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Geomorphology of the north-eastern area adjacent to Petuniabukta and the northern shores of Adolfbukta, central Spitsbergen

Studies taken up in the northern landward segment of Billefjorden where English, Norwegian and Russian expeditions began work earlier have concentrated most on the little-known landward end of the fjord. It is an area where glacial episodes affecting part of Billefjorden during the Würm and Holocene commenced and terminated as well as that reached by successive periodic sea surges.

A preliminary geomorphological and palaeogeographical field survey was made by two independent groups. One worked in an area from Hörbyedalen as far as Ebbadalen, while the other explored the region between Ebbadalen and Nordenskiöldbreen. Such exploration enabled discussions to be conducted by a given group only, without interference from the other. At the end of expeditions the resulting data were compared. They proved somewhat different because of a differing methodological approach and a different interpretative point of view. This is well documented by the articles presented here. Both outlooks are deliberately discussed. Cursory and naturally incomplete observations on geomorphologic setting and palaeogeographic characteristics of the study area are regarded as a null hypothesis which has yet to be tested throughout further detailed examination.

The results of exploration conducted between Hörbyedalen and Ebbadalen include general identification of interactions between marine processes and glacial morphogenesis in combination with ^{14}C and TL dates. During fieldwork Norwegian air photos of 1961 proved very helpful in locating distinguishable sedimentary series and land morphologic details in space. Field observations are represented by an autogrammetric hypsometric base-map with data based upon the above air photos. The present authors have not taken up the compilation of a map because of the present state of available information. A pertinent article presented in this volume reviews an input approach.

The research workers engaged in the exploration of the region between Ebbadalen and Nordenskiöldbreen focused their attention on different assumptions. The collected field material was analysed in detail in terms of sedimentology. The available field and laboratory geologic-geomorphological data have been superimposed on the autogrammetric hypsometric base-sheet

of the Norwegian air photos of 1961. The resulting map is presented in this volume. The authors also give a broad outline of palaeogeography of the study area with reference to the Late Pleistocene and Holocene.

The present contributions differing in contents and form are thus intended to be scientific debates. They indicate difficulties in searching for good reference sites which will illustrate palaeogeographical changes in vast areas and interpretative troubles, even with respect to the exposed and apparently simple modern polar environment. It may also turn out that the research results obtained by the two groups are not contradictory but point to distinctive characteristics of the palaeogeographical development of a given portion of the study area affected by ice streams of different dynamics.

The third article that presents the research results obtained in 1984 describes mineralogical and chemical properties of the Late Pleistocene and Holocene glacial deposits laid down around Petuniabukta. New sediments deposited in the modern polar environment are compared with the Pleistocene glacial tills of Poland. The aim of this study is to attempt to present environmental inter-relationships between climate and geology, as well as postdepositional alterations in sediments due to direct accumulation by glacier ice.

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An outline of morphogenesis of the region between Hörbyedalen and Ebbadalen, Petuniabukta, Billefjorden, central Spitsbergen

ABSTRACT: Extensive floors of well-developed ancient trough-like valleys around Petuniabukta were subject to glacial, marine and alterations caused by gravity movements during the Late Pleistocene and Holocene. Palaeogeographical changes took place and are still occurring under the influence of land uplifting movements. The earliest recognizable phase of glaciation occured during the so called Billefjorden Stage about 35.000 to 45.000 years ago. The available evidence suggests that the glaciation was divided into two stages, first the major advance and then, a minor ice advance. This glacial episode was followed by morphological alterations conditioned largely by the action of sea and gravitational factors. About 6.500 years BP a short-term, though rather extensive glacier advance took place and afterwards, the processes of marine morphogenesis recurred. The last notable glaciation phase traced from the land surface can be identified with the Little Ice Age. The Holocene changes in morphology are reflected in extensive outwash plains and a tidal plain.

Key words: Arctic, Spitsbergen, Billefjorden palaegeography.

Introduction

The objective of a pilot survey of the region between Hörbyedalen and Ebbadalen was to recognize general geomorphologic characteristics, demonstrate inter-relationships between the Late Pleistocene and Holocene landforms and deposits, and establish their sequences. An attempt to arrange geomorphological events in a definite order was based on the geomorphological analysis supplemented by a few ^{14}C and TL dates.

The effects of complex morphogenetic processes which took place in central Spitsbergen and were conditioned by land uplift, a succession of glacial episodes, fluctuations of sea level and extent, and extensive gravitational processes have been recorded in the northern area surrounding Petuniabukta as diverse interlocked deposits and landforms.

Extensive flat fjelds and impressive deeply-incised trough-like valleys constitute the main palaeogeographical background of Petuniabukta. This study is not intended to place the formation of glacial valleys in a time framework. Nevertheless, they provide a standard for the palaeogeographical changes that affected this area during the Late Pleistocene and Holocene.

The distinguishable zones of glacier advances relating to the Little Ice Age (Fig. 1 LIA) and Billefjorden Stage, as understood by Mangerud and Salvigsen (1984), provide the chronological framework for the present palaeogeographical analysis. Studies of numerous exposures and land morphological features with a reliable sedimentological record enabled an attempt to be made to trace glaciation phases, periods of sea action and gravitational changes in the morphology.

The spatial distribution of observation and measurement points, as well as sites of sampling for laboratory investigations is illustrated in Fig. 1. The autogrammetric hypsometric base-map of rock relief, based on the Norwegian air photos of 1961, contains the essential information for this drawing. The contours of glaciers are deliberately omitted on the base-map so that the extent of the neo-glaciation called the Little Ice Age may be well-marked. Figure 1 also shows selected elements of geomorphology of the study area, which will serve as the starting-point of future compilation of a geomorphological map.

Late Pleistocene and Holocene palaeogeographical changes

Extensive fjelds and deeply incised ancient trough-like valleys display very diverse geomorphologic characteristics. The lower portions of the valleys have been filled with glacial and marine sediments and with deposits resulting from gravitational modification.

Many sedimentary units of different origin, *i.e.* glacial and marine sediments, have been recognized in Hörbyedalen. The earliest glacial deposits occur as thin layers of till (*cf.* Fig. 2, sample 13). In view of data provided by Troicki *et al.* (1969), Boulton (1970), Mangerud and Salvigsen (1984), the age of a glacial episode to which they relate may be tentatively correlated with over 70.000 years BP. The till is overlain by marine or coastal clayey deposits (*cf.* Fig. 2, sample 12). As the above suggestion about the age of tills is on insecure grounds, the whole basal sedimentary complex is regarded as a record of the onset of the Billefjorden Stage glaciation phase.

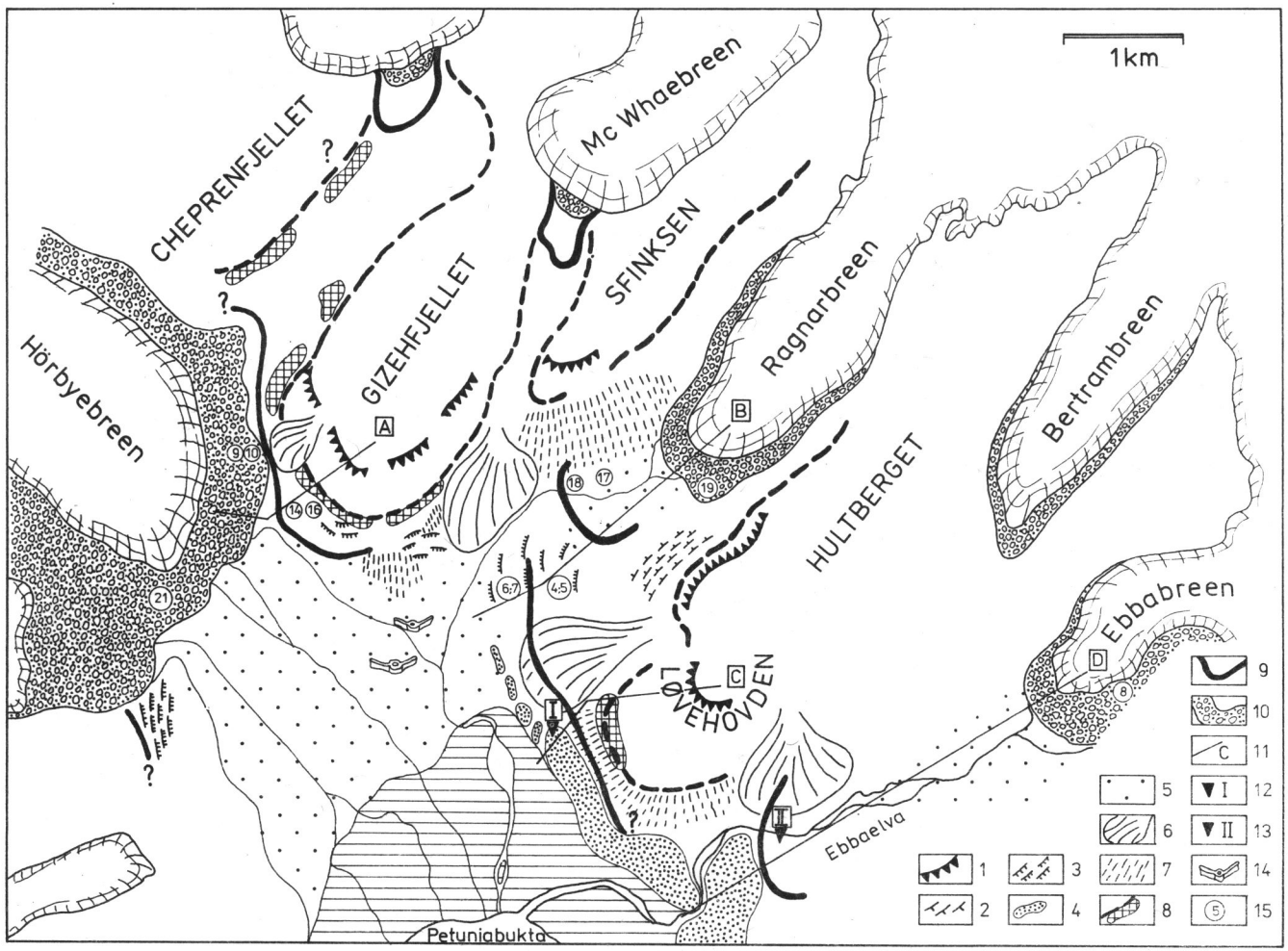

Fig. 1. Geomorphological sketsch-map of the northern landward segment of Billefjorden

1: upper edges of trought-like valleys, 2: edge relief due to plucking, 3: marine abrasion beaches, 4: marine acumulative relief, 5: outwash plains, 6: alluvial fans, 7: gravity landforms, tallus concess solliluction mantle, 8: advance line and morainic ridges of Billeforden Stage, 9: glacier advance line abour 6.500 years BO, 10: advance line and inner recesivezones during the Little Ice Age, 11: lines of schematic geomorphologic-geologic sections A, B, C, D (*cf.* Figs 2—5), 12: radiocarbon-dated site near Ebbahytta, 13: radiocarbon-dated site in, Ebbdalen, 14: whale bone remains, 15: sampling sites, sample numbers

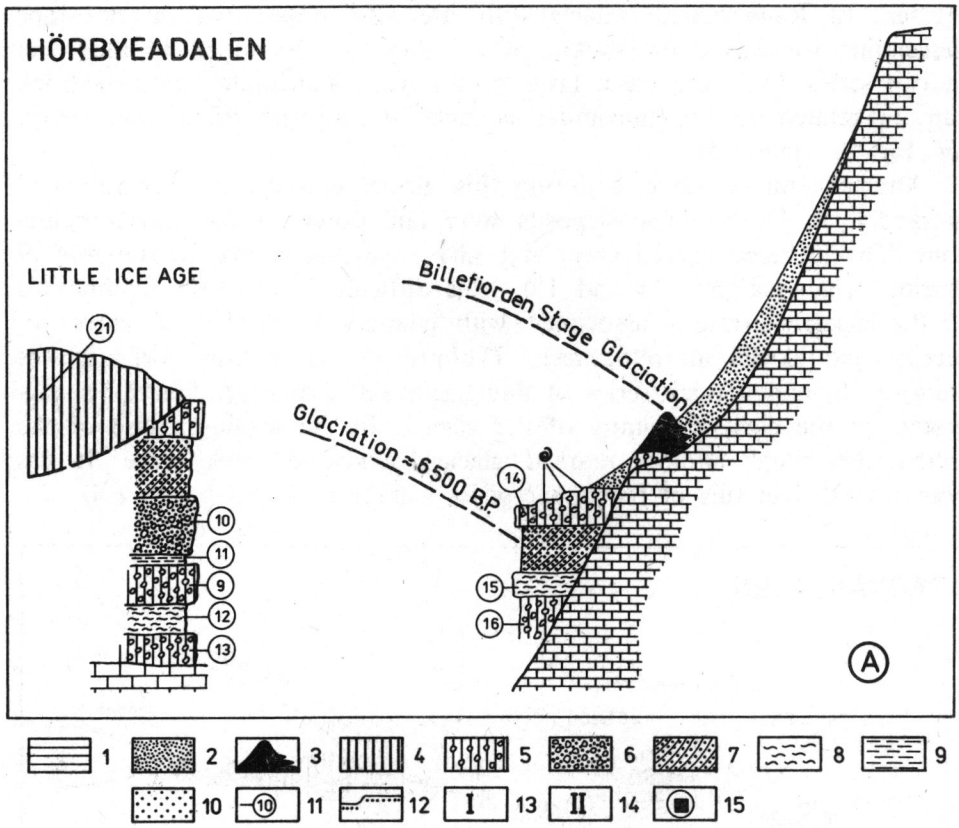

Fig. 2. Schematic geomorphologic-geologic section through the southeastern part of Hörbyedalen (A after Fig. 1)

1: solid rocks, 2: talus cones and alluvial fans, 3: morainic ridges, 4: Little Ice Age deposits and relief, 5: glacial tills, 6: mixtures of deposits, 7: glacio-aqueous sediments, 8: clays, 9: silts, 10: outwash plains, 11: sampling sites, sample numbers, 12: marine accumulative deposits, 13: radiocarbon-dated site near Ebbahytta, 14: radiocarbon-dated site in Ebbadalen, 15: site of marine deposits beneath glacial tills in Ragnardalen Symbols are pertinent to Figs 2—5.

The main Late Pleistocene advance during the Billefjorden Stage left a clear sedimentological and morphological record within Petuniabukta. The study has demonstrated glacial tills in Hörbyedalen (*cf.* Fig. 2, samples 9, 16). Complementary morainic sediments occur as thin layers of tills at the southwestern foot of Gizehfjellet. They underlie forms created by marginal accumulation throughout the maximum ice advance during the Billefjorden Stage (*cf.* Figs 1 and 2). In Ragnardalen the record has been preserved in the glacial tills which cover the scarp relief resulting from plucking (sample I) and in tills underlying morainic ridges at the foot of Løvehovden (sample 2). Morainic sediments resulting from the maximum advance during the Billefjorden Stage make up the topmost portion of the closing

segment of Ragnardalen. Glacial tills are also widespread on its slope descending towards Petuniabukta, where they are developed in the form of two series. Only the basal layer of till lying immediately over bedrock can be related to the maximum advance during the Billefjorden Stage (*cf.* Fig. 3, sample 5).

After the major advance during this glacial episode, glaciers retreated markedly. In Hörbyedalen deposits were laid down in the extramarginal zone. The included varved clays and silty-clayey sediments, presumably of marine origin (samples 11 and 15). It is difficult to establish fluctuations of the glaciar terminus associated with changes in the lateral extent of marine and glacial morphogenesis. The presence of mixtures of deposits (sample 10) and a thick series of fluviglacial sediments (*cf.* Fig. 2) is suggestive of the close proximity of the glacier. In the waning phase of the Billefjorden Stage another marked glacier re-advance took place. It has been recorded in tills of the upper series (samples 14 and possibly 4).

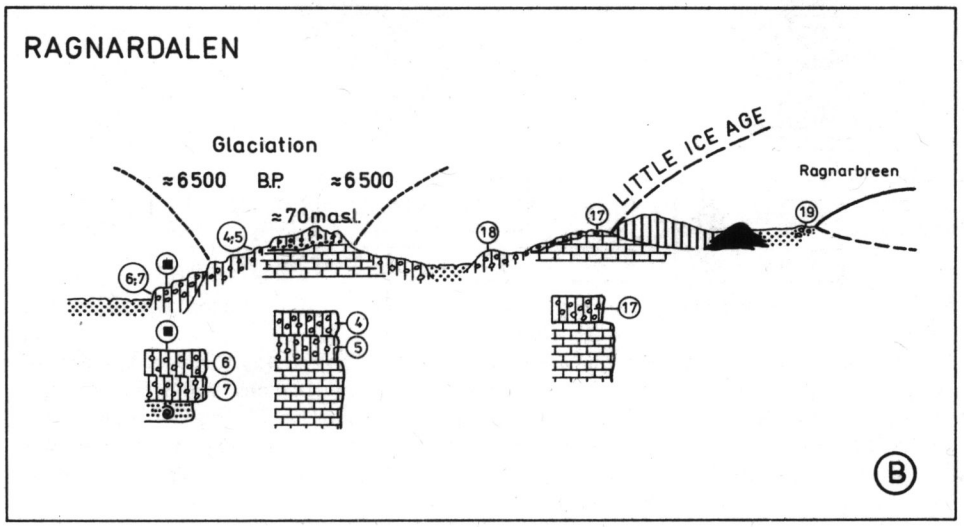

Fig. 3. Schematic geomorphologic-geologic section along Ragnardalen

The recession of glaciers in the second phase of the Billefjorden Stage initiated the long-term action of extensive marine processes (Kasprzak *et al.* 1985). Land uplift led to the formation of numerous marine, largely abrasion terraces at the southwestern foot of Gizehfjellet and in the Ragnardalen and Løvehovden regions, as well as created marine abrasion-accumulative terraces in Ebbadalen. Conspicuous marine beaches are of common occurence up to a level 70—75 m a.s.l. In the zone where abrasion beaches prevail (Ragnardalen), there are small and thin marine accumulative mantles composed of shell-containing sandy-gravelly sediments. The highest patch of these deposits is found about 67 m a.s.l. (*cf.* Figs 1 and 4).

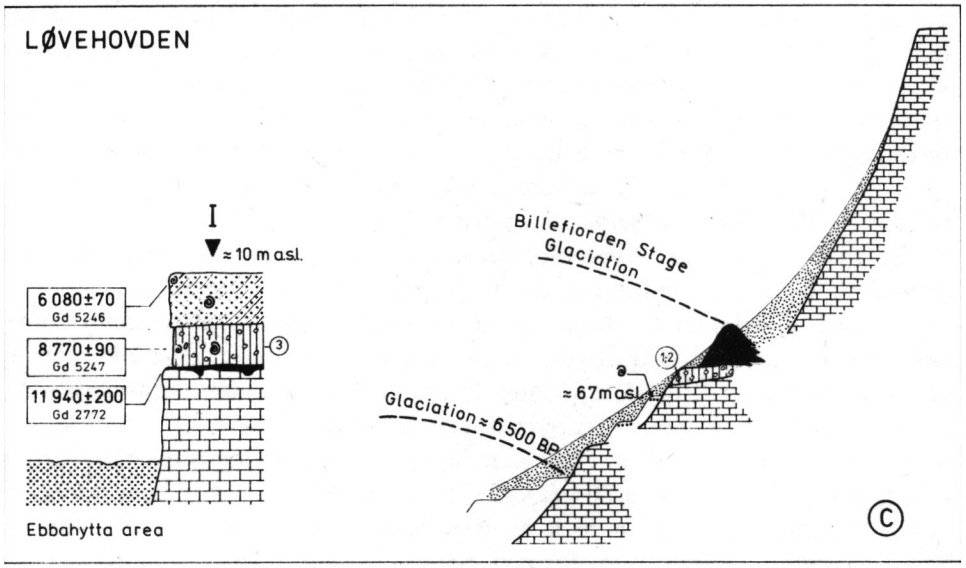

Fig. 4. Schematic geomorphologic-geologic section of the base of Løvehovden

Over a long period of marine morphogenesis gravitational processes were active in the entire area (Kasprzak *et al.* 1985). Talus cones and alluvial fans developed. Stony and mud flows remained active. Processes occurring in the subareal and subaquatic enivironments have affected landscape changes in the major part of the study area up to now. Only the lowermost axial portions of the trough-like valleys were influenced over not too long distances by the Holocene glacial episodes.

The major Holocene glaciation of Petuniabukta took place about 6.500 years BP. It was presumably the result of a sudden advance of Hörbyebreen that occupied nearly the entire bay. The Ragnardalen and Ebbadalen glaciers did not have such an extent, not reaching Petuniabukta. The Ragnarbreen terminus rested on the east-facing slope of the closing segment of Rag-

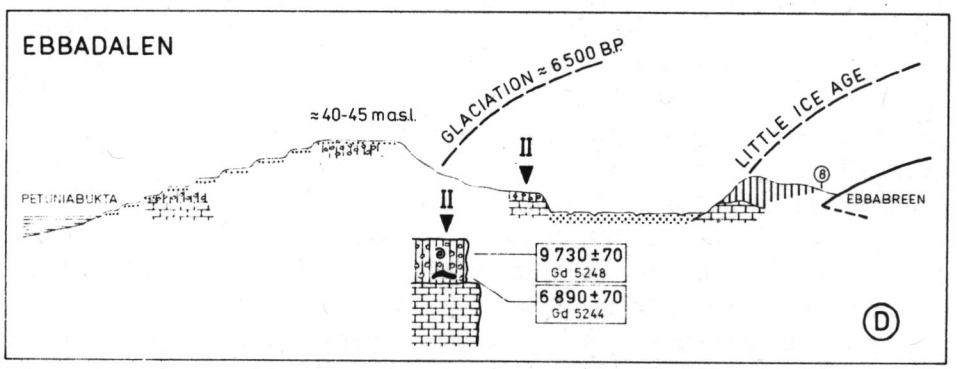

Fig. 5. Schematic geomorphologic-geologic section along Ebbadalen

nardalen (*cf.* Fig. 1). The Ebbabreen reached the terminal part of the valley but no total remodelling or even overtopping of marine terraces about 40 m a.s.l. high resulted. The position of the tongue margins has been marked by a sharp undercut with an eastern exposure from the marine terraces (*cf.* Fig. 1) and by a deep and narrow gap through them. Sandy--gravelly marine sediments covering the remodelled recessive glacial relief of Billefjorden Stage underwent scouring.

Morphological and sedimentological data, as well as ^{14}C and TL dates provide a basis for identifying the major Holocene ice advance.

There is a sedimentary sequence of palaeogeographical importance somewhat to the north of Ebbahytta in the present-day lower part of a valley in Løvehovden (*cf.* Fig. 4, exposure I). A weathering mantle enriched with organic matter has been recognized on bedrock making up the base of a marine terrace of 10 m. Its sample was dated using the radiocarbon dating method to 11.940 ± 200 (Gd-2772) years BP. Under marine morphogenetic conditions abrasion rock beaches and those cut into the Billefjorden Stage morainic material were formed. Sandy-gravelly series containing pieces of shells were laid down (the basal part of exposure a in Fig. 3). The main water basin existing in Petuniabukta entered Ragnardalen, Ebbadalen and Hörbyedalen to form tiny bays. Water basins contained invertebrate fauna which was later incorporated in glacial deposits relating to the glacial advance that occured about 6.500 years BP.

Glacial tills due to that advance in Ebbahytta (sample 3) cover the rock base with the weathering core. Shells contained in the tills have given a radiocarbon age of 8.770 ± 96 years BP (Gd-5247). Studies of the same shells derived from glacial tills of Ebbadalen (site II: Fig. 1) have demonstrated an age of 9.730 ± 70 years (Gd-5248) for these sediments. Identical shells, though not dated so far, are numerous in glacial tills of Ragnardalen (sample 18: Fig. 1). Also of importance has been the absence of marine shells from a morainic mantle of the same age which covers a rock elevation in the foreland of Ragnarbreen (sample 17: Fig. 1). The latest date recorded on a till cover relating to that advance has been reported from Ebbadalen (site II: Fig. 1). An inclusion of plant organic matter incorporated in the basal tills has been assigned a ^{14}C date of 6.890 ± 70 years BP (Gd-5244).

Dated evidence suggests that a suddenly developed and rapidly completed glacial episode dates to some time after 6.890 years ago, or to about 6.500 years BP as a result of convention. Lateral expansion of the glaciers was accompanied by a marked increase in their capacity and thickness. This has been reported from pass settings where glacial forms have been produced, for example in the pass between Sfinksen and Gizehfjellet and between Tarantellen and Chephrenfjellet (*cf.* Fig. 1).

As a consequence of glacier recession, marine morphogenesis recurred in valley floors, especially in the northern portion of Petuniabukta. It is evident

in the marine accumulative series found at the profile top for the Ebbahytta region (*cf.* Fig. 4, site I). Shells incorporated in the upper marine sandy-gravelly deposits can be dated ^{14}C to 6.080 ± 70 years BP (Gd-5246).

The present height of the marine terrace in question approaches 10 m a.s.l. Due to its age of about 6.000 years BP, the mean land uplift rate of 1.64 mm every year can be estimated for this part of Spitsbergen. This average rate of uplift supports a rough age estimate of ca. 40.800 years for the overlying marine deposit fragments found at the base of Løvehovden at the height of about 67 m a.s.l. (*cf.* Figs 4 and 1). As a consequence of the literature considerations of the past tendencies towards rapid uplift of Spitsbergen (Boulton *et al.* 1982, Landvik, Mangerud and Salvigsen 1987), the extrapolated age of the terrace of 67 m should be reduced but not later than to between 33.000 and 35.000 years. It is just the age that appears probable, at least in the context of the date of 38.400 ± 650 years BP applicable to a terrace fragment of 60 m in C-Skardtjønn (Landvik, Mangerud and Salvigsen 1987). Such general estimates and extrapolation results must be treated with caution because of known variable rates of uplift of particular Spitsbergen areas. A reflection of this are age estimates provided by Landvik *et al.* (1987) who suggest a different age for fragments of terraces of similar heights and simultaneously, assign similar dates to beaches of different heights.

The analysis of age of relief features in the area around Petuniabukta has been based on ^{14}C dating, attempts at age extrapolation and TL dating. The latter was carried out in the TL Laboratory of the Department of Geomorphology and Geology at the University of Gdańsk. Surprising absolute results shown below as a listing have been achieved.

Deposit type	Age	
	^{14}C shells and plant organic matter	TL mineral sediments
glacial tills due	9.730 ± 70	89.900 ± 18.000
to the major	8.770 ± 90	Ebbadalen
Holocene advance	6.890 ± 70	131.500 ± 24.400 Ebbahytta
10-m-high terrace marine sediments	6.080 ± 70	110.000 ± 18.000 Ebbahytta
67-m-high terrace sediments	—	166.600 ± 24.000 the base of Løvehovden

The TL dates, are extremely different from the ^{14}C dates. They seem to involve some systematic laboratory error or that resulting from the characteristics of Spitsbergen deposits. If the TL dates are seen in the context of absolute age, the results are comparable to the ^{14}C dates. Even the applied extrapolation of age of the terrace of 67 m must be generally accepted as reliable. The conclusion drawn from the applied testing of various dating methods is that the TL dates on Spitsbergen deposits must be used with great caution. Furthermore, there is a distinct lack of reliability of single TL dates or even ^{14}C dates as a basis of the palaeogeographical analysis.

The glacial episode occurring about 6.500 years BP resulted in a decline in the predominance of marine processes over short distances for a short time only and brought about modification of the extent of relief changes due to gravitational processes in the vicinity of Petuniabukta. During deglaciation the marine processes were still active shaping abrasion beaches and accumulative terraces. Sea level may then have risen markedly with respect to the mineral substratum. Abrasion landforms prevail in the northern closing segment of Petuniabukta, for example in the foreland of Svenbreen at the southeastern foot of Gizehfjellet and in the lower portions of the west-facing slopes of the closing segment of Ragnardalen. Marine accumulative covers are found in the lowermost portion of the Løvehovden base. They occur as a series of pronounced accumulative beaches which occupy vast areas at high altitudes in the Ebbadalen region. The base of the marine accumulative series contains glacial tills, strips of blocks which are likely to be fragments of scoured ancient marginal zones, and outcrops of solid rocks.

The remains of whale bones have been recovered from outwash deposits of Hörbyebreen. They are indicative of a much larger long-term extent of marine water than nowadays, especially in the northern Petuniabukta region. Bone fragments have been found far beyond the present extent lines of tides and storm waves. (*cf.* Fig. 1).

The recurrence of extensive marine processes and intense relief changes under the influence of gravitational factors has been reflected in interlocked deposits of the sedimentary environments. The process of land uplift remained permanent as well. Developing talus cones and alluvial fans, as well as the activity of solifluction processes resulted in burying of a number of marine terraces in many localities. The form and distribution of present-day relief features in the entire northern Petuniabukta region are the imprints of the long-term predominance of processes in the subareal and subaquatic environments.

During the Little Ice Age the latest glacier advance occurred on a small scale only. Glacial relief details relating to unrecognized glacial episodes of the earlier part of the Later Holocene may have been buried then. Conspicuous marginal zones provide a picture of the Little Ice Age glaciation. The maximum advance was followed by a major retreat after which retrens-

gression occurred. This re-advance is well marked on the surface by a bipartite zone of lateral moraines of Ragnarbreen at the foot of Sfinksen. A successive advance coincided with the existing marginal zones related to the Little Ice Age. At present glaciers tend to retreat. In the case of Ragnarbreen and Svenbreen a number of retreat oscillations occur. Three phases of recession can be recognized. The largest glacier affecting the Petuniabukta region under investigation, *i.e.* Hörbyebreen, is characterized by an areal retreat pattern.

During the later part of the Holocene, *i.e.*. after glaciation dating from 6.500 years ago, relief features of the immediate northern closing segment of Petuniabukta developed. The extending outwash fans of Hörbyebreen and Ragnarbreen occupied the bay. The distal parts of outwash plains were and still are under the influence of tides. The present tidal range that is 1 m determines the extent of a vast tidal plain. The eastern coastal part of Petuniabukta falls in the zone of deltaic accumulation by Ebbaelva. The main surface expression of the closing segment of Petuniabukta is the result of the action of sea.

References

Boulton G. S. 1979. Glacial history of the Spitsbergen Archipelago and the Problem of a Barents Shelf Ice Sheet.-Boreas, vol. 8: 31—57, Oslo.

Boulton G. S., Baldwin C. T., Peacock J. D., McCabe A. M., Miller G., Jarvis J., Hordefield B., Warsley P., Eyles N., Chroston P. N., Day T. E., Gibbard P., Hare P. E. and Brunn V., 1982. A glacioisostatic facies model and amino acid stratigraphy for late Quaternary events in Spitsbergen and the Arctic.—Nature 298: 437—441.

Kasprzak L., Kłysz P., Kostrzewski A., Lindner L., Marks L., Rygielski W., Stankowski W. and Wysokiński L. 1985. Morfogeneza obramowania Petuniabukta w pleni-Würmie i Holocenie.—XII Sympozjum Polarne — (materiały referaty, sprawozdania, komunikaty), Akademia Rolnicza w Szczecinie, Wydział Rybactwa Morskiego i Technologii Żywności. 2—4. Szczecin.

Landvik J. J., Mangerud J. and Salvigsen O. 1987. The Late Weichselian and Holocene shoreline displacement on the west—central coast of Svalbard.—Polar Research 5: 29—44, Norsk Polarinstitutt, Oslo.

Mangerud J. and Salvigsen O. 1984. The Kapp Ekholm section, Billefjorden, Spitsbergen.—Boreas, 13: 155—158.

Troicki S., Zinger E. M., Korjakin W. C., Markin W. A. and Mihalew W. J., 1975. Oledienije Szpicbergena (Svalbarda).—Rezultaty issledowanij po meždunarodnym geofiziskim projektam.—Izdatielstwo Nauka: 276, Moskwa.

Received December 15, 1988
Revised and accepted May 24, 1989

Streszczenie

Pilotowe badania paleogeograficzne północnego obramowania Petuniabukta doprowadziły do rozpoznania interakcji procesów glacjalnych, morskich i grawitacyjnych podczas późnego plejstocenu i holocenu. Przez cały ten czas aktywne były procesy wznoszące lądu.

Przestrzenny rozkład punktów obserwacyjnych i stanowisk pomiarowych oraz miejsc poboru próbek do badań laboratoryjnych ukazuje fig. 1. Ryciny 1 oraz 2 do 5 prezentują wzajemną relację rozpoznanych elementów geomorfologii obszaru, serii osadów oraz ukazują wyniki datowań rediometrycznych.

Punktem wyjścia analizy paleogeograficznych przemian obszaru jest faza glacjacji Billefjorden Stage, której wiek odnieść trzeba do około 35—45 tys. lat temu. Billefjorden Stage odznaczał się dwufazowością. Po tej fazie glacjalnej nastąpił długi okres dominacji procesów morza i procesów grawitacyjnych. Wyrazem są sięgające do rzędnych 70—75 m abrazyjne półki morskie oraz drobne w rozprzestrzenieniu morskie serie akumulacyjne. Najwyższy płat tych osadów stwierdzono na rzędnej ok. 67 m npm. Wydaje się bardzo prawdopodobne, że pochodzi on z okresu około 33—35 tys. lat temu (*por.* fig. 4). Morfogenetyczne przemiany obszaru przede wszystkim pod wpływem czynników subarealnych i subakwatycznych w osiowych dolnych częściach dolin żłobowych były przerywane awansami lodowców. Podstawowa holoceńska faza glacjacji dokonała się około 6500 lat BP. Najpełniej dokumentuje to profil geologiczny w pobliżu Ebbahytta (*por.* fig. 1 i stanowisko I). Po tym gwałtownym i krótkotrwałym epizodzie glacjalnym ponownie o morfogenezie obszaru decydować zaczęły czynniki morza i procesy grawitacyjne. Ostatni czytelny powierzchniowo holoceński okres glacjacji rozegrał się w postaci niewielkiego nasunięcia lodowców podczas Małej Epoki Lodowej.

Współczesne północne zamknięcie Petuniabukta pozostaje od bardzo dawna pod wpływem akumulacji sandrowej i rozwoju równi pływowej. Brzegowa wschodnia część Petuniabukta jest miejscem deltowej akumulacji Ebbaelva.