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DE DANSKE EKSPEDITIONER TIL ØSTGRØNLAND 1936—38

UNDER LEDELSE AF LAUGE KOCH

ON THE PRE-CAMBRIAN
TO CAMBRIAN SEDIMENTATION
IN NE-GREENLAND

BY

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WITH 10 FIGURES IN THE TEXT AND 1 PLATE

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INTRODUCTION

In 1936 the writer had the opportunity to join the Danish Two-Year Expedition to Northeast Greenland under the leadership of Dr. LAUGE KOCH. His main task was to map the post-Devonian formations of Traill Ø and Geographical Society Ø jointly with H. STAUBER. This was done in the autumn of 1936 and the spring of 1937. The winter months were spent at the expedition's base on Ella Ø and during this time the writer mapped the area surrounding the station.

The station is situated on the north coast of Ella Ø, about 1 km SE of Kap Oswald, a low promontory formed by the core of an anticline which traverses the island from N to S (see figs. 1 and 2), and which is a well exposed subject for tectonical studies within easy walking distance from the winter house. Additional interest was provided by the stratigraphical sequence of the area which reaches from beds of probable pre-Cambrian age into the Cambrian and includes two thick bodies of tillites. Since the Pre-Cambrian is not metamorphic and since no major unconformity had been found at the base of the Cambrian, a stratigraphical investigation could be expected to yield interesting data on the conditions prevailing in NE Greenland in those remote times when the Caledonian geosyncline was forming (ref. 11).

The field work was started in November 1936 and carried on into February 1937. At a northern latitude of nearly 73° this means very short days and severe cold. Only during one or two hours at midday does it get light enough to make observations in the field. Many snow storms interrupted the work, but the snow does not usually impede the mapping as it is blown away by the fjord winds and hardly accumulates on outcropping rock. The intense cold, however, is not conducive to detailed observation. Many parts of this paper must therefore necessarily be sketchy, but it should nevertheless prove that useful work can be done in selected areas of NE-Greenland even in winter.

The area was mapped to the scale of 1:10,000 on the basis of a topographical map surveyed in previous years by the Danish Geodetic Institute, Copenhagen. About 300 samples were collected and most of them were later thin-sectioned, though a number of them were lost in

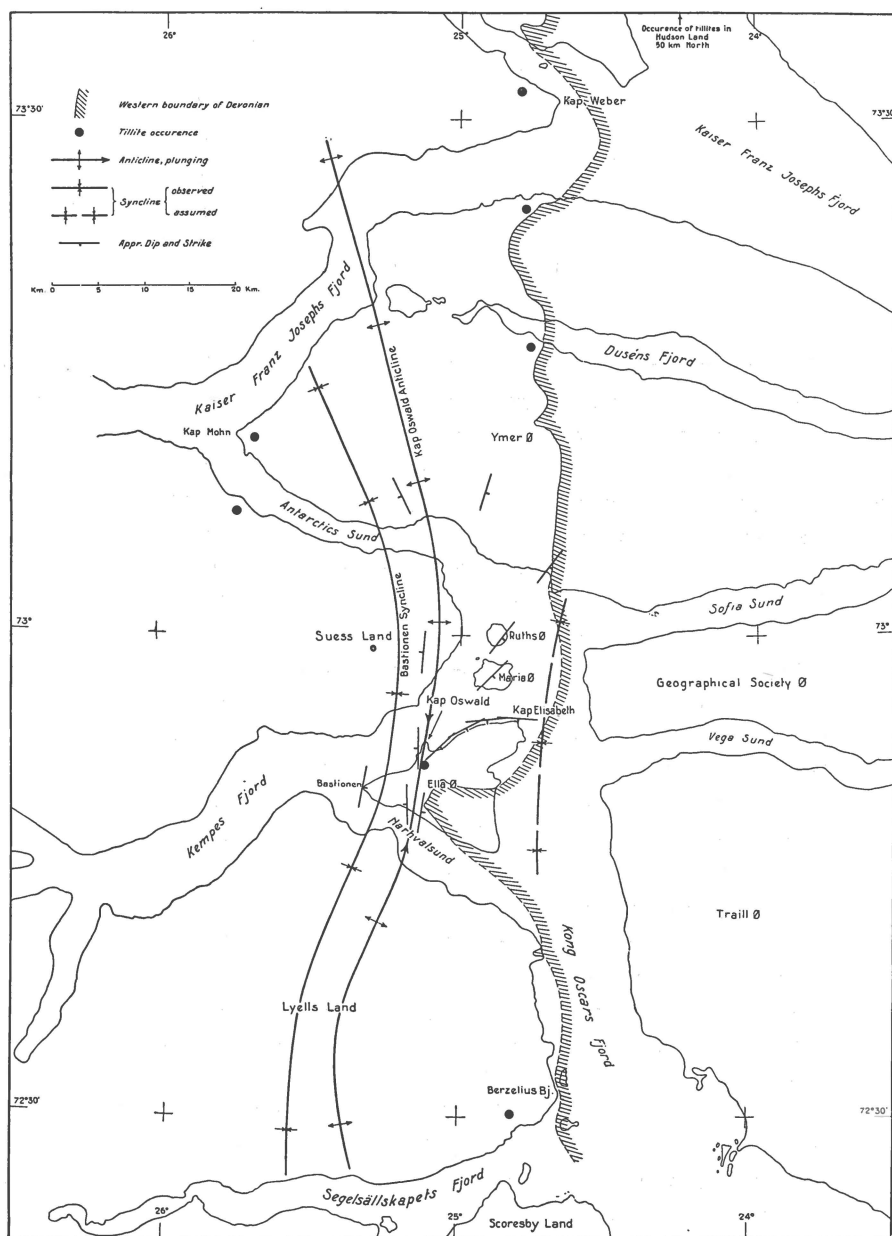


Fig. 1. Sketch map showing the situation of Ella Ø and tillite localities known in NE-Greenland.

transit. Map, field notes and thin sections are the basis for the present report which was written in 1949 at Stanford University, California. The samples themselves were not available at that time but had been studied macroscopically some years before.

The writer wishes to express his sincere thanks first of all to Dr. LAUGE KOCH, the leader of the expedition, to whose initiative most of the recent geological investigations of NE Greenland are due. He is grateful to Drs. C. E. WEGMANN and H. BÜTLER for helpful advice and encouragement, and to the crew of Ella Ø station, in particular to Mag. TH. HEINRICHSON and Dr. H. STAUBER, for the comradeship during the winter 1936—37. The writer also wishes to thank DEAN A. I. LEVORSEN of the School of Mineral Sciences of Stanford University for the facilities which were at his disposal while writing the present paper, and to professors S. W. MULLER, E. BLACKWELDER, G. THOMPSON and others for discussion of the results.

STRATIGRAPHY OF KAP OSWALD

In 1929 O. KULLING (ref. 12) discovered several formations near Kap Oswald which seemed to be remainders of glaciation. He observed similar beds on Lyells Land and on Suess Land, and CHR. POULSEN found them simultaneously near Kap Weber (Andrées Land) (ref. 14). The age of these tillites could not be determined exactly owing to lack of fossils in the underlying Eleonore Bay formation. The latter is regarded as Pre-Cambrian by all authors. Lower Cambrian fossils occur at a certain distance above the tillites. Both KULLING and POULSEN left the age question open, but L. KOCH (ref. 11) assigned the tillites to the Pre-Cambrian.

The sequence exposed in the neighbourhood of Kap Oswald includes the upper part of the Eleonore Bay formation (Pre-Cambrian), the tillites and associated beds, and the overlying Cambrian limestones. The Cambrian was not mapped by the writer owing to lack of time.

In the following the stratigraphical sequence will first be described as observed in the field. It will then be attempted to interpret the petrographic characteristics of the rocks in terms of sedimentation and environment, and finally the significance will be discussed.

Fig. 2 shows the tectonical conditions under which the formations occur at Kap Oswald. The thicknesses indicated for the different beds are based on direct measurements in the field or on construction of cross sections on the basis of the detailed map.

1. Stratigraphical sequence.

(See plate 1).

The following stratigraphical sequence can be observed in the Kap Oswald area, from top to bottom:

- | | | |
|----|---|---------|
| 50 | Massive-bedded, compact, dark grey to black limestone, which weathers brown (Hyolithus Creek formation, quoted from ref. 14, pag. 310)..... | ± 200 m |
| 49 | Thin beds of more or less pure, grey limestone, some of which are developed as intraformational conglomerates | |

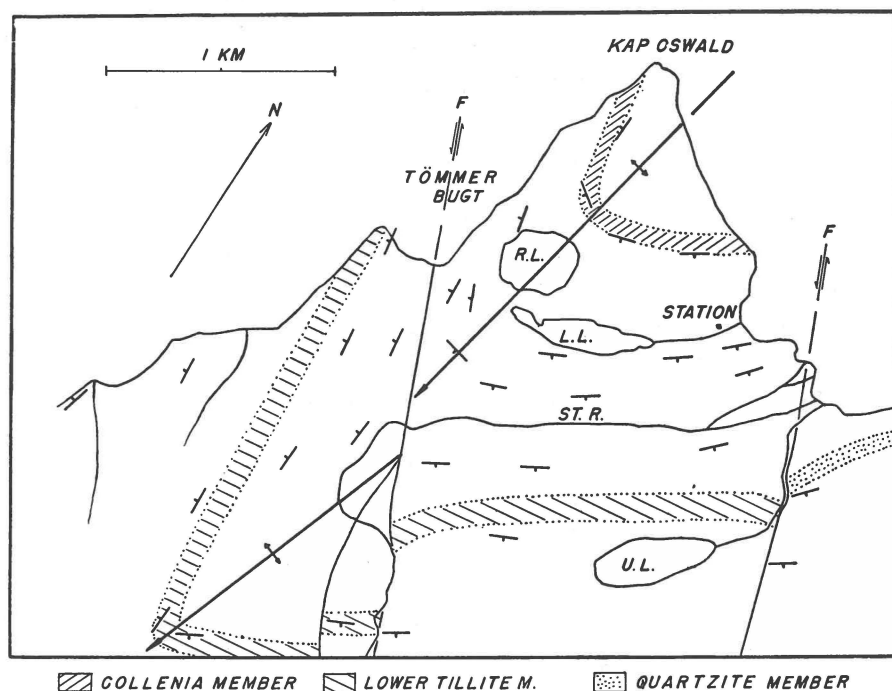


Fig. 2. Tectonical sketch map of the Kap Oswald area, Ella Ø. Only three key beds are indicated in order to show the southeasterly plunge of the anticline and the faulting.

Abbreviations: RL Rund Lake
 LL Lang Lake
 UL Ulve Lake
 ST.R Store River
 F Fault

with very small pebbles of dark grey limestone, alternating with thin beds of grey, very fine-grained calcareous sandstone which are beautifully cross-bedded (Ella Island formation, quoted from ref. 14, pag. 309) ± 50 m
 Disconformity.

- 48 Arenaceous shale, the lower half of which is brown to purple, micaceous and devoid of fossils, whereas the upper part is greyish green, glauconitic, fossiliferous and containing thin beds of light brown to yellow sandstone with the same fossils (upper part of Poulsen's Bastion formation, quoted from ref. 14, pag. 308). ± 150 m
- 47 White to pink, yellow to brown-red weathering, cross-bedded, massive quartzite. ± 60 m

- | | | |
|----|--|--------------|
| 46 | Pink to dark brown-red or greenish-grey quartzitic, micaceous sandstone. Bedding streaky, irregular. Bedding planes accompanied by mica flakes and by shale streaks which are greenish in upper half, red in lower half of bed | 1 m |
| 45 | Whitish-grey to red, brown-grey to dark brown-red weathering chert with shale streaks | 0.3 m |
| 44 | Grey, yellow weathering, slightly silty dolomite with streaks and lenses of shale and dark red-brown chert. Bedding is wavy-streaky, irregular. A breccia of dolomite pebbles in a sandy matrix occurs 30 cm below top of bed Gap. | 4 m
± 5 m |
| 43 | White-grey, yellow to light-brown weathering, fine-grained sandstones with cross-bedding and ripple marks. The bedding is very irregular, bedding planes are accompanied by streaks of green or dark brown-red, micaceous sandy shale. The lower bedding planes of the sandstones are often covered with casts of salt crystals (see fig. 10) which reach a diameter of 1.5 cm, and with some mud cracks.. | 12 m |
| 42 | Dark-grey, black-green weathering, very fine-grained silt, with very irregular, lenticular bedding, resting with sharp contact on bed 41 | 0.3 m |
| 41 | Whitish-grey, yellow weathering, dolomitic sandstone with irregular black bedding planes and shale streaks. Gradual transition from bed 40 | 1.5 m |
| 40 | White-grey, yellow to brown weathering, conglomeratic, fine to coarse-grained streaky sandstone which contains small pebbles of light-grey, streaky, silty dolomite derived from bed 39. The sandstone lies with biangular unconformity (fig. 9) and a glauconitic basal conglomerate on bed 39. The dolomite pebbles are subangular to rounded and diminish in size from several centimeters near the unconformity to a few millimeters higher up | 2 m |
| 39 | Light grey, yellow weathering, silty, streaky, dolomite with irregular bedding planes. At base a breccia of angular to subangular pebbles of a slaty dolomite in a sandy matrix. Contact with underlying beds undulating but no unconformity visible in single outcrops | 1 m |
| 38 | Grey to dark grey, yellow weathering, silty to sandy, streaky dolomite with irregular bedding planes. Uppermost 2 meters are an intraformational breccia. Pebbles are slaty, only little reworked dolomite pieces 1.5—3.0 cm long, 0.2—0.5 mm thick, in a sandy, oölitic dolomite... | 9 m |

- 37 Grey to dark-grey, yellow weathering, silty, streaky-banded, partly shaly, well bedded dolomite. Just below top 2 m of light-grey, yellowish or brown weathering, slightly siliceous limestone with round, badly defined bodies of concentric texture (algal colonies?)..... 20 m
- 36 Dark-grey, mostly yellow to brown-grey weathering, banded, cross-bedded and lenticular siltstones. These beds include in their upper half numerous layers and lenses of whitish weathering sun-cracked laminae which have been slightly reworked and redeposited (fig. 8). The lower half of the formation is composed of banded, cross-bedded, silty dolomites ± 70 m
- Gap of observation, probably covering a transition between beds 35 and 37 ± 60 m
- 35 Grey to dark brown-red, mostly brown-red weathering, banded, silty dolomites (see ref. 14, fig. 20, pag. 306)... ± 70 m
- 34 Dark grey, brown to red-brown weathering conglomeratic sandstone with subangular pebbles of carbonate and igneous rocks 0.5 m
- 33 Greenish-grey, fine-grained, cross-bedded sandstone 1 m
- 32 Dark red-brown tillite with few, small erratics..... ± 80 m
- 31 Red, easily weathering tillite 10 m
- 30 Yellow weathering, quartzitic sandstone ± 30 m
- 29 Dark red-brown, fine to coarse-grained tillite with many angular to subangular pebbles of dolomite, porphyry, etc. Some striated pebbles were observed. The tillite includes several irregular beds of light grey to pink, cross-bedded, fine grained quartzitic sandstone..... ± 100 m
- 28 Greenish-grey to dark red-grey, slightly calcareous, cross-bedded sandstones, somewhat micaceous. Not fully exposed ± 160 m
- 27 Black, fissile shales..... ± 35 m
- 26 Brown-grey, red-brown weathering, slightly calcareous sandstones, unbedded in upper part, well bedded near base. Cross-bedding and ripple marks common ± 30 m
- 25 Dark-grey, yellow-grey weathering, calcareous tillite. The pebbles consist mainly of limestone. They reach a diameter of 10 cm or more and often show striae and the typical flat iron shape due to transportation by the ice..... ± 100 m
- 24 Dark-grey, partly laminated, fine silty shales..... ± 100 m
- 23 Dark-grey, yellow to light-grey weathering limestone. Much of this bed is an intraformational breccia (fig. 7)

	in which a thin-bedded limestone is broken up and re-deposited	6 m
22	Grey, hard, splintery shale with intercalated beds of grey, thin-bedded to laminated limestone and dolomite. The shales are poorly exposed while the limestones and dolomites are more resistant to weathering and stand out above the surface of the shales. A dolomite breccia occurs about 12 m below the top of the formation.....	± 60 m
21	Laminated silty dolomites composed of thin (1—5 mm) layers of wine-red, dark-brown weathering silty dolomite and thicker (2—55 mm) layers of bluish-grey to light-grey, yellow weathering dolomite and dolomitic limestone. The red layers weather much less than the light-coloured ones (fig. 6). Red layers are predominant in upper half, grey layers in lower half of the formation	15 m
20	Red-grey and blue-grey laminated, brown weathering, silty dolomite, very hard and resistant to weathering..	1 m
19	Grey to dark-grey, brown-grey weathering, laminated, crumbling dolomitic shales and siltstone.....	19 m
18	Light-grey to grey, brown-yellow weathering, well bedded, slightly laminated, silty dolomite	5 m
	Gap, probably underlain by similar limestone as bed 17	30 m
17	Light-grey, yellowish or whitish weathering, thin-bedded limestone. The contact with bed 16 is not exposed.....	160 m
16	Dark-grey to black, thin-bedded limestones	80 m
15	White-grey, yellowish weathering dolomite. Two beds of 5 m	10 m
14	Dark to black-grey, grey weathering, well to thin-bedded limestones	330 m
13	Light-grey, yellowish-grey weathering, unbedded limestone composed of <i>Collenia</i> colonies (fig. 4)	4 m
12	Yellowish weathering, unbedded limestone.....	6 m
11	Light-grey, unbedded limestone composed of <i>Collenia</i> colonies	4 m
10	Black, grey weathering, well bedded limestone.....	4 m
9	<i>Collenia</i> limestone as above	4 m
8	Black, grey weathering, partly pisolitic limestone.....	11 m
7	Grey, yellowish-grey weathering, thin-bedded limestone	4 m
6	Light-grey <i>Collenia</i> limestone.....	3 m
5	Grey, partly pisolitic limestone (fig. 3)	10 m
4	Dark-grey, light-grey weathering, unbedded limestone with thin, laminated intercalations. These are partly broken up and form intraformational pebbles.....	6 m

- | | | |
|---|--|-------|
| 3 | Dark-grey limestone interbedded with black-grey, pisolitic limestones. Irregular parts of the beds (20—50 cm in diameter) are silicified | 150 m |
| 2 | Dark-grey, pisolitic limestones. Dark-grey pisolites (1—4 mm in diameter) lie in light-grey limestone..... | 2 m |
| 1 | Dark-grey, well-bedded limestone. Single oölites and pisolites appear in upper half and form whole beds near top | 20 m |

The total thickness of the described sequence, including gaps of observation, is approximately 2300 meters. Only beds 1 to 49, however, have been actually mapped by the writer. It should be kept in mind that this is only part of a much larger section which continues several thousand meters below bed 1 and a good 1000 meters above bed 50.

A thin covering of Quaternary, viz. glacial, fluvial and marine deposits, hides the older formations in many places.

2. Subdivision of the sequence.

In subdividing the sequence exposed at Kap Oswald the writer has relied mainly on lithologic considerations. From this point of view three groups of formations can be recognized, from top to bottom:

3. an upper limestone group (beds 49, 50 and younger)
2. a group of clastic sediments (beds 18—48)
1. a lower limestone group (beds 1—17)

The lower limestone group is the uppermost part of the so-called Eleonore Bay formation which was originally defined by L. KOCH (ref. 9, 10) and includes at present all pre-Cambrian sediments below the Lower Tillites (ref. 11). Only a small part of it is exposed on Ella Ø. O. KULLING (ref. 12) estimated the thickness of several sections in the Eleonore Bay formation and arrived at a figure of 4000 to 4600 meters for these, but the total thickness is probably considerably higher since KULLING did not observe the base of the formation (see ref. 21). He distinguishes a Quartzite series (1600—1750 m) and a Limestone-Dolomite series (2480—2840 m). The latter corresponds, though not exactly, to our Lower Limestone group (see below). It is certain that this thick sequence will be subdivided into a number of formations if and when it is mapped in detail. This cannot, however, be done on the basis of the small part of the formation exposed at Kap Oswald and we shall therefore retain the name Eleonore Bay formation for beds 1—17, but subdivide its upper part on Ella Ø into four lithologic members:

Grey limestone member (bed 17)

Black limestone member (beds 14—16)

Collenia member (bed 6—13)

Pisolite member (beds 1—5).

These members are probably of local value only. They have been given lithologic designations mainly because geographical names are scarce on Ella Ø.

Beds 18 to 50 have been gathered into the second group for which the name Tømmer Bay group is proposed because the upper part of the group is exposed on the southern shore of Tømmerbugt. Beds 18 to 23 were included by KULLING in the Eleonore Bay formation. The criterion for assigning them herewith to the next higher group lies in the appearance of clastic material from bed 18 upward which the writer considers as a characteristic of the Tømmer Bay group. An additional criterion is the predominance of dolomite over calcite throughout the Tømmer Bay group.

Beds 20 to 47 correspond to KULLING's Tillite series. This name should be eliminated because the term "series" denotes in modern stratigraphical usage a time-rock unit corresponding to the time unit called epoch, i. e., it denotes the total of strata deposited during a specified epoch, independent of lithology (for a recent discussion see ref. 23, pp. 15—17). Furthermore, it is general usage to apply geographical names to rock units whenever possible.

Bed 48 has also been included in the Tømmer Bay group on account of its clastic character. The fact that Cambrian fossils were found in the upper part of bed 48 presents no obstacle since this subdivision is made on lithologic grounds without any implication as to the age of the beds included in the same group. The Tømmer Bay group itself has been subdivided into 11 members, as follows:

Sandy Shale member (bed 48)

Quartzite member (beds 46, 47)

Salt Cast member (beds 40—45)

Sun-cracked member (beds 36—39)

Varve member (bed 35)

Upper Tillite member (beds 29—34)

Intertillite member (beds 26—28)

Lower Tillite member (bed 25)

Silty Shale member (bed 24)

Breccia member (bed 23)

Banded Dolomite member (beds 18—22)

Here again lithologic names have been given for the reason already mentioned.

A different nomenclature was applied to the Tømmer Bay group

Table 1. Subdivision of sequence exposed at Kap Oswald, Ella Ø.

Present paper			CHR. POULSEN 1929	O. KULLING 1929
Group	Member or formation	Bed		
Upper Limestone group	Narwhale Sound formation		Narwhale Sound formation Cape Weber formation Cass Fjord formation Dolomite Point formation Hyalolithus Creek formation Ella Island formation	Cambrian
	Cape Weber formation			
	Cass Fjord formation			
	Dolomite Point formation			
	Hyalolithus Creek formation	50		
	Ella Island formation	49		
Tømmer Bay group	Sandy Shale member	48	Bastion formation	Tillite series
	Quartzite member	46, 47		
	Salt Cast member	40—45	Spiral Creek formation	
	Sun-cracked member	36—39	— — — ? — — — ? — — —	
	Varve member	35	Tillite Canyon formation	
	Upper Tillite member	29—34		
	Intertillite member	26—28	Cape Oswald formation	
	Lower Tillite member	25		
	Silty Shale member	24		
	Breccia member	23		
	Banded Dolomite member	18—22		
Lower Limestone group (Eleonore Bay form.)	Grey Limestone member	17	Eleonore Bay formation	Limestone—Dolomite series of Eleonore Bay form.
	Black Limestone member	14—16		
	Collenia member	6—13		
	Pisolite member	1—5		

by CHR. POULSEN (ref. 14). His Kap Oswald formation comprises the tillites and intervening beds (25—34). His Tillite Canyon formation, Spiral Creek formation and Bastion formation are also included in the Tömmer Bay group of the present report. These terms will not be used here mainly because the Tillite Canyon and Spiral Creek formations cannot be identified too well with the detailed section, and furthermore because the name "Tillite Canyon formation" is confusing as the formation does not include any tillites.

The third group comprises the limestone formations overlying the Tömmer Bay group and includes not only beds 49 and 50, but also the higher Paleozoic formations underlying the great Devonian unconformity (Dolomite Point formation, Cass Fjord formation, Kap Weber formation, Narwhale Sound formation, see ref. 14).

Table 1 summarizes the subdivision of the Kap Oswald sequence as proposed here and shows its correlation with POULSEN's and KULLING's formations. Only a regional study of these beds can show whether our subdivision is of general value and whether it is justified to group the various members into formations.

SEDIMENTATION

The following observations and conclusions are based mainly on a study of thin-sections in addition to the field observations and macroscopic study of the collected specimens including tests of limestones and dolomites with hydrochloric acid. Thin-sections had to be resorted to on account of the great consolidation of the rocks. Unfortunately a number of specimens were lost during the ten years between their collection and the moment when the writer saw them again. The microscopic study is therefore not as complete as desirable. Furthermore, it was somewhat cursory owing to other occupations and several interruptions by travelling. Nevertheless it was possible to obtain a good deal of information on the origin of these rocks and the conditions under which they were formed and thereby to get an outline of the geologic history of Northeast Greenland in late pre-Cambrian to Cambrian times.

The description of rocks and conditions of sedimentation proceeds from the older to the younger beds.

1. Lower Limestone Group: Upper part of Eleonore Bay formation.

a. Pisolite member (beds 1—5).

The lowermost beds exposed on Kap Oswald consist of black, microcrystalline limestones interbedded with pisolitic limestones. The relation between these two types of rock is such that the pisolites appear gradually in the black limestones. The first ones are small (1—3 mm in diameter) and rare but they increase upwards in number as well as in size (to diameters of 5—6 mm) until most of the rock is composed by them. The boundary towards the next higher, non-pisolitic limestones is—at least in some cases—sharp (see fig. 3), but whether this is the rule bears further study in the field.

The black limestones consist predominantly of calcite but much dark matter, probably clay and perhaps organic matter, is also present. It occurs in thin films separating the calcite crystals and causes the dark colour of the limestones. The pisolitic rock contains less of this dark matter.

The pisolites show concentric structure without the presence of any nucleus. They consist either predominantly of calcite or predominantly of silica. In the first case the calcite of the pisolites is much better crystallised than the surrounding matrix. Little of the original concentric structure can be seen, except that the crystals forming the outer parts of the pisolites are arranged in concentric layers and minute inclusions are concentrated in zones, sometimes along the border of the pisolite, sometimes in deeper layers. Yellow, zoned dolomite rhombs are enclosed in some of the pisolites.

In the second case the concentric structure of the pisolites is well marked by slight changes in the grey colour of the silica and by zones of minute inclusions. Commonly part of the pisolites is not replaced by silica and consists of small dolomite rhombs or more often of calcite crystals with very ragged outlines. Small areas of calcite are often separated from the bigger ones but under crossed nicols they extinguish together with the nearest crystal. This shows clearly that the calcite was replaced by silica but originally composed the whole of the pisolite. The silica itself is microcrystalline. Usually the replacement affects only the pisolites but sometimes it has also started to a smaller degree in the matrix.

Most of the pisolites are spherical but in some beds they are of irregular shape and enclose two or three smaller bodies of concentric structure.

The origin of the pisolites is problematic. There is no reason to assume that they were not formed in situ. If they were directly precipitated they would be "indicative of saturated waters" according to F. J. PETTIJOHN (ref. 13, page 308) who states furthermore that "rather higher than normal salinity and temperature, therefore, is implied". According to W. H. TWENHOFEL (ref. 19, page 577) pisolites "do not seem to form in very cold water" and "are not known to form in deep waters". As the pisolites in question do not seem to be products of replacement of other particles (see ref. 13, page 76) the conditions reigning during deposition of beds 1 to 5 can probably be described as shallow marine and relatively warm. The water was at times saturated with calcium carbonate, silica was present in colloidal form and there was some influx of very fine clay material. It is not clear why pisolites formed only at intervals. Changes in temperature might be responsible but possibly varying influx and deposition of clay and organic matter had something to do with it. Conditions of sedimentation were stable except during the deposition of bed 4 which was broken up and redeposited as an intraformation breccia.

It should be pointed out that there is no direct evidence for the marine origin of these limestones. However, there can be little doubt

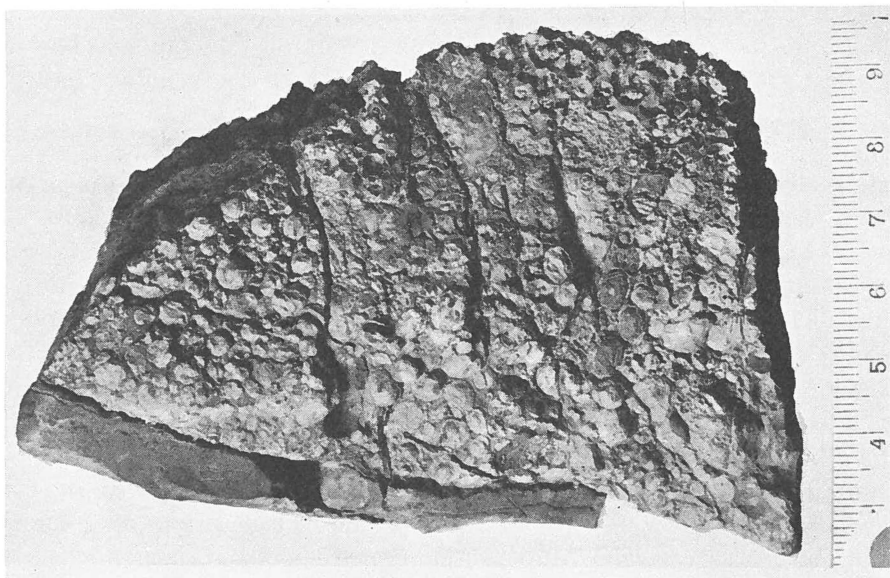


Fig. 3. Pisolitic limestone overlain with sharp boundary by black-grey limestone.
Scale in cm.

about this since the majority of limestones belonging to the fossiliferous periods are marine and since freshwater limestones are rarely very thick and of different aspect from the limestones on Kap Oswald.

b. *Collenia* member (beds 6—13).

The characteristic of this group of strata is the presence of a *Stromatolite* probably belonging to the genus *Collenia*. Beds 6, 9, 11 and 13 are composed entirely of colonies of this problematic alga. The organic origin of the *Collenia* colonies cannot be ascertained under the microscope owing to crystallisation. This is the usual difficulty encountered in the study of *Stromatolites* and gives rise to the doubt whether they are to be considered as fossils. The question has been discussed in extenso by C. L. FENTON (ref. 5) and there is no need to go into it as little new argument can be adduced. The writer is inclined to agree with FENTON and to assume an organic origin of *Collenia*.

Fig. 4 gives a good cross section of a *Collenia* growth from Kap Oswald. It resembles most closely *Collenia undosa* WALCOTT which was described first by CH. D. WALCOTT (ref. 20, p. 113 and pl. 13, 14) and later by C. L. and M. A. FENTON (ref. 8, p. 1947 and pl. 11, fig. 3, 4) from the pre-Cambrian Belt Series of Wyoming, U. S. A.

CH. D. WALCOTT, in his description of the genus *Collenia*, makes the following statement regarding the distinction between *Collenia* and *Cryptozoon* (loc. cit., p. 114): "The resemblance between the structure

of *Collenia* and *Cryptozoon* Hall is marked in hand specimens but when we compare the mode of growth we find that *Collenia* has an encrusting-like growth that forms a dome-shaped body with edges of the lamellae pointing downward, while *Cryptozoon* grows in a cup-shaped form with the edges of the lamellae on the upper surface . . .". It is obvious from this description that the Stromatolite occurring on Kap Oswald belongs to the genus *Collenia* and not to *Cryptozoon*.

The *Collenia* limestones are continuous beds which can be followed over the whole width of the Kap Oswald anticline and are thus conforming to the definition of biostromes. They are conspicuous on account of their light-grey colour and the fact that they weather easily and form shallow trenches in the hill sides. However, the *Collenia* limestones are not as pure as this would seem to indicate. Deposition of light-grey limestone is interrupted by thinner layers of darker limestone apparently containing some clayey and organic matter. This lamination causes the macroscopic aspect of the *Collenia* colonies. Deposition of calcium carbonate was probably due to the growth of the algae which was apparently very often interrupted by the influx of clayey material, perhaps at regular intervals.

The strata separating the *Collenia* biostromes (beds 7, 8, 10, 12) consist of dark-grey to black, partly laminated, partly pisolitic limestones. Under the microscope it can be seen that the dark colour is caused by black, probably clayey and organic matter separating the calcite crystals. The lamination is caused by varying distribution of this dark matter which occurs partly in very thin laminae (ten to twenty per centimeter), partly in bigger cycles in which the laminae are of increasing darkness and thickness as sedimentation progresses. A sharp boundary, sometimes a small unconformity limits the cycle and the next one begins again with lighter, more calcareous laminae.

The environment in which the biostromes of *Collenia* formed was probably little different from the conditions under which the preceding beds were deposited. There is still influx of very fine clastic material into a sea containing much calcium carbonate. The repeated interruptions of growth of the algae, indicated by the intercalations of dark limestones between the biostromes as well as by the lamination of the colonies described above seem to show that the algae did not thrive when too much clayey material was deposited, apparently they preferred clear water. If *Collenia* is really an alga it can be assumed to have been dependent on photosynthesis, a process which is inconsequential below 60 fathoms according to F. P. SHEPHARD (ref. 17, p. 254). This would indicate shallow water, and the fact that many of the colonies are broken up could be due to wave action, which is a very common occurrence in reefs and biostromes. C. L. and M. A. FENTON arrive at

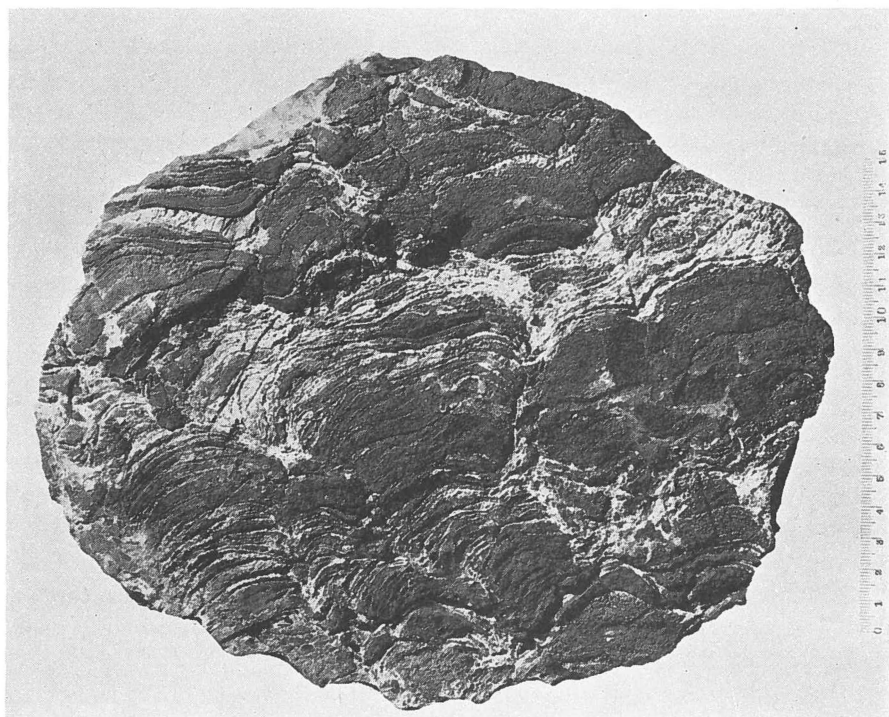


Fig. 4. *Collenia* colonies. Kap Oswald. Scale in cm.

similar conclusions regarding the environment of *Collenia* in the Belt Series (ref. 6).

c. Black Limestone member (beds 14—16).

Bed 14. — Dark coloured, well to thin-bedded limestones compose this bed. Calcium carbonate makes up the bulk of the sediment though there is a bed of chert exposed on the small peninsula in Lang Lake. The dark colour of the limestones is caused by thin films of dark, probably clayey and organic matter between the calcite crystals. Lamination is common and is due to concentration of the dark matter in thin laminae. These are similar to those described by W. H. BRADLEY (ref. 3) from marine rocks in the United States and must be connected with recurring changes in deposition, but the writer would not venture an opinion regarding the nature and cause of such changes.

Quartz in small, angular to subangular grains of silt size, though not common, occurs in some samples and is sometimes concentrated in thin layers coinciding with a conspicuous change in the colour banding, thus indicating a sudden influx of clastic material. Other beds contain no quartz.

The chert mentioned above includes a great number of small (0.1 mm), round to elliptical bodies composed of crystallised silica in contrast with the cryptocrystalline texture of the surrounding groundmass. No structure is visible in these bodies but they might be of organic origin (radiolaria?).

The conditions of sedimentation are still marine with influx of some coarser, clastic material at rare intervals. The absence of pisolites and *Collenia* provides a negative criterion, conditions were unfavorable to the formation of either. The main reason of this may be the deposition of a considerable amount of clay, perhaps also some changes in temperature and salinity.

Bed 15. — Bed 15 is distinguished from the subjacent and overlying strata because it is composed of dolomite instead of calcite. Unfortunately the contact of the dolomite with the limestones is nowhere exposed as the dolomite forms an isolated ridge just south of Lang Lake which can be observed intermittently from a point 180 m west of the western end of Lang Lake to a point 100 m east of the station house. The dolomite contains little dark matter in comparison with the surrounding limestones and no quartz has been observed, thus the influx of clastic material was greatly reduced.

The origin of the dolomite is not clear. Primary deposition of dolomite has not been observed under the present marine conditions and replacement of calcite is usually assumed and has been well established in many cases. The samples available present no evidence for such an origin and, since the relations of bed 15 with the surrounding limestones are unknown, it is difficult to understand why the dolomitisation should be restricted to a zone of 10 meters surrounded by limestones.

Bed 16. — The strata of this bed consist mainly of calcium carbonate. They contain a considerable amount of black, amorphous matter which is present in thin films separating the calcite crystals or has accumulated along irregular streaks parallel to the bedding and in individual patches of irregular shape. The nature of this matter could not be determined under the microscope but it may be, partly at least, of organic origin. If so, this would indicate the development of considerable life during the deposition of bed 16 and anaerobic conditions of sedimentation preventing decay of the organic matter. O. KULLING has described these limestones as bituminous.

Coarse clastic material such as quartz is absent, but clay may be present in the dark limestones.

A sample from the upper part of bed 16 provides special interest (see fig. 5). The weathered bedding planes are marked by low ribs about 2 mm wide separated by narrower hollows about 1 mm wide. Thin sections show that these ribs are the expression of a vertical segregation

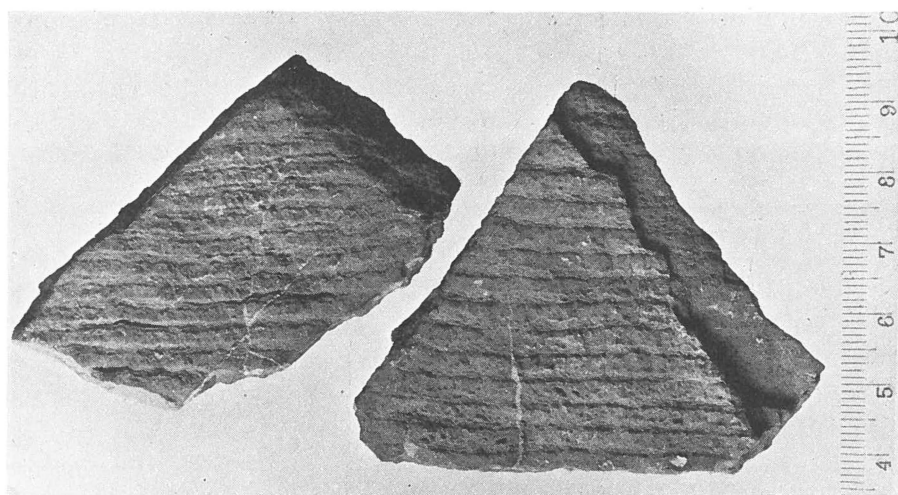


Fig. 5. Vertical segregation in a limestone. Scale in cm.

in the limestone which is not confined to the bedding planes but traverses the stratum. The wider bands are darker in colour than the narrow ones and seem to contain more dark matter. The narrow bands are not quite continuous but spotty. The only other difference noticed is the size of the calcite crystals composing the bands. Generally speaking they are bigger in the light than in the dark bands. The cause of this segregation is not known. The only other instance of such segregation that has come to the writer's attention is pictured by C. L. and M. A. FENTON (ref. 8) from the Newland formation of the Belt Series in Wyoming, U. S. A. These authors state that segregation of black limestone and grey dolomite is the cause of the vertical banding. Possibly a similar chemical segregation is present in the specimens from Kap Oswald. Certainly the dark bands are more resistant to weathering than the light-coloured ones and form therefore protruding ribs on the bedding planes. This might be due to protection of the calcite against solution by the thin films of dark matter separating the crystals.

The conditions of sedimentation can probably be described as shallow marine with little or no influx of clastic material. Conservation of much organic matter would seem to indicate anaerobic conditions, thus perhaps a closed basin with little circulation.

d. Grey limestone member (bed 17).

Calcium carbonate forms the bulk of the sediment. Dark, possibly organic matter is next in importance and a little dolomite is also present. The dark colouring occurs mainly in irregular streaks and patches arranged parallel with the bedding and gives the limestone a laminated

aspect. Pyrite is common, but no quartz or other detrital minerals were found.

There is a gap of observation between beds 16 and 17 but apparently the conditions of sedimentation did not change much, i. e. it continued in a shallow sea.

2. Tömmer Bay Group.

a. Banded Dolomite member (beds 18—22).

The common characteristic of this group of beds is the banded stratification which is very well visible in the field, and the predominantly dolomitic composition. It must obviously be our first task to determine the nature of the banding before any statement on the origin of the formation can be made. A total of 27 thin sections were available for this purpose, most of them oriented with respect to top and bottom of the strata.

Bed 18 is composed of light-grey, fine-grained dolomite with thinner, not sharply defined bands of a darker grey. The latter are from 1 to 3 mm thick and spaced 2 to 20 mm. The light-coloured bands are composed mainly of dolomite in small, anhedral grains, rarely any quartz. Angular to subangular quartz grains of silt size are very common in the darker bands and may compose an estimated fourth to nearly one half of the sediment in the best developed bands. Clay seems to make up part of the dark bands, the remainder being carbonates.

Bed 19, according to the two slides available, is composed of shales with intercalated, partly cross-bedded siltstones. Both rocks contain dolomite but it occurs only in small, often euhedral crystals and forms a minor part of the sediments. The quartz grains in the silts are angular and reach a size of 0.05 mm.

Bed 20 resembles bed 19 but dolomite makes up a greater percentage of the rock than in bed 19. One slide shows a sharp unconformity between a predominantly dolomitic bed and the overlying, predominantly silty bed. There is a gradation in the latter from the base, where it is mainly composed of quartz grains, upward into the following dolomitic band. The amount of quartz grains diminishes and their size decreases.

The best banding could be observed in bed 21. Thin (2—5 mm) bands of wine-red colour are intercalated between thicker (10—50 mm) light-grey bands in those parts of the section where the banding is most characteristically developed. Microscopical study shows that the red bands usually follow with a sharp contact on the underlying grey band. They consist of angular quartz grains, clay and opaques, mainly pyrite in process of oxydation. The iron oxydes seem to cause the colour of the dark bands. The clastic components decrease upwards in

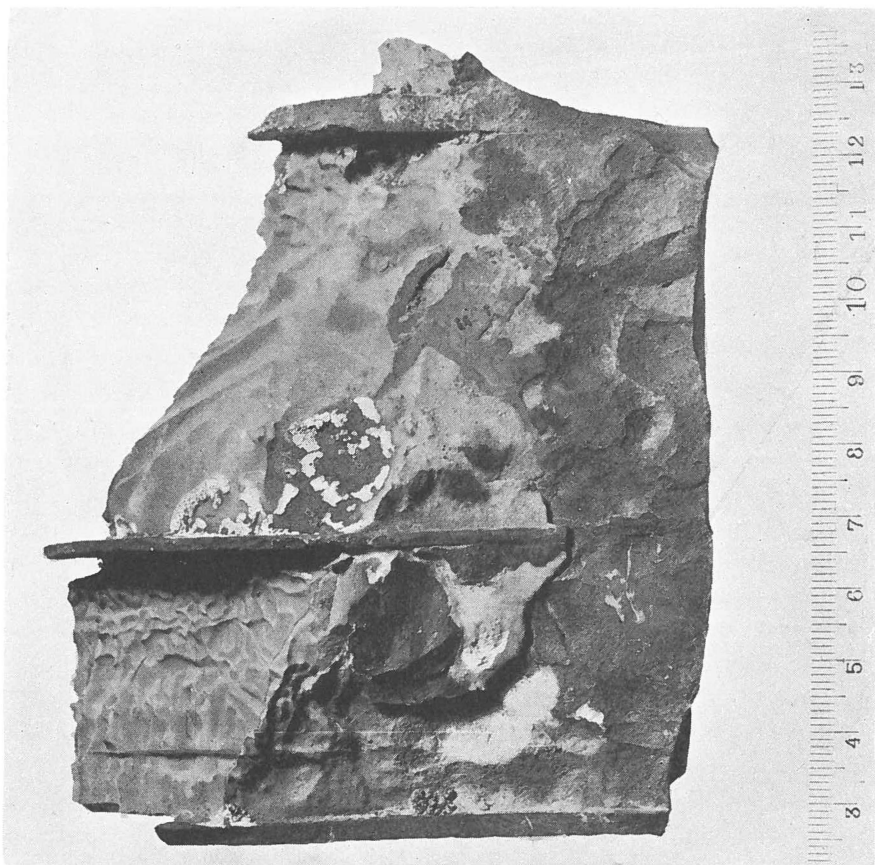


Fig. 6. Banded dolomite from bed 21. The specimen shows the thin silt bands which weather much less than the thicker carbonate layers. Notice the action of solution on the carbonates. Scale in cm.

number as well as in size, very fine crystalline dolomite replaces them gradually so that the upper part of the light-coloured bands consists only of dolomite.

In the uppermost part of bed 21 it is the dark-red bands which are thicker and compose most of the rock but here, too, a decrease in size and volume of clastic material from the bottom of the dark bands upwards was observed.

In many cases, the contact between a dark band and the underlying light-coloured band is not sharp, in others, such as the sample shown in fig. 7, there is also a well defined boundary at the top of the dark band. Above this line no or very little clay is found but the deposition of quartz continues upward into the light band at a reduced rate for some time. The upper portion of the light band is composed mainly of dolomite.

Bed 22 shows banding to a less degree than bed 21, but where present it is accompanied by graded bedding with sharp contact at the base of the clastic section of the cycle. In many parts of the bed the matrix is calcitic instead of dolomitic and other parts consist of shales and silts. A conglomerate observed about 12 m below the top of the bed seems to be intraformational.

The conditions of sedimentation under which the Banded Dolomite member was deposited, can be briefly described as follows:

First, the environment is still marine, as shown by the continued deposition of carbonates.

Secondly, in contrast with the preceding beds, there is a considerable amount of clastic material present, and

Thirdly, the influx of this material seems to be cyclical at least in part of the member and imparts definite varve characteristics to the beds.

Increased influx of clastic material into a marine area of sedimentation could presumably be caused by changes in the marine conditions such as gradual filling of the basin of sedimentation or shifting of the course of marine currents, and changes in the areas of erosion would not necessarily be implied. The rhythmical deposition of silt, however, could hardly be due to marine conditions alone. It would rather seem to be due to periodical changes in the borderlands of the area of deposition and thus to indicate that the sudden increased influx of clastic material after a long period during which no, or very little, such material was deposited, is also due to changes in the areas of supply resulting in increased erosion. This might be caused by climatic changes in an old borderland, uplift of such a borderland or diastrophic events resulting in the formation of mountain ranges. Unfortunately the contact of the Banded Dolomite member with the underlying beds which might provide some clue, is not exposed. Evidence contained in the Lower Tillite member, however, suggests that strong diastrophic movements may have taken place before the Banded Dolomite member was formed.

Periodical changes in deposition can very often be traced back to annual climatic variations affecting the rate of erosion and run-off from a land area. Several processes may cause great increase in the influx of clastic material into the sea during a short part of the year, such as rainy seasons, spring floods due to thawing and melting of glaciers in summer. Since glaciation is known to occur not much later in the geologic history of NE Greenland, it would not seem improbable that the hinterland was glaciated during the deposition of the Banded Dolomite member and that the cyclical deposition represents glacial varves, though the other possibilities cannot be excluded.

It might be objected that the rhythmical sediments described in

the preceding pages differ greatly from the glacial varves investigated principally by G. DE GEER and E. ANTEVS (ref. 4, 1 and 2) in Sweden and North America. These Pleistocene varves were formed in lakes during the retreat of the Pleistocene glaciers. Each varve consists of a light-coloured silt layer deposited in summer which grades into a dark-coloured winter layer of fine clay. In the present case, however, the silt layer is dark-coloured and contains most of the clay deposited during the cycle while the light-coloured part of each bed consists of carbonates mainly. This difference seems to be caused by the marine environment of deposition.

It is sometimes stated (e. g. ref. 19, p. 499) that glacial varves cannot form in sea water because the clay would flocculate quickly, and settle out together with the silt. Nothing would then remain in suspension, a distinct winter layer could not form and the yearly deposits could not be distinguished. MATTI SAURAMO has shown, in his studies on the glacial varves of southern Finland (ref. 16), that clay indeed flocculates in sea water and therefore settles together with the silt, a process which he calls *symmixis*. Nevertheless SAURAMO could still distinguish the yearly deposits on account of the graded bedding.

In the present case, the clay and silt carried into the sea by the melt water in summer would settle out quickly together due to flocculation and form a thin, dark-coloured summer layer. However, this takes place in an environment of predominant carbonate deposition which continues during the remainder of the year, forming a light-coloured winter layer which consists mainly of dolomite. The sediments of the Banded Dolomite member could therefore quite well represent glacial varves and thus indicate a period of glaciation considerably earlier than recorded by the Tillite members of the Tömmér Bay group. Obviously, however, it was less extended than the later glaciations. Ice rafted pebbles have not been found so far in the Banded Dolomite member. This could mean that the glaciers did not reach out to sea.

No evidence was found that the dolomite formed by replacement of calcite. It is thus possible that this is a case of primary deposition of dolomite, but further study would be required to solve this problem. This statement applies to the whole Tömmér Bay group, in which the carbonates are predominantly dolomitic.

There is not much evidence for the depth of the sea in which the Banded Dolomites formed, but there is no reason to suppose that a great change in depth took place. It can thus be assumed that deposition took place in a shallow marine area of sedimentation bordering a recently uplifted area of erosion from which clastic material was carried into the sea in yearly cycles possibly caused by glaciation. Assuming further an

average thickness of 1 cm for the yearly deposit, we would obtain a duration of 10.000 years for the interval of the Banded Dolomites.

b. Breccia member (bed 23).

Bed 23 consists predominantly of calcium carbonate, clastic minerals are absent. The main characteristic of the bed is its brecciation. Apparently a thin-bedded, light-grey, nearly pure limestone was broken up after deposition and the resulting fragments were redeposited in a limestone matrix which is dark-coloured, probably by organic matter and clay, but also by a considerable amount of pyrite.

The fragments of the breccia do not show signs of transport. They have often a rectangular cross-section and pieces obviously once connected are still found side by side. In some places a lateral transition from undisturbed beds to breccia can be observed. Some solution of smaller limestone particles seems to have taken place and these have cloudy, poorly defined outlines. Autigenic feldspar is common in some samples and has formed mainly along the edges of the limestone pebbles and in the smaller, ill defined fragments mentioned above.

The breccia is not connected with an unconformity, it is intraformational. Folding and breaking up of the original limestone beds seem to indicate that the brecciation was caused by submarine sliding of the limestones before they were much indurated. Possibly such slides accompanied tectonical movements of a regional character, and there might be some connection with the fact that the influx of detrital quartz ceased before the deposition of the Breccia member but returned after it.

The Breccia member provides an easily mappable unit in the Kap Oswald area as it generally forms outstanding outcrops.

c. Silty Shale member (bed 24).

Bed 24 consists of argillite which is partly silty. Some samples contain numerous euhedral crystals of dolomite which have been partly dissolved. The presence of dolomite would seem to indicate that the environment was still marine. A gradual transition apparently connects the Silty Shale member with the over- and underlying formations.

d. Tillite member (bed 25).

Bed 25 is a typical tillite with the characteristic poor sorting, no or very little bedding and the presence of striated pebbles of flat-iron shape. The general appearance of this rock is quite similar to that of Pleistocene tills exposed in the Kap Oswald area, but the old tillites are of course much more consolidated.

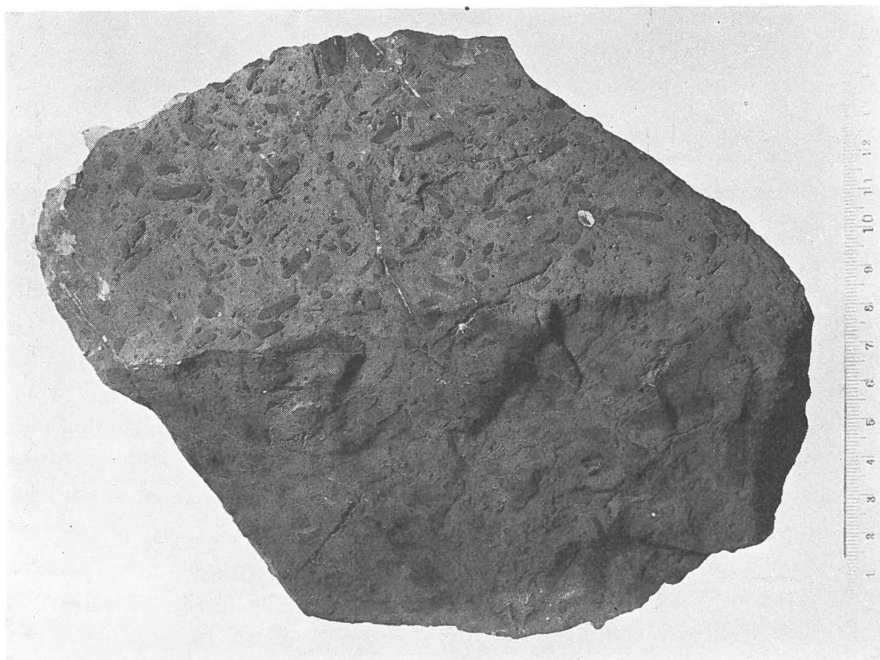


Fig. 7. Intraformational breccia from the Breccia member (bed 23). Scale in cm.

The Lower Tillite member includes some beds of sandstone and conglomerate in which sorting took place but they are lenticular and cannot be mapped as separate beds over any larger distance.

The pebbles and larger components of the Lower Tillite consist without exception, as far as the writer could observe (see also ref. 12), of carbonate rocks (mainly limestones, rarely dolomites). The limestones include oölitic and pisolitic types, small fragments resembling the *Collenia* limestones, and fine-grained, dark-coloured limestones. All these rocks could very well be derived from the upper part of the Eleonore Bay formation as exposed at Kap Oswald (beds 1—17). No pebbles of the Banded Dolomite member have been found, however.

The smaller components of the tillite (sand and silt size) consist mainly of quartz and limestone and a few chert grains. The grains of sand size are very well rounded in comparison with similar fractions of other tillites (see microphotographs of tillites in ref. 13, plate 13). This is understandable for the limestone grains which are not hard and could probably be rounded during glacial transport. The quartz grains are, however, also well rounded, and this is probably due to aqueous transport long before glacial transportation took place. This checks well with the absence of igneous or metamorphic rocks in the Lower Tillite member. The quartz cannot be derived from such rocks, it must come

from a sedimentary source, probably from the thick quartzite series of the Eleonore Bay formation described by O. KULLING. The matrix of the tillite consists of carbonates and clay and has a dark-grey colour.

The presence of tillites in the Cambrian to Pre-Cambrian of NE-Greenland provides a number of clues regarding the conditions prevailing in this area during their deposition. In the first place a land area of considerable extent is required on which the glaciers could form. Tillites of approximately the same age are now known to occur over a distance of nearly 200 kilometers and are thus not of local importance only. Furthermore, this land area must have been quite high because the erosion was considerable, and formations deposited not much earlier—geologically speaking—formed part of this land area. This proves that strong tectonical movements took place in the interval between the deposition of the Eleonore Bay formation and the Lower Tillite member. It is probable that they occurred, at least in part, before the deposition of the Banded Dolomite member, for it is in those beds that clastic material first appears after a long interval of purely marine sedimentation. Also, no banded dolomite pebbles were found in the tillites, thus the Banded Dolomite member was not probably exposed in the source area of the glaciers, possibly because this area had already been elevated at the time of deposition of the Banded Dolomite member. Further movements may have occurred when the breccias of bed 23 were formed.

The tillites prove, of course, that the climate was very cold during an extended time interval. This is a second considerable change from the conditions reigning during the deposition of the Eleonore Bay formation, if our conclusion that the pisolites and other limestones of this formation were formed in a warm sea is correct.

The deposition of the glacial till did not probably take place on this land area but in a shallow sea extending in front of it, i. e. under conditions similar to those which must have reigned outside the coast of New England (the northeastern United States) during the Pleistocene glaciation, e. g. in the Gulf of Maine (ref. 17). This is made probable by the absence of a break in sedimentation and of a striated surface at the base of the tillites. No signs were observed that the underlying shales have been disturbed by the advancing ice. Marine currents might account for the grading of the material in the sand and conglomerate lenses.

In conclusion it can be said that the Lower Tillite member provides definite proof for the formation of a large land area and for a considerable climatic change. Both events, however, may have preceded the deposition of the tillites considerably and took possibly place before the Banded Dolomite member was formed.

e. Intertillite member (beds 26—28).

Bed 26 — Quartz is the main constituent of this sandstone. It occurs in grains of sand and silt size, the bigger ones being well rounded, the smaller ones angular to subangular. A small amount of well rounded limestone grains is also present. The grains are mainly cemented by calcite but limonite is distributed in small particles throughout the cement and imparts its red-brown colour to the rock.

The clastic components of the sandstone clearly resemble the material of corresponding size contained in the Lower Tillite. The deposition took place in a shallow body of agitated water, as shown by cross-bedding and ripple-marks. The sandstone apparently formed during and after the retreat of the glaciers and represents an outwash of the moraines exposed to fluvial erosion. The coarser components of the till were probably deposited nearer the shore while the clay particles were carried farther away. Washing by wave action may have added to the clean composition of the sand. The deposition took probably place in a shallow sea not too far from the coast of the old land mass.

Bed 27. — The hand specimens collected from this bed were lost in transit and no thin-sections are thus available. According to the field description, the bed is composed of black, fissile shales. This would seem to indicate that clay and silt are the main constituents of the rock which is probably the result of continued erosion on the hinterland and deposition in a shallow sea, though the succession of a fine shale on a coarse sandstone might indicate a deepening of the basin and thus possibly an advance of the sea. This would be consistent with the idea that large glaciations lower the sea level which rises after the glaciers have disappeared.

Bed 28. — The sandstones of bed 28 are mainly composed of quartz with a small admixture of feldspar, mica and chert. Limestone grains are common in the lower part of the section where they occur in irregular streaks interbedded in the pure quartz sand. The cement of the quartz sands consists of quartz in optical continuity with the sand grains while calcite cements the calcarenitic streaks.

The renewed influx of coarser clastic material in great quantity and the presence of feldspar is noted. This mineral appears here for the first time in the sequence and indicates that igneous or metamorphic rocks were being eroded in the hinterland.

The Intertillite member as a whole, intercalated as it is between two bodies of glacial tillites, represents certainly an interglacial period of long duration.

f. Upper Tillite member (beds 29—34).

The Upper Tillite member consists mainly of unsorted and unbedded glacial till but includes also several sandstone beds in which considerable sorting took place before deposition. Two thin breccia and sandstone layers at the top of the member may represent glacial outwash formed just after the retreat of the glaciers. The sandstones intercalated in the tillites seem to be mostly lenticular and may be the result of current action on the till, but a thick sand body in the middle of the member may be more consistent and represents perhaps a short withdrawal of the glaciers. This point bears further investigation.

The glacial origin of these tillites is just as plain as that of the Lower Tillite member. With the exception of the mentioned sandstones and conglomerates they are unsorted, unbedded and contain pebbles and cobbles showing the typical flatiron shape and striation. The matrix consists of clay and carbonates and is dark-red in colour, probably due to finely distributed hematite. Euhedral rhombs of dolomite are frequent in the matrix and indicate, together with the weak to negative reaction with hydrochloric acid, that the carbonate consists mainly of dolomite.

The detrital material ranges in size mainly from silt to cobbles, though O. KULLING (ref. 12) mentions blocks of 10 m in diameter. The silt consists of quartz with a small amount of feldspar. The grains of sand size are usually subrounded to well rounded and consist of quartz, some feldspar, limestone and rarely chert. The larger components are made up of limestones which are often pisolitic or oölitic, and of red coloured igneous rocks and metamorphics. O. KULLING (ref. 12) mentions quartzporphyries, granophyres, red and grey gneisses and granites, and diabases.

Obviously a considerable change took place in the source of the clastic material between the two glaciations represented by the Lower and Upper Tillite members. Sediments of the Eleonore Bay formation were the exclusive source for the Lower Tillite. The presence of a good percentage of igneous and metamorphic components in the Upper Tillite prove that these rocks were subject to erosion in extended areas of the hinterland. Such a change could, in the writer's opinion, only be caused by one or several of the following events:

a. The till carried by the glaciers was derived from different areas, i. e. the glaciers did not come from the same direction during the two glaciations.

b. Erosion had stripped part of the source area of its sedimentary cover during the first glaciation and particularly in the interglacial time and had exposed igneous rocks and metamorphics.

c. Diastrophic movements took place during the interval between the glaciations and were accompanied by intrusions and metamorphism. Erosion bared these rocks before the glaciation returned.

The sedimentary record contains nothing that would confirm the last-mentioned possibility, and the time interval filled by the interglacial period might seem too short for large-scale diastrophic movements to take place, particularly since feldspar appears already in bed 28. While the possibility of diastrophism cannot be entirely discounted, it would seem easier to explain the appearance of igneous and metamorphic rocks in the Upper Tillite member by one of the other hypotheses or a combination of them and thus to assume that the igneous and metamorphic rocks had been in place at least since the last period of diastrophism which occurred some time before the deposition of the Lower Tillite member.

g. Varve member (bed 35).

The Upper Tillite member is overlain conformably by a sequence of dolomitic layers which shows lamination throughout but particularly in its lower half. Immediately above the tillite, the lamination is clearly visible due to a colour contrast and has been described by CHR. POULSEN (ref. 14) as varve structure and additional proof for glaciation. The lamination is less distinct in the upper part of the member.

Microscopical examination of samples from the lower part of the member reveals an alternation of thin, brown-red laminae composed mainly of clay, fine silt and dolomite crystals, with thicker, light-red to white laminae consisting mainly of dolomite with little silt and reddish clay matter.

The dark-red bands vary in thickness from 0.1 to 2 mm, the light-red ones from 0.1 to 5 mm. However, gradation between the dark and the light bands makes it often difficult to determine their boundaries. Some dark layers rest with a sharp boundary on the light one and grade imperceptibly into the next higher, light-coloured lamina. Others are not sharply separated from the subjacent bed but terminate with a sharp boundary at the top. Also, the dark layers are often composite or they may consist of several, very thin, wavy streaks. It is doubtful whether the last-mentioned case represents the original structure. It would rather seem to be caused by solution, i. e. the wavy streaks may be stylolitic seams on which the red clay matter contained in the dolomitic layers in small quantity accumulated when the dolomite dissolved. Bifurcation of the seams occurs, or they die out laterally. Usually they contain little or no silt, in contrast to the regular dark layers, since the dolomitic beds which were dissolved also contained little silt. All this makes the interpretation of these wavy features as stylolites very probable but

unfortunately they are quite common and complicate the study of these beds considerably. It is often difficult to decide whether the sharp boundary at the top or bottom of a dark-red layer is original or caused by solution, and in some cases the stylolitic planes are massed and simulate a dark-red layer of sedimentary origin (see ref. 14, fig. 20, p. 306).

Nevertheless, it can be stated that there is an original lamination due to an alternation of predominantly carbonatic and of predominantly clastic sediments. The lower part of the Varve member resembles bed 21 of the Banded Dolomite member very much if the stylolitic solution is discounted. Deposition was also symmet in the dark-coloured bands, i. e. clay and silt settled out together. This indicates sedimentation in salt water, thus probably marine conditions. Deposition of carbonates also points to a marine environment.

With regard to the origin of the lamination it is only reasonable to think of the annual melting of glaciers in summer since there is definite proof of glaciation in the subjacent beds. Fine detritus was carried into the sea by the melt water. Both silt and clay settled out together rapidly due to flocculation of the fine clay particles in the salt water and formed the dark-coloured summer layer. Dolomite was deposited during the remainder of the year, thus forming a light-coloured winter bed.

The red colouring of the clay-silt layers disappears upwards in the sequence but the lamination persists though it changes its character. In the upper half of the Varve member, the silt is associated with the dolomite, and there seems to be a definite, proportional relation between amount and size of quartz grains and amount and size of dolomite crystals. Clay matter occurs throughout the rock but is predominant only in thin layers in which both dolomite and silt are rare, the latter usually absent. Graded bedding is often quite well developed. A cycle starts with the deposition of much and coarse silt accompanied by big carbonate crystals. Upward the silt diminishes in size and number as do the dolomite crystals. The cycle ends with a predominantly clayey zone in which there are only a few, often euhedral dolomite crystals. A new cycle begins thereafter. This seems to be quite the reverse of the conditions in the lower part of the Varve member. It is difficult to explain this change. Possibly deposition took no longer place in normal sea water but in slightly brackish or even fresh water. In this case the silt would settle out quickly during summer, shortly after reaching the area of sedimentation while most of the clay would remain in suspension and settle only slowly during winter, but it is difficult to understand why the carbonate should form proportionally with the deposition of the silt, unless it is also clastic and not due to chemical sedimentation.

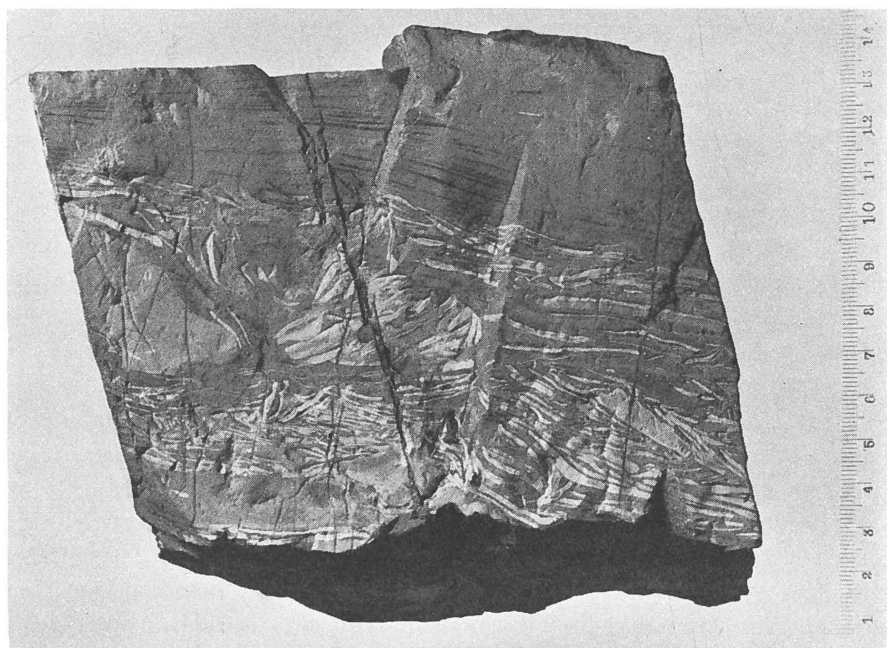


Fig. 8. Sun-cracked laminae, bed 36, Solitærbugt. Most of the laminae lie more or less parallel to the bedding planes but some are standing on edge. Notice the lamination in the upper part of the specimen. Scale in cm.

h. Sun-Cracked member (beds 36—39).

Bed 36.— Beds 35 and 36 are separated by a gap of observation of approximately 60 m by estimation. However, since there is no great change in sedimentation, it is thought that the gap covers a gradual transition. The deposition of carbonates, clay and fine silt continues undisturbed in the lower half of bed 36. Dolomite is the main constituent of the rock. Varying influx of silt results in lamination of the sediment which is often cross-bedded. The grain size of the quartz varies only within narrow limits, grains with a maximum diameter above 0.05 mm occur only rarely. Therefore, graded bedding is hardly observable and the lamination is mainly due to alternating deposition of much and little quartz. The laminae are usually thin (1—2 mm) and not separated by sharp boundaries.

In the upper half of bed 36, a great number of intraformational breccias (see fig. 8) are found which are composed of thin pieces of fine silty, dolomitic shales in a sandy, dolomitic matrix. The slabs are 1—2 mm thick, 0.5—5.0 cm wide and usually lie flat in the sediment but occasionally they stand edgewise. The matrix contains angular silt but also a considerable number of larger quartz grains which are often well

rounded. A maximum diameter of 0.5 mm has been observed. The conglomerates are lenticular and vary in thickness from 1 to 10 cm. Usually they begin with a sharp boundary at the base and grade upwards into laminated, silty dolomites.

It seems clear that these intraformational breccias are due to desiccation and cracking of dolomitic muds very similar to those which form the strata including the breccias. The dried mud laminae were washed up by the returning water and redeposited, filling the shallow depressions in the surface on which they settled. This explains the lenticularity of the breccia beds. There is no indication that brecciation might be due to subaqueous sliding.

It is thus clear that bed 36 was formed in very shallow water. The first indication of this is the cross-bedding observed in its lower part. Later the basin of deposition filled up and temporary withdrawal of the water was possible, perhaps not everywhere but certainly in extended areas. The returning water not only washed up the dried mud laminae but also brought considerable amounts of coarse quartz not usually present in the area. Since coarse clastic material does not occur in the normal sediments deposited in the intervals between the formation of the breccias, it may be assumed that the water came from a source area for such material, i. e. from the land side, perhaps as river floods.

The conditions of sedimentation can thus be visualized as extended shoals in front of a land mass from which the clastic material is derived. The hinterland was enough removed so that only components of silt and clay size could reach the area of deposition under normal conditions. The continuous deposition of much carbonates seems to indicate that the area of sedimentation was part of the sea. The repetition of desiccation and return of the water cannot probably be tied to any periodical event such as annual dry and wet seasons, i. e. it can hardly be assumed that the process was repeated every year and that every breccia represents, together with the overlying silty dolomites, the deposition of one year. This would require a yearly deposition of 10—30 cm after diagenesis. Though such rates of sedimentation have been observed (ref. 13, p. 472), they cannot be expected in sediments which consist to a great extent of carbonates, clay and fine silt, even though the breccia itself may be 5 to 10 cm thick. It seems more reasonable to assume that the conditions necessary for the formation of the breccias were exceptional and occurred only at intervals of many years.

Fine lamination has also been observed in the normal sediments below and between the breccias. These might be due to annual deposition but their lenticularity and cross-bedding are not indicative of conditions in which annual layers would be preserved. The fresh sediments were

probably exposed to currents and wave action, and the lamination is due to the quicker settling of the silt.

The presence of these intraformational breccias in the sequence indicates that the sedimentation proceeded at a more rapid rate than the subsidence. Since most of the strata described so far have the aspect of shallow marine deposits it can be inferred that the subsidence was continuous and approximately as great as the rate of sedimentation. This equilibrium was disturbed during the deposition of the Sun-Cracked member. As there is not much reason to assume a greatly increased rate of deposition (see above) it would seem that the rate of subsidence decreased. One might think of isostatic adjustments occurring after the retreat of the glaciers and counteracting subsidence but such adjustments could hardly occur such a long time after the end of the glaciation. The decreased subsidence is more probably connected with the tectonical events which resulted in the formation of an unconformity a little higher in the sequence.

Bed 37. — The lower part of bed 37 resembles the undisturbed strata of bed 36 but the clastic material and the lamination disappear gradually upwards in the section, and intraformational breccias are absent. Carbonates compose most of the rock, dolomite is the main constituent of the lower 18 m, calcite predominates at the top.

The limestone layer at the top of bed 37 shows the typical structure of Stromatolite colonies similar to the *Collenia* colonies of the Eleonore Bay formation. The first occurrence of these structures, however, was noted already near the base of bed 38. No organic structure can be recognized owing to crystallisation but slides show a concentric lamination which builds up stems similar to those pictured by C. L. FENTON (ref. 5) from the Belt Series of Wyoming. A silty limestone fills the intervals between the colonies and contains some black, possibly organic matter.

It is clear that the sedimentation was undisturbed and took place in deeper water than present during the deposition of bed 36. Influx of clastic material was reduced and algal colonies found the environment favourable for a while.

Bed 38 and 39. — Bed 38 is mainly dolomitic but the influx of often clastic material was greater than in the underlying limestone. The quartz grains reach a diameter of 0.6 mm, the bigger grains are well rounded. Some feldspar is also present. Streaks of silt and fine sand are intercalated in the dolomite. The sedimentation was often disturbed, as is shown by small unconformities and intraformational breccias in which the dolomite has been broken and redeposited in a silty-sandy matrix which in places infiltrates between the bedding planes of the dolomite. All these features are connected with increased influx of clastic material

but essentially the silty matrix of the intraformational breccias does not differ from the silt streaks within the dolomite, and it grades upwards into dolomite. Some of the pebbles in the breccias, on the other hand, appear to be conglomeratic themselves while others are cut by small calcite veinlets which do not continue into the matrix and must thus have been formed before the pebbles were reworked. This means that erosion of consolidated rock went on during the deposition of bed 38.

Some of the sandy, conglomeratic streaks are oölitic. The oölites often formed around quartz grains or small pieces of dolomite. Others include elongate bodies having the shape of a tube which may perhaps belong to some algae. A few spherical bodies with a radial structure were also observed which suggest algal origin but were too much crystallized to retain their original structure. The size of the oölites varies from 0.1 to 0.2 mm for the round ones to 1 mm for those of elongate or irregular shape.

The influx of coarser quartz and of some feldspar would seem to indicate that the area of erosion was less distant than before, or that erosion had increased due to climate changes (e. g. more rainfall) or uplift. In addition, erosion of marine formations already lithified but of similar composition as the dolomites forming concurrently took place, perhaps along the coast line. It is thus not excluded that uplift of the hinterland resulted in increased erosion. The presence of detrital feldspar is, according to F. J. PETTIJOHN (ref. 13), a good index of diastrophism.

Bed 39 is essentially a continuation of bed 38 and has been distinguished only because a breccia at its base is particularly well visible in the field.

i. Salt Cast member (beds 40—45).

Bed 40. — Bed 40 consists of conglomeratic sandstone containing many dolomite pebbles of various texture, partly silty, partly oölitic. The sand grains are well rounded and reach a diameter of nearly 1 mm. They include besides quartz also feldspar and chert. Glauconite is common near the base of the bed and occurs in microcrystalline aggregates between the clastic components of the sandstone. The matrix consists mainly of dolomite but may be clayey in thin streaks.

Bed 40 lies with visible, biangular unconformity on bed 39 (see fig. 9). This must mean that the preceding beds were tilted or folded and eroded, after which the sea advanced over the slanting, irregular, erosional surface. An angle of approximately 10° was observed in one place on the SE flank of the Kap Oswald anticline between the stratification of beds 39 and 40, but it is doubtful whether this represents the original inclination of bed 39 at the time bed 40 was deposited, or it is due partly to local irregularities along the unconformity. In exposures



Fig. 9. The unconformity between beds 40 and 39. Scale in mm.

on the W flank of the anticline, bed 40 lies about 20 m above the uppermost lenses of mud-cracked laminae as compared with 29 m on the SE flank. Since the distance between the exposures on both sides of the anticline is about 5 km when taking the folding into account, it is obvious that the overall dip over this distance was very small. It is concluded that the tectonical movements preceding the deposition of bed 40 probably resulted in slight warping of the underlying beds. These movements possibly also affected the source area of the clastic components of the sandstone since coarser sand grains reached the area of sedimentation than at any time since the glaciation.

Bed 41 — Bed 41 consists of dolomitic sandstone at the base, of sandy dolomites in its upper half. It represents a continuation of the

preceding sedimentation in which the size of the clastic material diminishes rapidly from a maximum size of 0.6 mm near the bottom to 0.2 mm at the top.

Bed 42. — This is a siltstone with dolomitic-shaly matrix. The maximum grain size observed is 0.16 mm, a further reduction from the larger grains observed in the preceding beds. Clay forms a greater part of the matrix than in the underlying beds but the sedimentation does not change otherwise.

Bed 43. — Bed 43 provides definite proof in the form of mud cracks and casts of salt crystals (fig. 10) that the area of sedimentation was at times exposed to desiccation. Thin mud layers intercalated between the sandstones and siltstones of bed 43 preserved the salt casts and mud cracks. Each mud intercalation represents the end of a cycle of deposition after which the sediment dried, cracked and was covered with salt cubes which left their imprint in the soft mud. When the water returned and sedimentation set in again, the salt crystals were dissolved and the new sediment, mostly sand or silt, filled the holes left by the crystals. Here again one might think of periodical, perhaps yearly occurrences but the sedimentation was very irregular, as shown by cross-bedding, and no definite conclusions can be drawn.

Bed 43 consists mainly of siltstones and sandstones. In the lower part of the formation the clastic material is predominantly silt but increases in size upwards. The largest grains observed in the upper part of the bed have a maximum diameter of 0.63 mm and are well rounded. At the same time the coarser clastics predominate and the rock can be called a sandstone. Feldspar and much mica are present throughout bed 43. Increasing erosion in the hinterland is thus indicated, possibly caused by uplift which at the same time may have been responsible for the lowering of the sea level in the area of deposition. Igneous and/or metamorphic rocks were apparently exposed in the hinterland.

The matrix of the sandstones and siltstones is dolomitic, rarely calcitic, and even the shale streaks contain carbonates. It is thus probably justifiable to assume a marine environment in which the subsidence did not keep pace with the deposition.

Bed 44. — A gap of observation of 5 m separates beds 43 and 44. The rock consists mainly of dolomite but sand streaks and an intraformational breccia indicate that the sedimentation was still essentially the same as in the preceding beds. Coarse quartz (0.9 mm) occurs in the matrix of the intraformational breccia. Chert nodules are frequent. There is little reason to assume that the gap mentioned hides any break in sedimentation, certainly there is no change in dip and strike.

Bed 45. — Bed 45 is a chert stained red by minute hematite grains. The chert retains in some parts the texture of the original rock which

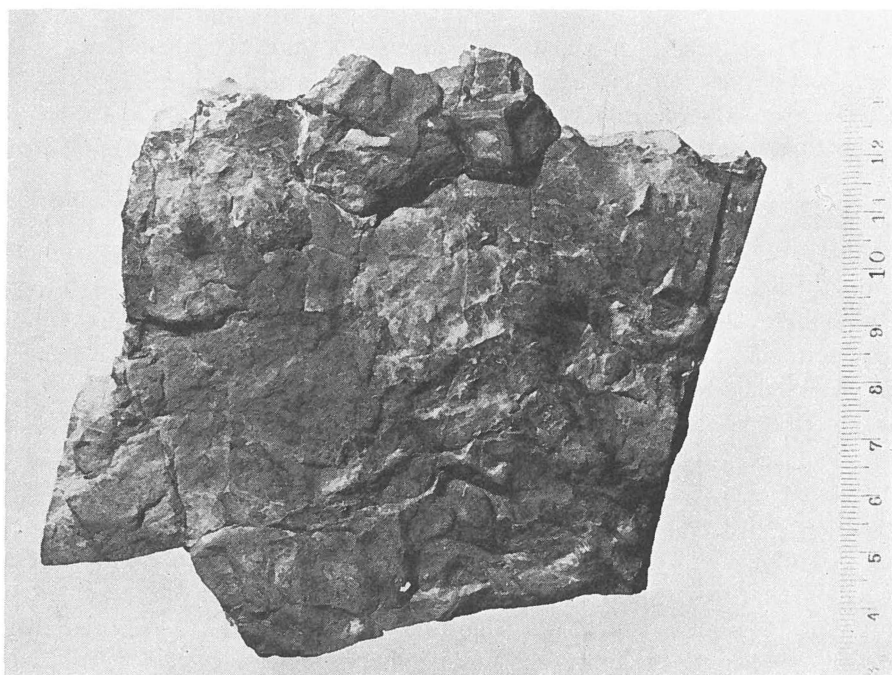


Fig. 10. Salt casts from bed 43. Solitærbugt. The picture shows the bottom of a sandstone bed. Scale in cm.

was apparently a clastic limestone or dolomite. Some rare dolomite rhombs are preserved but no detrital minerals could be seen.

k. Quartzite member (beds 46 and 47).

Quartz is the predominant component of the Quartzite member and occurs mainly in sand size (maximum diameter observed 0.9 mm). The bigger grains are often well rounded, the smaller sizes vary from angular to subrounded.

The basal zone (bed 46) consists of thin streaks of silt ($1\frac{1}{2}$ —2 mm thick) and thicker layers of sandstone (2—10 mm thick). These laminations are discontinuous, lenticular-crossbedded and probably due to deposition in currents. The silts have a shaly matrix of dark-red colour caused by hematite and include much mica. The coarser sand is cemented by quartz in optical continuity with the quartz grains. Feldspar grains are quite common.

The greater part of the Quartzite member (bed 47) consists nearly exclusively of quartz grains cemented by quartz. Some mica and feldspar occur just above bed 46, but were not observed higher in the sequence. The pink colour of the sandstone is caused by minute grains of hematite in the matrix.

Bed 47 certainly can be classified as an orthoquartzite according to P. D. KRYNINE's classification. This author distinguished first-cycle orthoquartzites which are the product of intense chemical decay and destruction of all original minerals except quartz, second-cycle orthoquartzites resulting from reworking of the first type, and lastly cleaned graywackes, i. e. local accumulation of clean sand in graywackes due to washing out of the clay and silt portions of a graywacke. Bed 47 belongs to the first type. Its thickness and uniform lithology already indicate that it is a blanket sand covering a large area, and it has indeed been observed by CHR. POULSEN (ref. 14) near Kap Weber and again on the S coast of Ella Ø, i. e. over a distance of 65 kilometers. Furthermore, the characteristics of second-cycle orthoquartzite such as reworked fragments of earlier quartzites, detrital chert and quartz grains with abraded secondary growth are absent.

First-cycle orthoquartzites are, according to P. D. KRYNINE, the result of intense chemical attack on the rocks exposed over a peneplaned land area. The red colour is also significant. Current opinion regards the red colour as derived from a deeply decayed regolith of lateritic type or as indicative of aridity (ref. 13, pp. 170—175). Aridity is not propitious for intense chemical decay. Therefore the red colour of the Quartzite member is presumably derived from lateritic soils. According to these ideas, the Quartzite member would thus indicate erosion over a large, peneplaned land area covered by a deeply weathered red soil. As laterites form at the present day in humid, warm climates, we can conclude that such conditions probably reigned in the land area from which the components of the Quartzite member were derived.

1. Sandy Shale member.

According to CHR. POULSEN's description of this member (upper part of his Bastion formation, ref. 14), the influx of detritus continues but changes its character. Mica appears again and clay seems to form a major part of the sediments. The red colour so typical of the Quartzite member is still present in the lower part of the Sandy Shale member but disappears upwards.

This seems to indicate that conditions in the source area have changed, presumably erosion was actively cutting into the peneplains formed earlier. Deposition took place under marine conditions, as shown by the presence of marine fossils and glauconite in the upper half of the Sandy Shale member.

3. Upper Limestone Group.

The Tømmer Bay group is overlain by a large thickness of limestones and dolomites which form most of the high cliffs of Ella Ø, particularly E and W of the Kap Oswald promontary and in Narhval-sund. CHR. POULSEN (ref. 14) estimates their total thickness at 1750 m. The group includes Poulsen's Ella Island formation, Hyolithus Creek formation, Dolomite Point formation, Cass Fjord formation, Cape Weber formation and Narwhale Sound formation.

It is sufficient for the purpose of the present paper to note that the sedimentation has once more become predominantly chemical and biochemical and that the conditions must have been nearly identical with those present during the deposition of the upper part of the Eleonore Bay formation, i. e. a shallow, warm sea far from any source of detrital material. Some clastic material is still deposited at the base, in the Ella Island formation, but thereafter the source area seems to have disappeared, possibly because it was covered by the advancing Cambrian sea.

AGE OF SEQUENCE

Only the age of the uppermost beds of the sequence exposed at Kap Oswald is determined by fossils. According to CHR. POULSEN (ref. 14), beds 48 and 49 contain a faunal assembly of Lower Cambrian age which resembles closely the Callavia fauna of the Atlantic province of the Cambrian. Later, POULSEN (ref. 15) correlates the Bastion and Ella Island formations with part of the Etcheminian of eastern Northamerica and with the Holmia Kjerulfi zone of Scandinavia.

The lower part of the sequence, on the other hand, belongs to the Eleonore Bay formation which is considered as Pre-Cambrian by all recent authors. We can certainly agree with this, since a major criterion for the Pre-Cambrian is the absence of hard-shelled fossils. Although the environment in which beds 1 to 17 were deposited (shallow sea, probably warm water) seems favorable enough for the development and preservation of a rich animal life, no definite trace of it has been found so far. In addition, the presence of Stromatolites of the genus *Collenia* indicates a possible correlation with the pre-Cambrian Belt Series.

The age of the intervening beds is problematic. Since no fossils are available we can only make some speculations. Cold climate and the nature of sedimentation might have prevented animal life to develop in the lower part of the Tömmer Bay group. It would, however, seem that conditions were favourable enough in the upper part, yet no fossils have been found so far. This would indicate that most of the group belongs to the Pre-Cambrian but the question is where to place the base of the Cambrian. The principle of this problem has recently been discussed by H. E. WHEELER (ref. 22), who proposes the base of the *Olenellus* biozone as the base of the Cambrian.

While this is certainly the right method to fix the base of the Cambrian at a time boundary, it "does not perforce establish the base of the Cambrian at all localities", as WHEELER has pointed out already. "Identification is contingent upon the local presence of diagnostic faunas." The difficulty in the present case would be to decide whether the base of the *Olenellus* biozone coincides with the appearance of the

first fossils or should be placed deeper. Since the Callavia zone to which POULSEN assigns the faunas from his Bastion and Ella Island formations occurs considerably above the first Cambrian faunas of the Atlantic province, it would seem that the base of the Cambrian should indeed occur deeper.

Obviously the problem can only be solved by intense search for fossils, if at all. In the meantime consideration of such physical evidence as is presented by the nature of the strata may help to place the base of the Cambrian tentatively in the section. It has been pointed out that the Quartzite member of the Tømmers Bay group may be the result of intense chemical attack on large areas of peneplanation. Such large scale peneplanation is known to have preceded the advance of the Cambrian seas over most of the North American continent. The base of the Cambrian is often accompanied by orthoquartzites very similar to our Quartzite member, sometimes even in colour. A genetic relation between the Quartzite member and the pre-Cambrian peneplanation is thus not improbable. This argument, however, should not be used to place the base of the Cambrian at the base of bed 48 without further examination. Even if all these different orthoquartzites are genetically related with the peneplanation preceding the Cambrian they need not be—and probably are not—contemporaneous, just as little as the transgression itself is contemporaneous. Thus it has been shown by WHEELER that the unconformity occurs in certain parts of the Basin and Range province about 2800 meters below the base of the Olenellus zone (Nopah Range, California), while further W, in the western Grand Canyon (Arizona) the Olenellus zone is found directly above the unconformity and in the Belt region of Wyoming it is the Middle Cambrian which lies unconformably on the pre-Cambrian Belt Series.

Stratigraphical studies of recent years have shown that lithologic units deposited in a transgressing sea have a tendency to ascend in the direction in which the transgression proceeds with relation to the time units. Therefore, a sandstone body which forms the base of the Cambrian in the area of the former continent may well be found considerably below the base of the Cambrian basinwards where the transgression began much earlier. Since in NE Greenland sedimentation was nearly uninterrupted from the Pre-Cambrian to the Cambrian and took place in a geosynclinal area, we would not expect the Quartzite member at the base of the Cambrian but lower. In any case we would not expect that the preceding strata belong to the Cambrian.

The speculative nature of these considerations cannot be stressed too much. Only in view of the lack of better criteria are they used to place the base of the Cambrian tentatively above the Quartzite member, for the sake of convenience at top of the quartzite.

Both CHR. POULSEN (ref. 14) and C. TEICHERT (ref. 18) place the base of the Cambrian considerably lower in the section. POULSEN assigns his Tillite Canyon and Spiral Creek formations to the Cambrian although there is no fossil evidence. TEICHERT thinks that the tillites belong to the Cambrian because they mark the beginning of a new cycle of sedimentation connected with sudden uplift. TEICHERT argues that the whole cycle should logically belong to the Cambrian. This general argument does not hold good when the conditions of sedimentation are examined in more detail. In any case there is no reason why the base of a new cycle of sedimentation in a geosynclinal area should coincide with the beginning of a new period.

SUMMARY AND SIGNIFICANCE

The results of the present investigation have been assembled in plate 1. Although the interpretation of the sediments remains in many respects conjectural, some statements can be made with a reasonable amount of certainty. They are valid not only for the local area, but for a large part of NE Greenland because conditions of sedimentation were remarkably equal throughout the Caledonian geosyncline, according to all observers.

1. During the late Pre-Cambrian and the Cambrian a thick section of sediments was deposited in a continuously shallow sea. Since the basin of sedimentation did never fill up for very long, continuous subsidence must be assumed. This is the characteristic of geosynclinal sedimentation.
2. Sedimentation was nearly continuous from the Pre-Cambrian to the Cambrian. A small unconformity was observed in one place, and CHR. POULSEN mentions disconformities at the base of his Bastion, Ella Island and Dolomite Point formations. There does not seem to be any reason to assume a break at the base of the Quartzite member (see also ref. 12, p. 331), and the disconformity between beds 48 and 49 seems to be of little consequence since both contain faunas of nearly equal age. Certainly in the NE Greenland geosyncline there is no sign of the major unconformity which precedes the Cambrian in many areas, no sign that major diastrophic movements resulted in mountain forming and metamorphosis in the geosynclinal belt itself. This holds also for the deeper parts of the Eleonore Bay formation which pass gradually into metamorphic rocks of Caledonian origin but were never found to transgress on an older, metamorphic series.
3. Three periods can be distinguished in the history of the E-Greenland geosyncline shortly before and at the beginning of the Paleozoic, as recorded in the sequence exposed at Kap Oswald:

- a. Marine deposition, mainly of chemical and biochemical character, little or no detrital material. Upper part of Eleonore Bay formation.
- b. Marine deposition of mixed character (clastic and chemical sediments mixed). Tömmer Bay group.
- c. Marine deposition, mainly of chemical and biochemical character. Little or no clastic sediment. Upper Limestone group, Cambrian and younger.

To judge from the mass of sediments involved we seem to deal with a large scale cycle of sedimentation. Information regarding the significance of the cycle can mainly be derived from the character of the clastic sediments deposited in the second group, which is related to the history of the source area of the clastic material. The chemical and biochemical sediments associated with the clastics of the second group and forming the two limestone groups, together with the structure of the sediments, are more important for the interpretation of conditions in the area of deposition.

The record preserved in the clastic sediments of the Tömmer Bay group contains much evidence for the presence of a large land mass bordering the geosyncline from which the clastic material was derived. Since nearly no clastic material was received by the area of deposition during the time of the upper Eleonore Bay formation, it can be assumed that the land mass was submerged or very much reduced in size. However, since the lower Eleonore Bay formation (Kulling's Quartzite series) consists predominantly of clastic sediments, a large land mass must already have existed earlier. The writer has no evidence that these two sources of clastic material were situated in the same general position but this is not excluded and could be expected in view of the continuity of land areas in general.

Several phases can be recognized in the history of the borderland because they left their traces in the sediments of the Tömmer Bay group:

1. Appearance of the border land as a source of clastic material, probably due to major diastrophism, but which did not extend to the geosyncline.
2. Repeated glaciation.
3. Some periods of increased erosion, possibly due to diastrophism.
4. Strong peneplanation.
5. Disappearance, presumably under the transgressive Cambrian sea.

The position of this borderland is at present unknown, but the writer would guess that it was part of the Canada-Greenland shield and

corresponds perhaps to the present, ice-covered interior of Greenland. This question may possibly be settled by a study of the texture of the tillites in the various localities of NE-Greenland where tillites are exposed.

The Tömmer Bay group thus probably represents the record of the history of an old landmass from its first appearance to the moment when it was worn down and disappeared under the advancing Cambrian sea. It would be highly interesting to know the time involved in the process as well as the duration of some of the phases in the development of the landmass, e. g. the glaciations. Only absolute age determinations by radioactive methods can give an answer to these questions.

As the geographical names forming part of the geological names are in several cases used in a form that differs from that used in the official maps, a list of the authorized forms of the particular geographical names is added below:

	Authorized form:
Tömmer Bay	Tömmerbugt
Eleonore Bay	Eleonores Bugt
Ella Island	Ella Ø
Narwhale Sound	Narhvalsund
Cape Weber	Kap Weber
Dolomite Point	Dolomitpynt
Hylolithus Creek	Hylolithuskløft
Spiral Creek	Spiralkløft
Tillite Canyon	Tillitkløft

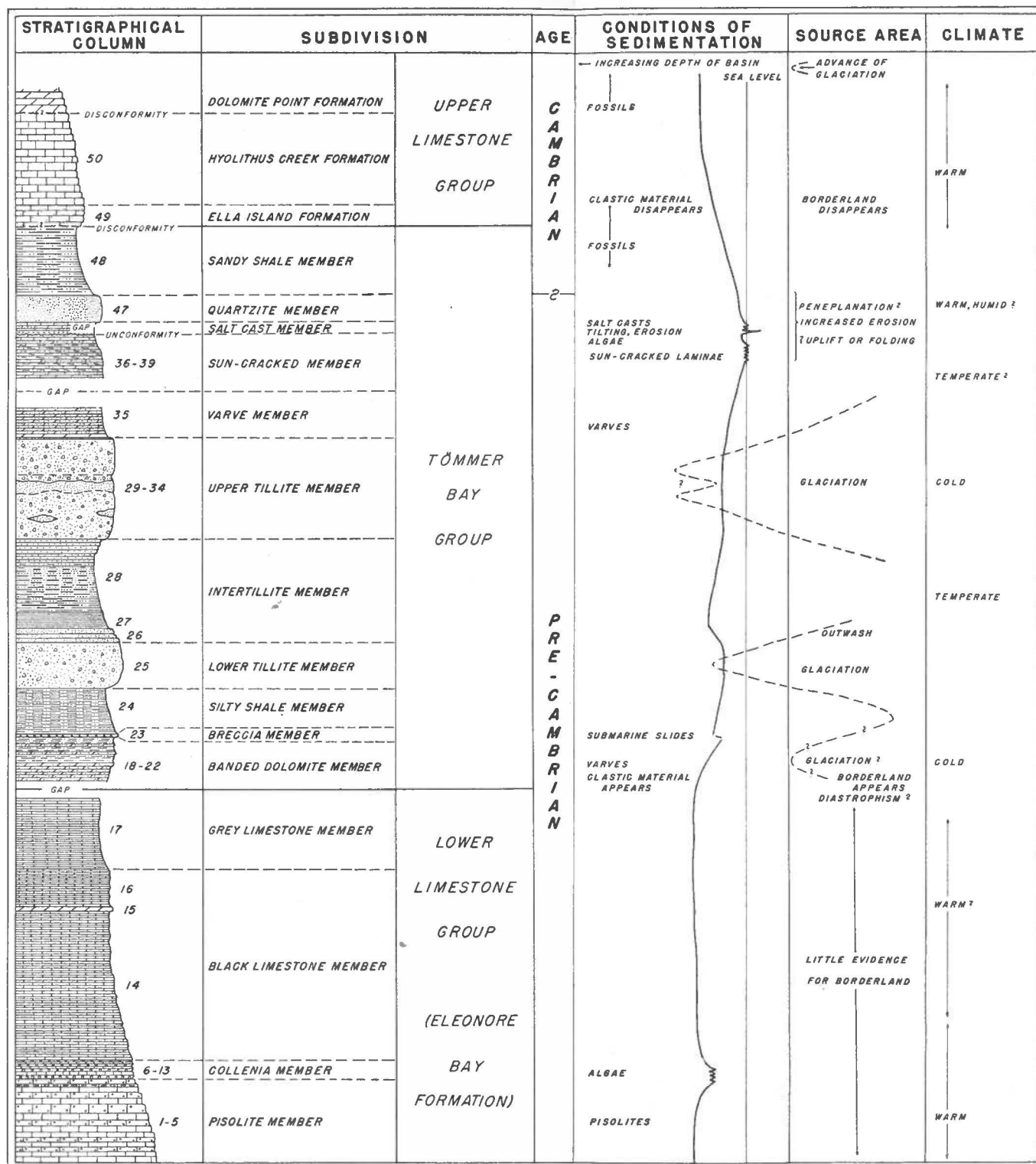


Plate 1. Pre-Cambrian to Cambrian sedimentation on Ella Ø, NE-Greenland. Scale 1:5000.