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Nr. 115

VALLEYS AND RAISED BEACHES IN BÜNSOW LAND CENTRAL VESTSPITSBERGEN

BY

G. E. GROOM AND M. M. SWEETING

I KOMMISJON HOS
UNIVERSITETSFORLAGET
OSLO 1958

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Valleys and Raised Beaches in Bünsow Land, Central Vestspitsbergen.

G. E. Groom and M. M. Sweeting.

I. Introduction.

Bünsow Land is a well-defined, compact area in central Vestspitsbergen. It is bounded on the west by Billefjorden, on the south by Sassenfjorden, on the south-east by Tempelfjorden, and on the north and east by the ice cap and glaciers which cover most of eastern Vestspitsbergen. It is about 16 miles

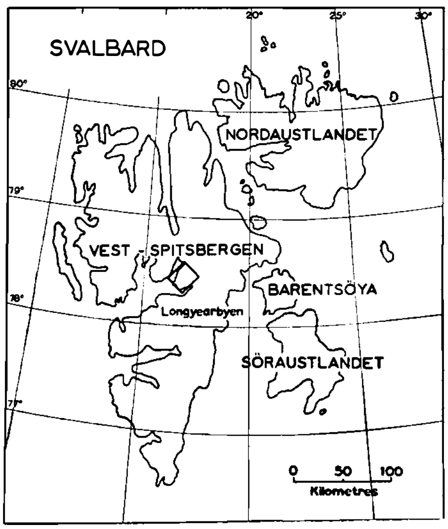

Fig. 1. The location of Bünsow Land in Vestspitsbergen.

from NNE—SSW, and about 13 miles from E—W; it is a relatively ice-free region, ice rarely concealing the main trends of its relief. Much of the original topographical and geological survey work in this area was carried out by the members of the Scottish Spitsbergen Syndicate who used Brucebyen in the NW as a base camp (Tyrrell 1919). In recent years this work has been greatly extended, particularly by the expeditions from Cambridge led by W. B. Harland (1952). The work described in this paper is based on that done while the authors were members of the Cambridge Spitsbergen (Physiological) Expedition, 1953, led by Dr. Mary Lobban. Over 50 miles of levelled profiles of the ice-free valleys and profiles of the raised beaches were obtained. This paper consists, therefore, first of a study of the main features of the ice-free valleys of the area, together with a discussion of the plateau surface; and, secondly, a consideration of the profiles of the raised beaches, particularly with reference to the tilted shorelines of the east side of Billefjorden (Balchin 1941). Much use was made of the relief and geological maps prepared by the earlier expeditions.

Bünsow Land forms part of the plateau region of Spitsbergen, and lies east of the area which was intensely folded during the Tertiary period, (Orvin 1940). The region is a dissected plateau of markedly tabular relief rising to over 3,000 ft. (1,000 m.) above sea-level in the north-east. It has a simple geological structure and is formed almost entirely of gently-dipping Carboniferous and lower Permian rocks, 3,000 ft.—5,000 ft. (900—1,500 m.) thick and dipping at about 1° to 3° to the south-west. This sequence is discussed in the work of Gee, Harland and others, (Gee, et al. 1951, p. 203).

The Carboniferous and lower Permian rocks of Bünsow Land rest unconformably upon pre-Devonian rocks (often known as the Hekla Hoek complex); in the area studied these pre-Devonian rocks are present only at the head of Gipsdalen (Fig. 2). The south-west corner of the area, near Anservika, is crossed by a well-marked fault-belt trending NNW—SSE. In the neighbourhood of this belt the rocks are much disturbed and dips as high as 55° have been recorded. The Carboniferous and Permian sediments are downwarped along this fault-belt; later movements have taken place in Cretaceous times, (when it is believed that the dolerite sill in the SW was intruded), and in the Tertiary period (Gee, et al. 1952, p. 32, and McWhae 1952, p. 230).

II. The Plateau Surface and Valley Profiles.

The most conspicuous feature of the relief of Bünsow Land is probably the rectilinear nature of both the coastlines and of the valleys (Fig. 2). The coastlines and the valleys trend in two main directions, approximately NE—SW and NW—SE. The total length of the valleys in the area is about 77 miles; about 44 miles, or 57 %, of this total length follows the NW—SW trendline, and about 24 miles, or 30 %, trends NW—SE. De Geer called attention to this rectilinear nature of the relief of Bünsow Land and referred to the "Blocks" or "Quarters" of the area (De Geer, 1912). He supposed that the straight coastlines and valleys lay along fault-lines. The results of recent geological work in the area do not bear out this supposition, though it is likely that Billefjorden owes its origin to erosion along the well-defined fault-belt already discussed. "A number of other faults are given in the literature, most of them introduced by De Geer, but they are largely based upon

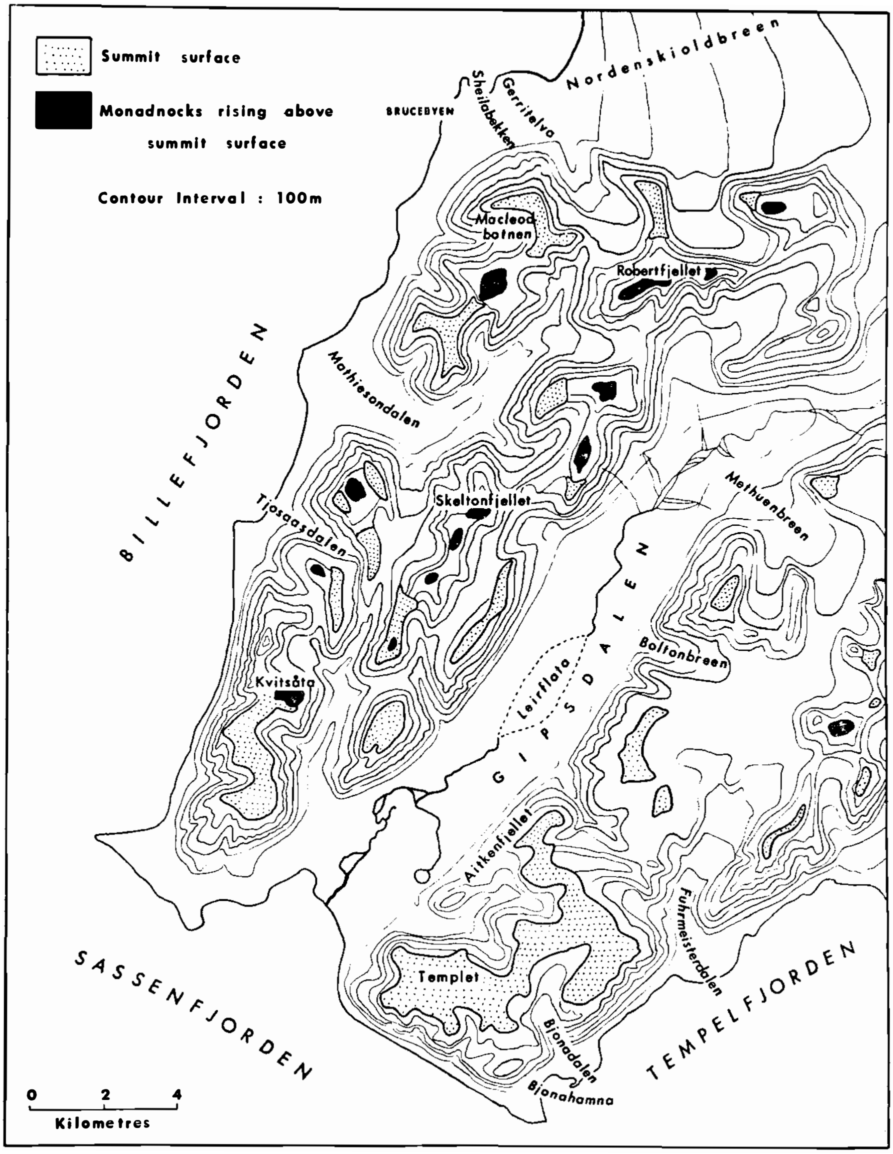

Fig. 2. Bünsow Land: the distribution of the summit surface and monadnocks.

assumptions and have been found to be non-existent." (Orvin 1940, p. 53). It would seem, however, that the two main valley trends are partly controlled by the directions of dip and strike of the rocks, which are also the lines of major jointing. Conclusive evidence for spring sapping at the base of the *Brachiopod Cherts* at their junction with the *Cyathophyllum Limestones* can be seen in several parts of Bünsow Land.

Between the valleys are broad plateau blocks which rise to an even summit level, at about 2,600 ft. to 2,950 ft. (800 m. to 900 m.) in the north, and at about 1,950 ft.—2,300 ft. (600 m. to 700 m.) in the south. The character of this summit plain or surface in Bünsow Land was examined by the authors, except in the north east part of the area where it is largely ice-covered. Where not covered by ice the flat summits consist of finely comminuted frost shattered rock, there being relatively few outcrops of unweathered rocks.

The distribution of the summit surface is shown in Fig. 2. It is least dissected and best preserved in the southeast where it lies at above 2,600 ft. (800 m.) in the north and between 1,950 ft. and 2,300 ft. (600 m. and 700 m.) in the south. Here it is developed mainly on the *Brachiopod Cherts;* these beds dip gently southwards at 2°, their base falling from + 2,300 ft. to — 980 ft. (+ 700 m. to — 300 m.) between Boltonbreen and Templet, at a gradient of 1 : 27. The summit surface slopes south at a gradient less than this. Locally the difference in gradient between the summit surface and the underlying beds is difficult to see, but when traced over a distance it can be shown to transgress over different bands in the *Brachiopod Cherts.*

Over much of the remainder of Bünsow Land, the summit plain is much more dissected. In the north-west, it is preserved upon a series of ridges where it occurs between 1,950 ft. and 2,780 ft. (600 m. and 850 m.) mainly on the *Cyathophyllum Limestones;* monadnock peaks, rising to over 3,000 ft. (1,000 m.) occur where the ridges converge, particularly in the east (Fig. 2). In the south west the summit surface occurs between 2,160 ft. and 2,520 ft. (660 m. and 770 m.) with monadnock hills, such as Kvitsåta and Skeltonfjellet rising up some 525 ft. (160 m.) above it; here the plain is found mainly on the *Brachiopod Cherts,* but it may also be traced to the *Cyathophyllum Limestones.* Locally, where the surface is found on the lower *Brachiopod Cherts* just above the horizon of the prominent *Spirifer Limestone* band, it may be structurally guided.

The height of the summit surface ranges from approximately 2,880 ft. to 1,950 ft. (880 m. to 600 m.). It is possible, especially in the south east, that it may be composite, being made up of two levels, one at about 2,600 ft. (800 m.) to 2,880 ft. (880 m.), the other nearer 2,230 ft. (650 m.), and each sloping gently southwards.

There is not yet sufficient evidence to explain either the mode of formation or the age of the summit surface in Bünsow Land. A similar summit or plateau surface occurs over large areas of Vestspitsbergen, especially in the north. This surface was first commented upon by De Geer, who discussed the area to the north of Bünsow Land and who referred to a "remarkable plain of denudation" (De Geer 1919, p. 166). He regarded this surface as a "Cretaceous base-level plain" mainly on the evidence of overlying basalts said to be of Upper Cretaceous age. De Geer considered that this "base-level plain" was uplifted to its approximate present level during the Tertiary earth movements, and his map (1919) shows suggested contours or eohypses of the plain drawn above present sea-level.

It is possible however that such summit plains, as exist in both northern Vestspitsbergen and in Bünsow Land, have been so altered by glacial erosion and by periglacial weathering that their present form represents neither the surface of an uplifted peneplain nor an uplifted plain of marine abrasion. Ahlmann (1933 a, p. 115) has said of such surfaces that "it is hardly justifiable to conclude that they form an old abrasion level and that the isohypses drawn up by De Geer are contour lines of the ancient sea-bottom. Probably the present even surfaces of the raised plateau blocks are the results of denudation processes, active more or less high above sea level during the pleistocene time." None the less, it is difficult to see how glacial and periglacial processes would produce such a plain of even relief as is seen in the summit surface of Bünsow Land if the initial relief was not also plain-like in character.

Great thicknesses of Tertiary beds, including coal measures, now occur in the area to the south of, and may even have covered, Bünsow Land. Thus, considerable denudation and peneplanation in the area now occupied by Spitsbergen took place during Tertiary time. It is therefore reasonable to assume that the summit plain in both Bünsow Land and in other parts of Vestspitsbergen has been partly formed in the Tertiary period.

In the valleys below the summit surface the rapid disintegration of the rocks into scree by frost action has given rise to steep valley sides with scree slopes up to 43° or 45°. This action has almost entirely obliterated any preglacial valley benches which may have existed; hence there is little evidence to show either whether processes other than periglacial ones were predominant in bringing about the dissection of the summit surface or in what ways the valleys were cut. There are well-marked cols, some ice-covered, at about 1,625 ft. (500 m.), (Fig. 2); these may have some erosional significance. In addition, there is occasional valley-side benching at about 980 ft. (300 m.) to 1,320 ft. (400 m.), but these may be associated with resistant bands of rock. Below about 330 ft. (100 m.) the valleys debouch on to the coastal plain or strandflat, which is of variable with (Fig. 2).

In the larger valleys, at the foot of the steep scree slopes, a more or less continuous solifluction terrace occurs along the valley sides; the valley-ward slope of this terrace is gentle, generally about 1°, forming a contrast with the steep scree slopes above. In the upper and middle reaches of the valleys, the solifluction terrace consists largely of a spread of old moraine and scree, upon the surface of which are well developed soil polygons; in Mathiesondalen, for instance, the terrace contains a high proportion of green and red sandstones which have been carried into the valley by a flow of ice from the area of *Culm Measures* in the north of Bünsow Land. In the lower parts of the valleys, the solifluction terrace, in addition to scree and moraine, consists of shingle from old raised beach deposits. The thickness of such unconsolidated material forming these solifluction terraces varies; in places it is as much as ten feet, while elsewhere it is a thin spread of superficial debris resting

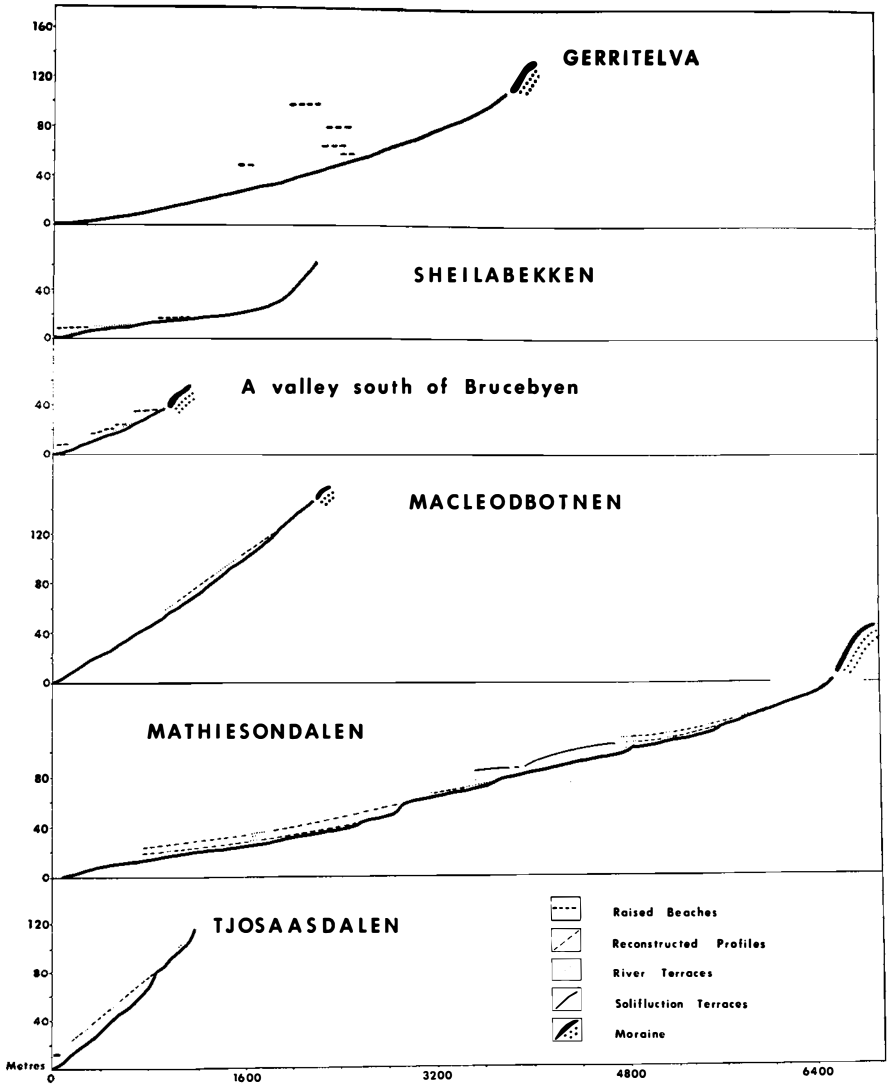

Fig. 3. Levelled profiles of valleys, west Bünsow Land.

on a rock bench. Such solifluction features were sometimes difficult to distinguish from true river terraces and from the older raised shingle ridges.

Profiles of the valleys which were levelled are shown in Figs. 3, 4 and 5. These profiles were obtained by levelling along the river bed from mean sea-level at the lower ends of the valleys to the glaciers at their upper ends; for Gipsdalen, the only river with an alluvial flood plain, the profile is nearly everywhere that of the inner margin of the flood plain, except for the uppermost two miles, where the profile is again that of the actual river bed. Levelling methods varied according to circumstances, but included tacheometric levelling in addition to less accurate methods using an Abney level or a surveying aneroid. The aneroid measurements have only been used where, by counter checks, an accuracy of ± one metre was assured.

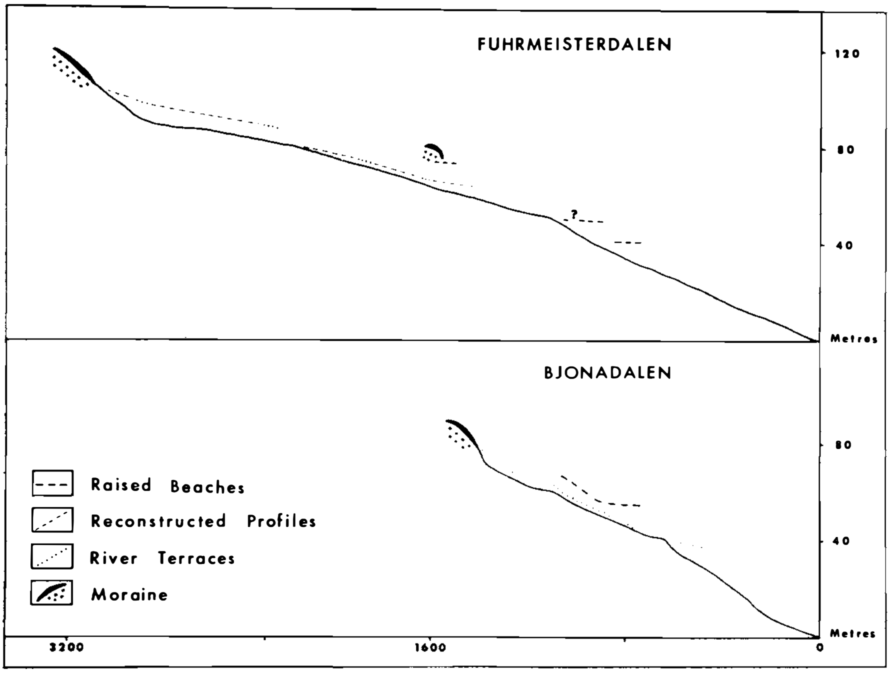

Fig. 4. Levelled profiles of valleys, south-east Bünsow Land.

Above the coastal plain, the higher parts of the valleys consist almost entirely of scree or moraine, which may be solifluncted, but there is little or no alluvial or boulder deposit. The gradient of such parts of the valleys is high, varying between 1 : 10 to 1 : 20, and they often contain dead ice, a good example is the Tjosaasdalen. In their lower courses the gradient of the valleys is less, normally below 1 : 30. The valley floor is here largely made up of deposits of a fluvial-glacial character; these frequently consist of coarsely rounded boulders and pebbles, often roughly stratified, and laid down in an alluvial or boulder fan. The average gradient of such boulder fans is from 1 : 20 to 1 : 30, i. e. about 2° or 3°. In the larger valleys, such as Gipsdalen and Mathiesondalen, deposits of sand and mud, often laid down in temporary lakes like the Leirflata, alternate with more steeply inclined boulder fans.

Well-defined river terraces occur along the rivers. The heights of these terraces and their extent were measured and are also shown on the profiles. The terraces shown were either definite rock cut benches or were made up of river gravel deposits. The existence of river terraces illustrates the fact that the present day streams appear everywhere to be cutting into their earlier deposits. It will be seen also that the river profiles possess definite convex breaks, or nick points. The main breaks in the profiles of Mathiesondalen, and in the profile at the head of Gipsdalen, are in solid rock. The most spectacular example is seen in the left bank tributary I of Gips river, between Aitkenfjellet and Templet, where the stream flows in a gorge 60 ft. deep

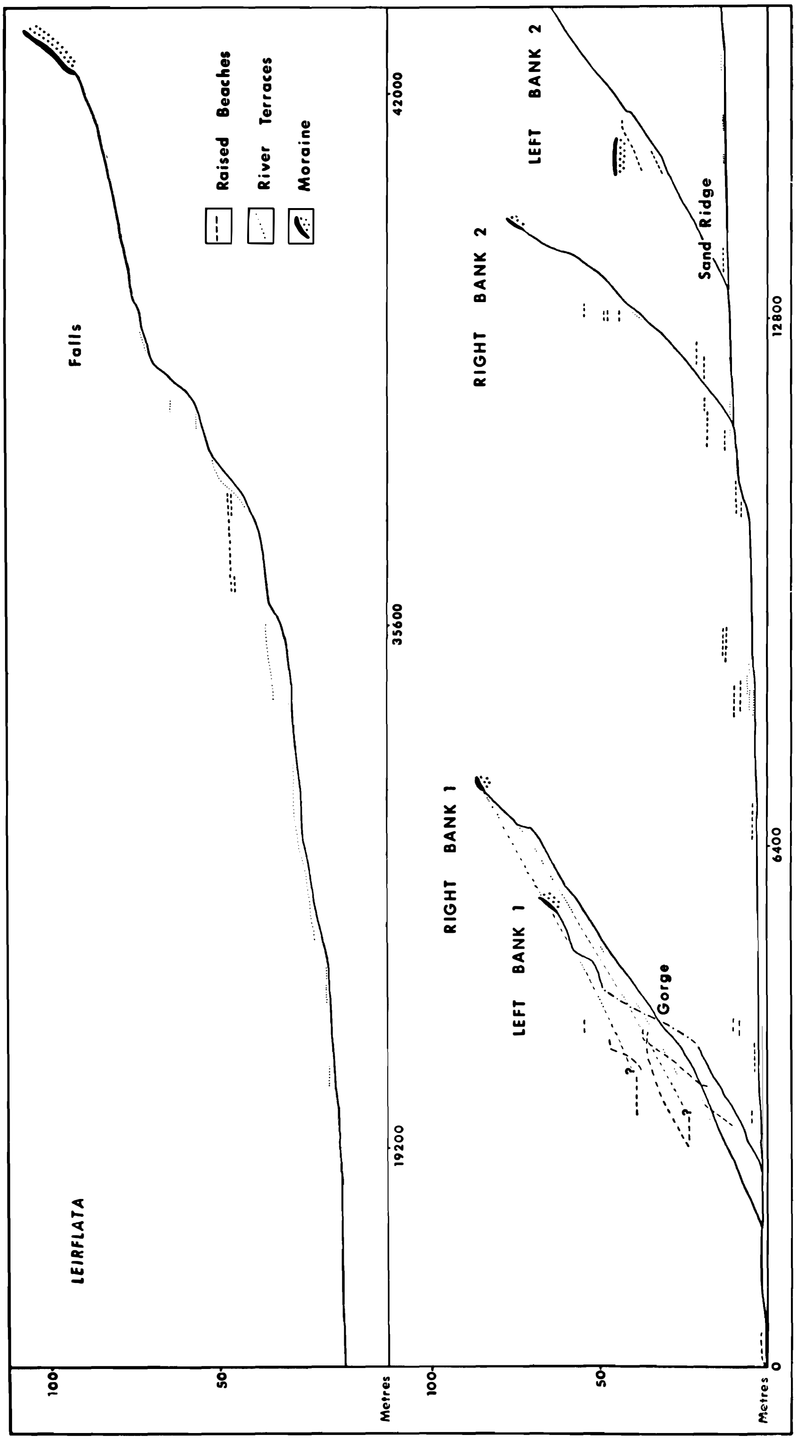

Fig. 5. Levelled profiles of Gipsdalen and its chief tributaries.

cut into solid rock and flanked by a solifluction-capped rock bench, (Fig. 5), (Balchin 1941, pl. 9.). In Figs. 3, 4 and 5, where correlations between nick points and river terraces appeared reasonable, reconstructions of the earlier profiles have been attempted.

Further evidence of the downcutting of the rivers is given by the composite nature of the boulder fans. In all the valleys investigated, the fans show evidence of formation in at least two periods, the more modern fans being incised into the older ones as in "cone-in-cone" structure (Balchin 1941, p. 369). In the older fans the boulders are more compacted and there is a thin carpet of vegetation, (usually *Salix polaris* and *Dryas octopetala*); the distributaries are now dry and deserted by the streams. In the newer fans, these boulders are much less compacted and the surface of the fan is more rough and uneven; vegetation is usually absent and the fan is more or less covered by the present-day melt streams. It is likely that the older fans are connected with the terraces which lie 3 ft. (1 m.) to 5 ft. (1.5 m.) above the present rivers (Fig. 5).

Explanations to account for the downcutting of the present rivers involve two main considerations. First, variations in the volume of the melt-water and in the size and quantity of the load; such variations depend largely upon fluctuations in climate. In recent years, there has been a marked recession of the glaciers of Bünsow Land and hence a corresponding increase in the amount of summer meltwater. During the summer melt period the volume of the rivers has therefore been greatly increased and this is one factor which may have led to the increased downcutting of the rivers.

Secondly, the downcutting may also be caused by variations in the base level of the fjords. In Bünsow Land there is good evidence of late Pleistocene negative changes of base level, as in the numerous raised beaches which are found on the coastal plain up to a height of about 330 ft. (100 m.). Such base level changes would also cause increased downcutting. Many of the details of the river profiles are probably the result of the complex interaction of these two main factors.

In summary, if these suggestions are correct, the main outlines of the denudation chronology of Bünsow Land may be as follows:

I. An early cycle of erosion represented by the summit peneplain, in part of Tertiary age. This probably modified an earlier surface.

II. Initial dissection of the summit surface, represented by the high level benches and cols in the main valleys.

III. Succeeding rejuvenation causing further incision of the valleys.

IV. Glacial and periglacial modifications.

V. Formation of terraces and gorges related to both the fluctuations of glacier recession and changes in base level.

III. The Raised Beaches.

Below about 330 ft. (100 m.) the most conspicuous feature of the relief of Bünsow Land is the coastal plain. This varies in width and may be up to about 1½ miles. It includes both plains of abrasion and deposition. Even where the plain is apparently depositional it is often possible to see traces of solid bench under a thin cover of superficial material.[1]

In Bünsow Land there are extensive stretches of raised storm beaches which possess a great variety of height and slope. These beaches occur at almost all heights up to about 330 ft. (100 m.) above the present sea-level, (Balchin 1941, Feyling-Hanssen 1955). They also occur not only along the southern and western coasts, but are found in the north of the area along the margin of the Nordenskiöldbreen and in upper Gipsdalen. This is what would be expected from the observations made by Högbom in 1911 on the extent in this part of Vestspitsbergen of the early Post-Glacial transgression (Högbom 1911).

It is well known that the shingle beaches along the western coast of Bünsow Land, (i. e. the eastern side of Billefjord), slope towards the north. The beaches were first described by Tyrrell (1919, p. 43) who considered that their tilt was caused by the isostatic readjustment of the land about a hinge-line which moved progressively further north towards the head of the fjord as the ice-cap receded. Professor Balchin, who mapped a considerable area of the beaches in 1939, also considered that their tilt was due to local isostatic uplift. He based his conclusion upon the presence of a number of raised wave-cut cliffs, the basal nicks of which are inclined towards the head of Billefjorden. This explanation involved the assumption that the area had suffered local block-faulting and that the isostatic readjustment of each block individually would account for the high degrees of tilt of the shorelines.

This explanation of the tilt of the beaches is improbable in the light of recent geological work in the area which makes localized recovery of fault blocks unlikely. Moreover, Feyling-Hanssen, (1950) criticised Balchin's interpretation of the raised features of Billefjord. His arguments were based, first, on the very high degrees of tilt for the shorelines, (recorded by Balchin), which are more than sixty times greater than the *Tapes* line in Fennoscandia; and secondly, upon the occurrence in the other parts of Vestspitsbergen of raised beach series at similar heights (e. g. Dinely 1953, Kulling 1931, Thompson 1953, Holland 1955).[2] As a result of his investigations elsewhere in Vestspitsbergen, Feyling-Hanssen suggested that the features which Balchin meas-

[1] The term strandflat (Reusch 1894) is probably more correctly used to distinguish the plain of abrasion from the raised sea beaches; the term is, however, frequently used to describe the coastal plain regardless of whether the plain is of erosional or depositional origin. (Dineley 1953, Thompson 1953.)

[2] See Feyling-Hanssen, (1950 a, p. 90) "The recovery suggested by Balchin must be extraordinarily local".

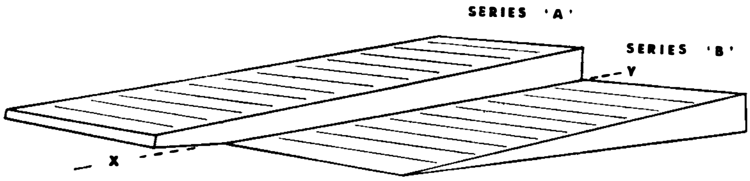

Fig. 6. Diagrammatic representation of raised shingle beach series.

ured were "not regular raised beaches but raised delta-plains or delta-terraces".

Because of this controversy, the authors gave some time to the question of the tilted shorelines of eastern Billefjord and were able to confirm that all the beaches mapped by Balchin are undoubtedly shingle ridges of marine origin.[1] In order, therefore, to study the nature of the beach tilts, several series of shingle ridges were levelled; the level lines were run perpendicular to the shingle ridges. It was observed that where the raised wave cut cliffs mapped by Balchin face on to a lower series of beaches, the slope of the basal cliff notch is the same as that of the beach series at its foot. Fig. 6 shows, in diagrammatic form, a typical beach association. The history of development of such a series would, according to Balchin's interpretation, be as follows:

I. Beach series "A" are formed, with some possible slight initial slope.
II. Erosion of series "A" by wave attack normal to the cliff line X—Y.
III. Tilting of the cliff line X—Y, which also causes the major part of the tilt of beach series "A".
IV. Beach series "B" are formed, and their present slope may be due to initial accumulation, or they too may have suffered tilting.

Balchin suggested this sequence of development to have occurred several times: beach formation, erosion, tilt, followed by further beach formation.

The present authors suggest the following interpretation of the beach and cliff development to be more correct:

I. Beach series "A" are formed having an initial slope of deposition as a result of a negative change in base level. Direction of wave approach parallel to X—Y.
II. Beach series "B" are formed with a similar initial slope of deposition due to a negative change in base level. Cliffing of series "A" proceeds by wave attack at the same time as accumulation is forming series "B"; sometimes accumulation at the lower end of series "A" still continues.

The suggested alternative sequence of development is illustrated by the series of beaches near Brucebyen. Here a series of beaches rises from Kapp Napier southwards to form the surface upon which the huts at Brucebyen

[1] A conclusion with which Feyling-Hanssen (1955, p. 17) is also in agreement in the light of his more recent work.

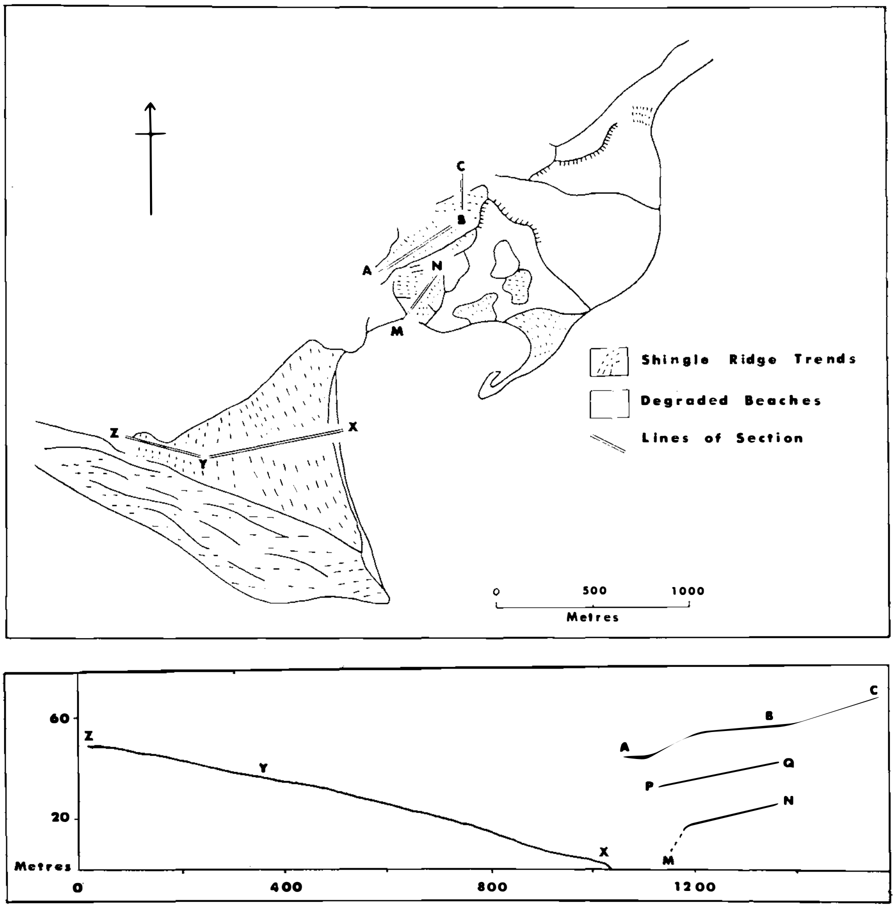

Fig. 7. Bjonahamna: map and levelled profiles of the shingle beaches.

are built; the western side of this continuous beach sequence is at present being cliffed by the sea. Further south, a second series of beaches rises from mean sea-level and lies at the base of the cliff cut into the first series. The angle of slope of the basal notch of this cliff is the same as that of the second or lower beach series. Thus, two beach series are being formed concurrently, and it is the slope of accumulation of the second beach series that determines the slope of the basal cliff notch. It is therefore suggested that the gradient of the raised wave cut cliffs observed by Balchin is largely that of the accumulation slopes at their foot, which are due to negative base level changes.

Nevertheless, part of the gradient of the beach series may be tilt due to variations in degree of isostatic readjustment. It seems likely, however, that such isostatic tilting, if it has in fact occurred, is of a more regional and general, and less local nature, than that envisaged by Balchin. This is illustrated by the shingle ridges in the south of the area, at Bjonahamna. Here, ridges of similar height, range and gradient flank either side of the bay, but with directions of slope or tilt which face one another across the bay. (Fig. 7.)

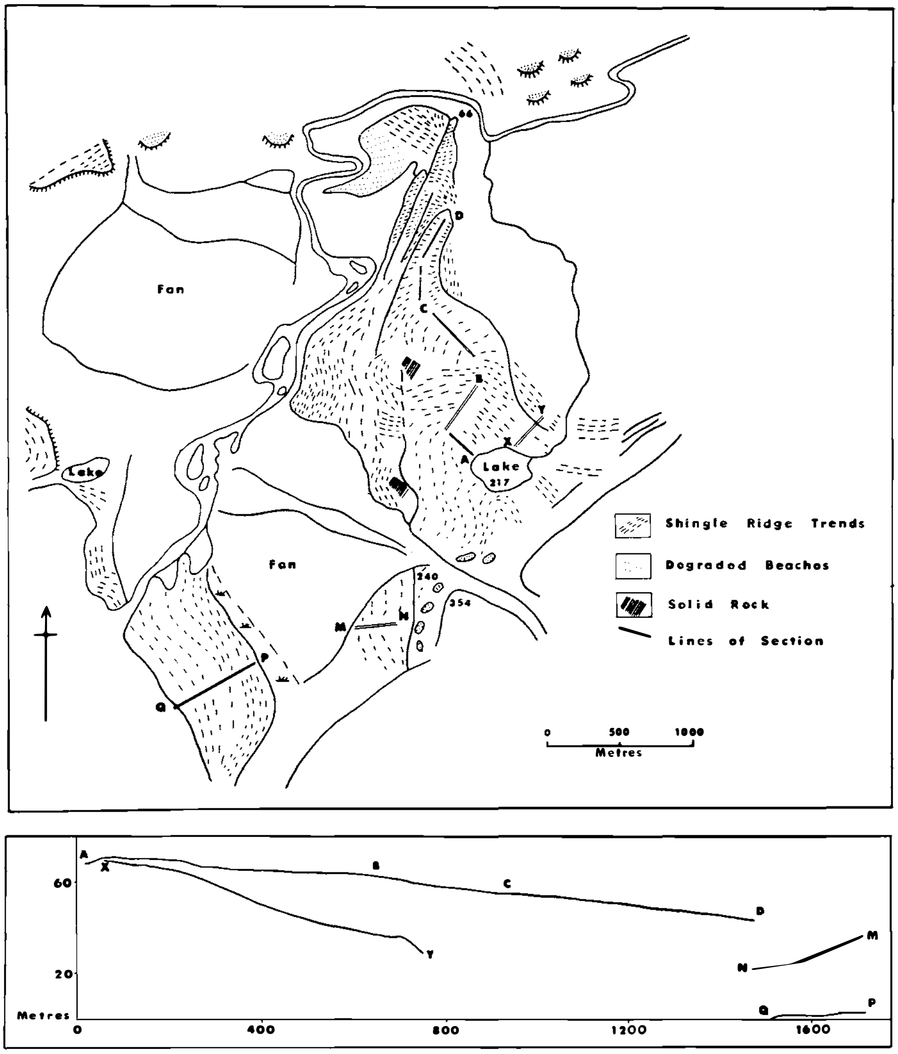

Fig. 8. Lower Gipsdalen: map and levelled profiles of the shingle beaches.

Such differing directions of slope in such a small area, show that it is difficult to visualise any local isostatic tilting since the formation of the beach ridges. This is further confirmed in lower Gipsdalen (Fig. 8), where there is a complex series of raised beaches. This also includes shingle ridge series which slope in opposite directions, while yet extending over similar height ranges.

The relationship between the varying rates of base-level change and the beach gradients cannot, however, be a simple one. The levelled profiles of a number of beach series showed that even when descending through the same height range, the gradients of series in close proximity to one another were not necessarily the same, and the steeper or more convex portions of their profiles were rarely coincident. These variations can only be explained by taking into account the changes in the direction and force of storm winds, in tidal currents and beach drifting, in supply of debris, and also differences in coastal configuration. All these are factors which, either singly or in combination, might cause local differences in the rate and character of the accumulation, and therefore lead to variations in the initial accumulation profiles of the beach series.

Faunal List.

Identifications by Mr. D. F. W. Baden-Powell.

Systematic collections were not made from all the beaches, but the following collections are recorded from beaches at the stated height ranges:

	1	2	3	4	5	6	7	8	9	10
Mytilus edulis Linn.	?	X						X	?	
Astarte borealis Chem.	X			X					X	
Astarte montagui Dillwyn. ..					X		X			
Tellina (Macoma) calcarea Chemnitz	X				X	X	X			
Mya truncata Linn.		X		X	X	X	X	X	X	X
tendency *uddevallensis* Hancock.		X			X		X			X
Mya arenaria Linn.	X									
Saxicava pholadis Linn.					X	X	X	X	X	
Saxicava arctica Linn.				X	X	X			X	
Gibbula cineraria[1] Linn.								X		
Littorina littorea Linn.								X		
Buccinium glacialis Linn.				X						
Algae	X		X		X		X			
Foraminifera			X							

No. 1 from beach at 20 ft.
Nos. 2, 3, 4 from beach at 25—30 ft.
Nos. 5, 6, 7, 8 from beach at 50—70 ft.
No. 9 from beach at 90—100 ft.
No. 10 from beach at 300 ft.

[1] According to Mr. D. F. W. Baden-Powell, this is new to Spitsbergen.

Since the completion of this present work an exhaustive study of the faunal content of these beaches has been published by Feyling-Hanssen (1955, see especially pp. 47—52) who has established a late-Pleistocene stratigraphical sequence for Billefjorden. This supports the contention of the authors that the slopes of the beach series have been formed by ordinary beach development during a negative change of base-level.

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