

MEDDELELSER OM GRØNLAND

UDGIVNE AF

KOMMISSIONEN FOR VIDENSKABELIGE UNDERSØGELSER I GRØNLAND

Bd. 103 · Nr. 10

DE DANSKE EKSPEDITIONER TIL ØSTGRØNLAND 1926-39

UNDER LEDELSE AF LAUGE KOCH

TECTONICS AND
MORPHOLOGY OF KAP OSWALD
(NE-GREENLAND)

BY

H. P. SCHAUB

WITH 10 FIGURES IN THE TEXT
AND 3 PLATES

KØBENHAVN

C. A. REITZELS FORLAG

BIANCO LUNOS BOGTRYKKERI A-S

1955

CONTENTS

	Page
Introduction	5
Recapitulation of Stratigraphy	7
Additional Remarks on the Tillites	10
Tectonics	15
1. General	15
2. Tectonics near Kap Oswald	15
3. Joints, fractures, faults	18
4. Conclusions	23
Morphology	25
1. Influence of underlying formations	25
2. Influence of structure	26
3. Active erosional forces	26
4. Stage of development	29
5. Conclusions	32
References	33

List of Illustrations.

A. Plates.

- Plate 1. Geological Map of Kap Oswald, Ella Ø. 1:10.000.
 Plate 2. Structural Map of Cape Oswald Anticline. 1:10.000.
 Plate 3. Cross Sections through Kap Oswald Anticline. 1:10.000.

B. Text-figures.

- Figure 1. Stratigraphical Subdivision of Section exposed on Kap Oswald..... 9
 — 2. Striated Pebble collected from Lower Tillite in Tømmerbugt..... 11
 — 3. Sketch Map showing the Situation of Ella Ø and Kap Oswald Anticline

INTRODUCTION

As a member of Dr. Lauge Koch's expedition, the writer spent the winter 1936—37 in the station near Kap Oswald on Ella Ø, NE.-Greenland. During this time he mapped the surroundings of the station, a task which was made easy by the accurate map of the area surveyed in 1931—32 by SIMONSON and STENØR of the Geodetic Institute at Copenhagen.

The stratigraphy of the Pre-Cambrian which is exposed on Kap Oswald was described in an earlier report (ref. 13). The present paper deals with the tectonical and morphological observations. The geological map is published as Plate 1.

The writer wishes to thank Dr. L. KOCH for the opportunity to make these studies and for his continuous interest in this work.

RECAPITULATION OF STRATIGRAPHY

For a detailed discussion of the stratigraphy reference is made to the writer's paper on the subject (ref. 13)¹⁾. The following sequence was described, partly based on the results of CH. POULSEN (ref. 11), from top to bottom:

		Narwhale Sound formation		
		Cape Weber formation		
Bed.		Cass Fjord formation	}	Upper Limestone group est. 1750 m
No.		Dolomite Point formation		
50	± 200 m	Hyolithus Creek formation		
49	± 50 m	Ella Island formation		
48	± 150 m	Sandy Shale member	}	Tømmerbugt group (1188 m)
46, 47	61 m	Quartzite member		
43—45	25 m	Salt Cast member		
36—39	100—130 m	Sun-cracked member		
35	70—100 m	Varve member		
29—34	± 221 m	Upper Tillite member		
26—28	± 225 m	Inter-Tillite member		
25	± 100 m	Lower Tillite member		
24	± 100 m	Silty Shale member		
23	6 m	Breccia member	}	Lower Limestone group (838 m) (Eleonore Bay formation)
18—22	100 m	Banded Dolomite member		
17	190 m	Grey Limestone member		
14—16	420 m	Black Limestone member		
6—13	40 m	Collenia member		
1—5	188 m	Pisolite member		

In later years, the same sequence has been studied regionally by other authors; by S. EHA on Suess Land, Ymers Ø and Ella Ø (ref. 3), by R. KATZ on Strindbergs Land (ref. 7) and by E. FRÄNKEL in E-Andréas Land (ref. 5). As a result stratigraphical subdivisions of a more regional value were proposed and these were discussed at a conference held by Dr. LAUGE KOCH and his collaborators in 1953. The resulting unified sub-divisions (ref. 5) compares with the Kap Oswald stratigraphy as shown in fig. 1.

This correlation is not entirely ascertained. EHA states that bed group 20 cannot be recognised with certainty in the Kløft elv. It is, however, possible that our Breccia member represents bed group 20, since it resembles the limestones of bed group 20 as described by R. KATZ

¹⁾ It should be mentioned here that the scale 1:5000 given on plate 1, ref. 13, is wrong and should read approximately 1:12500.

(dark grey, thin bedded limestones which form a dark cliff) and E. FRÄNKEL. In that case it is not quite clear whether our silty shale member belongs also to bed group 20 or already to the Tillite Series.

The boundary between Canyon Series and Spiral Creek Series is also not too well defined because the original study (ref. 11) was rather cursory due to circumstances inherent to arctic exploration. We have here assumed that the unconformity observed on Ella Ø between beds 35 and 36 represents the boundary.

It is quite obvious that the results of detailed stratigraphical investigations which must be restricted to easily accessible sections do not necessarily coincide with the views obtained during a regional survey. Where such detail work can be done it will serve to fill in the large framework provided by the regional surveys.

The age of the sequence has been discussed by many authors, because it would be highly interesting to date the glaciations which left their trace in the Tømmer Bay group. The facts are shortly as follows:—

The first fossils of Lower Cambrian age were found by POULSEN in the Sandy Shale member of the Tømmer Bay group, in the upper part of his Bastion formation. They do not, however, represent the earliest Cambrian faunas known from other areas (ref. 12). The Upper Limestone group belongs to the Cambrian and Ordovician and is unconformably overlain by the Devonian (ref. 1).

The Lower Limestone group belongs to the Eleonore Bay formation which is generally considered as Pre-Cambrian and was assigned by L. KOCH to the Greenlandian. This seems reasonable since the beds of the Lower Limestone group, although deposited under similar conditions as those of the Upper Limestone group, do not contain any fossils except *Collenia cf. undosa* Walcott, a so-called Stromatolite usually considered as an alga. This suggests possible correlation with the Belt Series of Wyoming, U.S.A. which is also of pre-Cambrian age and unconformably overlain by Middle Cambrian (ref. 4).

The main question is thus whether all or part of the Tømmer Bay group belongs to the Cambrian and where to place the base of the Cambrian. The writer, basing himself on a study of the sedimentation, has tentatively placed the boundary at the base of the Quartzite member. This would seem to be confirmed by the absence of fossils in the underlying beds, excepting some probable remains of algae. The cold climate might have prevented life during the earlier part of the Tømmer Bay deposition, but there is no indication that it remained unfavourable. We come thus to the conclusion that the glaciations occurred in the late Pre-Cambrian.

The same view has been adopted by Dr. L. KOCH in the new standard sub-division (see fig. 1).

SUBDIVISION 1950		NEW SUBDIVISION 1953		AGE
<i>DOLOMITE POINT FORMATION</i>	<i>UPPER LIMESTONE GROUP</i>	<i>DOLOMITE POINT FORMATION</i>		<i>CAMBRO - ORDO - VICIAN</i>
<i>HYOLITHUS CREEK FORMATION</i>		<i>HYOLITHUS CREEK FORMATION</i>		
<i>ELLA ISLAND FORMATION</i>		<i>ELLA ISLAND FORMATION</i>		
<i>SANDY SHALE MEMBER</i>	<i>TÖMMER BAY GROUP</i>	<i>BASTION FORMATION</i>		<i>GREENLANDIAN</i>
<i>QUARTZITE MEMBER</i>		<i>SANDSTONE SERIES ?</i>	<i>TILLITE FORMATION</i>	
<i>SALT CAST MEMBER</i>		<i>SPIRAL CREEK SERIES</i>		
<i>SUN-CRACKED MEMBER</i>		<i>CANYON SERIES</i>		
<i>VARVE MEMBER</i>				
<i>UPPER TILLITE MEMBER</i>				
<i>INTERTILLITE MEMBER</i>		<i>TILLITE SERIES</i>		
<i>LOWER TILLITE MEMBER</i>				
<i>SILTY SHALE MEMBER</i>				
<i>BRECCIA MEMBER</i>		<i>? BED GROUP 20</i>	<i>(UPPER) ELEONORE BAY FORMATION</i>	
<i>BANDED DOLOMITE MEMBER</i>		<i>BED GROUP 19</i>		
<i>GREY LIMESTONE MEMBER</i>	<i>BED GROUP 18</i>			
<i>BLACK LIMESTONE MEMBER</i>	<i>BED GROUP 17</i>			
<i>COLLENA MEMBER</i>	<i>BED GROUP 16</i>			
<i>PISOLITE MEMBER</i>	<i>BED GROUP 15</i>			
	<i>BED GROUP 14</i>			

Fig. 1. Stratigraphical Subdivision of Section exposed on Kap Oswald.

ADDITIONAL REMARKS ON THE TILLITES

The nature of NE-Greenland's pre-Cambrian tillites is still sometimes questioned, most recently by E. FRÄNKEL (ref. 5, page 67). This is very desirable if we want to ascertain their true origin. H. R. KATZ (ref. 7) has stressed the tuffogen character of the tillites. It may therefore be useful to discuss the question more fully, particularly since FRÄNKEL points out that striated pebbles and cobbles have only been observed by one author.

In the writer's opinion, one of the points which speaks most in favour of the glacial origin is the great similarity of these sediments with recent moraine material. However, there are other observations which can closely be compared with the description of tillites given by F. J. PETTJOHN in his treatise on sedimentary rocks (ref. 10).

Striated pebbles were observed by the writer in several localities near Kap Oswald:

14th Nov. 1936: Two striated limestone pebbles noted from the Lower Tillite member.

17th Nov. 1936: Striated pebbles were observed in Lower Tillite beds in the Kløftelv. These beds contain only limestone pebbles.

17th Jan. 1937: Well rounded and striated pebbles were noted and collected 7 m above the base of the Lower Tillite member in the Tømmerbugt (see fig. 2).

The pebble shown in fig. 2 is a limestone. It is astonishingly similar to the pebbles illustrated by PETTJOHN (plate 12, p. 215 of ref. 10). It was definitely taken from the rock whereby it broke in half. There is no possibility of it having been striated by recent glaciation, yet it shows the typical form of a faceted and striated flat-iron.

The fact that limestones are notably better marked than other rocks explains why striated pebbles are rare or absent in the Upper Tillite member where crystalline rocks are predominant. Random samples of pebbles collected in tillites are reported to contain only few striated cobbles: Limestones 10%, other rocks 1% (ref. 10, pp. 217—18). Thus striated rocks, though typical, are not very numerous.

Fig. 2 also shows the sub-parallel pattern of striation parallel to the long axis of the pebble which is preponderant in striated pebbles (ref. 10, p. 217).

It has been demonstrated that till stones are often oriented parallel to the ice flow. In fact the direction of ice movement can be determined



Fig. 2. Striated Pebble collected from Lower Tillite in Tømmerbugt.

by a study of the orientation of glacial pebbles. The writer had no time for such studies but the following observation was noted in the Tømmerbugt:

The larger till stones show a definite orientation. Flat pebbles lie parallel with the bedding plane. The long axes, if present, appear to lie parallel with the direction of dip (in this particular outcrop). On the pebble illustrated in fig. 2 the direction of the striae was also parallel to this direction. The pebble was lying in the matrix on its striated surface, and it can be seen that the subparallel striae are the youngest, hence

strongest. It is tentatively concluded that the ice flow was either E.—W. or W.—E., but this should be confirmed by further fabric studies. The writer has already guessed that the origin of the glaciation must be sought in the West (ref. 13, p. 49).

The description of older tillites given by PETTIJOHN (p. 222, ref. 10) could be applied almost word for word to the Greenland tillites. Only two points will be mentioned. PETTIJOHN states that the smallest rock fragments are generally somewhat more angular than the larger cobbles and boulders. The writer's observations in Tømmerbugt confirm this. Small material up to 3 cm is angular, larger pebbles sub-angular.

PETTIJOHN also states, that the tillites may include lenses of normal conglomerate and arkose, as do the younger till deposits. The tillites on Kap Oswald are no exception to this. Conglomerates and sandstones have been observed W. of the Kløftelv in the upper part of the Lower Tillite member. Similar inclusions were found in the Upper Tillite member.

PETTIJOHN gives a list of salient features (in *Italics* below) of glacial till. In the following they will be checked one by one for the tillites exposed on Kap Oswald:

1. *High range of sizes usually unsorted.*

Very apparent in Cape Oswald tillites, though not checked by grain size analysis.

2. *Shape, roundness and surface markings of rock fragments.*

a) *Usually subangular or angular with several facets.*

Checks.

b) *Some rounded pebbles or boulders.*

Checks.

c) *Fragments blunted at one end or another.*

Checks (see fig. 2).

d) *Fragments levelled on one side or more.*

Checks (see fig. 2).

e) *Concave features.*

No observations.

f) *Striated fragments.*

Present (see fig. 2).

3. *Lithology of fragments.*

a) *Greatly varied.*

Checks.

b) *More local than foreign.*

Very marked for Lower Tillite members, but not for upper Tillite.

4. *Fabric and packing of fragments.*

Preferred orientation parallel to flow.

See observations above.

5. *Matrix usually clay, usually greatly in excess of fragments.*

Checks.

6. *Lower part of till has finer matrix and more striated pebbles than top.*

At least the second part of this point checks in the tillites of Kap Oswald. Striated pebbles were found in the Lower Tillite member particularly in the lowermost beds in the Tømmerbugt, hardly any in higher parts. In the same section it was observed that the size of the pebbles increased from a maximum of 2 cm at the base to 5 cm at 2 m, to 20 cm 4 m above the base.

The pebbles in the lower part of the Upper Tillite member are also rarely larger than 1 cm.

7. *Till often rests on grooved and striated rock pavement.*

This is not the case in NE. Greenland but can be explained by assuming that the glaciers entered the sea and deposited their load there.

8. *Unstratified.*

This is certainly the case in NE Greenland.

9. *Near the top of the till, intercalated stratified lenses may be found.*

Such nests and layers are usually contorted.

Contortions were not observed, but both Tillite members include conglomerate and sandstone lenses in their upper part as mentioned already.

10. *No evidence of weathering or decomposition.*

No such evidence was found in the tillites of Kap Oswald.

11. *Chemical composition.*

We have little information on this, except that the matrix of the Cape Oswald tillites is somewhat calcareous but otherwise consists mainly of clay minerals.

Summing up this examination we can state that nine out of the eleven salient features of glacial till mentioned by PETTJOHN are present in the tillites exposed at Kap Oswald. This leaves little doubt as to their nature and origin. Much new evidence would be required to prove or even maintain the argument for a different origin. Even if the statement by H. R. KATZ (ref. 7, page 28) that the tillites show tuffogen

character can be supported by further studies, at least for Strindbergs Land, this would not disprove the essentially glacial origin of the tillites as glaciation and volcanic activity are not mutually exclusive (e. g. volcanoes in Antarctica).

One point which is puzzling is the occurrence of well rounded quartz grains as mentioned by the writer (ref. 13, pp. 29 and 32). This may be explained by loading or addition of previously sorted material, as mentioned by PETTIJOHN (ref. cit. p. 213).

All in all, there can remain little doubt that the pre-Cambrian tillites of NE. Greenland are the deposits of several large scale glaciations.

Just for the record, it might be mentioned that a cobble of grey granite was observed in the Lower Tillite member in Tømmerbugt, in the top of the member. No sample was taken and therefore not too much value can be attached to the observation which, however, underlines the fact that crystalline material is very rare if not completely absent in the Lower Tillite member.

TECTONICS

1. General.

(See fig. 3).

The anticline exposed on Kap Oswald is part of a structure which runs from Ymers Ø in the North through Suess Land and Ella Ø to Lyell Land South of Narhvalsund and was called Eastern or Border anticline by various authors (ref. 3, p. 39). To the West it is accompanied by a syncline with steep flanks and flat bottom which is well exposed in Bastionen on Ella Ø where it is about 4 km wide.

To the East of the Cape Oswald anticline, the tectonical elements of the Caledonian orogeny are hidden under the Devonian conglomerates described by H. BÜTLER (ref. 1), but there is little doubt that a wide, flat syncline existed East of the anticline. The west flank of this syncline is exposed on Ella Ø between Solitærbugt and Kap Elisabeth.

On Ella Ø, the Cape Oswald anticline has a southerly plunge which is about 25° near Kap Oswald. Thus we find the Eleonore Bay formation outcropping in its core on the north coast of the island whereas in Narhval sund the oldest exposed layers belong to the Tømmerbugt group.

2. Tectonics near Kap Oswald.

(Plate I—III).

The area mapped by the writer covers only a very small part of the Cape Oswald anticline but it gives a good picture of the folding and faulting which took place. The structural data have been assembled in the structural map (plate II) and the cross sections (plate III), and a detailed description is not necessary. Only the main characteristics shall be discussed shortly.

The Cape Oswald anticline is assymetric with a steep west flank and a more gentle southeast flank. It strikes NNE.—SSW. and plunges 25—40° southwards. In both flanks several small faults of minor importance can be observed. In addition three small folds were mapped in the core of the anticline, where stronger compression caused differential folding in apparently less competent beds. Small, sharp flexures exist also in the

limestone ridge S of Lang Lake. They hardly exceed a few meters in diameter.

Two major faults occur near Kap Oswald and complicate the simple anticlinal tectonics. Both strike SSE. and cut the formations in a steep to vertical plane.

One of them, the Kløft fault, can be studied in the steep gorge of the Kløftelv SE. of Ella Ø station where it cuts the southeastern flank of the anticline at an angle of 70° with the strike and places the Quartzite member of the Tømmerbugt group in the eastern wall opposite the base of the Lower Tillite member in the western wall, a displacement of about 850 meters perpendicular to the bedding planes. Whether the movement along the Kløft fault was horizontal, vertical or a component cannot be decided within the mapped area, nor is it possible to state which side moved and which remained in place. All that is evident is a relative displacement of one side with respect to the other which amounts to about 1200 m if it took place horizontally. The fault would be classed as left lateral according to M. L. HILL (ref. 6). The fault plane is not exposed but is probably nearly vertical. S. EHA (ref. 3) assumes an eastward dip of about 70° .

The second fault runs from Tømmerbugt in south-southeastern direction with the same strike as the Kløftelv fault. About 1 km inland it splits into two branches which enclose a narrow wedge of the southeast flank of the anticline. The wedge is approximately 250 m wide and at least 2 km long as it reaches far beyond the mapped area.

It may be noted here that the interpretation given by H. BÜTLER (ref. 2, fig. 5) is better than the one by S. EHA (ref. 3, fig. 14). The western branch of the Tømmer fault passes to the W. of the small hill mentioned by EHA which is part of the wedge lying between the fault branches.

The displacement of the Tømmer fault is about 400 m along the eastern branch, about 100 m along the western branch, measured horizontally in both cases. The western branch, for instance places the yellow sandstone (bed 26) of the Inter-tillite member in the eastern wall against the Banded Dolomite member in the western wall. This represents a stratigraphic interval of about 250 m. The fault is also a left lateral.

The Tømmer fault, however, affects not only the southeast flank of the anticline but also its axis which is displaced about 250 m southwards on the west side of the fault in comparison to the east side. From this it can be deduced that the movement along the Tømmer fault had a strong horizontal component (approximately 200 m). However, there is also a vertical component, and calculation shows that it amounted to approximately 260 m. This is somewhat in contradiction with the

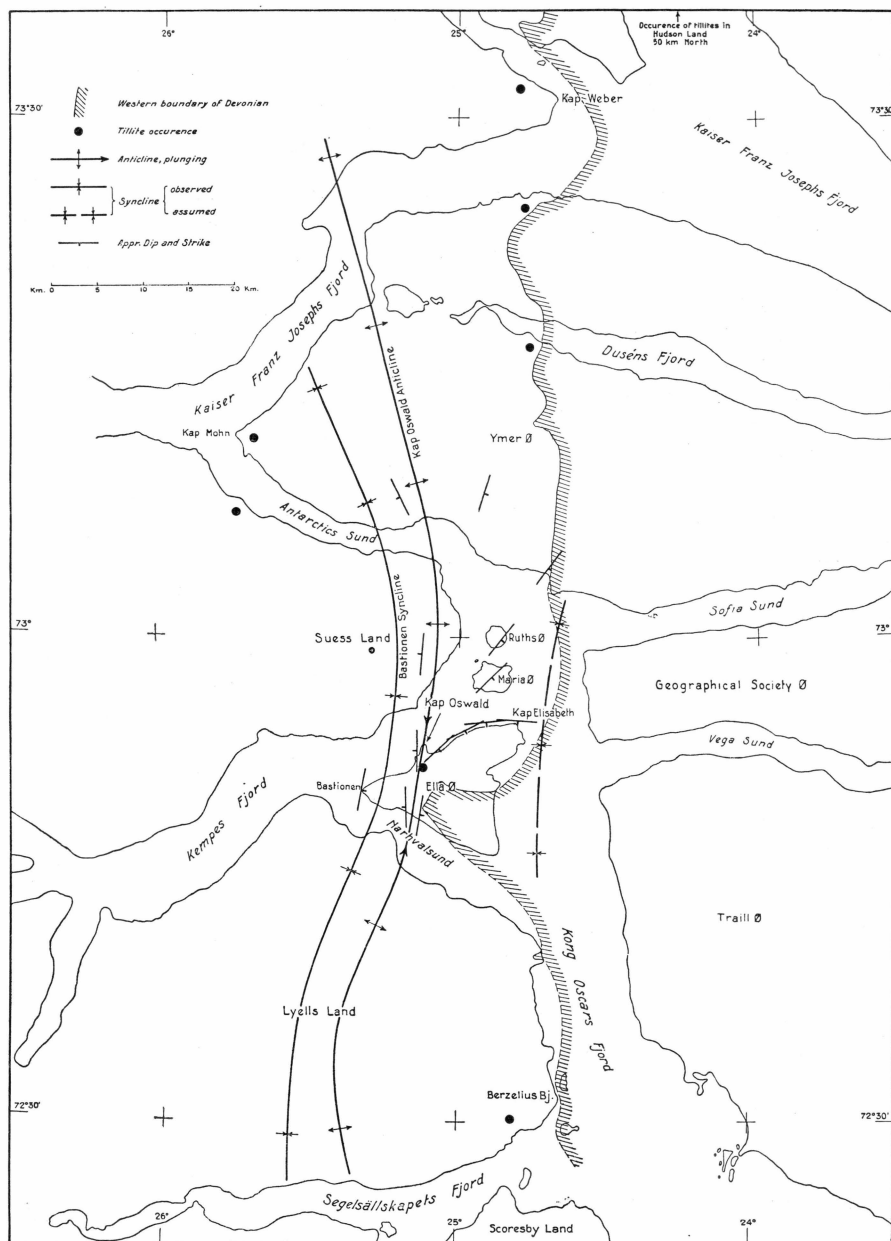


Fig. 3. Sketch Map showing the situation of Ella Ø and Kap Oswald Anticline.

statement by S. EHA that "the movement mainly followed vertical components" (ref. 3, p. 64).

The tectonical conditions in the neighbourhood of pt. 95 m make it probable that it was the western side of the fault which moved

while the eastern side remained in place. This is indicated by the steep folding and compression of the beds exposed at pt. 95 m which seem to be dragged along the fault plane. Also the fault wedge mentioned above lies to the West of the main fault plane. In the writer's opinion this supports the idea that it was the western side of the fault which was the moving block.

Taking the above data and assumptions into account we come to the conclusion that the western side of the Tømmer fault was pushed southward and at the same time upward at an angle of about 50 degrees. The upward movement seems to be proven by the considerable extension of the Eleonore Bay formation W. of the Tømmer fault, on the plunge of the anticline, which cannot be ascribed to horizontal displacement alone.

Tømmer fault and Kløft fault belong apparently to a fault system. A similar, though smaller fault exists outside the mapped area about 1.3 km E. of the Kløft fault, and about 2.5 km E. of the latter there is another fault of considerable displacement which brings Cambrian limestones on its east side opposite the uppermost beds of the Tømmerbugt group (see ref. 2, fig. 5). This fault is plainly visible from the distance because it cuts off the terrace formed by erosion of the soft Cambrian shales overlying the Quartzite member of the Tømmerbugt group. Both faults dip nearly vertically and have approximately the same strike as the Kløft fault.

Since all these faults are similar in strike, dip and resultant displacement it is reasonable to assume that they belong to a system of faults of equal age. It can also be assumed that the movement was similar along all of them, i. e. the western side was pushed southwards and upwards with respect to the eastern limb. The faulting resulted in a stretching of the Cape Oswald anticline (± 200 m along the Tømmer fault, perhaps 350 m along the Kløft fault) and counteracted the southerly plunge (Tømmer fault by over 260 m, Kløft fault possibly by 600 m). The stress causing these big shear faults would seem to have come from the West and from below.

According to the geological map of S. EHA (ref. 3, plate 2), this fault system seems to be restricted to Ella Ø though one would perhaps expect it to continue to Suess Land.

3. Joint, Fractures, Faults.

When the writer began to map the Cape Oswald anticline he noted the great number of joint planes intersecting the bedding planes and each other. Several hundreds of joints and bedding planes were measured during the field work, notably along the limestone ridge striking from

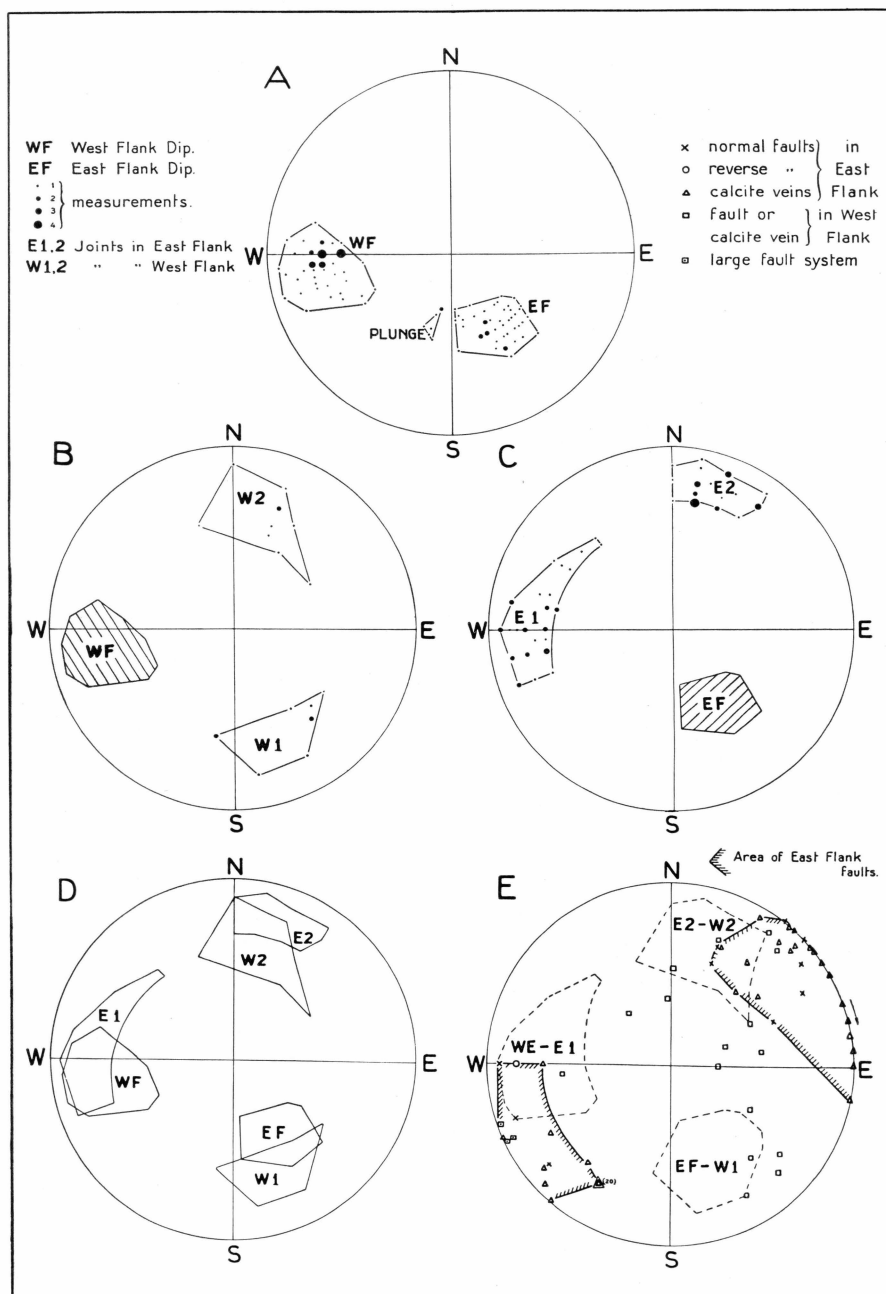


Fig. 4. Projections of Bedding Planes, Joints and Faults measured on Kap Oswald.

Tømmerbugt S. of Langsø to Solitærbugt and along the coast of Kap Oswald. They were later assembled in diagrams in order to see whether the joint systems had any relation to folding or faulting (see fig. 4).

In diagram A¹⁾ the various dip measurements have been assembled. Accordingly the figure shows three groups of points, one belonging to the south-east flank, one to the west flank and a small one representing the axial dips.

In diagram C the joints measured in the southeast flank are assembled with the dips of this flank. Field observations had shown that several types of joints, veins and small faults could be distinguished. Two groups of joints shown are characterized by smooth, plane surfaces which are spaced approximately one meter apart or sometimes less, and slice cleanly through the formations. No displacement of the surrounding beds could be noticed but often there was a little separation of the walls of the joints, filled in many places with thin calcite veins (1—10 mm). The average dip of these joint systems is 70° N. 20° E. and 65° W. respectively.

Diagram C shows clearly that these joints form a system of 3 intersecting planes with the bedding planes. Often, the bedding planes also are accompanied by thin calcite veins filling a narrow space between the beds. These joints occur in all formations, as far as could be observed, but they are not always as well visible as in the limestones.

In addition we find on the southeast flank another type of fractures which are wide, steep and filled by irregular calcite veins varying in thickness from 0.1 to 2.0 m. Often they are associated with fault breccias and it seems that some movement took place along these fractures though it was not great. The veins occur frequently in great number over a small distance and they are accompanied by feather fractures. They have mainly been observed in the ridge of resistant limestone S. of Langsö, not in other formations. This may, however, be due to lack of observations in other parts of the structure. The measurements of these faults and veins have been assembled in diagram E. It is interesting to note that their general strike varies from SE. in the region E. of the lake to S in the crestal zone S of Rundö (indicated by the arrow in diagram E) while their dip is always steep, mostly around 90 degrees. They strike approximately perpendicular to the strike of the beds.

¹⁾ The following projection was used to obtain diagrams A—E:—

It was assumed that all planes to be represented intersect in one point which is the center of a sphere. The normals of all planes would then intersect the sphere at determined points and these could be projected on a horizontal plane by use of W. SCHMIDT's equal area projection.

A different procedure was used to obtain fig. 5. Here the directions of dip measured on faults, east flank joints and west flank joints were assumed to intersect in the centre of a circle. In each group the greatest number of measurements falling into any one direction were put equal radius of the circle, and the numbers of measurements in other directions plotted proportionately. In addition the average direction of dip on the plunge and the two flanks of the anticline were indicated.

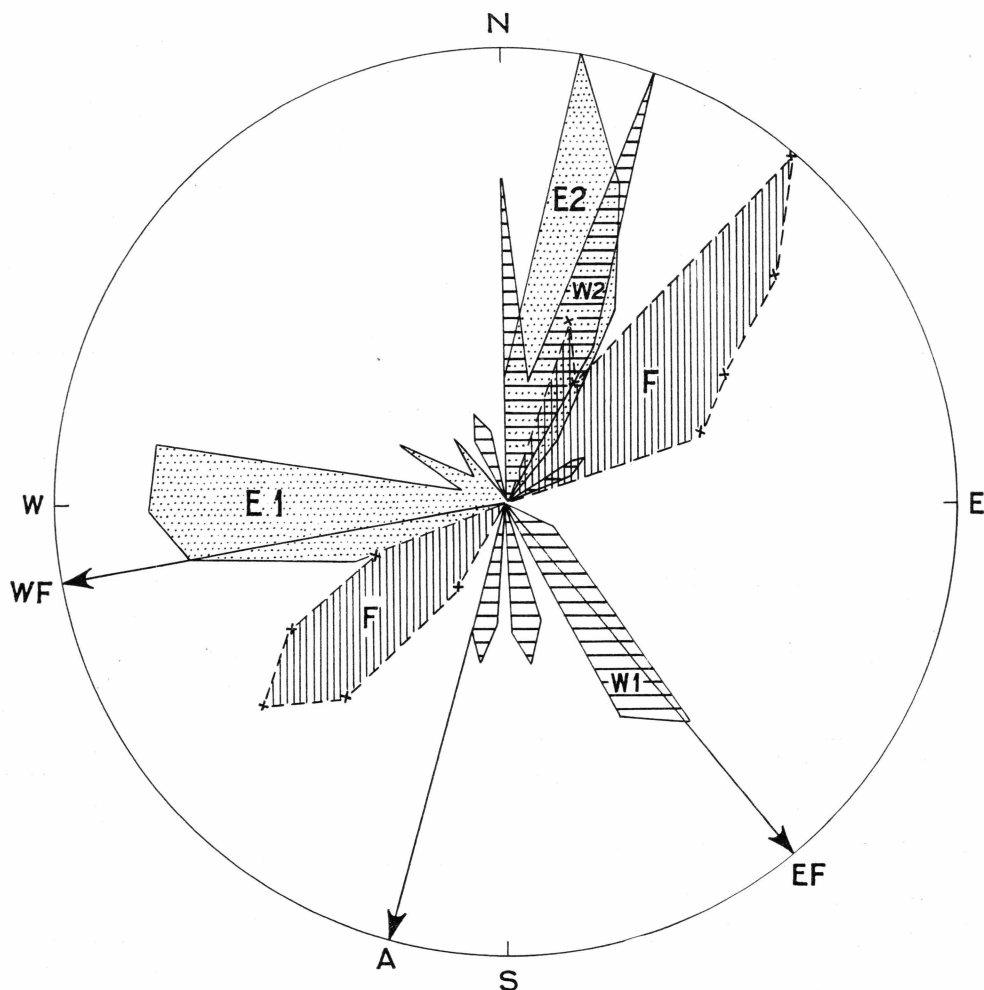


Fig. 5. Diagram of Fault and Joint Systems.

The writer has little doubt that they are tension fractures intimately related to the mechanism of folding. As they cut and displace the joints described above it is evident that they must be somewhat younger than the latter.

A well developed system of joints was also observed in the west flank of the anticline, though fewer measurements are available than on the east flank. The measurements have been assembled in diagram B and here, too, it is obvious that two groups of approximately parallel joints form a system together with the bedding planes. The joints show smooth, plane surfaces cutting cleanly through the beds. Thin calcite veins may fill them and are also found along some of the bedding planes.

Comparison of diagrams B and C (see diagram D) shows that the joint systems on the two flanks correspond closely if we disregard small displacements due to steeper dip of the west flank. Joint plane E-1 of the southeast flank takes the place of the west flank bedding planes and vice versa. This fact may give a clue to the origin of the jointing. In the writer's opinion it must be explained as shear jointing which oc-

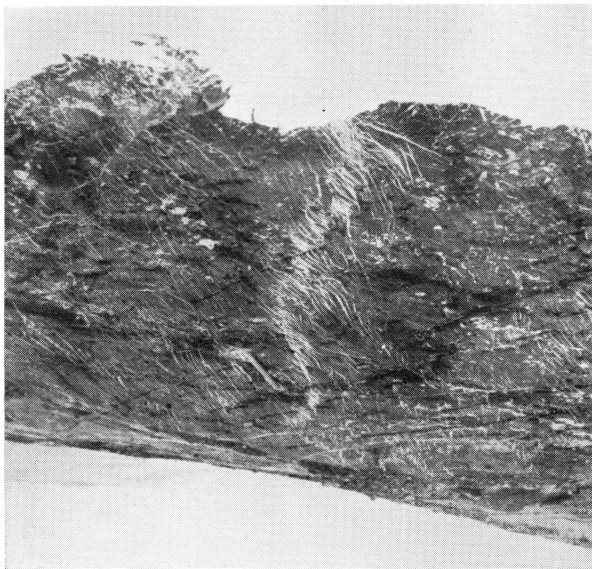


Fig. 6. Feather fractures W. Rundso.

curred during the folding but at an earlier moment than the tension fractures described from the southeast flank.

Diagram E shows, in addition to the combined fields of the described joint systems, the faults and fractures with observed displacement. The many fractures measured in the SE. flank stand out conspicuously, mostly vertical but straying somewhat either way. Small normal and reverse faults of the SE. flank seem to be associated with them. The change in the strike of these fractures has already been mentioned.

Some fractures and small faults fall into the fields of the joint systems. This seems quite normal as the joints formed during the faulting must have been predisposed, as it were, for later movements. The majority of these fractures, however, fall into a separate field shown in diagram E.

The large fault system seems rather closely associated with the fractures in the SE. flank of the structure, though they have been shown on the opposite side of the diagram. This may find its explanation in the

assumption that the relatively gentle and broad SE. flank of the Cape Oswald anticline presented the main resistance against forces acting from the NW., which therefore caused further rupture along existing planes of weakness in the SE. flank.

Small faults were also observed in the W. flank. These have also been shown in diagram E, however, they seem too strong and do not fall into any well-defined field.

Fig. 5 shows the distributing of joints and small faults on both flanks in some more detail. It can easily be seen that the joint direction 2 of each flank coincides and cuts the axis of the anticline at right angles while the other two joint directions coincide approximately with the general dip of the opposite flank. The small faults are clearly independent and cut the SE. flank at approximately right angles.

Finally, it can be mentioned that the limestones are strongly broken and splintered along the axis of the anticline. All limestone ridges are obliterated due to this in the area S., SW. and W. of Rundstö. Feather fractures are common in this area (see fig. 6).

4. Conclusions.

The preceding consideration of the tectonics at Kap Oswald makes it fairly clear that strong tectonical movements took place at two different times:

1. Folding with jointing. Tension fractures form at a later stage of the folding.
- b. Shear faulting.

While the folding belongs to the Caledonian orogeny the age of the faults is not as easily defined. It cannot be determined in the mapped area but H. BÜTLER's (ref. 2) and S. EHA's (ref. 3) studies indicate that these faults cut the Devonian basal conglomerates though to a lesser degree than older rocks. A Devonian to post-Devonian revival of the faults seems probable but the main movement should be pre-Devonian.

A third tectonical phase may be indicated by the smaller faults.

The writer has considered the question whether the joint systems might have been present before the faulting took place. This does not seem very probable. It would require that the joints present on both flanks should fall into the same place after the anticline has been smoothed out and the beds returned to their original approximately horizontal position. The writer has submitted this problem to Dr. W. L. SCHEEN, The Hague, who was kind enough to make some calculations. These showed that some differences would show up if the joint planes were

turned together with the bedding planes but they are within the limits of the different strike directions occurring in the joint systems, and therefore no conclusion can be drawn. However, it is very probable that the jointing was caused by the folding of the anticline.

It is obvious that much information can be gained from a careful study and analysis of faults, fractures, small folds and joints but it is recognized that only a beginning has been made and that many more observations will be needed to give an accurate picture of the tectonics of Kap Oswald.

MORPHOLOGY

Any landscape is influenced by four groups of factors which can be summarised in the order of their importance, as follows:—

1. Nature of underlying rocks.
2. Tectonics of underlying rocks.
3. Erosional forces active in area.
4. Stage of development.

We shall now try to outline these influences on Kap Oswald. The mapped area is very small but has the advantage that it can be studied in detail.

1. Influence of Underlying Formations.

The different beds of the sequence underlying the Kap Oswald area differ widely in their composition, texture, and bedding and consequently in their resistance against weathering and erosion. As a result each of them shows characteristic erosion profiles which appear clearly on the cross sections (plate III). Some instances may be cited:

The Cryptozoon limestones are less impure than the surrounding black limestones. Hence they are more rapidly eroded and form shallow trenches between the neighbouring, more resistant beds, probably mainly due to solution.

The nearly unbedded Lower and Upper Tillites members are more resistant to erosion than the over and underlying beds. They form conspicuous ridges, sometimes with typical dip and face slopes. The same is true for the reddish sandstone (Quartzite member, lower part of Bastion formation) at the top of the Tillite series which is quartzitic and also nearly unbedded (Sect. 1, plate 3).

Contrariwise the more slaty parts of the Eleonore formation, the soft shales underlying the lower Tillite, and the shales and sandy shales between Lower and Upper Tillite are easily eroded and form wide valleys or talus covered slopes under the outstanding ridges of the harder formations.

2. Influence of Tectonics.

In accordance with the tectonical movements which have been active in the Kap Oswald area we find that the morphological picture is mainly influenced by folding and faulting. The joint systems have been of little importance.

Different dip due to folding is responsible for the different morphological aspect of the same beds on the west and southeast flanks of the Kap Oswald anticline. A good instance for this is provided by the Lower Tillite member which forms rounded hogback ridges on the steep west flank, typical *cuestas* with inclined dip slope and steep face slope on the southeast flank. While the former do not indicate the direction of the dip but only the strike both dip and strike can be easily observed on the latter.

The faults observed near Kap Oswald had a strong influence on the erosional processes. Fig. 9 shows clearly that both Storeelv and Kløftelv follow partly the two main faults. It is very probable that the course of the former was even more determined by the fault before the glaciation when the Storeelv flowed towards Tømmerbugt.

3. Active Erosional Forces.

Many erosional forces have been or are at work in the Kap Oswald area: Flowing water, flowing ice, wave action, chemical solution, action of freezing water, to mention only the most conspicuous.

All these agencies are strongly influenced by the severe climate of Northeastern Greenland. Flowing water does not exist during a great part of the year, the action of the waves, of freezing water and of solution are all nearly non-existent during winter. The action of flowing ice, on the other hand, was dependent on a still colder climate and does not occur on Ella Ø today.

River erosion has had great influence on the morphology of Kap Oswald both before and after the glaciation. The deep gorges cut by the bigger rivers can be attributed to the interval since the retrocession of the glaciers, but the valleys themselves had been formed as unimportant branches of the great valley which is now the Kempes Fjord.

The importance of river erosion can be judged by the amount of float which has been deposited mainly by the Storeelv, since the glaciation and in several stages. Its present delta and alluvial fan are more than $1\frac{1}{2}$ km long.

The action of freezing water, though restricted to spring, summer and autumn, adds much to the disintegration of the rocks. It is assisted by the intensive jointing and by the slaty nature of many beds. The

large cones of debris occurring along the steeper slopes are a measure for its efficiency.

Wave action can be observed everywhere along the shore of the Kap Oswald peninsula. High wave-cut cliffs, partly with deep undercuts can be observed around Kap Oswald where the more resistant formations reach the coast line (see fig. 7). In Tømmerbugt the waves have cut under glacial deposits and caused them to break down. Of



Fig. 7. Wave-cut cliff between station and Kap Oswald. A thick cornice of wind blown snow is overhanging the cliff.

course the cliffs are not as high as they might be on an open coast but they are an indication that sea level has been stationary within narrow limits for considerable time.

Along the flat beaches of Solitær and Tømmerbugt the wave action was not erosional but results in the formation of shore bars which reach up to one meter in height. They consist mainly of rock fragments derived from the surrounding cliffs and may dam off a flat, swampy part of the beach as is the case near Ella Ø station.

Wave action is probably assisted by the action of the fjord ice in winter time. The movements of the fjord ice, due mainly to the tides and to currents, result in piling the ice on to the beaches and against the cliffs, and there is little doubt that this helps in eroding the cliffs and throwing up the shore bars.

The influence of flowing ice on the landscape of Kap Oswald has been considerable. A distinction must be made between the general

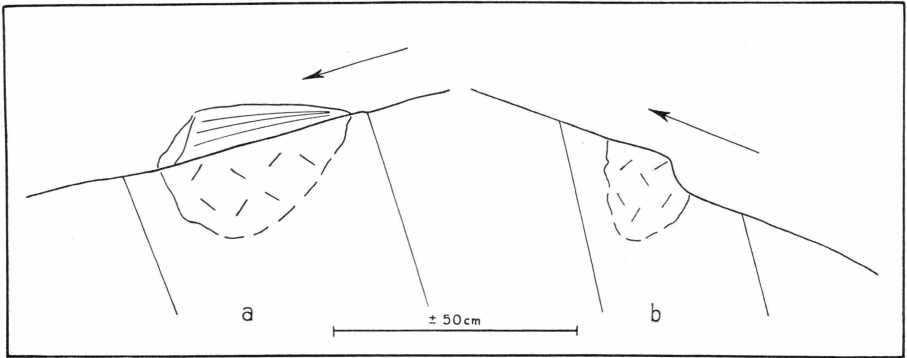


Fig. 8. Silicified parts of Eleonore Bay formation resist glacial abrasion.

glaciation which is responsible for many of the characteristics of the fjord landscape and small local glaciers existing on Ella Ø during a later stage of this glaciation.

Kap Oswald is, of course, much too restricted an area for a study of the great glaciation. Its local influence consisted of abrasion and rounding of the resistant formations, the widening of monoclinical valleys in the less resistant beds and deposition of a thin moraine cover in the areas protected from direct scouring by the ice. Thus the hill at Kap Oswald itself shows beautiful striation in many places. The abrasion must have been considerable because the silicified parts of the Eleonore Bay formation which are very hard, protrude up to 10 cm above the striated plane. On the side from which the ice came they are pointed and striated while the opposite side is abrupt (see fig. 8).

In other places the silicified knobs protected a small ridge of lime stone against abrasion. This shows clearly that flowing ice attacks underlying rock by abrasion and it can be assumed that this was also the case on the floor of the large valleys which are now filled by the fjords. They were probably deepened considerably by the force of the great weight of ice moving through them.

The big glaciation also widened the lower Storeelv valley and scooped out the small basins of Rund and Langsö. A thin cover of ground moraine was left by the glaciation, mainly in the depressions formed by the softer formations. This cover supports the scarce vegetation of the area. In two places (E. of pt. 95 m and S. of Tømmerbugt) the valley of the Storeelv was filled with thick deposits of moraine material which deviated the river into a new course after the recession of the ice. It is interesting to note that the old valley ran perpendicular to the flow of the main glacier (Northeast) and provided thus a protection against the scouring action of the glacier. The new course of the river was either cut deeply into the rock (at pt. 95 m) or deviated into

a monoclinial depression already deepened by the glacier (lower Storeelv) (see fig. 9).

The area of Kap Oswald is, however, of peculiar interest because it is one of the few spots in Northeastern Greenland, excepting the valleys at the heads of the inner fjords, where moraines of the retreating glaciation can be observed. The frontal moraines of the greatest extension of the ice lie certainly outside of Northeast Greenland's east coast. Perhaps they were deposited as marine sediments comparable to the pre-Cambrian Tillites. Moraines belonging to the retreating glaciers, if present, are mostly hidden at the bottom of the fjords. On Ella Ø, however, a small glacier existed for a long time after the main glacier had retreated into the interior of Kempes Fjord. It was situated in the protected corner NE. of Bastionen, just S. of Kap Oswald, which is open towards North only.

This glacier filled the monoclinial valleys between the more resistant ridges of the Cape Oswald anticline. It threw up a frontal moraine which bars the natural outlet of the Ulvesø towards Storeelv. The water of the lake was thus deviated toward a new outlet along the Kløftelv fault but had to cut a deep channel into the intervening formations. Another part of this moraine bars the Bjørnesø (see fig. 7).

A landslide which can be observed in the same area dates from a later stages of the local glacier. The recession of the ice must have caused many land slides because the glacial erosion had shaped very steep mountain walls but the ice had also supported them. After the retreat of the glaciers many parts were liable to break down. The particular land slide descended from Bastionen where the scar can still be seen. It consists of Cambro-Ordovician limestone blocks which are easily recognized on the beds of the Tillite series.

Near Bjørnesø the slide extends as far as the frontal moraine of the local glacier. From there it stretches westwards over hills and creeks with several salients. On the ridge of the Lower Tillite S. Tømmerbugt a number of the boulders are found in an isolated patch ahead of the main part of the land slide. This distribution shows clearly that the slide broke down at a time when part of the local glacier was still existing. The blocks slid over its surface and were thus spread over hills and depressions and generally much farther than would have been the case otherwise.

4. Stage of Development.

As most landscapes, Kap Oswald is not the product of one single cycle of erosion. The starting point for Northeast Greenland's present morphology was probably a peneplaned surface on which erosion was renewed after considerable uplift. The old peneplain is beautifully visible

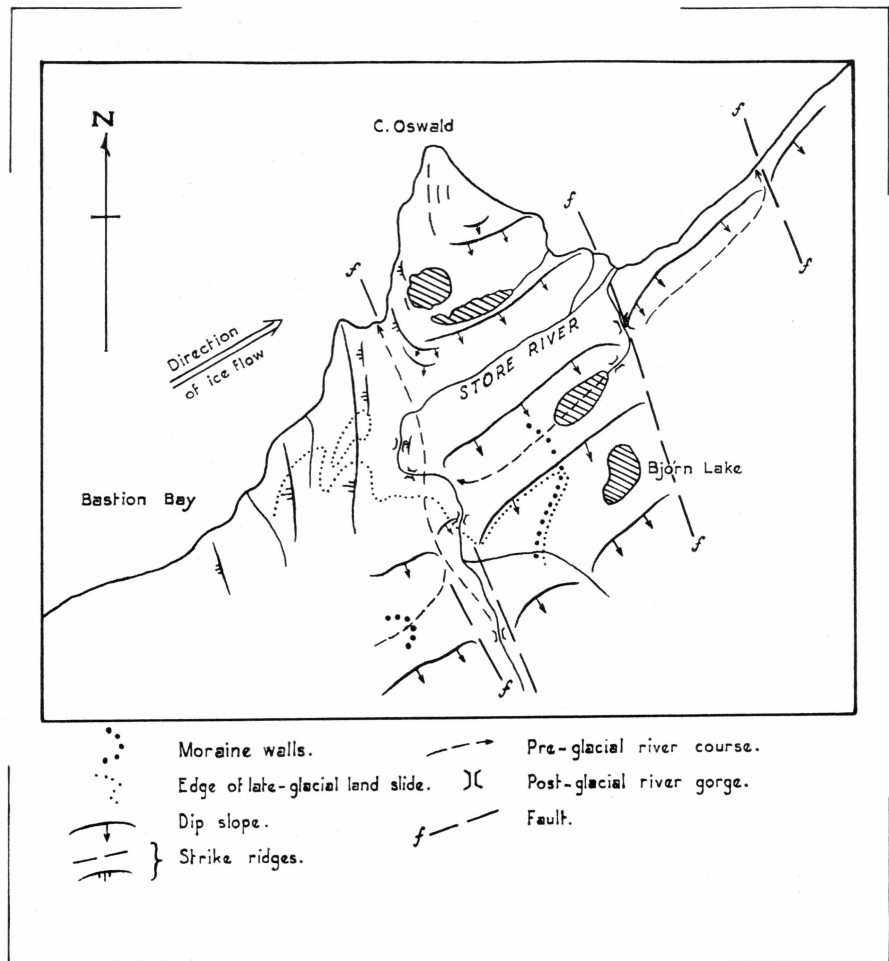


Fig. 9. Sketch map of morphological features observed in Kap Oswald area.

on aerial photographs of the area and is represented by the large flat tops of the highest summits. The resulting valley system had not yet reached maturity at the beginning of the glaciation since large areas of the old peneplain were not destroyed.

When the glaciation set in, the great valleys were widened and deepened by the glaciers. By removing the debris from the flanks of the valleys they made retrograde erosion possible and left nearly vertical mountain walls. During or after the retrocession of the glaciers the large valleys were drowned either by subsidence or by a general rise of sea level due to the release of water from the large glaciated areas or by a combination of both. Fluvial erosion was renewed but from a very different base level. It follows in general the lines of the previous

cycle and the resulting landscape e. g. at Kap Oswald has therefore not a very young aspect while the fjord landscape in general is dominated by the old peneplain intersected by the deep fjord valleys with their perpendicular walls, an opposition which is very startling and provides a thought-provoking problem for the geomorphologist.

These phenomena, can, of course, not be adequately treated on the basis of such a restricted survey but some smaller changes in base



Fig. 10. Shore-bars at Ella Ø station.

level left their traces on Kap Oswald. It is well known that sea level was considerably higher after the glaciation than nowadays. Subrecent marine deposits containing *Mytilus edulis* L. and other shells were found at elevations considerably above sea-level (ref. 9).

Today's sea level was reached in several stages, some of which can be observed in the Kap Oswald area.

In the lower part of Storeelv valley we find three terraces situated approximately at 30—40 m, 45—50 m, and 55—60 m above sea level respectively. The two higher ones (stages 1 and 2) are the remainders of deltas (see Plate 1). They have a slightly inclined surface and relatively steep edges (8—13°) towards the sea. The latter are the submarine slopes of the former deltas. They contrast sharply with the steep erosional escarpments which the river cut later into the terraces.

The lowermost terrace (stage 3), although undoubtedly part of a delta, shows no original submarine slope since most of it has been eroded by the river.

It is interesting to note that during stage 1 and 2 the Storeelv flowed into an arm of the fjord which separated two small islands at Kap Oswald from Ella Ø. The canyon cut by the river into the Eleonore Bay formation W. of point 95 m dates from the second stage and later times. The valley floor of the first stage can be observed on top of the outcrops near point 95 m and corresponds to the level of the highest delta.

It can be concluded that the sea-level was stationary for some time at the respective elevations of the three deltas. During the interval between stage 3 and the time when the recent level was reached a more gradual uplift must have taken place. This is shown by a succession of raised beaches which are indicated by their shore-bars.

Thus 25 old shore-bars can be counted in the low saddle between Rund sø and Tømmerbugt between sea level and an elevation of 19 m. 35 shore-bars, mostly very small, were counted between sea level and 12 m at the winter station (see fig. 10). Recent shells occur at an elevation of 34 m (S. Station) and 38 m (N. of Rund sø), in both cases on moraine material.

5. Conclusions.

Obviously the Kap Oswald area is too small to reach general conclusions regarding uplift and subsidence of Greenland as a whole. It is believed that a regional study of these phenomena together with the other morphological characteristics would allow very interesting deductions on the relative movements of the island. It is now known that the ice cap does not lie on an elevated highland but fills a deep trough reaching below sea level in the place where the ice is thickest. The question arises whether this trough existed already before the glaciation or was formed under the heavy weight of the accumulating ice. If it existed before the glaciation began, where was the watershed between the interior basin and the river system on the east flank of the Caledonial mountains? What was the cause for the rejuvenation of the landscape after the very strong peneplanation? How deep were the resulting valleys before the peneplanation and how much were they deepened and over-deepened by the glaciers? Many of these and other questions can probably not be answered because the necessary data are not available but the answers should be sought in as much as possible.

REFERENCES

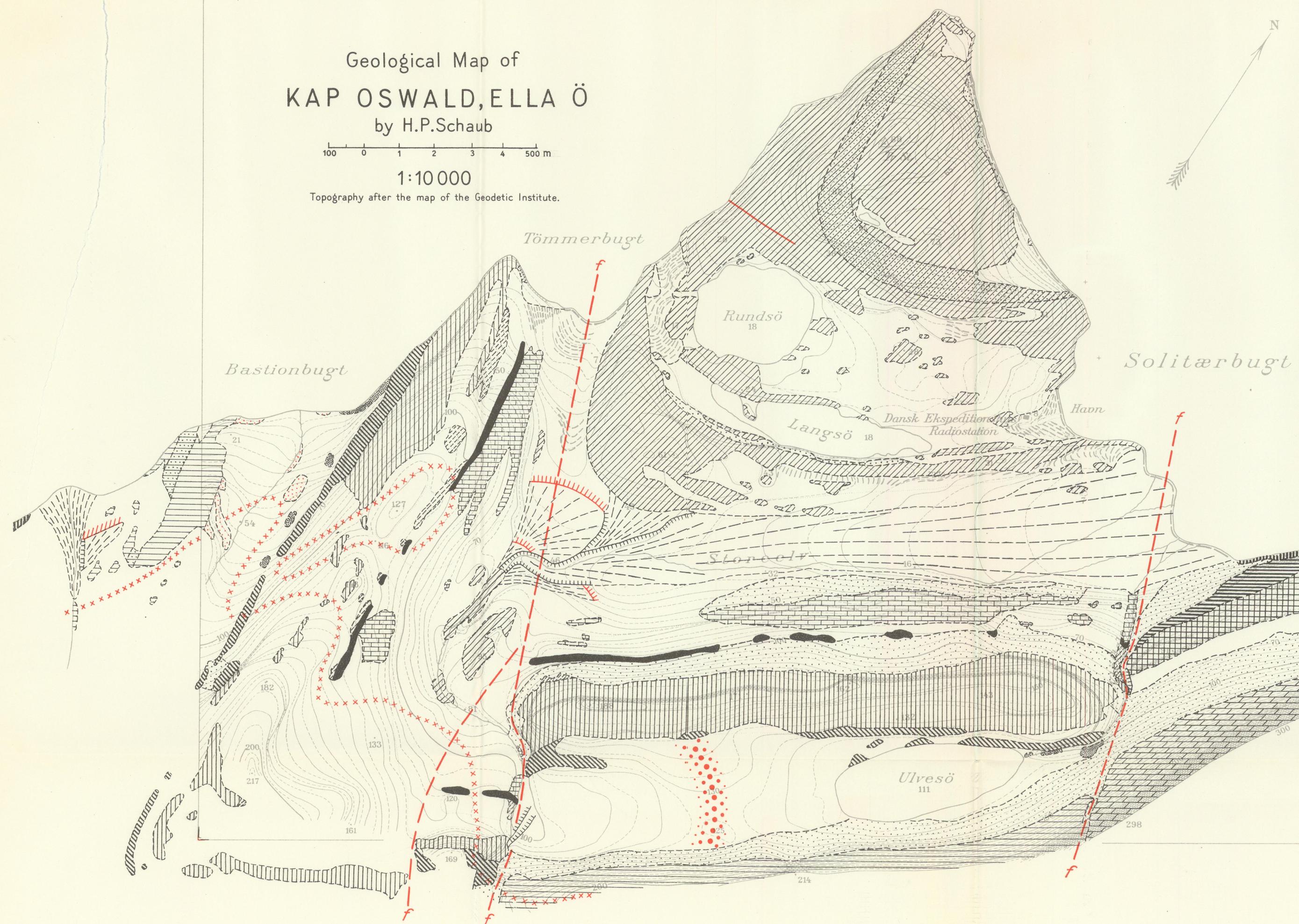
1. BÜTLER, H. Some new Investigations of the Devonian Stratigraphy and Tectonics of East Greenland. M. o. G. vol. 103, no. 2, 1935.
 2. — Erläuterungen zu einigen Bildern der Ellainsel in Ostgrönland. Mitt. Naturf. Ges. Schaffhausen, Heft XIII, 1937.
 3. EHA, S. The pre-Devonian Sediments of Ymer Ø, Suess Land and Ella Ø (East Greenland) and their Tectonics. M. o. G. vol. 111, no. 2, 1953.
 4. FENTON, C. L., and M. A. FENTON. Belt Series of the North: Stratigraphy, Sedimentation, Paleontology. Bull. Geol. Soc. of America, vol. 48, 1937, pp. 1873—1970.
 5. FRÄNKEL, E. Geologische Untersuchungen in Ost-Andréas Land (NE.-Grönland). M. o. G. vol. 113, no. 4, 1953.
 6. HILL, M. L. Classification of Faults. Bull. Amer. Assoc. of Petr. Geologists, vol. 31, 1947, pp. 1669—73.
 7. KATZ, H. R. Zur Geologie von Strindbergsland (NE.-Grönland). M. o. G. vol. 111, no. 1, 1952.
 8. — Ein Querschnitt durch die Nunatakzone Ostgrönlands (ca. 74° n. Br.). M. o. G. vol. 144, no. 8, 1952.
 9. NOE-NYGAARD, A. Remarks on *Mytilus edulis* L. in raised Beaches in East Greenland. M. o. G. vol. 95, no. 2, 1932.
 10. PETTJOHN, F. J. Sedimentary Rocks. Harper & Brothers, New York, 1949.
 11. POULSEN, CH. Contributions to the Stratigraphy of the Cambro-Ordovician of East Greenland. M. o. G., vol. 74, 1930.
 12. — The lower Cambrian Faunas of East Greenland. M. o. G. vol. 72, 1934.
 13. SCHAUB, H. P. On the pre-Cambrian to Cambrian Sedimentation in NE.-Greenland. M. o. G. vol. 114, no. 10, 1950.
-

Geological Map of KAP OSWALD, ELLA Ö by H.P.Schaub

100 0 1 2 3 4 500 m

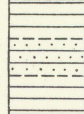
1:10 000

Topography after the map of the Geodetic Institute.



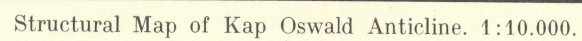
Legend:

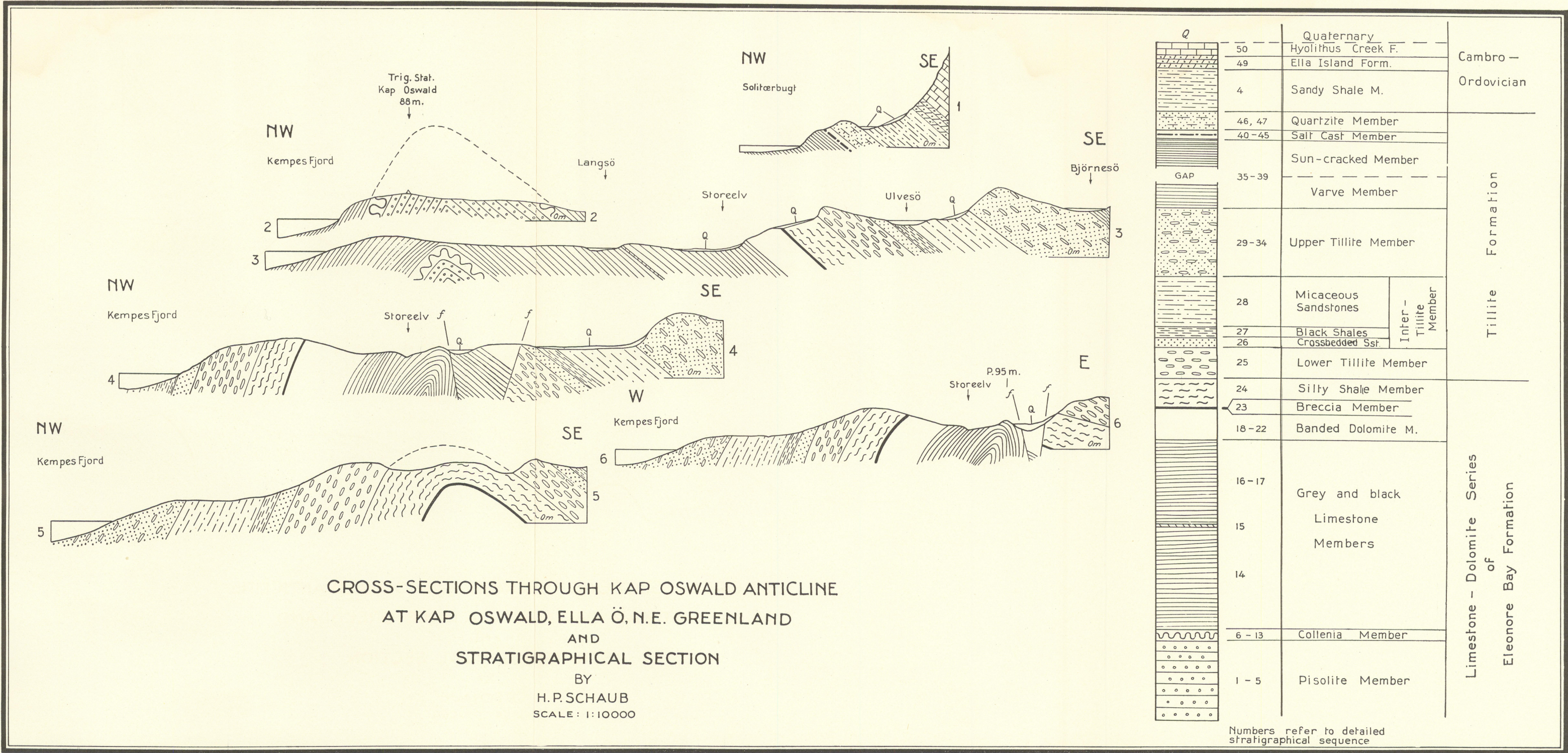
- Fault
- Moraine
- Boundary of late glacial landslide material
- Alluvial fans
- Talus
- Glacial deposits
- Edge of raised delta
- Escarpment
- Recent shore bar
- Raised beaches

Beds	Detailed subdivision (ref.13, 1950)		Subdivision 1953 (ref.5)	
		Cambro-Ordovician	Cambro-Ordovician	
	46, 47	Quartzite Member	Sandstone Series	Tillite Formation
	40 - 45	Salt Cast Member	Spiral Creek Series	
	36 - 39	Sun-Cracked M.	Canyon Series	
	29 - 34	Upper Tillite M. with intercalated sandstone	Tillite Series	
	28	Micaceous sandstones		
	27	Black, fissile shales		
	26	Crossbedded sandstone		
	25	Lower Tillite M.		
	24	Silty Shale M.	Limestone-Dolomite Series	(Upper) Eleonore Bay Formation
	23	Breccia Member		
	18 - 22	Banded Dolomite M.		
	14 - 17	Grey and Black Limestone Members		
	6 - 13	Collenia Member		
	1 - 5	Pisolite Member		

Note:

Bed 35 is not exposed in area mapped. Numbers refer to detailed stratigraphical sequence (ref.13).





Cross Sections through Kap Oswald Anticline. 1:10,000.