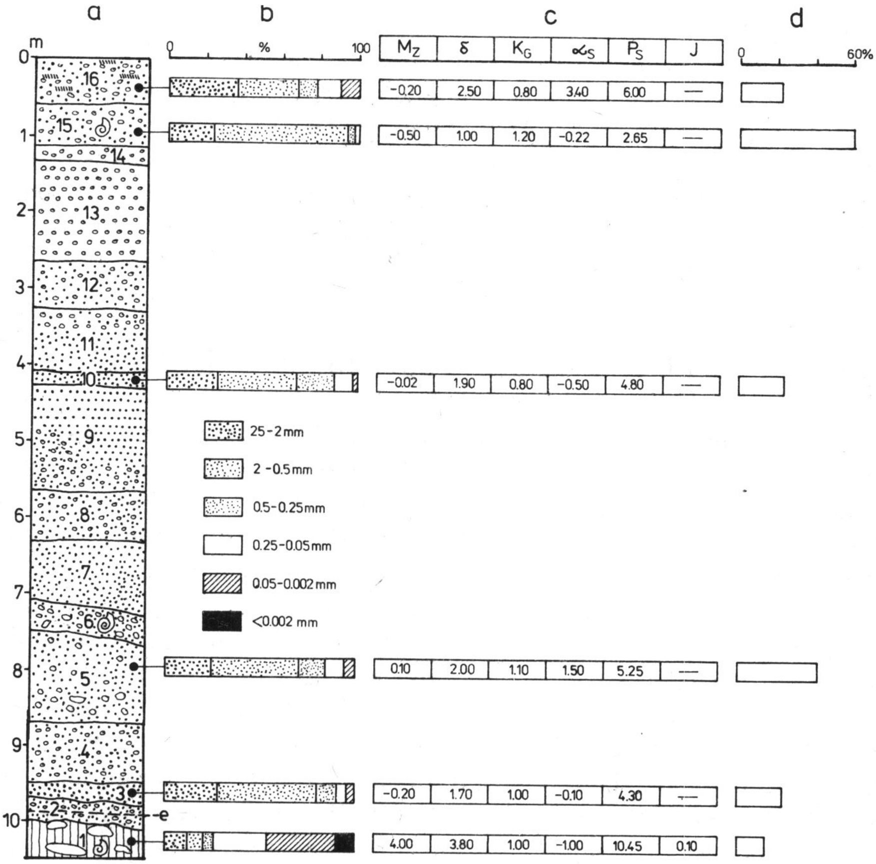

Fig. 2. Profile of exposure A in the marine terrace scarp of 12—15 m a.s.l. in the mouth section of Ebbaelva. Black dots indicate sites of sampling for particle-size distribution analysis. a: lithology — 1: greyish-olive$_3$ clayey-silty glacial till with pebbles up to 40 cm in diameter, mollusc shells and $CaCO_3$ concretions on rock clasts, streaked at the top, 2: gravels 4—5 cm in diameter with lenses and thin intercalations of glacial till, 3: sand--containing grey gravels up to 5 cm in diameter, 4: coarse gravels 2—6 cm in diameter with pebbles up to 10 cm in diameter, 5: grit bits up to 4 mm in diameter with pebbles up to several cm in diameter, containing sand and sparse mollusc shells at the top, 6: poorly abraded yellow gravels up to 5 cm in diameter with purple mollusc shell fragments, 7: grey gravel varying in particle size with grit, 8: horizontally streaked grits with admixed gravels up to 5 cm in diameter, containing fine detritus of purple mollusc shells, 9: gravels up to 5 cm in diameter with admixed fine detritus of purple and white mollusc shells, 10: gravel-containing grey medium-grained and coarse sand with mollusc shell fragments, 11: grits with gravels up to 5 cm in diameter, thin intercalations of fine sand, pebbles up to 10 cm in diameter, mollusc shell fragments, 12: grit with admixed gravels up to 5 cm in diameter and mollusc shell fragments, 13: horizontally laminated gravel with cobbles up to 15 cm in diameter, purple and white mollusc shell fragments, 14: grits and gravels up to 1.5 cm diameter, 15: horizontally laminated gravels up to 5 cm in diameter, containing humus sand streaks and mollusc shells, 16: weathered gravel with numerous humus sand streaks. b: particle-size distribution. c: size parameters — Mz: mean grain diameter. δ: standard deviation, KG: kurtosis, s: asymmetry index, Ps: sorting, I: clay ratio, d: $CaCO_3$ contents

particle-size distribution. The main grain mass consists of gravels and coarse sands which, on the average, account for 76,7% of the total deposit with 94,4% at a maximum (Fig. 2). This receives confirmation from the statistical parameter of the mean grain diameter Mz which has negative values included in the range of 0.02—0.5 phi. According to Folk and Ward (1957), sorting of the deposit is poor (δ = 1.0—2.0) or even extremely poor (δ = 2.5), as reported from the surface part of the terrace. This is also reflected in values of the sorting index Ps within the range of 2.65—6.0.

The sedimentary analysis indicates varying, though generally high $CaCO_3$ contents of the order of 22.0 to 60.8% (Fig. 2). This high degree of saturation of sediments with calcium carbonate should be accounted for by the marine environment where the sediments were laid down. A high concentration of $CaCO_3$ may thus be due to the crystallization of evaporites from sea-water. It may be additionally increased due to the presence of bone fragments resulting from abrasion and the crushing of mollusc shells (*cf.* Gradziński *et al.* 1976). This presumption is supported by the fact that mollusc shell fragments and unbroken shells occur in the terrace deposits.

Glacial till occurring at the base of the terrace deposits (Pl. 2, Fig. 2) has a different particle-size distribution. Its scatter is on a larger scale. The concentration of grains is well marked within the fine fraction of particles smaller than 0.25 mm (Fig. 2). They represent 73,8% of the total deposit, including 45,9% of the silt- and clay-sized fraction finer than 0.05 mm. This is indicated by a high positive index Mz of 4.0 phi. Sorting of the deposit is considerably poorer than that of the terrace cover (δ = 3.8, Ps = 10.95). The clay ratio I that is a weight ratio between the amount of the colloidal clay fraction and other fractions within a sample is 0.10. The $CaCO_3$ contents are lower than those of the terrace cover, reaching 15.4%.

Similar geologic structure of the terrace of 12—15 m a.s.l. has been found to the north of the Ebbaelava mouth (exposure H on the map and in Figs 1, 9).

The marine terrace of 5—8 m a.s.l. has been investigated in the mouth section of Ebbaelva (exposure B on the map and in Figs 1, 3). The thickness of terrace deposits exceeds 3 m there. They consist of gravels up to 6 cm in diameter which contain an admixture or intercalations of coarse sand and fine gravel. No fragments of molluscan shells have been found in the deposits.

Sediments of which the terrace of 40—45 m a.s.l. is built up have been studied at two sites (C and F on the map and in Figs 1, 4, 7). One site (C on the map and in Fig. 1) is located at the foot of Wordiekammen in the southern portion of Ebbadalen. The exposed wall shows a 4.0 m thick profile of the terrace deposits. At the top the terrace is covered with an about 0.8 m thick bed of glacial till underlain by series of marine deposits, as viewed macroscopically (Fig. 4). However, the analysis of particle-size distributions shows that an interlayer with size parameters similar to those of till

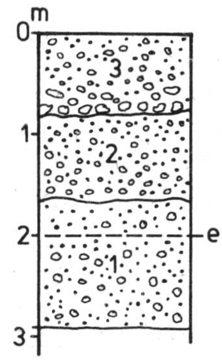

Fig. 3. Lithologic profile of exposure B in the marine terrace scarp of 5—8 m a.s.l. in the mouth section of Ebbaelva. 1: gravels 2—6 cm in diameter with grit and sand, 2: gravel-containing coarse sand, 3: angular gravels with intercalations of coarse sand and grit, humus-streaked silty gravel at the top, e: permafrost top

is present at the depth of 2.0 m. Particles of both the surface till and clayey interlayer are distributed in all fractions. This is reflected in the indices δ of 3.0—4.4 and Ps of 7.58—11.3 indicative of extremely poor sorting. A more detailed analysis of the particle-size distribution (Fig. 4) indicates a certain regular characteristic. There is a marked concentration of particles in the coarse fraction larger than 0.5 mm (42.2% on the average). Thus, the distribution of particle sizes is bimodal. It is regarded as a characteristic of glacial tills (Dreimanis 1969, Dreimanis and Vagners 1971, Olszewski and Szupryczyński 1985). The clay ratio I is low and is included in the range of 0.02—0.05. Thus, it approaches that available for supraglacial material (I= 0.01) from the terminus of Werenskiöldbreen (Karczewski and Wiśniewski 1979). The $CaCO_3$ contents are 10 to 22% (Fig. 4). It may be presumed that the upper till was laid down by a small glacier contained there in the nearby cirque (see the map). The interlayer falls under clay flows which took place throughout the formation of a marine terrace series.

The particle-size distribution of marine deposits differs markedly from that of glacial deposits. The coarse fraction larger than 0.5 mm dominates the distribution. It represents 71.5 to 82.7% of the whole grain mass (Mz= – 0.03—0.25 phi). According to Folk and Ward (1957), the sorting of deposits is poor (δ = 1.4) but it is markedly better than that of morainic sediments. This receives confirmation from other distribution indices (*cf.* Fig. 4). The $CaCO_3$ contents vary but are higher than those of morainic sediments as they are 23.4 and 53.4%.

According to this approach to the two types of sediments under investigation, *i.e.* glacial material and a series of marine sands and gravels of which terrace covers are built up, the percentage $CaCO_3$ contents appear to be one of rather sensitive parameters having differentiating functions.

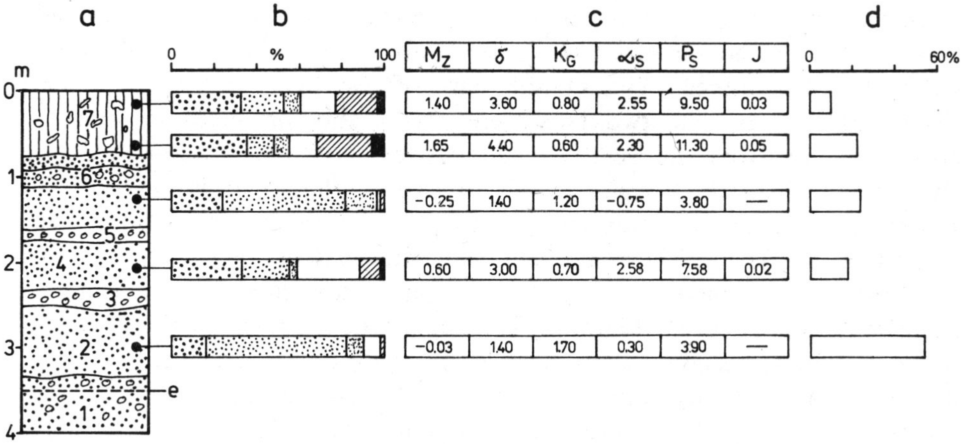

Fig. 4. Profile of exposure C in the till-covered marine terrace scarp of 40—45 m a.s.l. at the north-western foot of Wordiekammen. Black dots indicate sites of sampling for particle-size distribution analysis

a: lithology — 1: well-scoured grit with gravels up to 5 cm in diameter and abundant mollusc shell fragments, 2: sand varying in particle size with admixed gravels up to 5 cm in diameter and abundant molluscan shell fragments, 3: grits and gravels up to 1.5 cm in diameter with mollusc shell fragments, 4: coarse sand with gravel and pebbles up to 8 cm in diameter and mollusc shell fragments, 5: well-scoured grits and gravels up to 1.5 cm in diameter with single large grains and sparse molluscan shell fragments, 6: coarse sand containing grits and gravels up to 4 cm in diameter and tiny mollusc shell fragments, intercalations of clasts up to 10 cm in diameter with admixed grits and gravels 2—5 cm in diameter and single mollusc shells, 7: glacial till with black pebbles of metamorphic rocks, sand—rich at the base, b: particle-size distribution, c: size parameters, d: $CaCO_3$ contents (*see* Fig. 2)

The base of the terrace of 40—45 m a.s.l. lies somewhat farther northward at an altitude of about 39 m a.s.l. close to the axial part of Ebbadalen (F on the map, Figs 1, 7). It is composed of brownish-grey boulder clay containing fragments of molluscan shells. The fine fraction dominates the distribution. It accounts for 67.3% of the deposit, including 11.8% of the clay-sized fraction (Mz = 3.2). Sorting of the deposit is extremely poor (δ = 4.5, Ps = 12.0). Particularly significant are a high clay ratio (I = 0.13) and concurrent low $CaCO_3$ contents of 4% (*cf.* Fig. 7).

Marine sands and gravels of which the terrace of 40—45 m a.s.l. is built up contain single fragments of mollusc shells. The thickness of marine deposits is about 7 to 8 m. They are covered with grey glacial till transported by solifluction and solifluction till blanketed with a mantle of aeolian sands. Numerous sandy intercalations within the solifluction deposits provide evidence for the annual rate of their accumulation of the order of about 3 cm.

Beneath the scarp of the terrace of 40—45 m a.s.l. occur sands and gravels of which the terrace of 30—35 m a.s.l. is built up (Fig. 7). Their thickness exceeds 1 m.

In the southern part at the outlet of Ebbadalen an outwash fan extends. It is located at the outlet of the above cirque containing a small glacier within Wordiekammen. The middle part of the fan contains a residual higher (older) fan. The two fans were presumably produced by outwash streams issuing from the nearby cirque when it contained a small glacier. The fans are incised into glacial till exposed at their margins (Figs 5, 6). In exposure D (on the map and in Fig. 1) the thickness of till exceeds 2 m (Fig. 5). The till displays similar characteristics of the particle-size distribution, as compared with the morainic sediments described above. The distribution is clearly bimodal. The deposit is, however, liable to vertical variation. The material thickens considerably with depth. Thus, till occurring at the surface (0.6 m) contains 43.5% of the coarse fraction larger than 0.5 mm and 50.1% of the fine fraction smaller than 0.25 mm. At the depth of 1.2 mm the coarse fraction represents 69.1% of the total deposit to become as much as 71.4% at the depth of 1.85 m. The fine fraction declines then to 26.2 and 23.7%, respectively. The index Mz of 2.3, 0.9 and 0.5 phi, respectively, indicates this decline.

Similarly to other studied profiles, sorting of the deposit is very poor (δ = 3.8—3.9, Ps = 9.9—10.9). The clay ratio I is low (0.04).

The $CaCO_3$ contents also vary vertically. They diminish with depth from 40.5% at the surface to 16.7% at the depth of 1.85 m (Fig. 5).

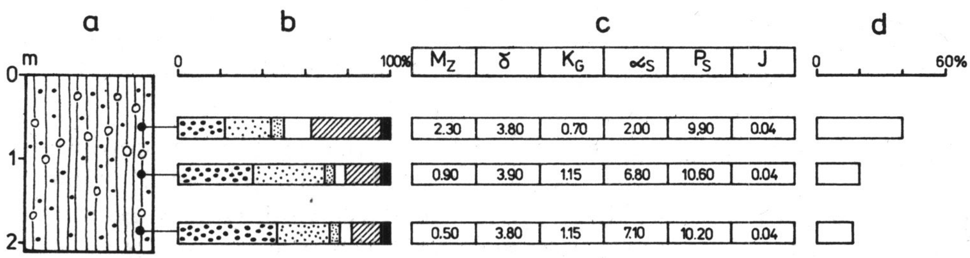

Fig. 5. Profile of exposure D at the residual moraine margin within an alluvial fan in the southern part of Ebbadalen. Black dots indicate sites of sampling for particle-size distribution analysis

a: lithology — glacial till, grey with abundant cobbles and pebbles at the base, sand-rich brown at the top, b: particle-size distribution, c: size parameters, d: $CaCO_3$ contents (*see* Fig. 2)

The top of the till between a residual marine terrace of 12—15 m a.s.l., the Wordiekammen slope and the southern extension of the outwash fan (E on the map and in Fig. 1) has been heavily remodelled by solifluction (Fig. 6). The particle-size distribution provides evidence for that since coarse grains dominate clearly the distribution (67.9%, Mz = −0.1). The fine fraction smaller than 0.25 mm makes up 19.8% of grains but the clay-sized fraction

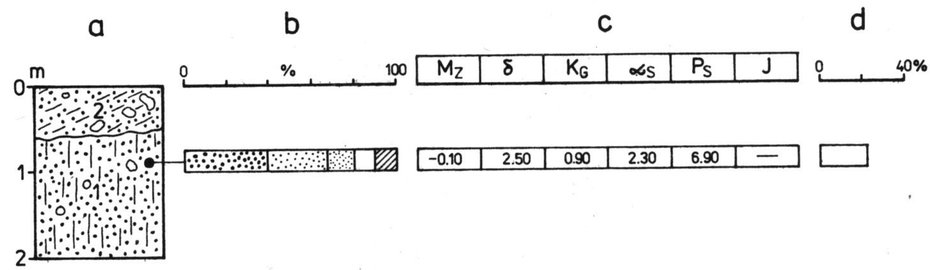

Fig. 6. Profile of exposure E in a cut through the solifluction mantle at the foot of the west-facing slope of Wordiekammen. Block dots indicate sites of sampling for particle-size distribution analysis

a: lithology — 1: grey clayey sand with pebbles (sand-rich glacial till), 2: clayey sand with pebbles and mollusc shelf fragments, transported by solifluction, b: particle-size distribution, c: size parameters, d: $CaCO_3$ contents (*see* Fig. 2)

is absent. Sorting indices are very high ($\delta = 2.5$, $Ps = 6.9$) but lower than those for glacial tills and similar to those for terrace deposits. The $CaCO_3$ contents are 22.5% (Fig. 6).

The middle and upper parts of Ebbadalen are largely filled with glacial deposits (Pl. 3. Fig. 1) laid down by the Ebbabreen at different stages of its development (*see* the map). Scarps of the marine terraces of 20—25, 30—35 and 40—45 m a.s.l. occurring in the lower valley section descend towards the valley centre and remain as closing segments on the seaward side. This is also the case for Lisbetdalen (Kłysz and Lindner 1981) and Revdalen (Karczewski *et al.* 1981) in south Spitsbergen. The formation of these scarps in Ebbadalen should be linked to the former occurrence of ice cliffs in a bay which can be referred to as Ebbabukta but which has disappeared as a result of coastline straightening in Petuniabukta. Such origin of the scarps is supported by the occurrence of trains of large erratics at the surface and within deposits of which the uppermost marine terraces of Ebbadalen are made up, especially at their stoss edges and behind them. The outlines of these trains which are concave in plan on the west side are indicative of the former occurrence of ice cliff.

The centre of Ebbadalen is occupied by an extensive sandy outwash plain lying at the height of 10—15 m a.s.l. It spreads over a distance of about 2.3 km and is 0.3 to 0.8 km in width. The sandy material is easily blown off by the wind and remains as aeolian mantles on the leeward side of the marine terrace system in the south-western part of Ebbadalen. The outwash plain of Ebbadalen continues to run through an about 2.6-km-long narrow gap section (50—250 m) across the marine terraces to the sea and becomes there an outwash valley (Pl. 1, Fig. 1). Nowadays Ebbaelva also runs through the gap (*see* the map). In the mouth section about 0.5 km long there is

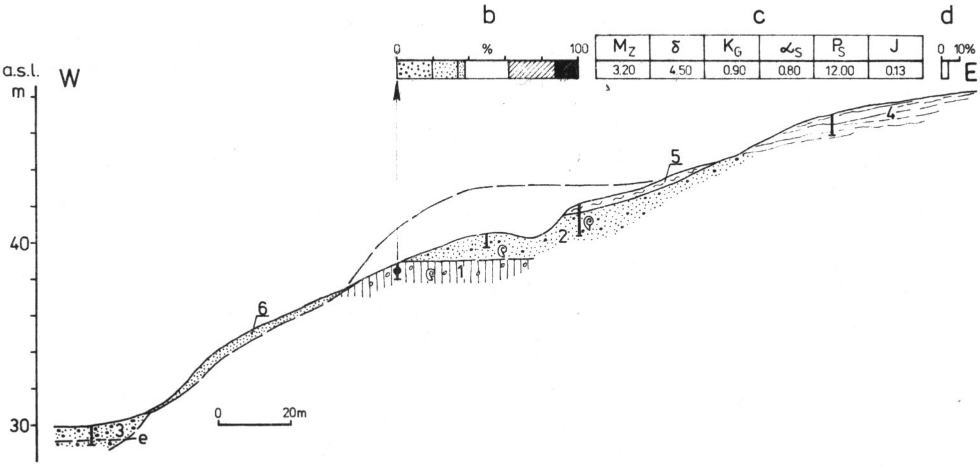

Fig. 7. Geologic section F along a cut through the marine terrace scarps of 30—35 and 40—45 m a.s.l. on the northwest-facing slope of Wordiekammen. Black dots indicate sites of sampling for particle-size distribution analysis

a: lithology — 1: brownish-grey glacial till with pebbles and mollusc shell fragments, 2: sands, gravels and pebbles 6—8 cm in diameter at the marine terrace of 40—45 m a.s.l. containing sparse mollusc shell fragments, 3: sands and gravels at the marine terrace of 30—35 m a.s.l., 4: grey till transported by solifluction, 5: solifluction till with a cover of aeolian sand, 6: alluvial fan sands, b: particle-size distribution, c: size parameters, d: $CaCO_3$ contents (*see* Fig. 2)

a lower outwash sheet associated with the present-day outflow of water from Ebbabreen (*see* the map).

In the eastern part of the gap section the outwash plain cuts into subglacial till resting on the Pre-Quaternary bedrock (Fig. 8). Rafts and bedrock fragments have been partially incorporated in the morainic material (Pl. 3, Fig. 2). The glacial till consists chiefly of the fine fraction smaller than 0.25 mm. This fraction is represented by 71.1% of the total grain mass, including 13.9% of the clay-sized fraction (Mz = 4.3 phi). Sorting of the deposit is extremely poor ($\delta = 0.16$). The $CaCO_3$ contents of the order of 2.9% are very low (Fig. 8). The glacial till contains distinct horizons with mollusc shells in a surviving position. Their presence is indicative of till deposition in the ice cliff zone in the glacio-marine environment.

To the east the outwash plain is closed by an ice-morainic ridge of Ebbabreen (Pl. 3, Fig. 1), lying partly over numerous roches moutonnées which project here and there onto the surface from beneath the ridge deposits and the Ebbabreen terminus (Kłysz 1985a, *see* the map). An extensive area of roches moutonnées in black carbonate rocks of the Hecla Hoek formation also occurs to the south of the Ebbabreen terminus (Pl. 3, Fig. 1). It lies as high as 200 to 300 m a.s.l. and is thus indicative of considerably greater expansion of Ebbabreen in the past.

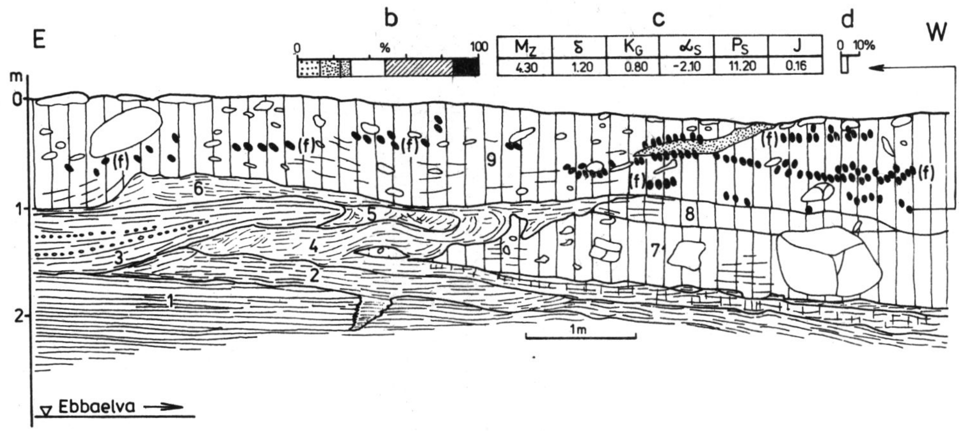

Fig. 8. Exposure G in the Ebbaelva gap section. Black dots indicate sites of sampling for particle-size distribution analysis

a: lithology — 1: poorly cemented and exfoliated grey-greenish fine-grained sandstone 2: grey-olive sandy silt with brown streaks and till-filled interstices, 3: sandy-clayey silt deformed due to overlapping inclusions of angular sandstone clasts, 4: weathered yellow sandstone shale, 5: sandstone shale debris, 6: brittle, weathered and deformed grey-yellowish sandstone shale, 7—9: brown glacial till with numerous cobbles and pebbles, distinct horizons of mollusc shells (f) and carbonate precipitates, b: particle-size distribution, c: size parameters, d: $CaCO_3$ contents (*see* Fig. 2)

In the upper reaches of Ebbadalen the outwash plain begins in four tributaries. Three of them originate from Ebbabreen, *i.e.* from numerous small valleys dissecting the end ice-morainic ridge and two (northern and southern) lateral outwash valleys. The fourth tributary has been produced by outwash water issuing from Bertrambreen, a glacier hanging in the mountain massif Hultberget. Its terminus is now at the height of about 380 m a.s.l. Outwash water flows through a narrow canyon and then falls onto the Ebbadalen floor, thereby causing a waterfall (*see* the map). Formerly the tongue of Bertrambreen descended to the floor in the northern part of Ebbadalen (Fig. 11). The evidence is contained in ice filling in this part of the valley slope and the presence of older moraines and glacial till at its floor (site J on the enclosed map and in Fig. 1). Two sediment samples were taken there, one from ground till and the other from lateral till. The analysis of particle-size distributions shows marked differences in size parameters. In the ground till the coarse fraction larger than 0.5 mm and the fine fraction smaller than 0.25 mm are almost perfectly symmetrically distributed, representing 48.2 and 47.2%, respectively. Particularly interesting is the absence of the clay-sized fraction (Mz = 1.6 phi). Sorting is very poor (δ = 3.4, Ps = 8.6) and the $CaCO_3$ contents are 4%. In the lateral till fine particles account for as much as 68.9%. Among them, only trace amounts of the

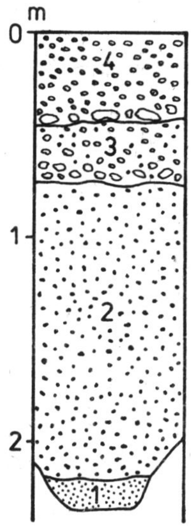

Fig. 9. Profile of exposure H at the edge of an erosional cut at the marine terrace of 12—15 m a.s.l. to the north of the Ebbaelva mouth

1: grit-containing sand varying in particle size, 2: gravel varying in particle size, predominant grains 2—4 cm in diameter, mollusc shells detectable, 3: gravel varying in particle size, predominant grains up to 4 cm in diameter and coarse particles at the base, mollusc shells detectable, 4: gravels up to 4 cm in diameter, with pebbles up to 12 cm in diameter at the base

clay-sized fraction are detectable (0.9%). The index Mz is considerably higher than above as it reaches 3.3 phi. Sorting is also very poor ($\delta = 3.3$, $Ps = 8.9$) and the $CaCO_3$ contents are the same as those of the ground till, *i.e.* 4%.

On the south-facing slope of Ebbadalen there are old lateral moraines lying at the height of 80—120 m a.s.l. Such moraines are also encountered in the cirque in Wordiekammen (*see* the map). At least two more older cirques and two undercuts sloping gradually down towards the valley outlet are also reported to occur there (Pl. 4, Fig. 1). The higher undercut lies at the height of 260—300 m a.s.l., whereas the lower one is found at 140—200 m a.s.l.

Slopes of the middle part of Ebbadalen are covered with diluvial fan sediments (Pl. 4, Fig. 2) and solifluction deposits (*cf.* Kłysz 1986), but within them there are many trains of large erratics. Over a distance of up to 1 km to the east of the entrance to the Ebbaelva gap section build-ups of mollusc shells are found. They are indicative of invasion of the middle part of Ebbadalen by the sea (Kłysz 1985a, *see* the enclosed map).

Foreland of Nordenskiöldbreen

Nordenskiöldbreen is one of the largest glaciers present in this portion of Spitsbergen. It mostly terminates in ice cliff in Adolfbukta. Its thickness reaches 450 m at a distance of about 9 km from the terminus (Macheret and Zhuravlev 1985). The present author's research has concentrated on the northern foreland of this glacier (*see* the map). Dominant relief features are numerous roches moutonnées formed of black carbonate rocks of the Hecla Hoek formation and of light granite intrusions (Pl. 5, Fig. 1). Diversified morphology of the older bedrock may account for severely fractured and cracked margins of Nordenskiöldbreen. Another landform of its foreland is a lateral ice-morainic ridge several to over twenty metres in height. It runs over a distance of about 5 km in a northeas-southwest direction, marking the position of the glacier margin during the Little Ice Age.

The present-day outwash valley (Pl. 5, Fig. 2) that cuts through the lateral ice-morainic ridge in the upper reaches is contained in the intramarginal zone. Traces of earlier outwash discharges are also detectable but glacial till prevails (Pl. 6, Fig. 1), sometimes resulting in a fluted moraine (*see* Kłysz 1985b; Plate 6, Fig. 2). Boulton's research (1970) has already been directed towards glacial deposition in this zone. A sample of subglacial till resting immediately on the solid rock close to a margin of active ice contains a large amount of the coarse fraction larger than 0.5 mm (60.6%) and a relatively small quantity of fine grains below 0.25 mm in diameter (29.7%) with merely 1.4% of the colloidal fraction (Mz = 1.1 phi). Sorting of the deposit is extremely poor ($\delta = 3.5$, Ps = 9.1) and the $CaCO_3$ contents are 4.6%.

A narrow strip of the marine terrace of 1—2 m a.s.l. extends along the Adolfbukta coast. Overlying it occur beneath the glacial deposit presumably earlier marine sediments since build-ups of mollusc shells are found there in places.

On the distal side the lateral ice-morainic ridge is in contact with the lateral outwash valley of Thomsonelva which formerly carried water not only from Nordenskiöldbreen but also from the De Geerfjellet slope where small cirque glaciers are presumed to have occurred here and there. Nowadays an outwash river flows in the upper reaches through the gap section into the intramarginal area.

Of considerable interest is a profile of deposits (Pl. 5, Fig. 1) found in one of gorges (K on the map and in Fig. 1) incised into the De Geerfjellet slope. The gorge enters the lower section of drying Thomsonelva (Pl. 7, Fig. 1). The top contains about 3.5 m thick glacial till which varies a lot in the particle-size distribution in the vertical profile. The coarse fraction larger than 0.5 mm represents 15.5 to 75.7%, while the fine fraction smaller than

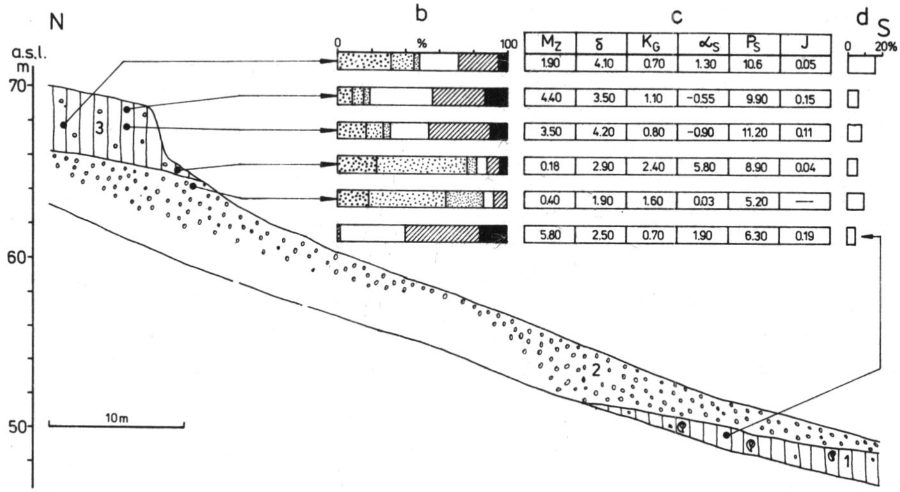

Fig. 10. Geologic section K along a cut at the foot of the southfacing slope of De Geerfjellet. Black dots indicate sites of sampling for particle-size distribution analysis.

a: lithology — 1: glacial till, 2: gravel with abundant pebbles up to 30 cm in diameter and sand intercalations, 3; glacial till with mollusc shells, b: particle-saize distribution, c: size parameters, d: $CaCO_3$ contents (*see* Fig. 2)

0.25 mm accounts for 17.5 to 81.1%. This distribution is supported by the mean grain diameter Mz that ranges from 0.18 to 4.4 phi (Fig. 10).

This overall particle-size distribution of four sediment samples (Pl. 7, Fig. 2) displays certain regular characteristics. In the upper sample (Fig. 10) the coarse (44.5%) and fine (52.1%) fractions are almost symmetrically distributed. The proportions become changed in the next two samples where the fine fraction gains a marked advantage, reaching 81.1 and 68.9% (Mz = 4.4 and 3.5 phi). A different particle-size distribution has been observed in the basal sample in which coarse particles assume dominance, making up 75.7% of the total grain mass. The fine fraction represents only 17.5% (Mz = 0.18 phi). Sorting of the deposit is poor and extremely poor ($\delta = 2.9$—4.2, Ps = 8.9—11.2). The sorting index is lowest for the lowermost sample ($\delta = 2.9$, Ps = 8.9). The clay ratio I is also variable as its highest values are recorded in the two intermediate samples, reaching 0.15 and 0.11, respectively. The lowest clay ratio is found in the basal sample where I is equal to 0.04. The CaCO contents are relatively low. The highest contents are reported from the top (16.0%), whereas they range from 6.0 to 8.3% in other samples.

Under this deposit occurs a several-metre-thick sandy-gravelly series in which coarse sands and gravels account for 63.8%, while fine particles with no contribution from the clay-sized fraction (Mz = 0.4 phi) represent only 13.7%. Sorting of the deposit is poor (δ = 1.9, Ps = 5.2) but markedly better than that of tills. Sorting indices are similar to those available for terrace deposits. The sandy-gravelly series differs from the latter deposits in the $CaCO_3$ contents that are low, of the order of 10.0% (Fig. 10).

The lower glacial till is almost composed of fine particles. Fractions finer than 0.25 mm make up 98.4% of the deposit, including 15.8% of the clay-sized fraction. Such composition is well demonstrated by the index Mz reaching 5.8 phi and by the clay ratio (I = 0.19). As compared to the above morainic sediments, sorting of the deposit is good (δ = 2.5, Ps = 6.3) although it falls under the category poor sorting according to Folk and Ward (1957). The $CaCO_3$ contents are low, *i.e.* are 5%. The till contains shells of sea molluscs.

Glacial till is also exposed in many cuts on the southeastern slope of De Geerfjellet. A sediment sample taken at site L (*see* the map) at an altitude of about 370 m a.s.l. contains evidence for till with an undoubtedly classic bimodal particle-size distribution (40.5% of the coarse fraction and 55.4% of the fine fraction, including 13.3% of clays; Mz = 2.8 phi). Sorting indices are extremely high (δ = 4.9, Ps = 12.6). The clay ratio of the till is high (I = 0.15), while the $CaCO_3$ contents are relatively low, *i.e.* of the order of 6.7%.

On the De Geerfjellet slope there are 2 to 7 glacial undercuts, their number being larger in the west. The heights of their occurrence (undercuts descend westwards) are 40—70, 160—200, 240—260, 280—320, 340—420, 400—480 and 500—600 m a.s.l.

Wordiekammen area

The massif is surrounded in the southeast by the valley of Pollockbreen. Its end ice-morainic ridge becomes a debris glacier (*see* the map). The glacier terminus occurs at the height of about 320 m a.s.l. (Pl. 8, Fig. 1). The former position of the lower glacier margin is marked by roches moutonnées in the lower part of the valley and by old morainic ridges and glacial tills entering the marine terraces in places. A system of outwash drainage occurs in the axial part of the valley.

Traces of a large-scale glaciation of the Wordiekammen massif are well visible. To the west of the Pollockbreen valley there is a vast cirque with numerous glacial undercuts. Patches of glacial till overlying upper marine terraces are found at its outlet (Fig. 12). In addition to the above cirque entering Ebbadalen, there is still another vast cirque, nowadays unoccupied, in the western portion of the massif. Water from a melting glacier which occupied it in the past flowed southwestwards, causing a waterfall in the

Rudmosepynten region where an extinct small outwash fan occurs nowadays. Old morainic ridges occurring there confirm that the glacier itself did flow from a plateau at one time, reaching the Petuniabukta coast.

A similar outwash fan was produced in Rudmosepynten itself at the outlet of a cut through the mountain slope by meltwater flowing from the lateral tongue of a glacier which occupied once the above vast cirque to the west of the Pollockbreen valley.

The western portion of the flat top surface of Wordiekammen, lying at the height of 400—500 m a.s.l., was formerly occupied by a fjeld glacier. A sediment sample from the height of about 430 m a.s.l. indicates the bimodal particle-size distribution characteristic of glacial till. There is a more marked contribution from the fine fraction smaller than 0.25 mm (63.4%), as compared to coarse particles over 0.5 mm in diameter (33.2%), since Mz is equal to 3.8 phi and the clay-sized fraction occurs in large amounts (14.2%, I = 0.16). Sorting of the deposit is extremely poor ($\delta = 4.7$, Ps = 12.3). The $CaCO_3$ contents are low (4.0%).

The Wordiekammen slopes mostly descend to the coast of Petuniabukta and Adolfbukta. They are covered with numerous talus cones. Parts of narrow strips of the marine terraces of 12—15 and 30—35 m a.s.l. are present on the Petuniabukta coast (Pl. 1, Fig. 1). Somewhat larger areas of the terraces of 3—4, 5—8, 12—15 and 20—25 m a.s.l. are found in Rudmosepynten. Only at the southern foot of Wordiekammen at the mouth of an outwash river issuing from Pollockbreen and at the outlet of a cirque lying east of the river, marine terraces extend inland as far as 400 m in the form of a full system of 1—2, 5—8, 20—25, 40—45, 50—55, 60—65 and 70—80 m a.s.l. The uppermost terraces are blanketed in places with till patches (Fig. 12, *see* the map).

Morphogenesis

The Ebbadalen-Nordenskiöldbreen region in question contains a numerous evidence of considerably larger expansion of glaciers during the Late Pleistocene and Early Holocene than nowadays. A strong evidence comprises remants of glacial deposits and landforms on the Wordiekammen plateau and slopes, as well as on the De Geerfjellet slopes, glacial till present on the surface of the uppermost marine terraces of 70—80, 60—65, 50—55 m a.s.l. in the northern area surrounding Adolfbukta and in the Ebbadalen, as well as at the base of marine terraces in the Ebbadalen. There is also a notable intervening thick sandy-gravelly fluvioglacial series in the foreland of Nordenskiöldbreen. Also of considerable importance is the stoss side of a slope bordering to the east on the marine terraces of 40—45, 30—35 and 20—25 m a.s.l. in the Ebbadalen and numerous trains of erratics which mark the positions of glacier snouts in this valley. The available geomorphological and geological evidence, as well as its analysis with respect to earlier Quaternary research in this portion of Spitsbergen (Salvigsen 1979, Boulton 1970, 1979, Mangerud and Salvigsen 1984, Kłysz 1983a, b, 1985, Marks and Wysokiński 1986) permit a tentative explanation of the morphogenesis of the study area to be put forward.

According to the present authors, the marine terraces of 70—80, 60—65 and 50—55 m a.s.l. being partially blanketed with glacial deposits must have been produced prior to the earliest and most extensive Late Pleistocene transgression of glaciers. This advance coincides with a period of the maximum expansion of the Würm glaciers in this portion of Spitsbergen (Salvigsen 1979, Boulton 1979, Mangerud and Salvigsen 1984). It is referred to as the Petuniabukta-Adolfbukta Stage. It was then that Ebbabreen and Bertrambreen, as well as most glaciers occupying cirques on the north-facing slope of Wordiekammen joined to produce a vast glacier (*cf.* Kłysz 1985a) with a terminus lying in the Petuniabukta region. A glacial undercut on the north-facing slope of Wordiekammen at the height of 260—300 m a.s.l. is the result of movement of that glacier (Fig. 11). In the Ebbadalen this event has been recorded in glacial till covering marine deposits which occur on the Wordiekammen slope (Fig. 11).

During the Petuniabukta-Adolfbukta Stage Nordenskiöldbreen expanded as far as the outlet of a cirque to the west of the Pollockbreen valley, thereby producing a glacial undercut on the south-facing slope of Wordiekammen at the height of 350—400 m (Fig. 12). The two glaciers and associated cirque glaciers coalesced to form a glacier occupying the entire eastern part of Adolfbukta. On the south-facing slope of De Geerfjellet a glacial undercut reaching 500—550 m a.s.l. is the imprint of movement of this glacier. The Wordiekammen plateau was then occupied by a fjeld glacier with a few hanging tongues.

Large-scale waning of glaciers occurred between the Petuniabukta-Adolfbukta Stage and the later glaciation, presumably of Early Holocene age. The later glacier advance took place in the entire study area. The studies have demonstrated it for Ebbadalen as the Ebbadalen Stage. Its extent is indicated by the stoss sides of the highest marine terraces and arc-shaped (concave) trains of erratics rooted to the terraces. The formation of a lower glacial undercut at (140—200 m a.s.l.) and older belts of lateral moraines on the slope of the western part of Wordiekammen is also related to that period (Fig. 11). Nordenskiöldbreen must have reached then the outlet of the Pollockbreen valley, resulting in a glacial undercut of 160—200 m a.s.l. On the north side of Thomsonelva older glacial till in profile K is the residual mass of debris. Therefore, this advance is referred to there as the Thomsondalen Stage (Fig. 12). In the axial part of Adolfbukta this glacier remained as ice cliff.

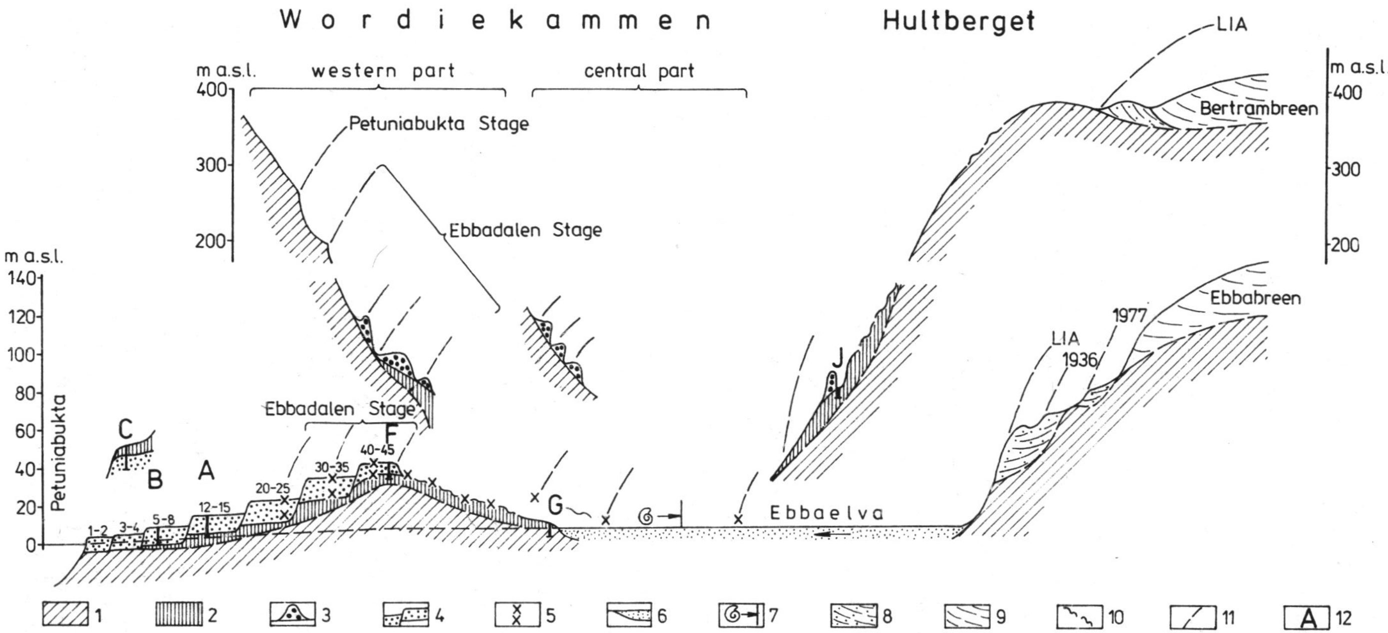

Fig. 11. Generalized scheme of major Quaternary landforms and deposits occurring in Ebbadalen and on slopes of the surrounding massifs Wordiekammen and Hultberget

1: Quaternary bedrock, 2: glacial till (ground, ablation and fluted moraines), 3: end and lateral moraines, 4: marine terraces, heights a.s.l. given, 5: large build-ups of erratics, 6: outwash deposits, 7: extent of marine malacofauna occurrence, 8: dead glacier ice with a morainic material cover (ice-morainic ridges), 9: active glacier ice, 10: solifluction and diluvial mantles, 11: extent lines of glacier snouts (LIA: Little Ice Age). 12: exposures and sections quoted in the text

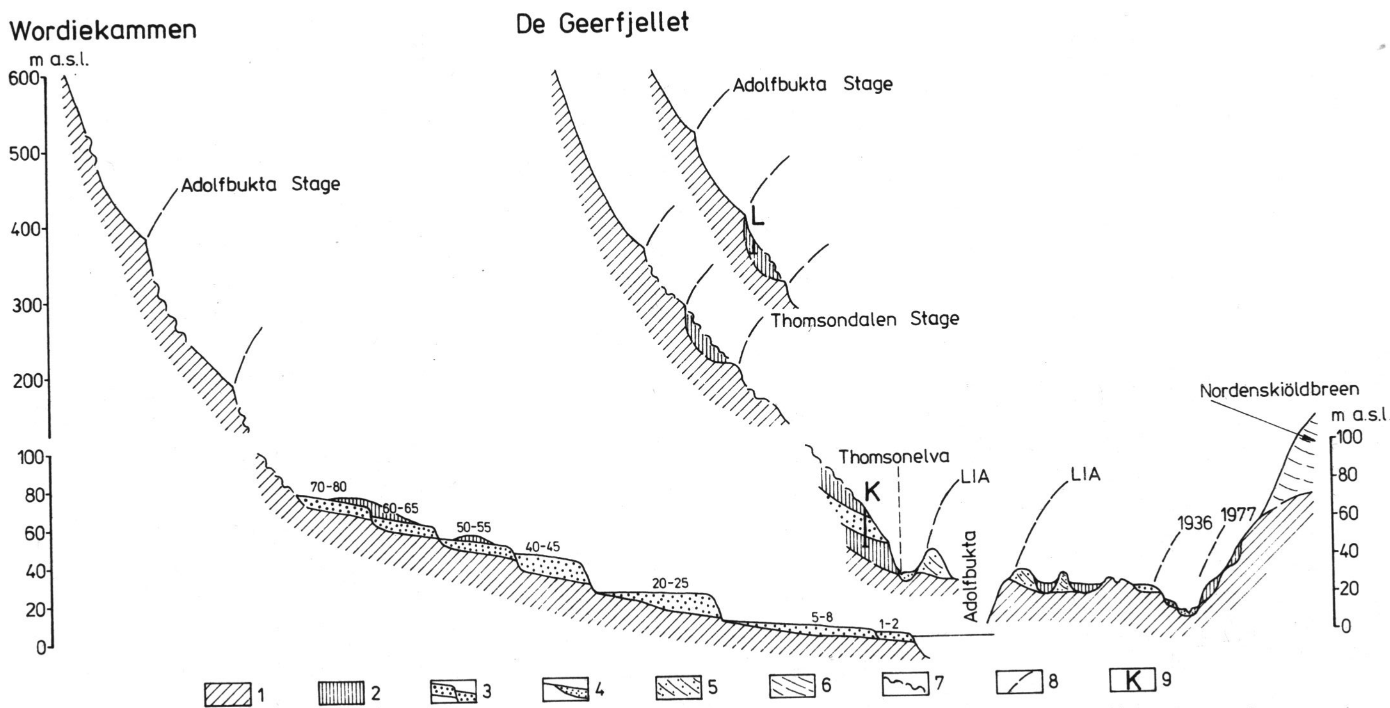

Fig. 12. Generalized scheme of major Quaternary landforms and deposits occurring in the foreland of Nordenskiöldbreen and on the south-facing slopes of Wordiekammen and De Geerfjellet. 1: Quaternary bedrock, 2: glacial till (ground, ablation and fluted moraines), 3: marine terraces, heights a.s.l. given, 4: outwash deposits, 5: dead glacier ice with a morainic material cover (ice-morainic ridges), 6: active glacier ice, 7: solfluction and diluvial mantles, 8: extent lines of glacier snouts (LIA: Little Ice Age), 9: exposures and sections quoted in the text

The maximum advances of the Late Holocene glaciers were favourable to the formation of lateral moraines on the slope in the centre of Wordiekammen and ice cliffs indicated by large build-ups of erratics on the Ebbadalen floor (Fig. 11). Betrambreen built then an independent hanging tongue on the Hultberget slope. Its position is marked by small lateral moraines and accompanying glacial till (Fig. 11). The Nordenskiöldbreen margins remained then slightly outside the zone of the present-day ice-morainic ridge. The evidence is contained in the upper glacial till in profile K and the lowermost glacial undercut of 40—70 m a.s.l. (*see* the enclosed map). The position of the Pollockbreen margin is marked by an end moraine persisting outside the present-day ice-morainic ridge (*see* the enclosed map). Because of the Late Holocene climatic amelioration, sea-water flowed as far as into the centre of Ebbadalen, still occupied to the east by glaciers. The extent of this transgression has been determined from the maximum occurrence of fragments of malacofauna (Fig. 11). The evidence for the Middle and Late Holocene marine deposition is provided by the lowermost marine terraces of 12—15, 5—8, 3—4 and 1—2 m a.s.l. around Petuniabukta and Adolfbukta (Figs 11, 12).

The position of glacier margins during the Little Ice Age (600—100 years BP) are marked by ice-morainic ridges dumped along the margins of all glaciers occurring in this area (Figs 11 and 12, *see* the enclosed map). Since the climax of the Little Ice Age these glaciers have retreated by about 600—700 (Ebbabreen) and 1200 m (Nordenskiöldbreen and Pollockbreen). The recession of Bertrambreen is scarcely by 200—250 m due to a slower rate of ablation occurring in a plateau located above Ebbadalen.

Conclusions

The Ebbadalen-Nordenskiöldbreen region displays extremely diverse morphologic characteristics. Interrelationships between glacial and marine landforms and deposits represent the basis for the morphogenetic explanation.

Three uppermost marine terraces of 70—80, 60—65 and 50—55 m a.s.l. are oldest among the existing landforms and deposits. They have been attributed to a period preceding the Petuniabukta-Adolfbukta Stage.

During the Petuniabukta-Adolfbukta Stage the terraces were partially covered by glaciers which joined one another to become most extensive and terminate in ice cliffs in Petuniabukta and Adolfbukta. The stages of glacier waning are indicated by systems of older glacial undercuts which persist on the slopes of Wordiekammen and De Geerfjellet. Over the later period of climatic amelioration these glaciers disappeared to a large extent and glacio-aqueous deposition took place. Their next advances occurred during the Earlier Holocene (the Ebbadalen Stage = the Thomsondalen Stage). There is evidence for stage-after-stage glacier waning in younger glacial undercuts on the slopes of Wordiekammen and De Geerfjellet and in systems of lateral moraines, as well as zones of ice cliffs found on lower marine terraces of 40—45, 30—35, 20—25 and 12—15 m a.s.l.

The lowermost marine terraces of 12—15, 5—8, 3—4 and 1—2 m a.s.l. and steady-state position (oscillations?) of glacier snouts marked in the foreland of Ebbabreen and Bertrambreen by lateral moraines are correlated with the Middle and Late Holocene. Seawater flowed then into the Ebbadalen. The last invasion of the study area by glaciers is associated with the Little Ice Age.

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Streszczenie

Obszar wschodniego obramowania Petuniabukta leży w zachodniej części Ziemi Olafa V w północnym zakończeniu Billefjorden (fig. 1, zał. mapa). Autorzy prowadzili w tym rejonie badania terenowe latem 1984.

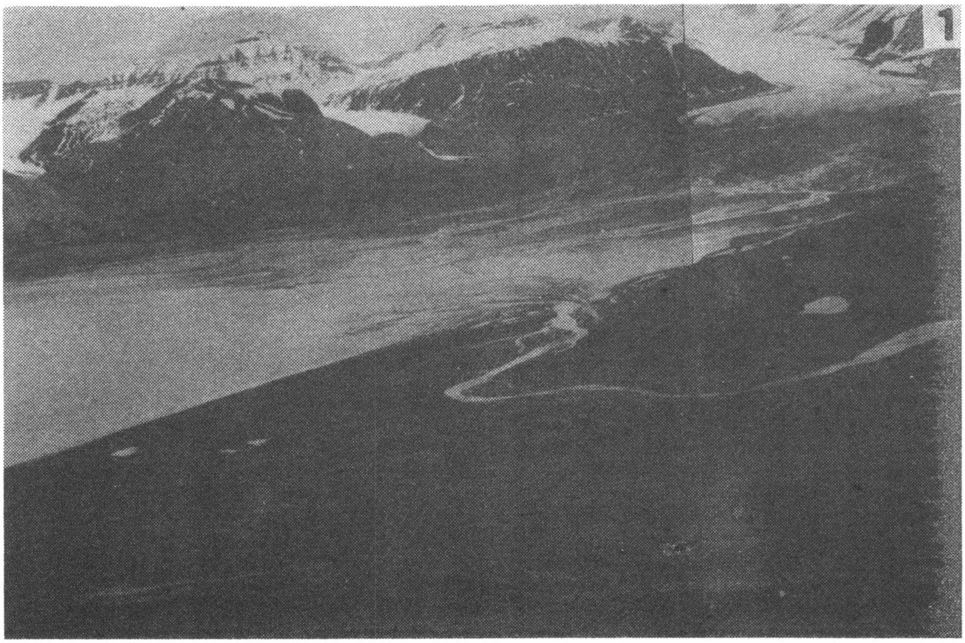
Zbadany obszar zawiera liczne dowody znacznie większego rozprzestrzenienia lodowców w późnym plejstocenie i w holocenie niż obecnie (fig. 2—12, pl. 1—8). Do najważniejszych z nich należą pozostałości osadów i rzeźby lodowcowej na płaskowyżu i stokach Wordiekammen oraz na stokach De Geerfjellet, obecność gliny morenowej na powierzchni najwyższych teras morskich (70—80, 60—65 i 50—55 m n.p.m.) w północnym obramowaniu Adolfbukta i w Ebbadalen, jak również obecność gliny morenowej w cokole teras morskich w Ebbadalen. Stwierdzono także rozdzielenie glin morenowych miąższą piaszczysto-żwirową serią fluwioglacjalną na przedpolu lodowca Nordenskiöldbreen oraz „dolodowcowy" stok ograniczający od E terasy morskie 40—45, 30—35 i 20—25 m n.p.m. w Ebbadalen oraz liczne nagromadzenia głazów narzutowych wyznaczających linie postoju czół (klifów) lodowców w tej dolinie (zał. mapa).

Terasy morskie o wysokości 70—80, 60—65 i 50—55 m n.p.m., częściowo przykryte osadami lodowcowymi, powstały zapewne przed najstarszą i największą w tym obszarze młodoplejstoceńską transgresją lodowców. Transgresję tę można skorelować z okresem maksymalnego rozwoju lodowców würmskich w tej części Spitsbergenu, określonej przez autorów jako stadiał Petuniabukta-Adolfbukta (fig. 11—12). Wówczas Ebbabreen i Bertrambreen oraz większość lodowców wypełniających cyrki na północnym stoku Wordiekammen łączyły się

w jeden potężny lodowiec, którego klif lodowy znajdował się na obszarze Petuniabukta. Lodowiec ten utworzył podcios lodowcowy na północnym zboczu Wordiekammen na wysokości 260—300 m n.p.m. W Ebbadalen moment ten dokumentuje glina morenowa przykrywająca osady morskie na zboczu Wordiekammen.

Podczas stadiału Petuniabukta-Adolfbukta Nordenskiöldbreen sięgał aż do ujścia cyrku położonego na W od doliny Pollockbreen wycinając podcios lodowcowy na południowym zboczu Wordiekammen na wysokości 350—400 m n.p.m. Oba wymienione lodowce oraz łączące się z nimi lodowce cyrkowe zlewały się tu w jedną masę lodową, zajmującą zapewne całą wschodnią część Adolfbukta. Na S zboczu De Geerfjellet śladem tego lodowca jest podcios lodowcowy 500—550 m n.p.m. Płaskowyż Wordiekammen był wówczas przykryty przez lodowiec fieldowy z kilkoma jęzorami wiszącymi. Młodsza transgresja lodowców w Ebbadalen została określona jako stadiał Ebbadalen. Jej zasięg wyznaczają „dolodowcowe" stoki najwyższych tam teras morskich oraz łukowato wygięte ciągi głazów narzutowych zakorzenionych w tych tarasach (zał. mapa). Z okresem tym należy wiązać także utworzenie niższego (140—200 m n.p.m.) podciosu lodowcowego i starszych ciągów moren bocznych na stoku zachodniej części Wordiekammen. Nordenskiöldbreen sięgał w tym czasie zapewne po ujście doliny Pollockbreen formując tam podcios lodowcowy 160—200 m n.p.m. Po północnej stronie Thomsonelvy jego pozostałością jest starsza glina morenowa w profilu K (fig. 10, 12), co stało się podstawą określenia tej transgresji jako stadiał Thomsondalen. W osiowej części Adolfbukta lodowiec tworzył klif lodowy.

Rozprzestrzenienie lodowców młodoholoceńskich jest udokumentowane morenami bocznymi na zboczu środkowej części Wordiekammen oraz nagromadzeniami głazów narzutowych na dnie Ebbadalen, reprezentującymi położenie dawnych klifów lodowych. Bertrambreen utworzył wówczas na zboczu Hultberget już samodzielny jęzor wiszący, którego położenie wyznaczają niewielkie moreny boczne i towarzysząca im glina morenowa. Zasięg Nordenskiöldbreen w tym czasie nieznacznie wykraczał poza strefę obecnego wału lodowo-morenowego, co jest dokumentowane górną gliną morenową w profilu K (fig. 10, 12) oraz najniższym w tym rejonie podciosem lodowcowym 40—70 m n.p.m. Ówczesny zasięg Pollockbreen wyznacza morena czołowa zachowana na zewnątrz od współczesnego wału lodowo-morenowego. Młodoholoceńskie ocieplenie sprzyjało wlaniu się wód morskich aż do środkowej części Ebbadalen zajętej na E jeszcze przez lodowce. Rozprzestrzenienie tej transgresji wyznacza maksymalny zasięg szczątków malakofauny. W strefie obramowania Petuniabukta i Adolfbukta środkowo i młodoholoceńską akumulację morską dokumentują najniższe terasy morskie (12—15, 5—8, 3—4 i 1—2 m n.p.m.). Zasięgi lodowców w czasie Małej Epoki Lodowej (600—100 lat BP) wyznaczają wały lodowo-morenowe wszystkich lodowców tego rejonu (zał. mapa).



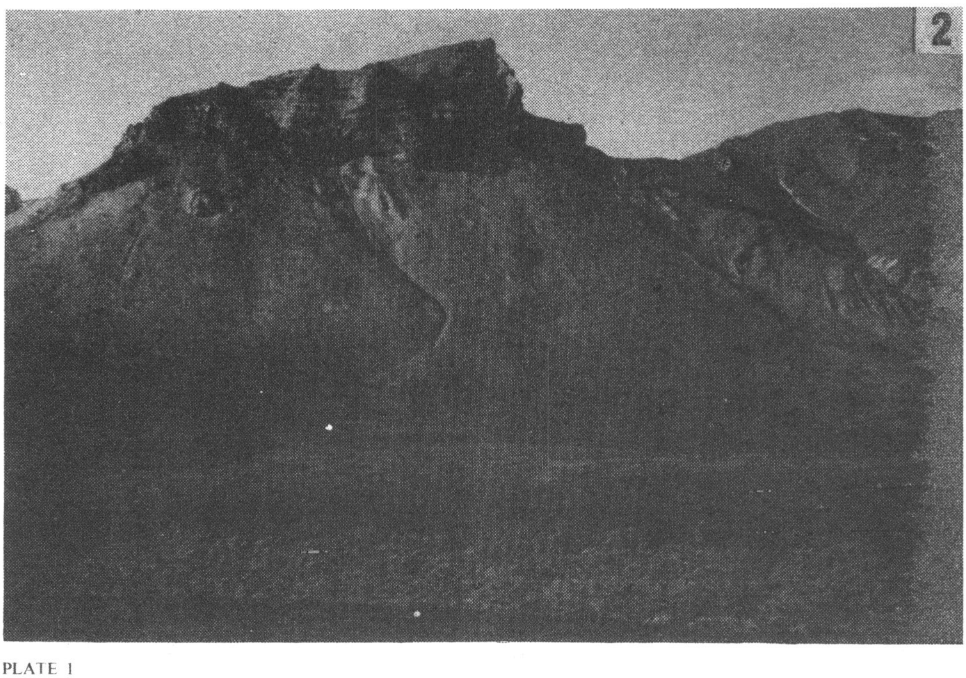
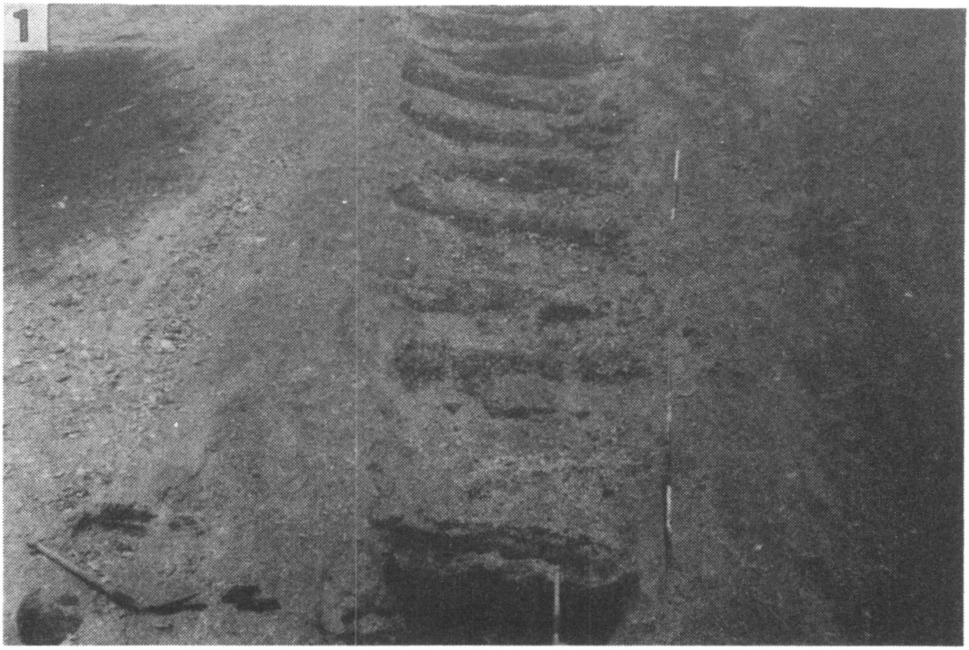


PLATE 1

Fig. 1. The mouth section of the Ebbadalen with a set of raised marine terraces

Fig. 2. Part of the marine terrace of 12—15 m a.s.l. in the gap section of Ebbaelva, the montain massif Løvehovden in the background



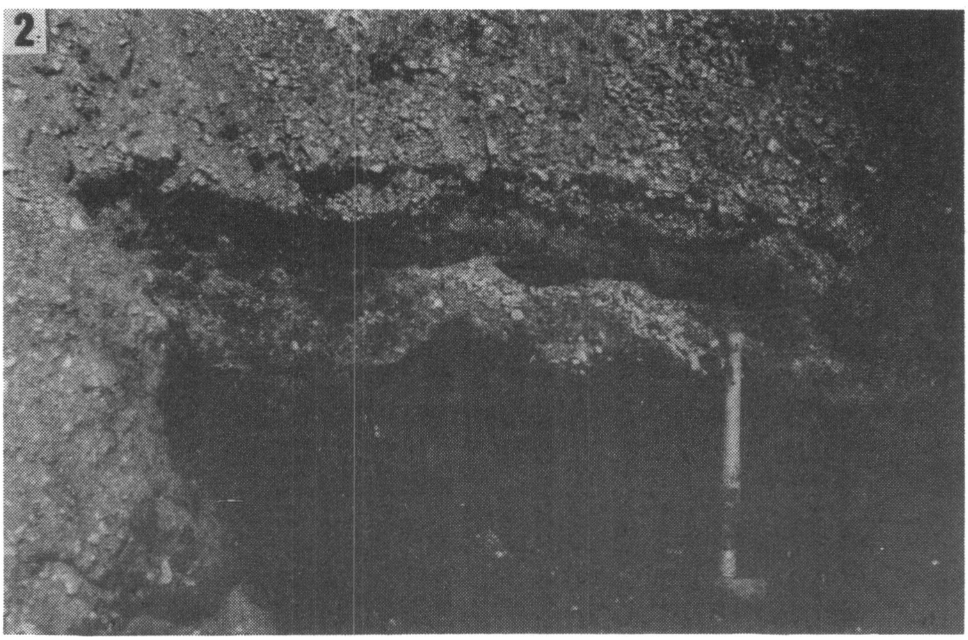
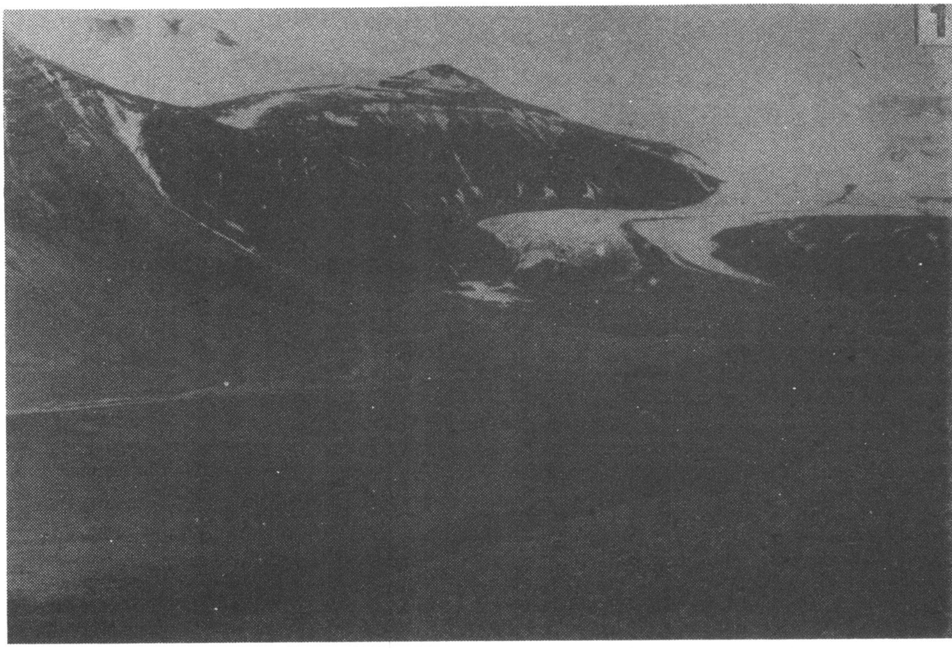


PLATE 2

Fig. 1. Profile of marine terrace deposits at 12—15 m a.s.l. in the gap section of Ebbaelva

Fig. 2. Glacial till at the base of marine terrace deposits at 12—15 m a.s.l.



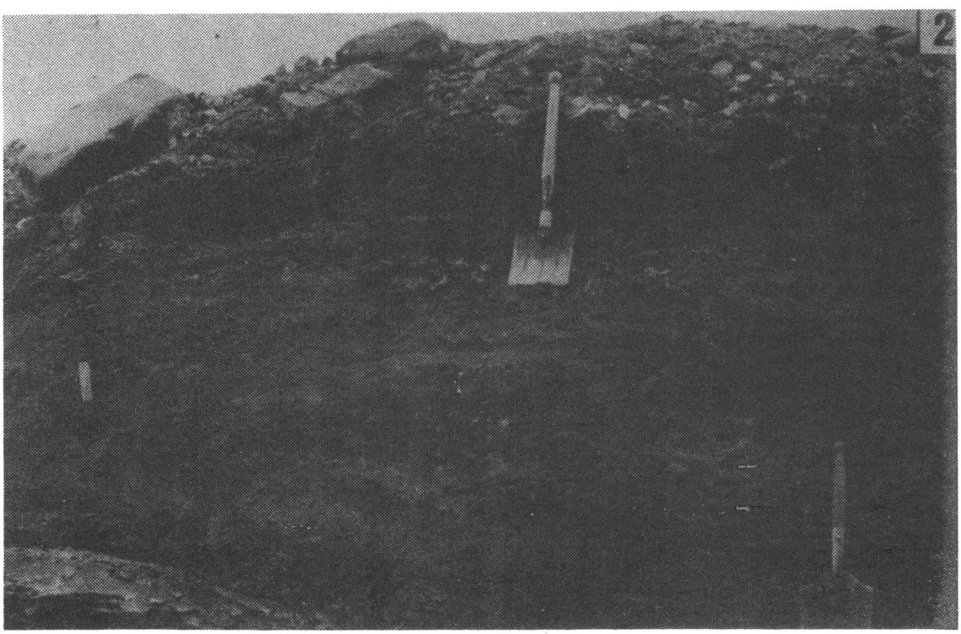
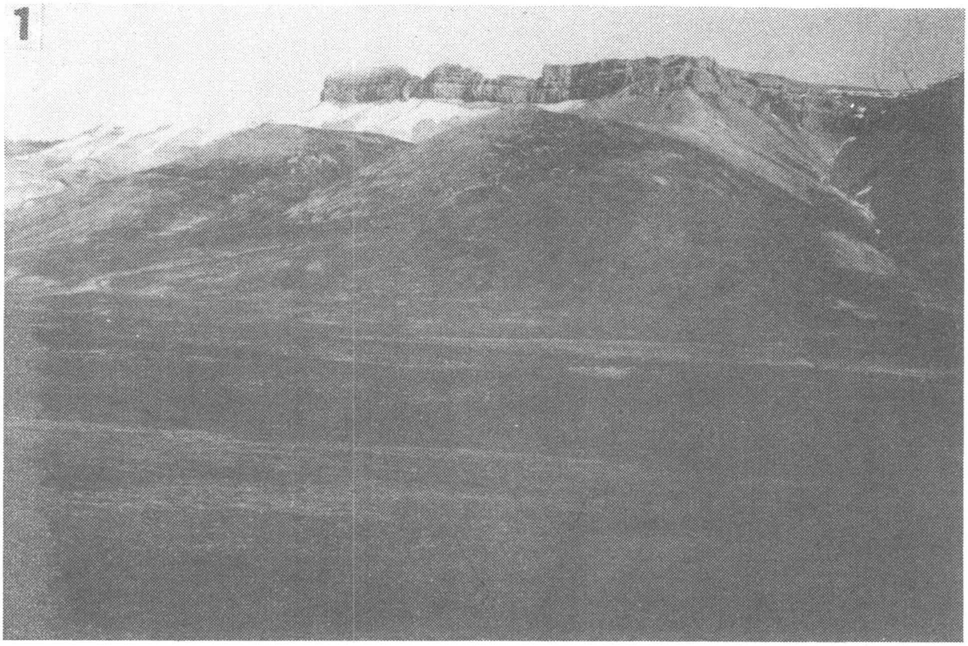


PLATE 3

Fig. 1. Upper and middle parts of the Ebbadalen closed by Ebbabreen

Fig. 2. Part of subglacial till exposure in the eastern gap section of Ebbaelva



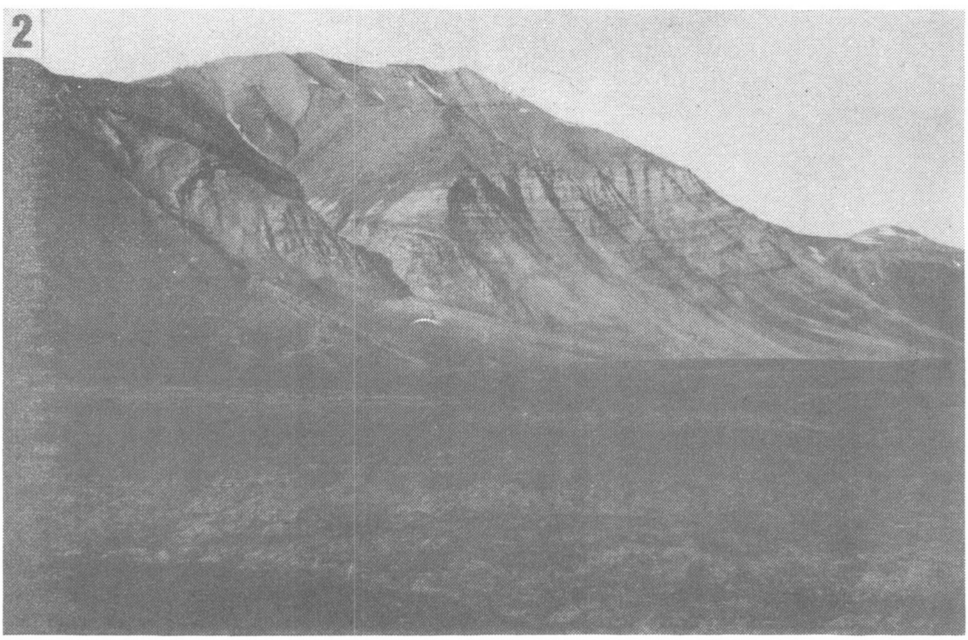


PLATE 4

Fig. 1. Part of the mountain massif Wordiekammen surrounding the Ebbadalen to the south

Fig. 2. Alluvial fans in the northern area surrounding the Ebbadalen

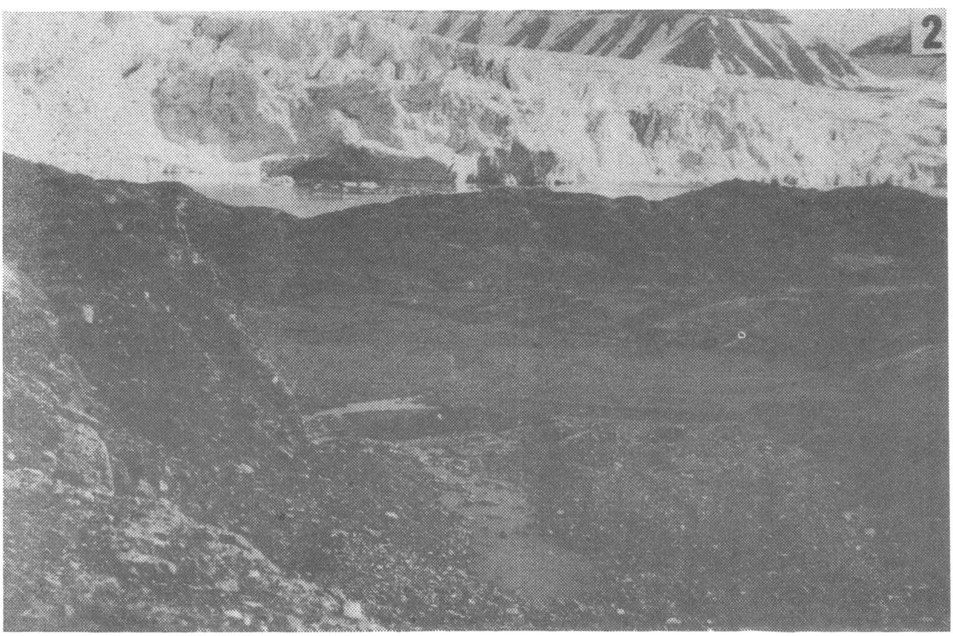


PLATE 5

Fig. 1. Roches moutonnées in the foreland of the Nordenskiöldbreen, the mouth section of the present-day outwash stream in the foreground

Fig. 2. The intramarginal zone of the Nordenskiöldbreen, outwash flow tracks of differing ages detectable

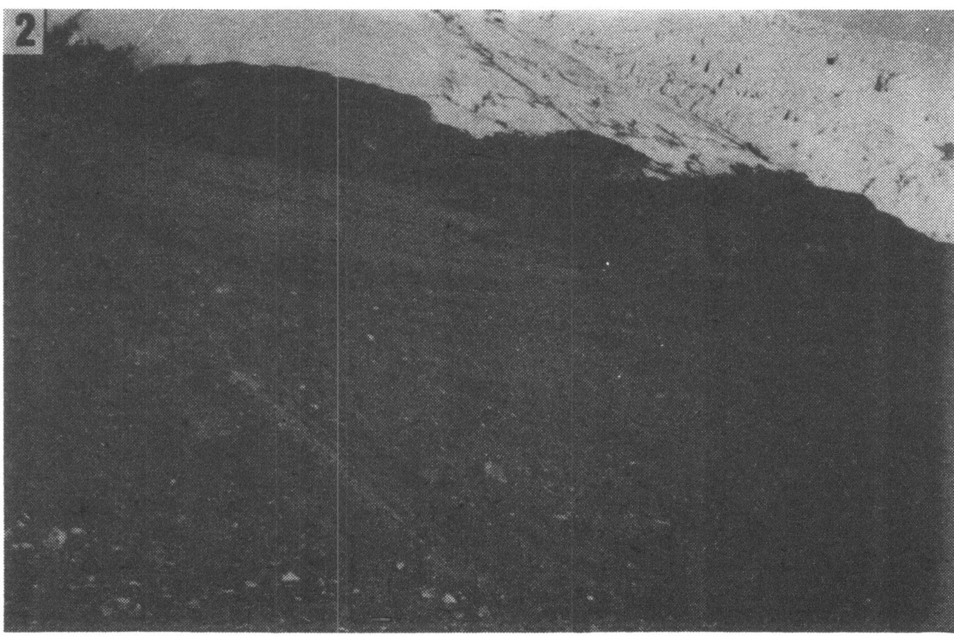
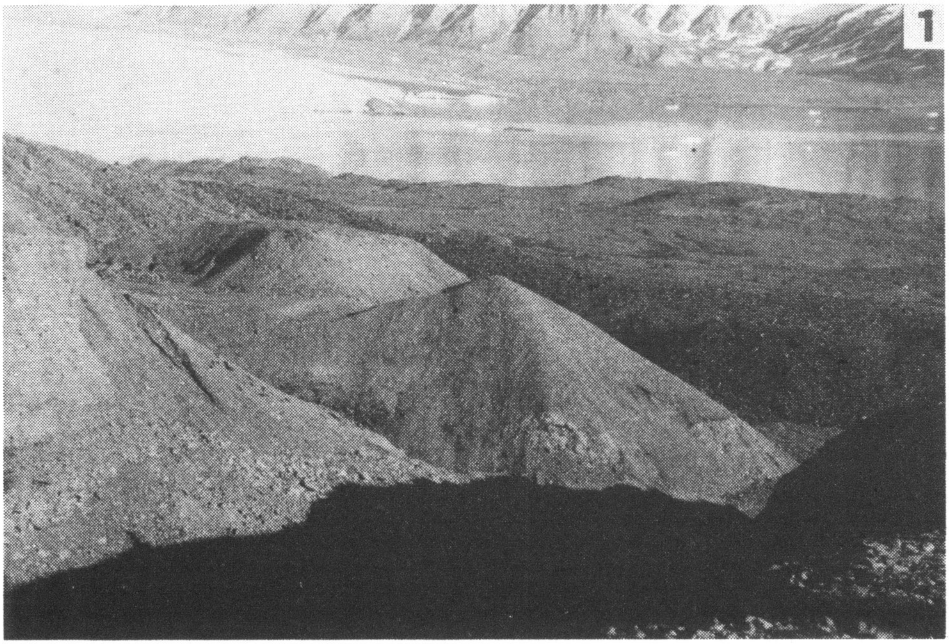


PLATE 6

Fig. 1. Subglacial till in the Nordenskiöldbreen foreland

Fig. 2. A fluted moraine in the Nordenskiöldbreen foreland



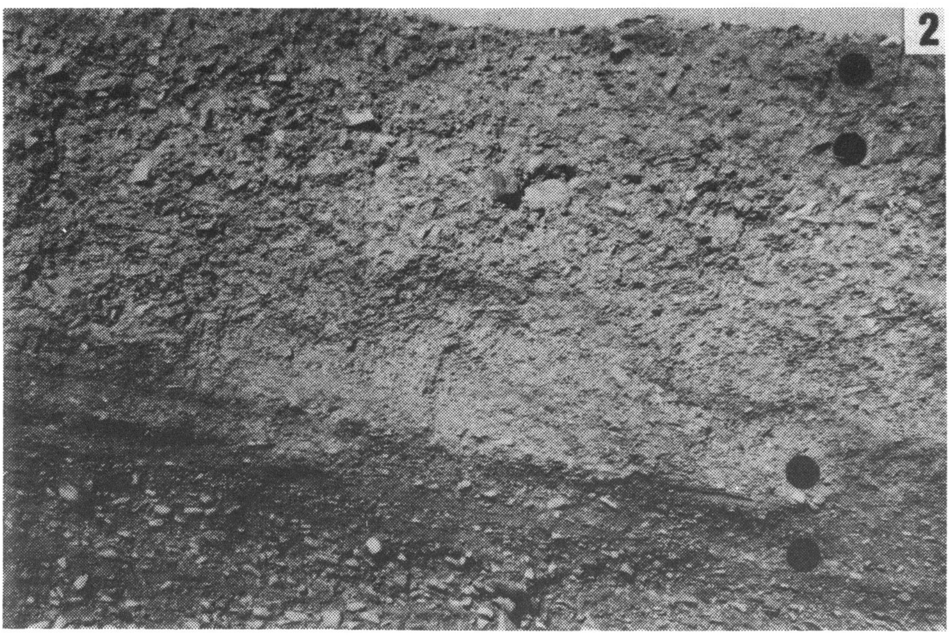


PLATE 7

Fig. 1. A gorge cut through the De Geerfjellet slope

Fig. 2. Profile of deposits exposed in the gorge wallincised into the De Geerfjellet slope. Black dots indicate sites of sampling

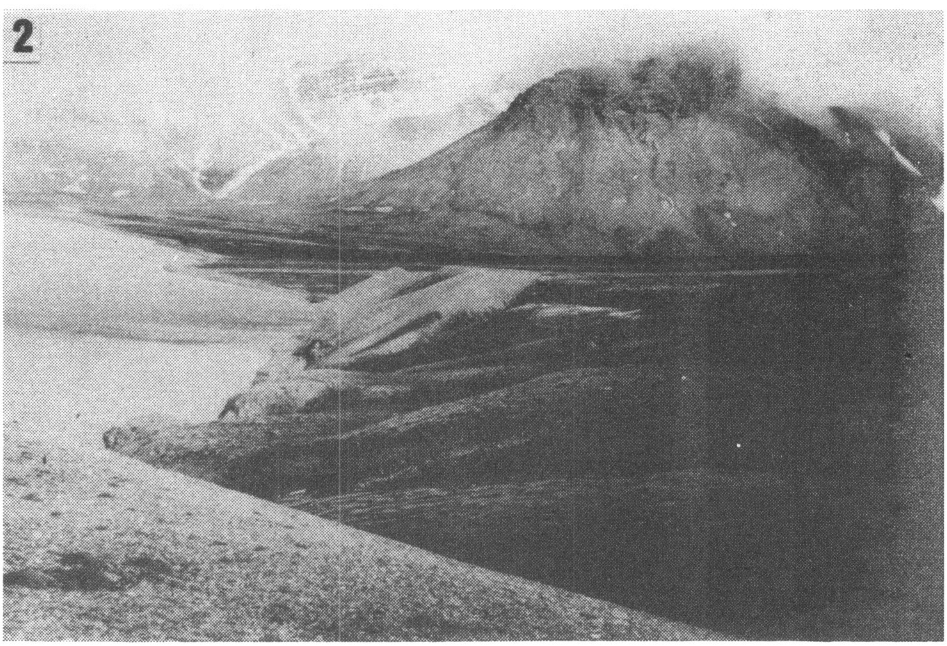


PLATE 8

Fig. 1. The Pollockbreen

Fig. 2. The west-facing slope of Wordiekammen descending to the Petuniabukta coast, platforms of raised marine terraces detectable